REPORT NO. NSS-MR-RP006
27 JUNE 1978

CR151870

MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE

FIRST INTERIM REVIEW

CONTRACT NAS9-15507
DRLT-1422
DRD DM-251T
LINE ITEM 4

(NASA-CR-151870) MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE Interim Review No. 1 (Grumman Aerospace Corp.) 252 p HC A12/MF A01 CSCL 22B

N79-16056

Unclas
G3/16 43387

Submitted To

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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PROGRAM OBJECTIVES

The two prime objectives for the Manned Remote Work Station (MRWS) Development Article study (NAS9-15507) is to first 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 detail manufacturing drawings and schedules for a simulator development test article.

The approach outlined on the opposite page, establishes flight article requirements based on past studies of Solar Power Satellite, orbital construction support equipments, construction bases and near term Shuttle operations.

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

PROGRAM OBJECTIVES

(1) ANALYZE AND DESIGN MRWS THAT CAN OPERATE FROM END OF LARGE CRANE & OTHER MULTI-ROLE FUNCTIONS

(2) DEVELOP DESIGN, SPECIFICATIONS, DRAWING, MFG REQMTS, COST & SCHEDULE FOR MWRS SIMULATOR.

APPROACH

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

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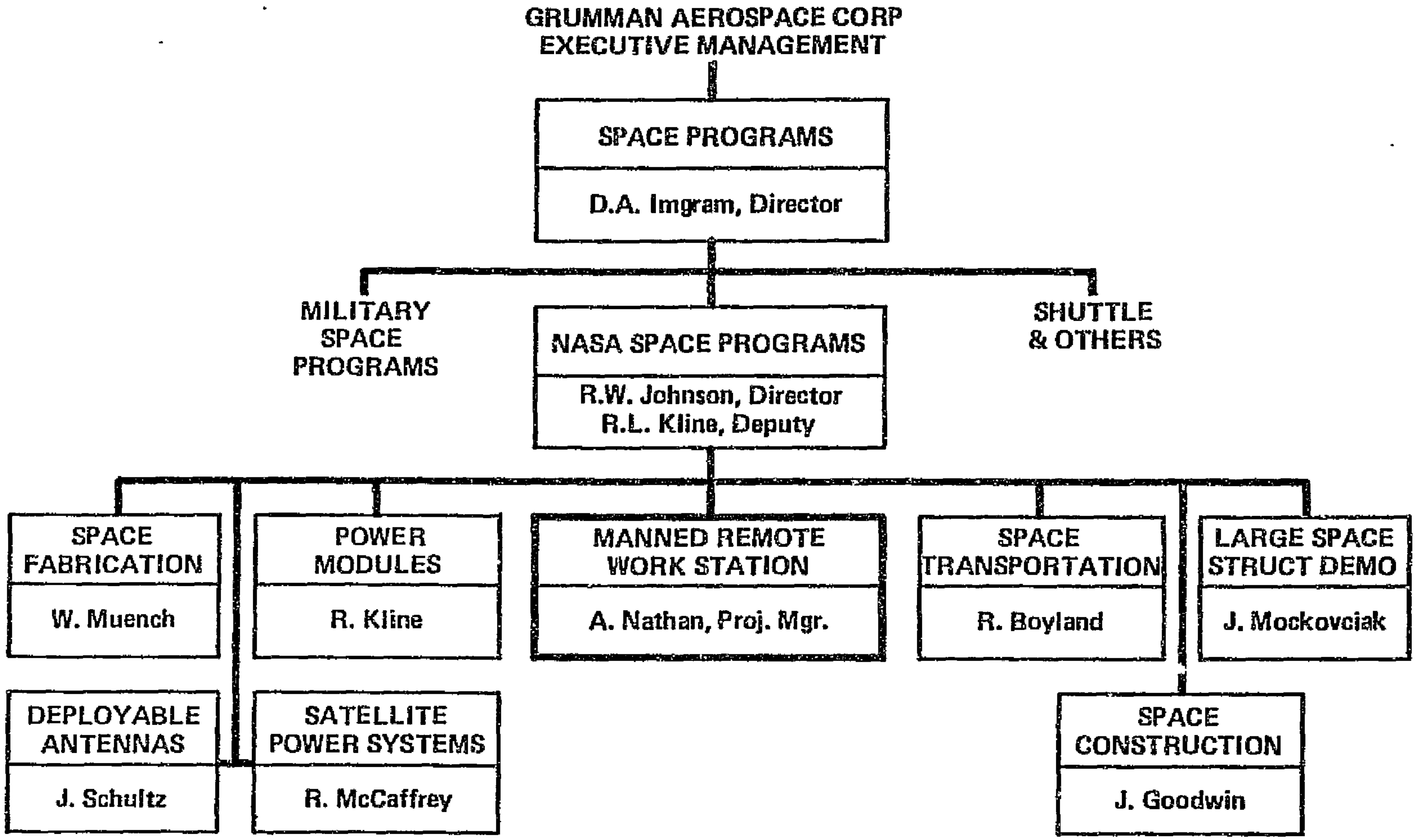
RELATIONSHIP OF MRWS PROJECT TO GRUMMAN AEROSPACE CORPORATION

The MRWS project will be undertaken by a team within the Space Programs organization headed by Donald A. Imgram, Director. Access to Grumman Management is through Mr. Ingram to Ross S. Mickey, Senior Vice President. The relationship of the MRWS team to the Space Programs organization and senior corporate management is shown on the facing page.

RELATIONSHIP OF MRWS PROJECT TO GRUMMAN AEROSPACE CORPORATION



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PROGRAM SCHEDULE

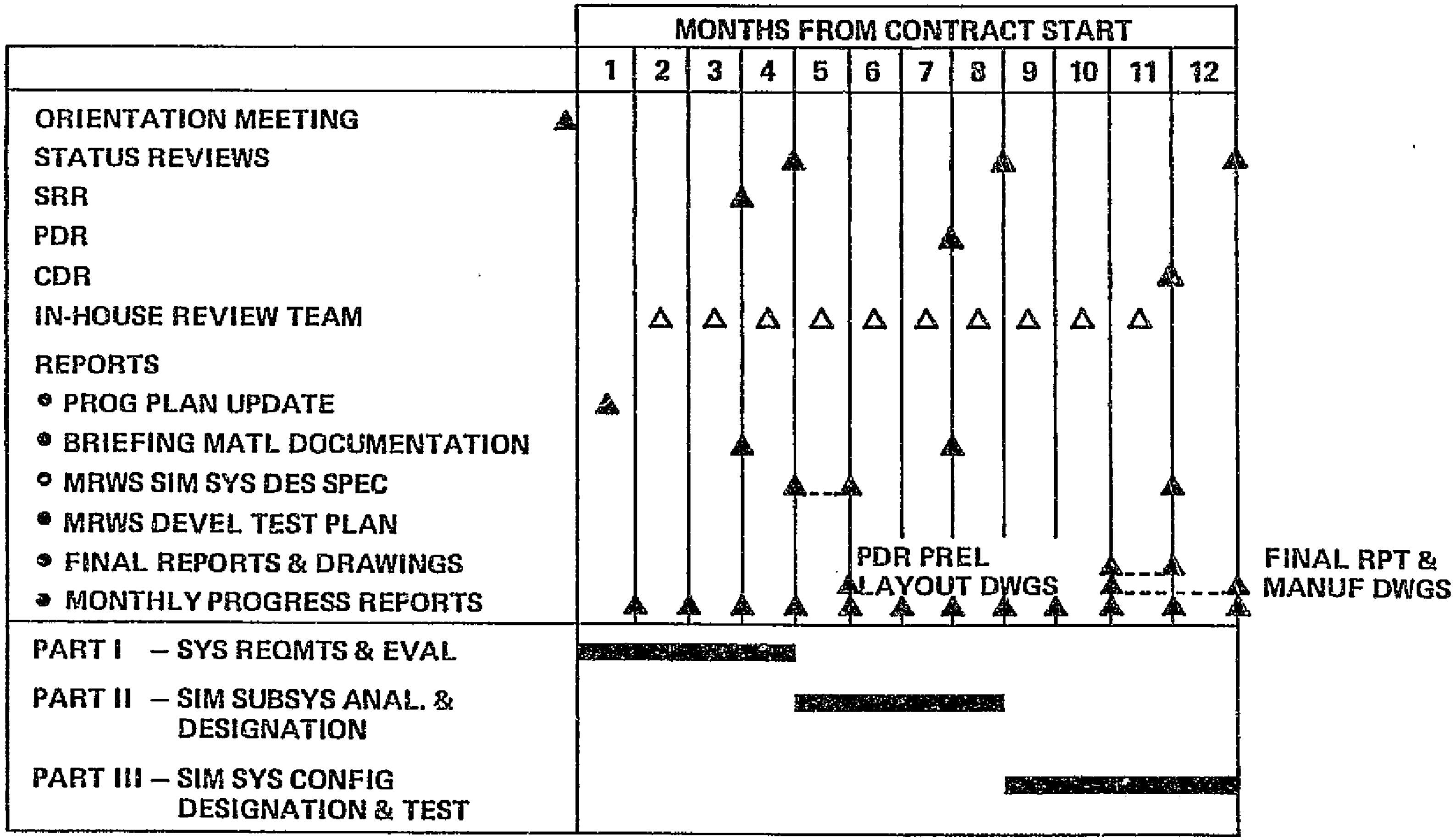
A schedule showing study tasks versus program milestones is shown on the opposite page. Each of the three study parts are scheduled for 4 months. The milestones include NASA review/decision points at SRR, PDR and CDR. Program status reviews are held at the end of the 3rd, 7th and 11th months. In-house MRWS review board meetings are scheduled at mid-monthly intervals prior to NASA reviews.

The first step (Part I) utilizes 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 are selected as the basis for definition of the Development Test Article (DTA). Concept designs for the DTA are 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 are evaluated and simulation/DTA requirements defined for the System Requirements Review (SRR).

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

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

PROGRAM SCHEDULE



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PART I – SYSTEM REQUIREMENTS AND EVALUATION

Of the five tasks that comprise Part I, the first two provide definition of representative MRWS flight articles. The last three tasks generate a simulation concept and a DTA specification. This flow is summarized on the opposite page with the five tasks running a total of four months, including two reviews.

Tasks 1.1 and 1.2 are the focal point of the flight article definition. Its key output is a data package that contains a top level description of the cherry picker flight system and detailed configuration definition. Expanded OCSE functional analysis of the appropriate operational tasks as well as an identification of the simulation objectives are included. The configurations, functional analyses, and simulation objectives of the unique features of alternate MRWS roles (crane, free flyer) are treated as deltas.

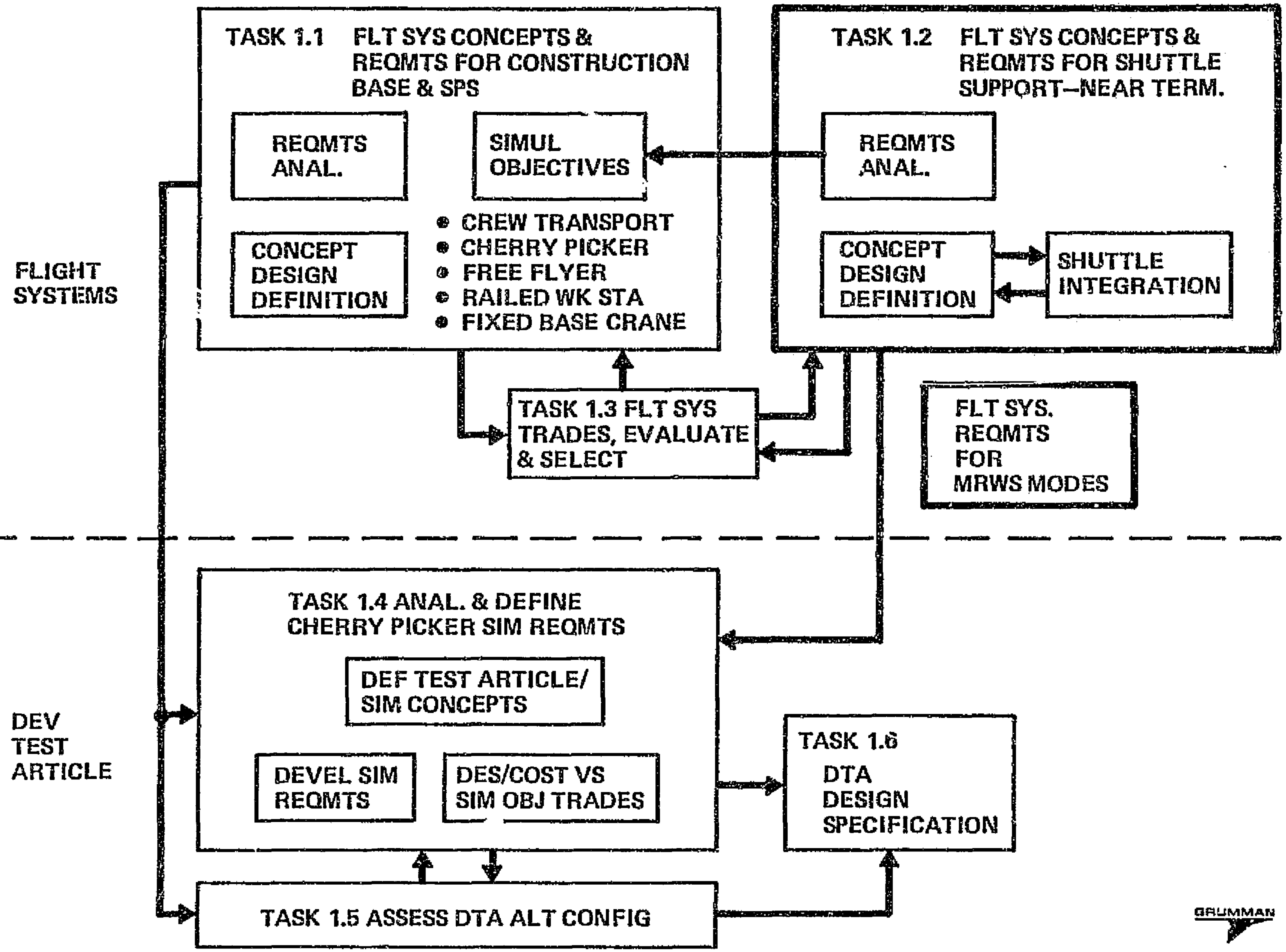
Flight article trades, Task 1.3, are limited to key issues, such as crew size, docking port locations, and the mounting geometry for the external manipulator arm. These are settled early, to minimize later expensive hardware changes on the Development Test Article (DTA). Issues better resolved by the actual simulation program are studied to establish a likely range of options and parameters.

Based on the MRWS flight article data packages, and the capabilities of the MDF, Task 1.4 develops alternative simulation concepts. These concepts focus on the cherry picker role and use various scale and modular DTA buildup approaches to provide development flexibility. Selections are made and reviewed with NASA.

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

The output of Task 1.6 is the DTA design specification which covers the simulation program and the key subsystems. This specification is based on the flight article data package from Task 1.1, the selected cherry picker simulation concept from Task 1.4, and the added simulation features identified in Task 1.5.

PART 1: SYSTEM REQUIREMENTS AND EVALUATION



ORBITAL CONSTRUCTION SUPPORT EQUIPMENT DEVELOPMENT
UNIVERSAL MANNED REMOTE WORK STATION

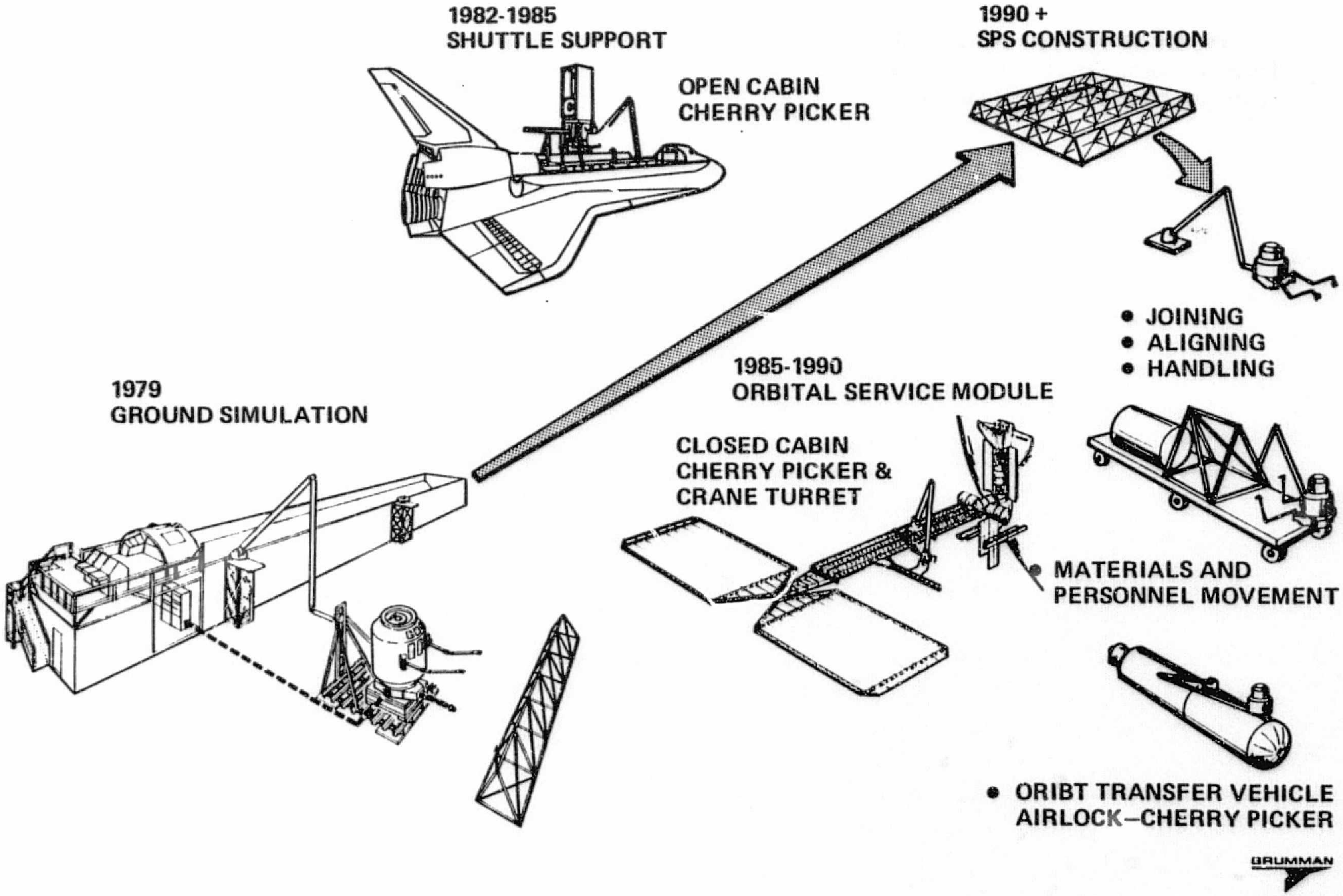
The exploration and utilization of space has witnessed a continuous growth in spacecraft size and weight. Many applications are now envisioned which require ultra-large space structures for implementation. Due to the restrictions of payload and volume limitations of current and projected launch systems, space construction of these ultra-large structures is essential. This report addresses the concepts and application of a key piece of construction equipment needed to support assembly of these large structures. The Manned Remote Work Station (MRWS) is a universal crew cabin to be used as a construction cherry picker, space crane turret, railed work station, or a free flyer. Concepts and requirements for this spacecraft are shown on the opposite page for early applications in support of Shuttle operations, applications in support of a mid to late 1980s construction base, and finally in support of constructing and maintaining the Solar Power Satellite.

Near-term applications of MRWS are in support of Shuttle operations as an open cabin cherry picker mounted to the end of the Shuttle Remote Manipulator System (SRMS). This MRWS provides a platform for EVA servicing of satellites, deployment and retraction of Spacelab experiments, and assembly of large space structures. A small open platform can transport the crew and tools to worksites within reach of the SRMS and provide a stable work station for detailed tasks best performed by astronauts. This device reduces the cost of EVA operations by bypassing the need to man-rate all hardware in the path of the Astronaut during transport to the worksite and would minimize physical contact with the payload once the Astronaut is at the worksite.

In the mid to late 1980s, several planned programs can 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. The longer duration and multi-shift missions will benefit from a CCP in terms of reduced radiation and longer crew work periods.

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

ORBITAL CONSTRUCTION SUPPORT EQUIPMENT DEVELOPMENT UNIVERSAL MANNED REMOTE WORK STATION



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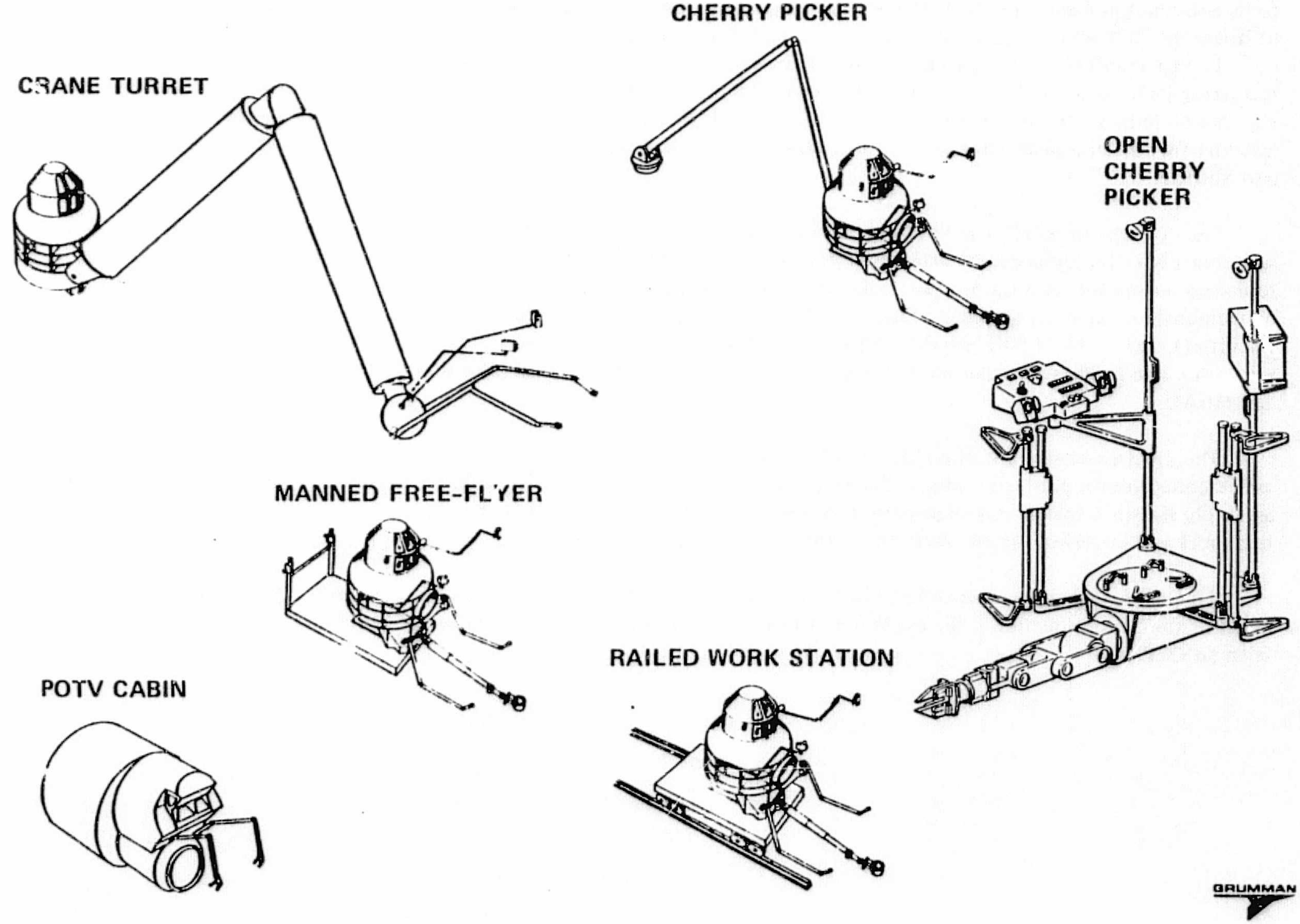
MRWS MULTI-ROLE CONCEPT

This program has studied ultimate uses of an MRWS flight article (shown on the opposite page), as applied to both near term (1980s) and long term (1990s) space activities. Although the principal emphasis has been placed upon the MRWS application in the large space crane/cherry picker mode, multi-purpose roles and design requirements have unfolded.

The MRWS has application as a cherry picker cabin, crane turret, free flyer, railed teleoperator cabin and Orbit Transfer Vehicle airlock. The goal to achieve a common cab design for all of these functions appears feasible with careful application of a modular design.

MRWS MULTI-ROLE CONCEPT IN SUPPORT OF LARGE SPACE SYSTEMS



OPEN CHERRY PICKER (OCP) MISSIONS

The opposite page lists potential OCP applications in support of Shuttle operations. A platform mounted at the end of the Shuttle Remote Manipulator System (SRMS) 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.

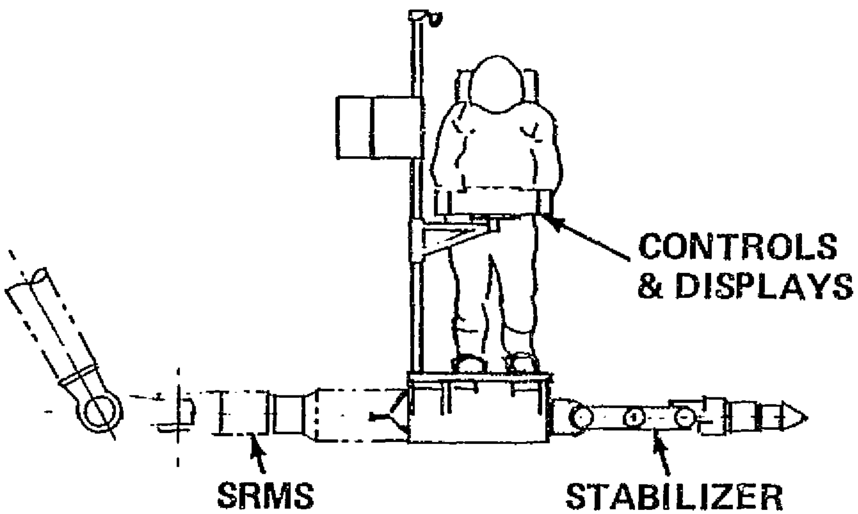
The OCP will enhance Spacelab Sorfie mission operations by providing a convenient means of deploying and retracting pallet-mounted experiments. The cost of experiments needing mechanical extension desired to clear the cargo bay can be reduced by utilizing EVA assistance in the deployment/retraction operations. 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.

The concept of in-orbit servicing of automated payloads can be enhanced with use of the OCP. The multi-mission spacecraft 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. Plans are also being prepared for in-orbit servicing of the Long Duration Exposure Facility (LDEF). The LDEF experiment trays, slightly larger than the MMS subsystem modules, can conveniently be serviced by an OCP. Other automated payloads with potential need for an OCP service are the Large Space Telescope and HEAO.

The most extensive use of an OCP can be envisioned for support of construction R&D activities using the Shuttle as the construction platform. Many studies performed over the past few years call out the need for EVA crews to deploy assembly 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 worksite.

An OCP can also have application in the checkout and in-flight repair of the Shuttle itself. All subsystems within reach of the SRMS, including the cargo bay doors, forward-mounted RCS and GN & C equipments, could be serviced with an OCP.

OPEN CHERRY PICKER MISSIONS



FUNCTIONS IN SUPPORT OF
SHUTTLE OPERATIONS

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

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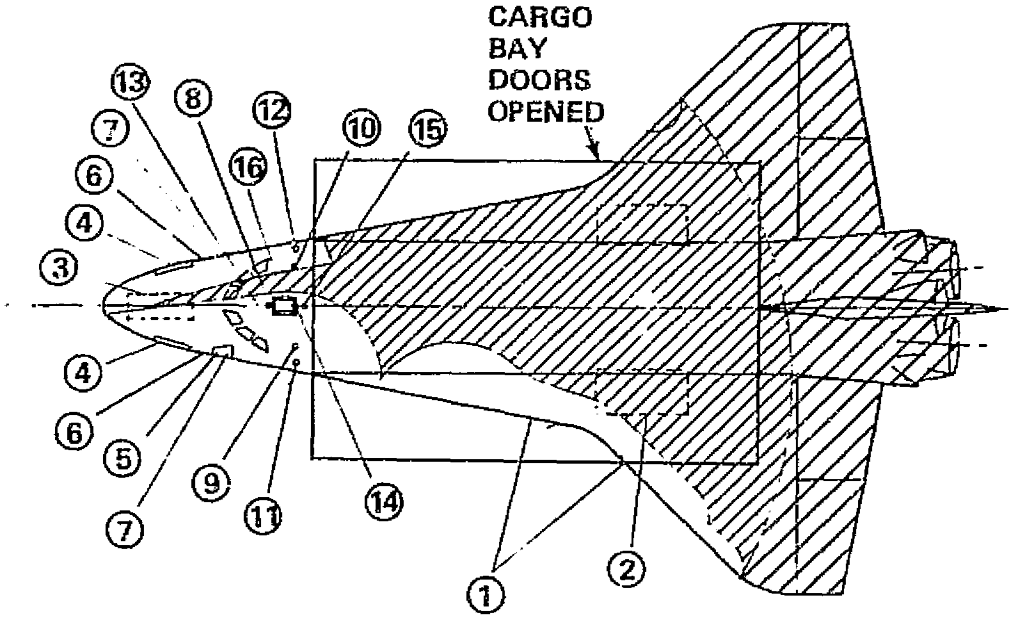
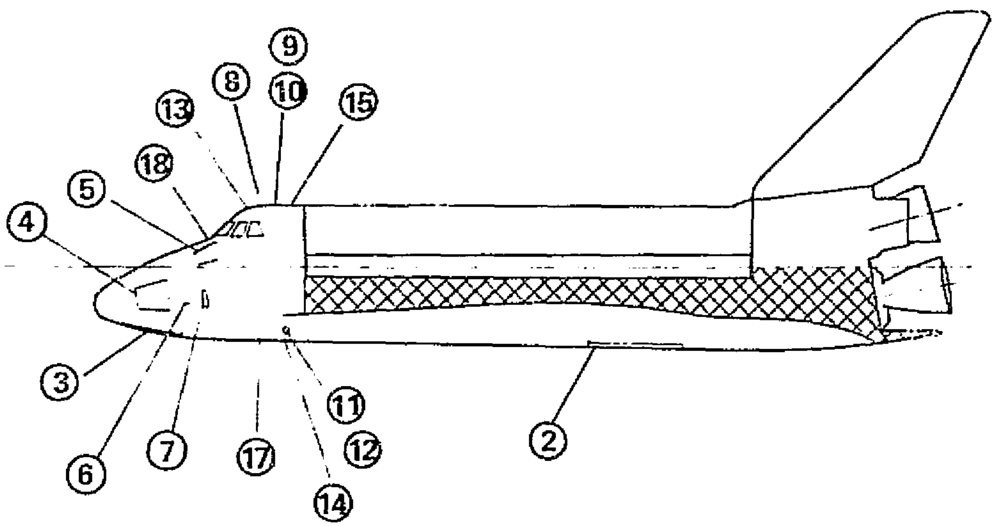
OCP ON-ORBIT INSPECTION, MAINTENANCE & REPAIR OF ORBITER

The open cab cherry picker operating from the end of the Shuttle RMS is capable of reaching areas of the orbiter outside of the cargo bay thereby allowing the EVA astroworker operating from the OCP to perofrm inspection, maintenance and possible repair of the Orbiter itself. Using the allowable limits for the shoulder, elbow and wrist of the Remote Manipulator as defined in NASA document JSC-07700 Vol. XIV, the illustration shown on the opposite page defines those Orbiter areas accessibie to a port side mounted RMS/OCP. Discreet items accessible for possible on-orbit inspection or repair are also identified in the accompanying chart. These candidate Orbiter items for servicing are located and identified on Rockwell International drawing VL70-000149.

OCP-ON ORBIT ACCESS TO ORBITER FOR INSPECTION, MAINTENANCE & REPAIR





ITEMS ACCESSIBLE	
1	L.H. WING LEADING EDGE TPS
2	L.H. MAIN LANDING GEAR DOOR
3	NOSE GEAR DOOR
4	RCS THRUSTER DEPLOY. DOOR
5	STAR TRACKER DOOR
6	ILS ANTENNA NO. 1 & 2
7	ILS ANTENNA NO. 3 & 4
8	L-BAND ANTENNA NO. 1
9	S-BAND TDRS ANT. NO. 1
10	S-BAND TDRS ANT. NO. 2
11	S-BAND TDRS ANT. NO. 3
12	S-BAND TDRS ANT. NO. 4
13	S-BAND TDRS ANT. NO. 5
14	S-BAND TDRS ANT. NO. 6
15	S-BAND TDRS ANT. NO. 7
16	EMERGENCY EGRESS HATCH
17	L-BAND ANTENNA NO. 2
18	UHF-LINK ANTENNA NO. 2

NOT ACCESSIBLE ORBITER BOTTOM SURFACE

NOT ACCESSIBLE ORBITER TOP & BOTTOM SURFACE

NOT ACCESSIBLE ORBITER L.H. & R.H. SIDE

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OPEN CHERRY PICKER (OCP)

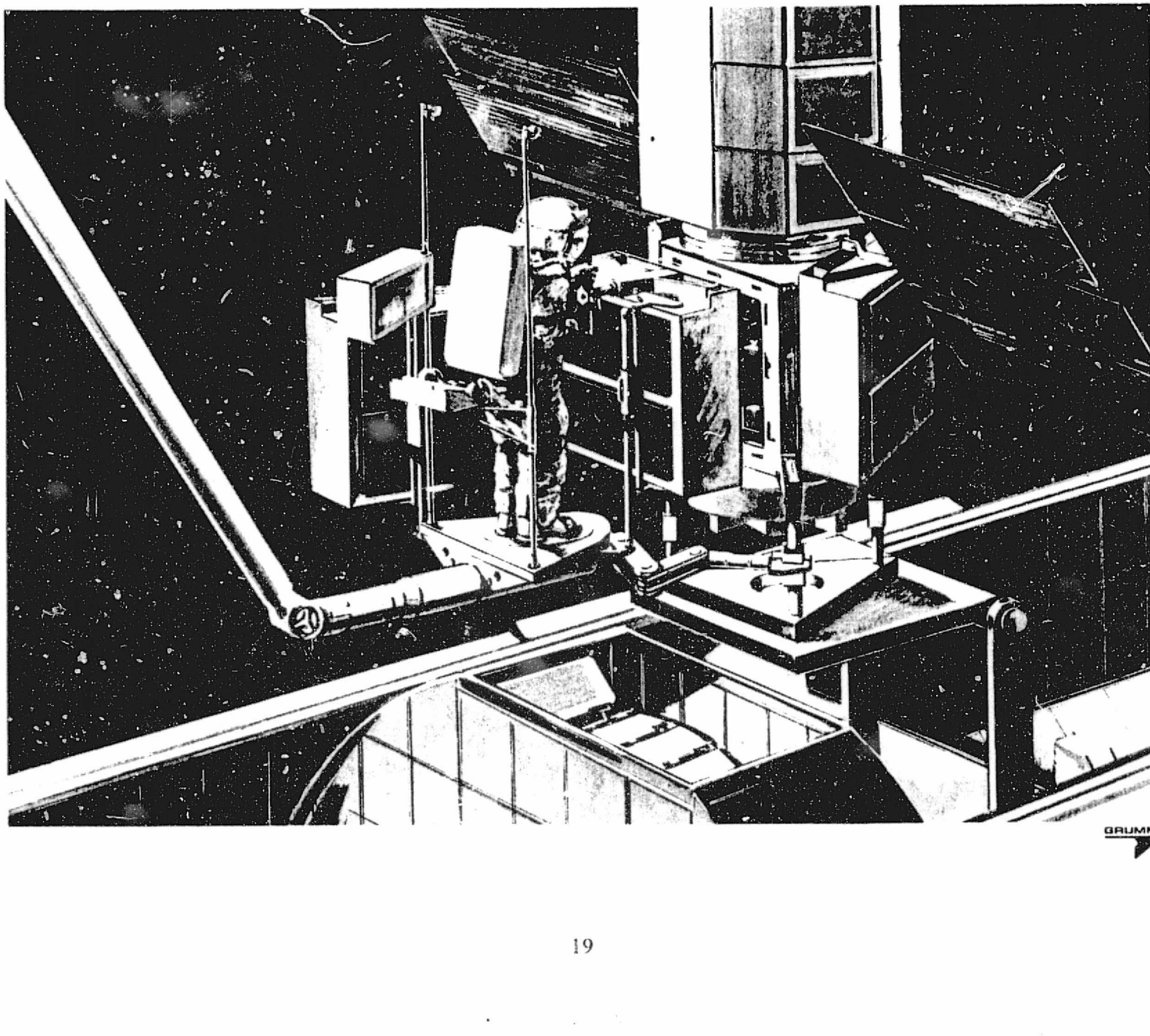
The opposite page is a rendering of the Open Cherry Picker (OCP) servicing the Multi-Mission Spacecraft. The platform is 91 cm (36 in.) wide and houses a foot restraint assembly on a rotary bearing for full 360 degree rotation by the astronaut. A 3 DOF stabilizer is mounted to the platform and is used to snare a worksite to minimize RMS motions during crew detailed work periods. A control console which includes MMU hand controllers and essential RMS controls and displays is mounted to a swivel. This feature allows the astronaut to rotate the control panel to the rear while working out the front of the cherry picker. Mission peculiar handling devices similar to the clamp mechanism shown for the MMS subsystem module are also mounted to the platform via a rotary joint. Two light stanchions are mounted to the rear of the platform and provide the astronaut with 20 foot candles of illumination at the worksite.

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 section of the cargo bay at the structural frames established for the MMU. The overall mass of the OCP is 197 kg including 25% contingency.

Mechanical and electrical interface with the SRMS 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 currently available in the SRMS 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.

The overall impact of introducing OCP into the Shuttle system is minimal. Development of the OCP also needs no special facilities. The equipments and capabilities already available at such JSC facilities as the Manipulator Development Facilities would be sufficient to flight-qualify the system as well as provide a training facility for the operational system.

OPEN CHERRY PICKER



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CLOSED CABIN CHERRY PICKER MISSIONS

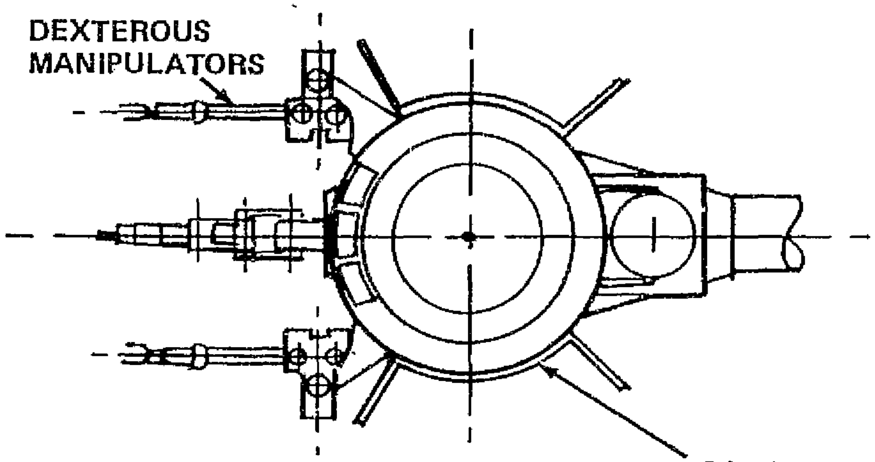
In the mid 1980s, an initial construction base will be deployed as an outgrowth of the power module. This base will initially be in a Shuttle-tended mode, meaning that the Shuttle provides the habitat during construction operations. Eventually, permanent habitats will be added and construction scenarios are planned that could require three shift operations of 30 to 90 days per Shuttle launch.

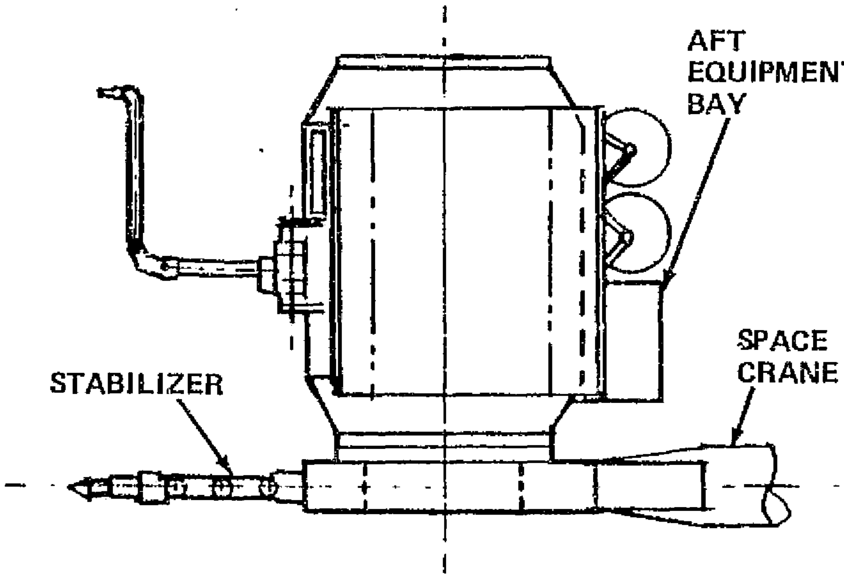
The longer mission durations and the need for three shift operations forces consideration of a closed environment for the Manned Remote Work Station. The radiation constraints of the South Atlantic Anomaly can impose a severe 30% reduction in overall mission productivity if a OCP is used during this time frame.

The facing page summarizes the functions performed by the cherry picker and the types of structure expected to be assembled by the MRWS. Studies performed over the past few years indicate that the likely candidates for in space construction are large radiometers, multi-beam communications antennas and Solar Power Satellite Development Articles The MRWS will perform the 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 itself.

The ultimate cherry picker application is constructing Solar Power Satellites. The functions performed are more specific for each task outlined on the opposite page. Each MRWS can be tailored to the task it is performing as opposed to the MRWS used at the mid 80s construction based where cherry picker tasks are more universal. It is expected that the design requirements for the mid 80s role will be more demanding than those for SPS construction.

CLOSED CABIN CHERRY PICKER MISSIONS





FUNCTIONS IN SUPPORT CONSTRUCTION & MAINTENANCE

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

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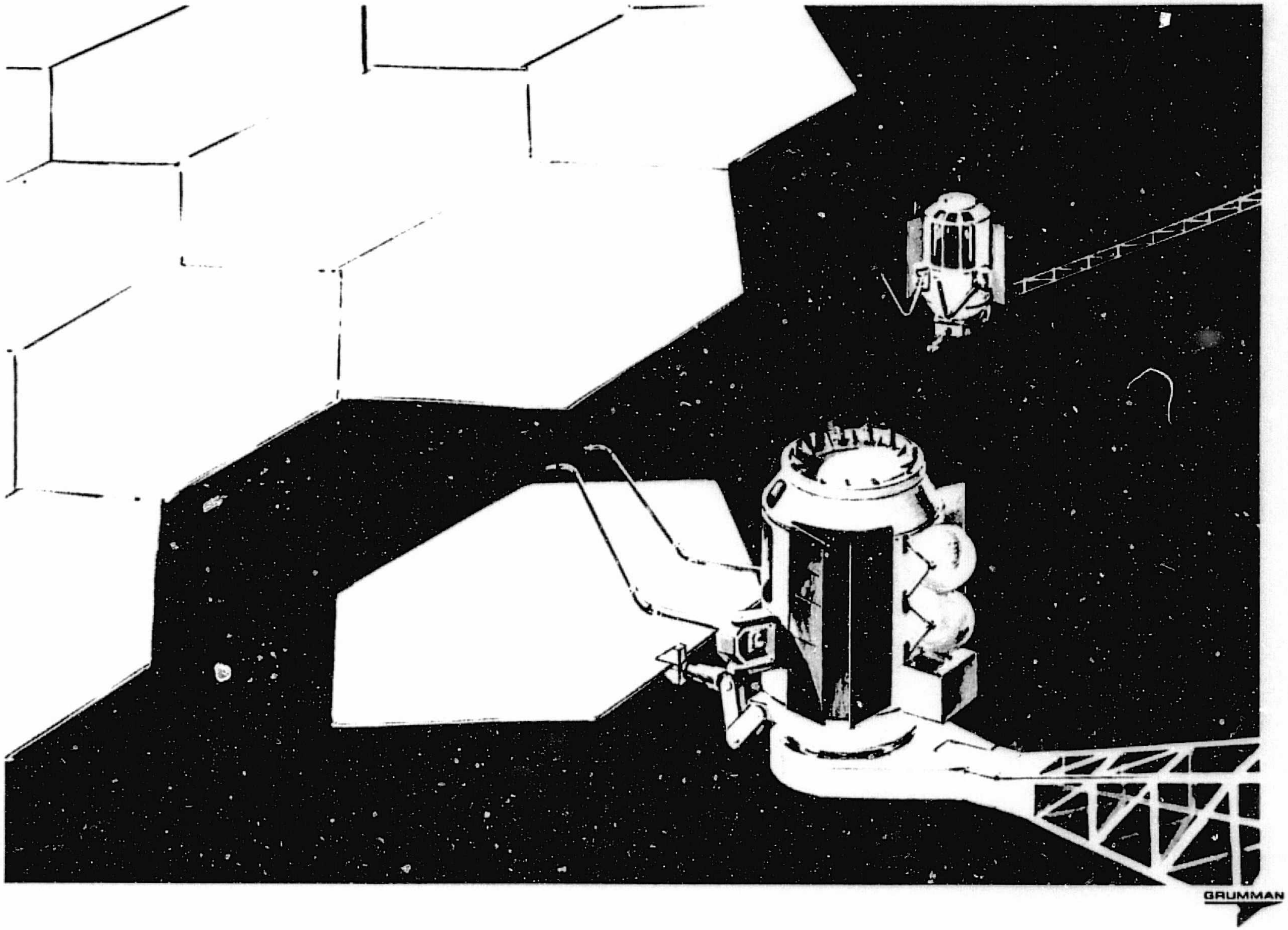
The opposite page displays a rendering of a closed cherry picker (CCP) handling a 4 m diameter aperture panel for a multi-beam communications antenna. The CCP is configured for one man operation from a single control console utilizing bilateral force-reflecting manipulators. The manipulator slaves are 2 m long while the masters located in the cabin are 50 cm long. Test data indicates that men operating BFR manipulators have the same productivity as a man in an EVA suit but benefit from the convenience of a shirt sleeve environment and can probably work longer shifts without fatigue.

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 49 cm resulting in an internal volume of 4.76 m^3. The cabin's atmosphere utilizes a two gas system operated at 14.7 psi. A total of 2.1 m^2 console area 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°-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) comprise the major portion of the total mass.

CLOSED CABIN CHERRY PICKER



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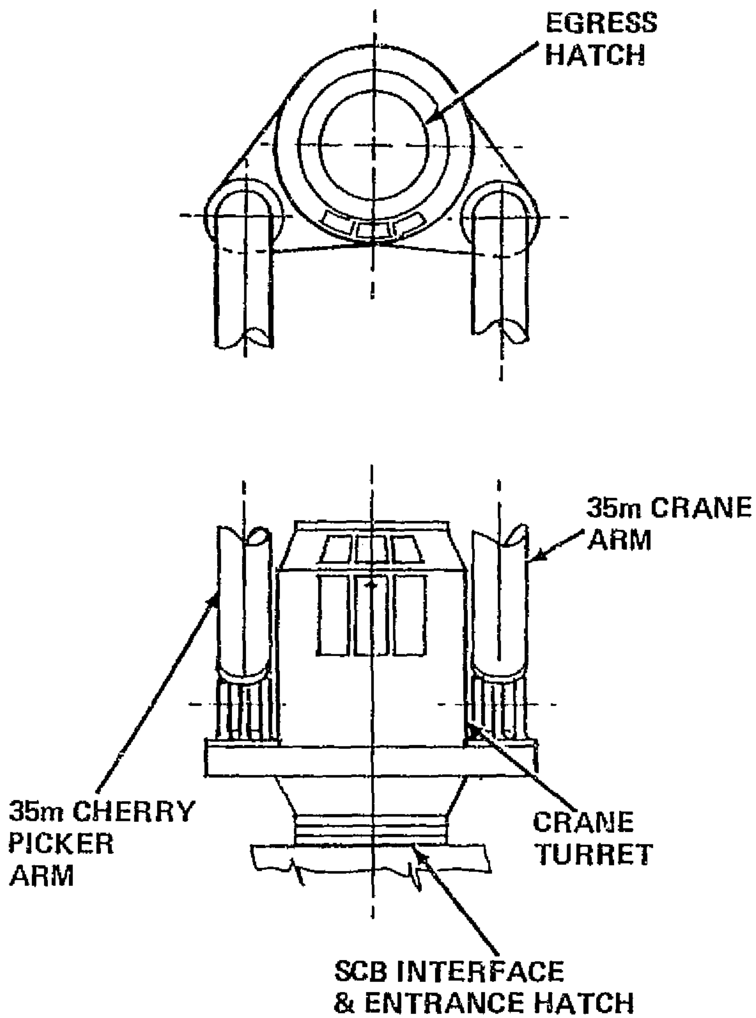
CRANE TURRET MISSIONS

The Space Station Systems Analysis Studies performed for JSC identified an initial construction base concept that utilizes two cranes controlled from a rotating crane turret mounted to a habitation module. The MRWS cabin selected for the closed cherry picker can meet the requirements for this construction role.

The opposite page summarizes the functions performed by the crane turret and presents a configuration concept that utilizes the MRWS. The MRWS is configured with hatches above and below, with the egress below through a rotary bearing required for crane turret operations.

CRANE TURRET MISSIONS



MRWS FUNCTIONS IN
SUPPORT OF SCB OPERATIONS

- OPERATOR STATION FOR LARGE SPACE CRANE
  - TRANSPORT & HANDLE STRUCTURE & SUBSYSTEMS
- BACKUP OPERATOR STATION FOR CHERRY PICKER CRANE ARM.
- AIRLOCK FOR TRANSFER OF CREW FROM SPACE CONSTRUCTION MODULE TO CHERRY PICKER

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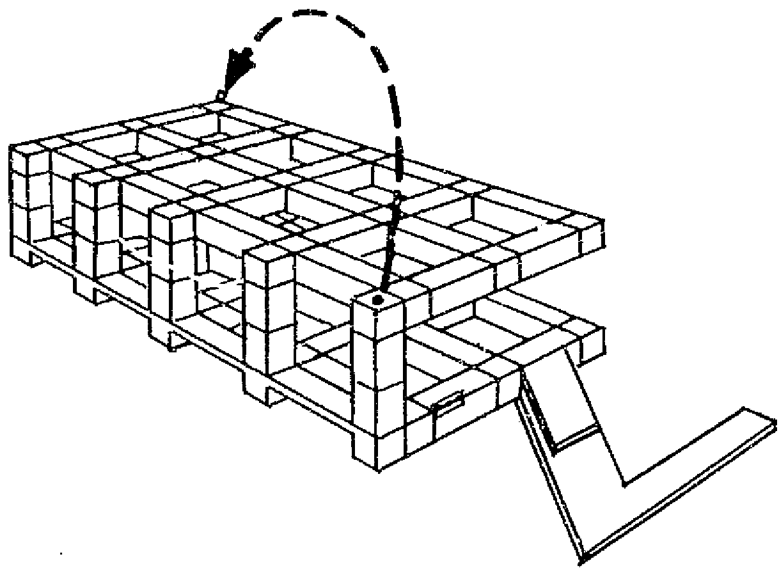
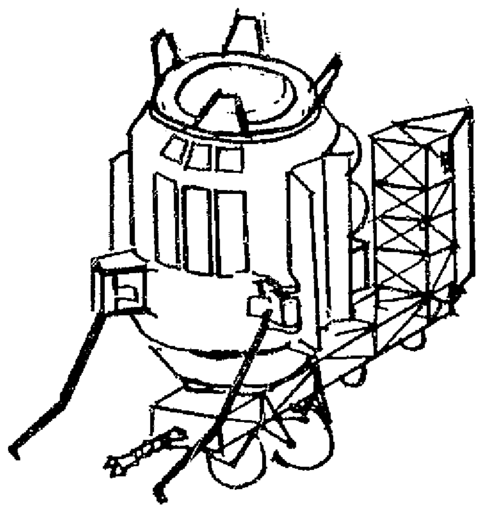
FREE FLYER MISSIONS

An construction technology is refined, assembly of Solar Power Satellites can become a reality. Construction bases in the 1990s may be as large as 1 to 2 km requiring a free flyer for quick repair, rescue and debris control. Operations will be performed in both low earth orbit (LEO) and in geosynchronous orbit (GEO) with assembly operations in GEO mainly concerned with berthing large structural segments of the SPS. A tug, similar to harbor tugs, will be required to assist in these berthing operations. The MRWS cabin is ideally suited to this role providing adequate volume and console area for the controls and displays required for rendezvous, stationkeeping and docking.

FREE FLYER MISSIONS





FUNCTIONS IN SUPPORT OF SPS CONSTRUCTION

- QUICK REPAIR
- RESCUE
- LARGE STRUCTURAL BERTHING OPERATIONS
- DEBRIS CONTROL

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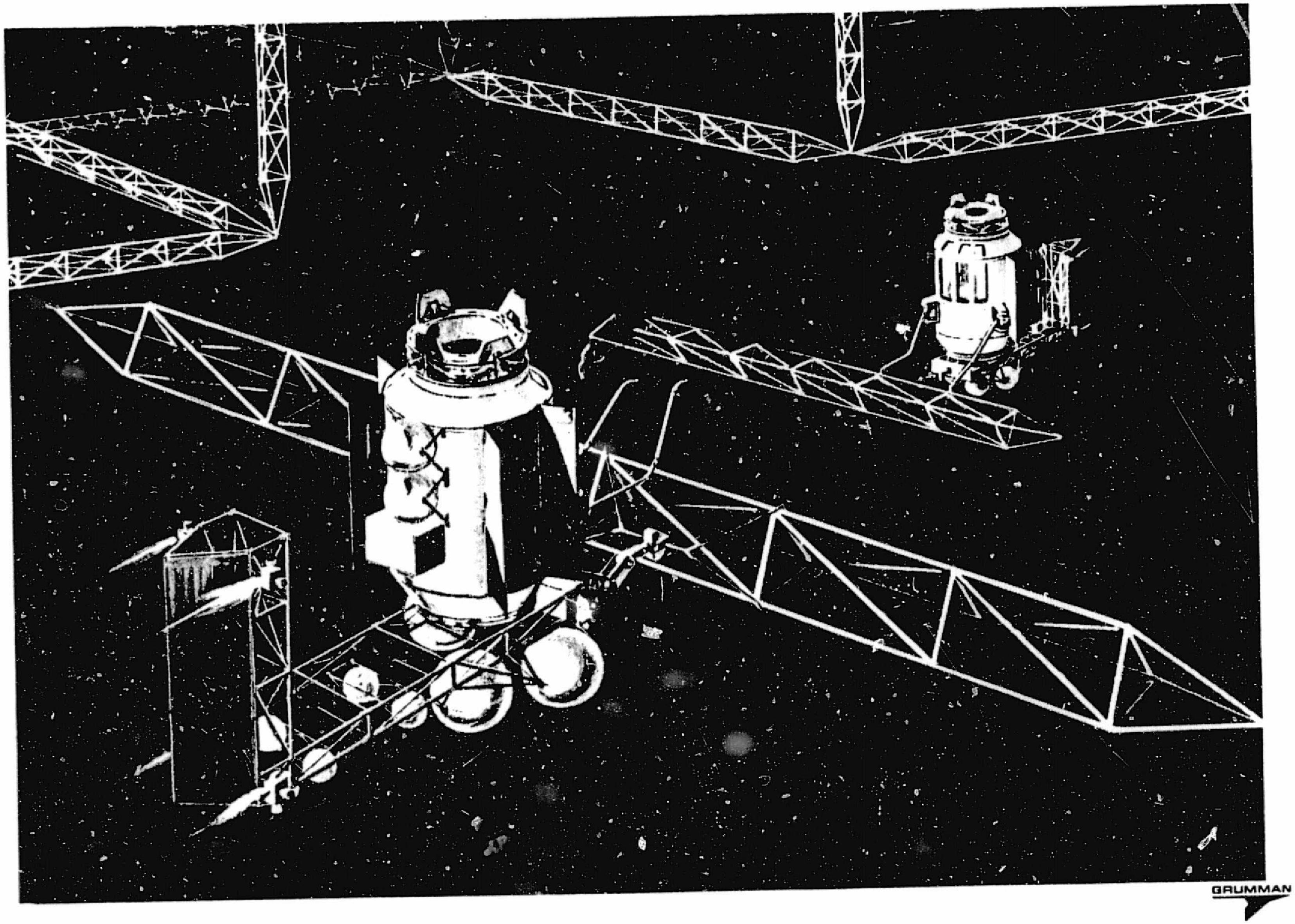
FREE FLYER

A rendering of an MRWS free flyer repairing a damaged structural element is shown on the opposite page. The MRWS cabin is mated to a platform that contains 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.

FREE FLYER

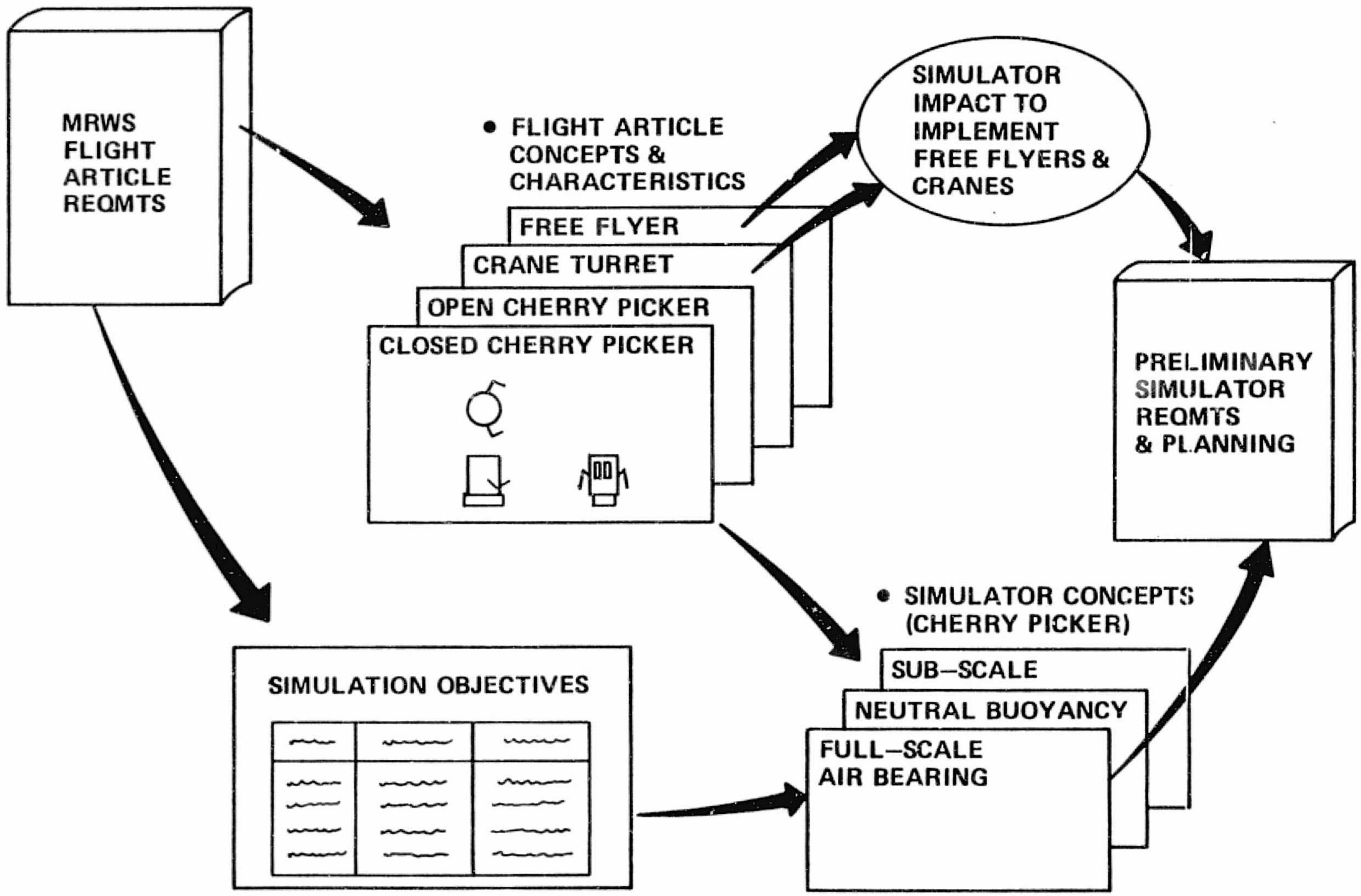


SIMULATION REQUIREMENTS DEFINITION APPROACH

The opposite page summarizes the approach used to transform MRW flight article requirements into simulation requirements. The Flight Article Requirements document, including mission roles for three times phases and supporting tradeoff and evaluation studies is used to identify key issues requiring simulation. These issues are then formatted into simulation objective which are analyzed for the type of simulator needed to meet the objectives. These simulator concepts have been broken down into full-scale simulations using an airbearing, neutral buoyancy and sub-scale simulators. Those falling into the category of full-scale simulation are used to repair the Preliminary Simulator Requirements and Plan.

The Simulator requirements document should be available in July and will be used as the basis for preliminary design of the Development Test Article.

SIMULATOR REQUIREMENTS DEFINITION APPROACH



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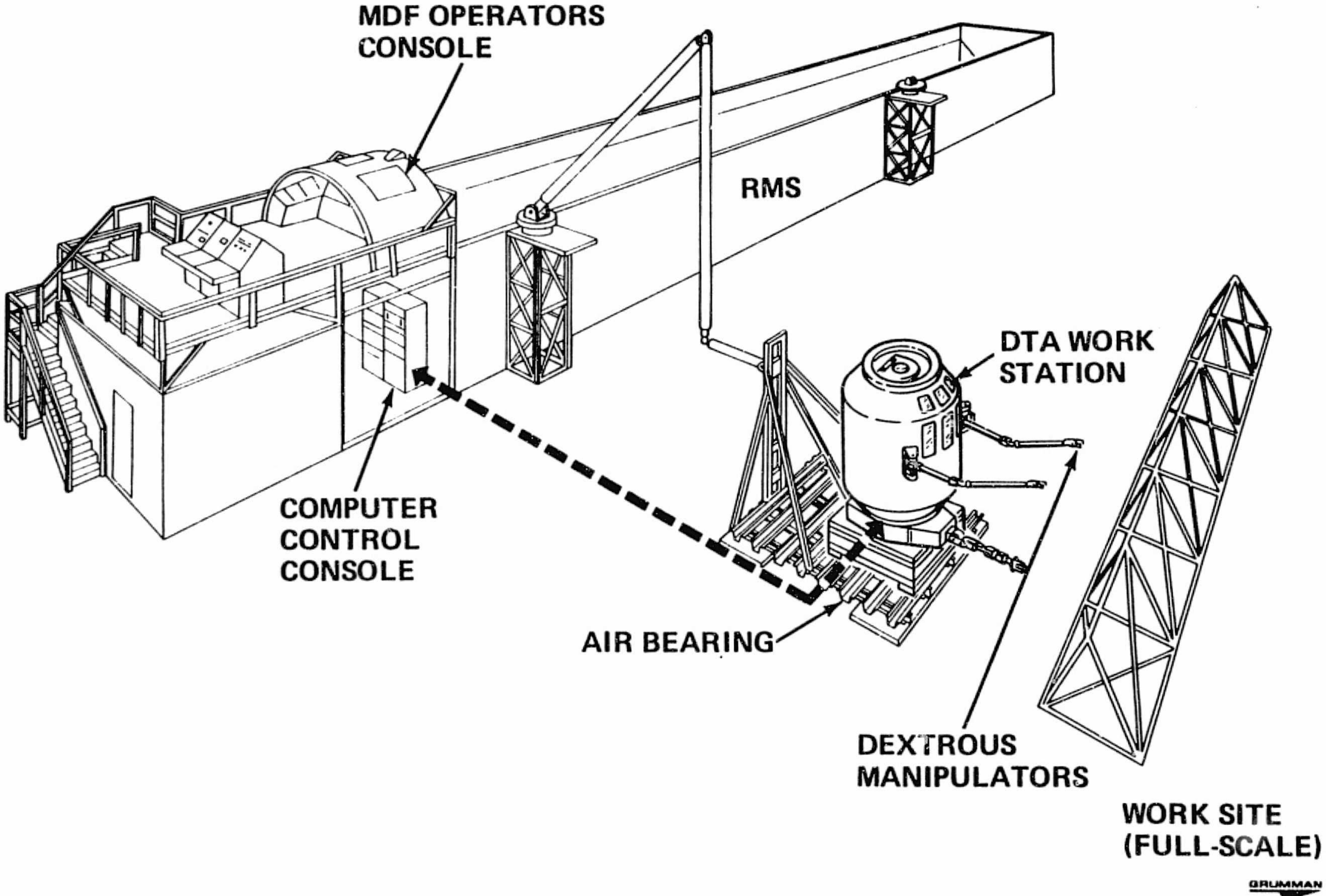
SIMULATOR APPROACH USING MDF AIR BEARING TABLE

Once a set of simulator objectives is compiled, preliminary design of the DTA is initiated for eventual installation in the Manipulator Development Facility (MDF). The concept shown on the opposite page utilizes the air bearing platform and RMS interface that already exists at the facility. Full-scale worksite elements are also positioned on the air bearing floor and will be configured with balloons or air bearing gimbals to achieve high fidelity zero g simulation.

SIMULATOR APPROACH USING MDF AIR BEARING TABLE



SIMULATOR PROGRAM OPTIONS

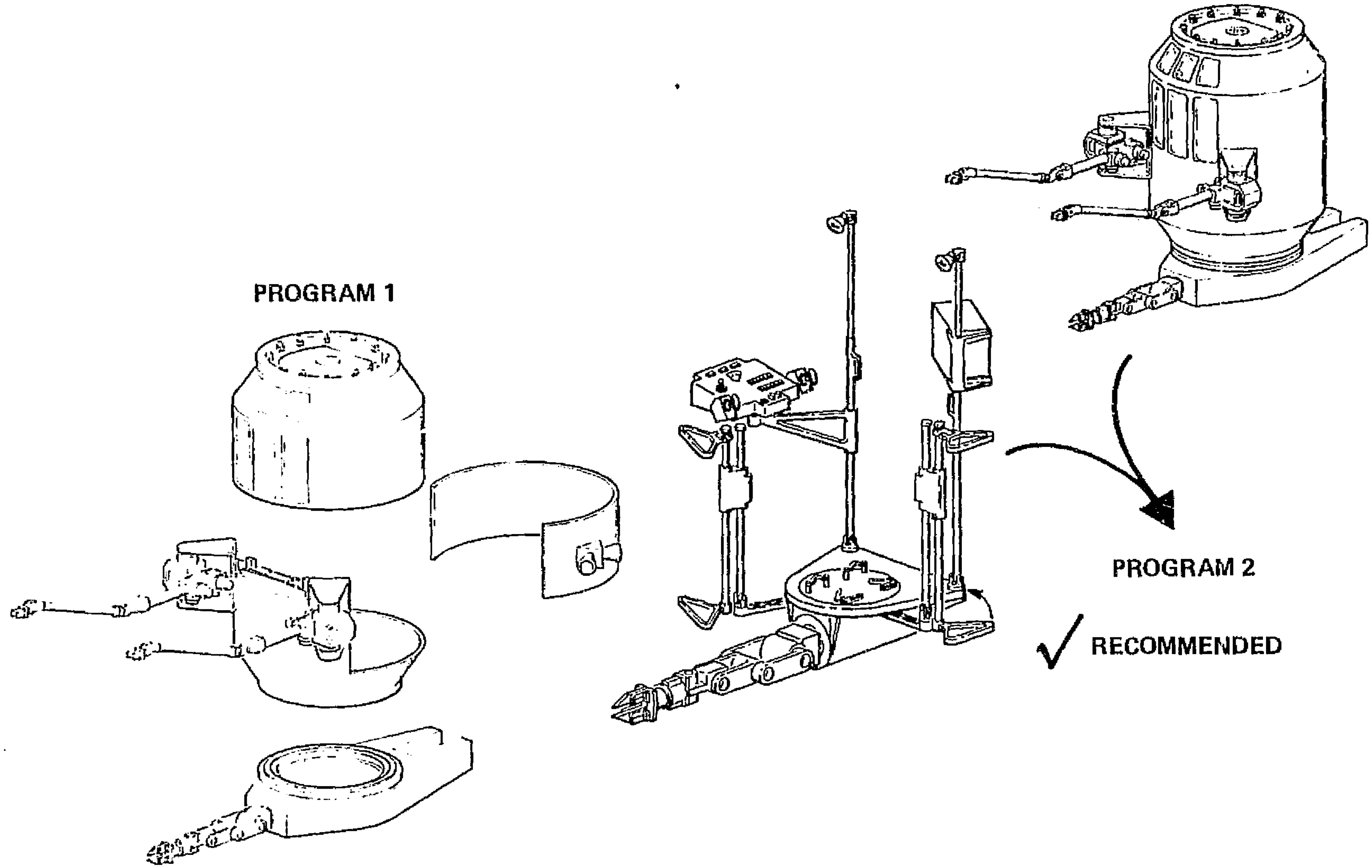
Two simulator program options have been studied that provide a growth in simulator capability over the next five years. The first approach (shown on the opposite page) is centered around a concept of modular buildup of the Development Test Article so that both the open cherry picker and closed cherry picker can be evaluated using the same hardware. In the second option, two dedicated DTAs are fabricated; the first is a high fidelity version of the open cherry picker and the second is a high fidelity article of the closed cherry picker.

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

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

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

SIMULATOR PROGRAM OPTIONS



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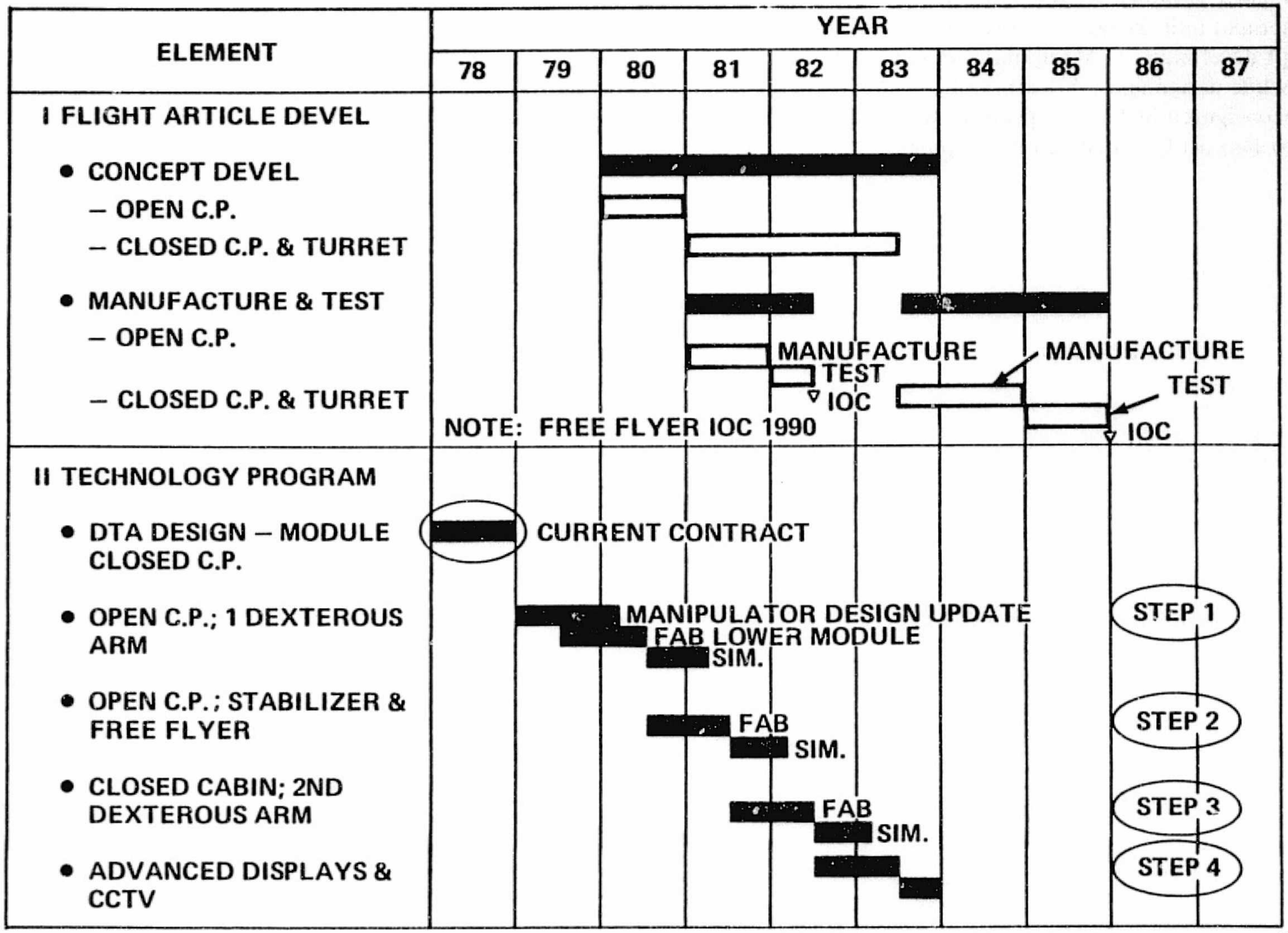
PROGRAM 1: DEVELOPMENT SCHEDULE

The opposite page summarizes the schedule for DTA development and how the simulation activity supports the flight article development. Based on mission analysis of MRWS flight article requirements an open cherry picker operated from the end of the Shuttle RMS is needed by mid 1982 or earlier to support automated payload servicing and construction R&D activities. It is anticipated that the closed cherry picker and crane turret will be phased into operation when the initial construction base is deployed in 1986.

The design of a closed cherry picker DTA that can be assembled in modules is performed in 1978 under the current contract. The lower module representative of the open cherry picker is fabricated in 1979 as is 1 dexterous manipulator. Testing of the OCP is then performed in 1980 in support of flight article concept development. A stabilizer and a jet system is added in 1980 and testing of free flyer operations in a open cabin configuration is performed in 1981. In 1981, the upper DTA structure is added as well as a second dexterous manipulator and testing performed in 1982. Advanced controls and displays are added in 1982 through 1983 in time to support concept development of the closed cherry picker flight article.

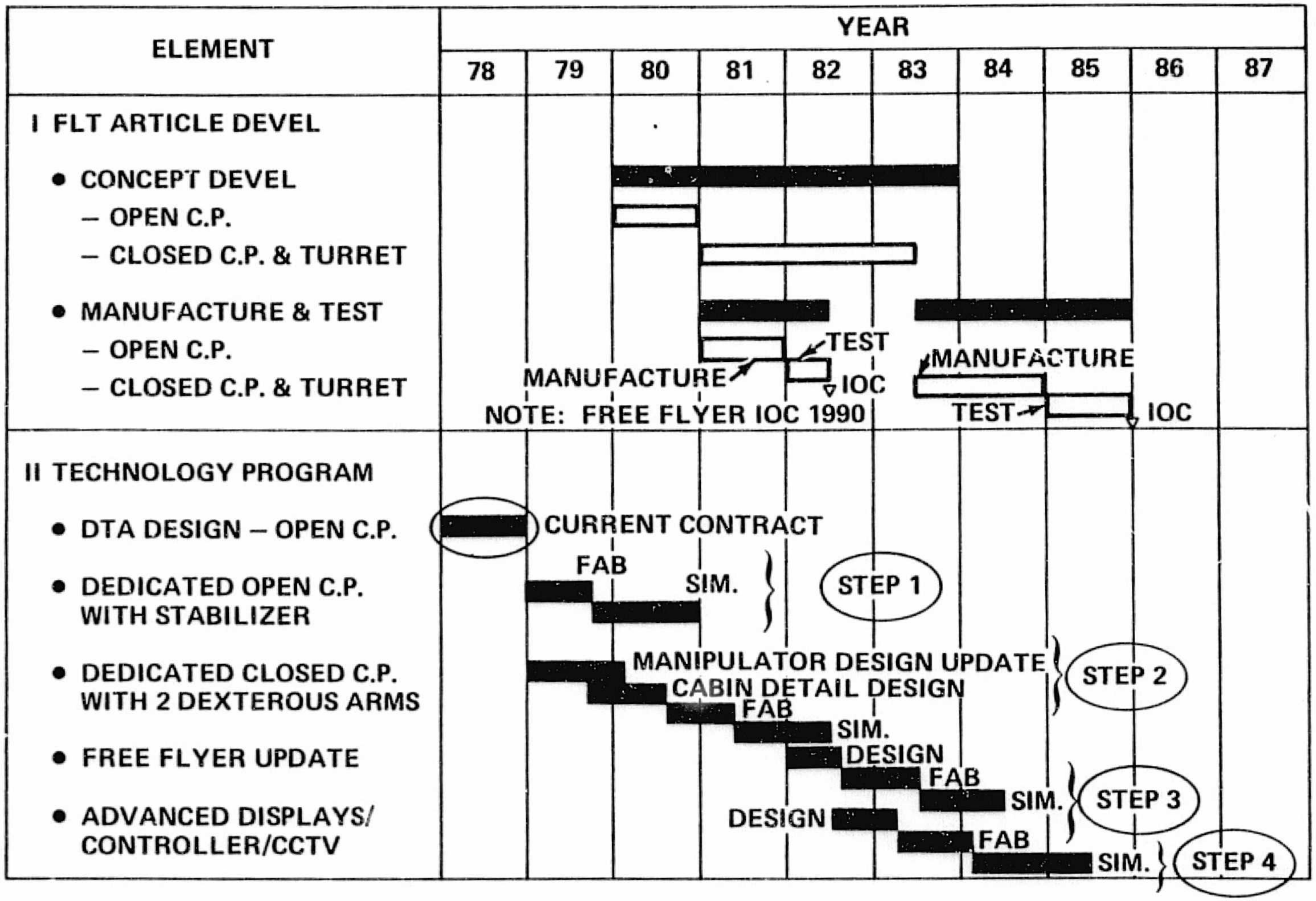
PROGRAM 1: DEVELOPMENT SCHEDULE



PROGRAM 2: DEVELOPMENT SCHEDULE

A summary of the steps in program 2 and how the simulation program phases with the flight article development and manufacture is shown on the opposite page. Design of a dedicated open cherry picker is performed under the current contract and built in the first 9 months of 1979. Open cherry picker testing is then performed into 1980 to support OCP concept development. Manipulator design and fabrication is also performed in 1979 and utilized in a bench test mode in 1980 while design and fabrication of the closed cherry picker is being performed. Testing of the CCP is initiated in 1981 and reconfigured in 1982 to perform free flight testing. Advanced controls and displays are added and tested in 1983 in time to support CCP concept development.

PROGRAM 2: DEVELOPMENT SCHEDULE



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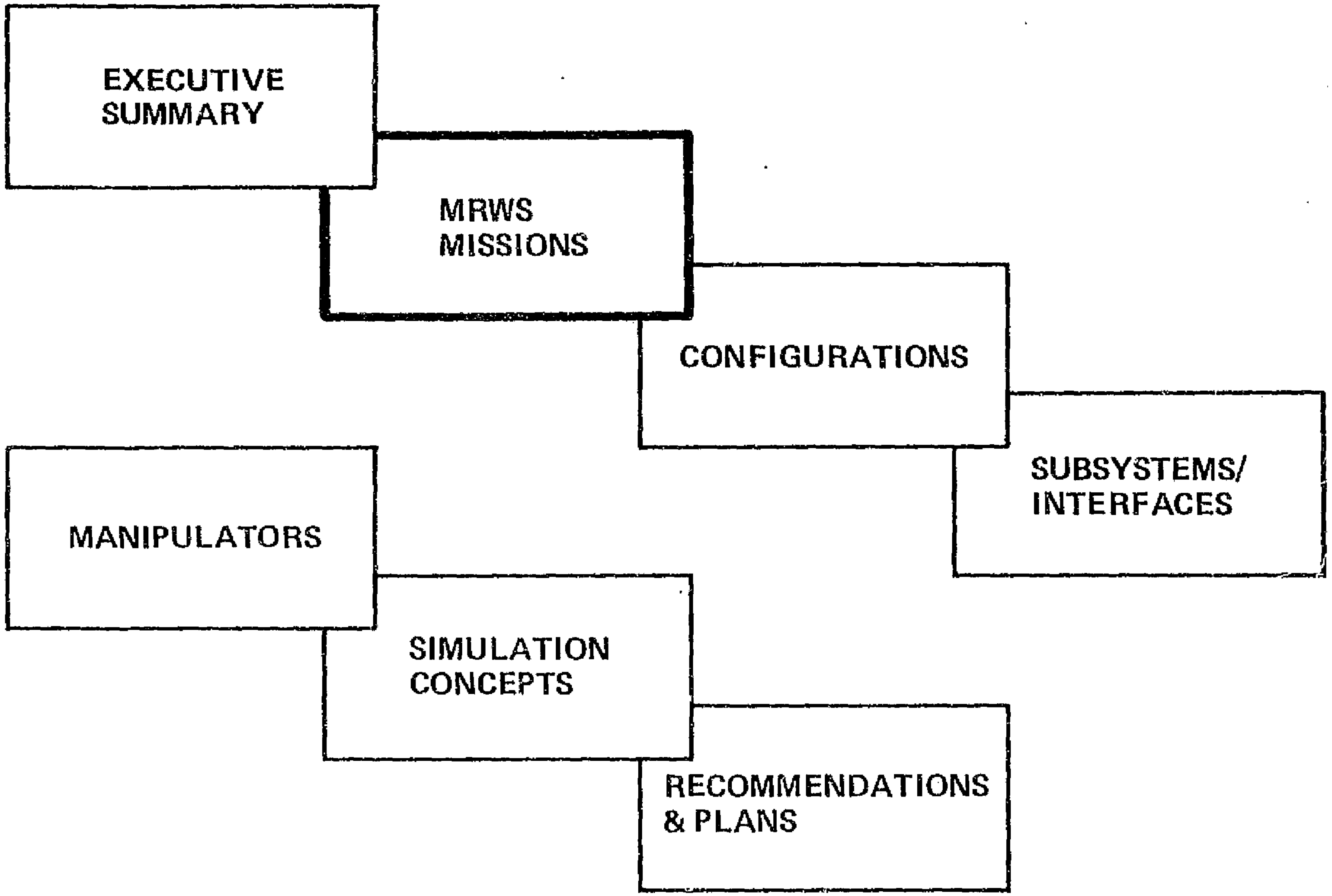
EXECUTIVE SUMMARY
MRWS MISSIONS
CONFIGURATIONS
SUBSYSTEMS/ INTERFACES
MANIPULATORS
SIMULATION CONCEPTS
RECOMMENDATIONS & PLANS

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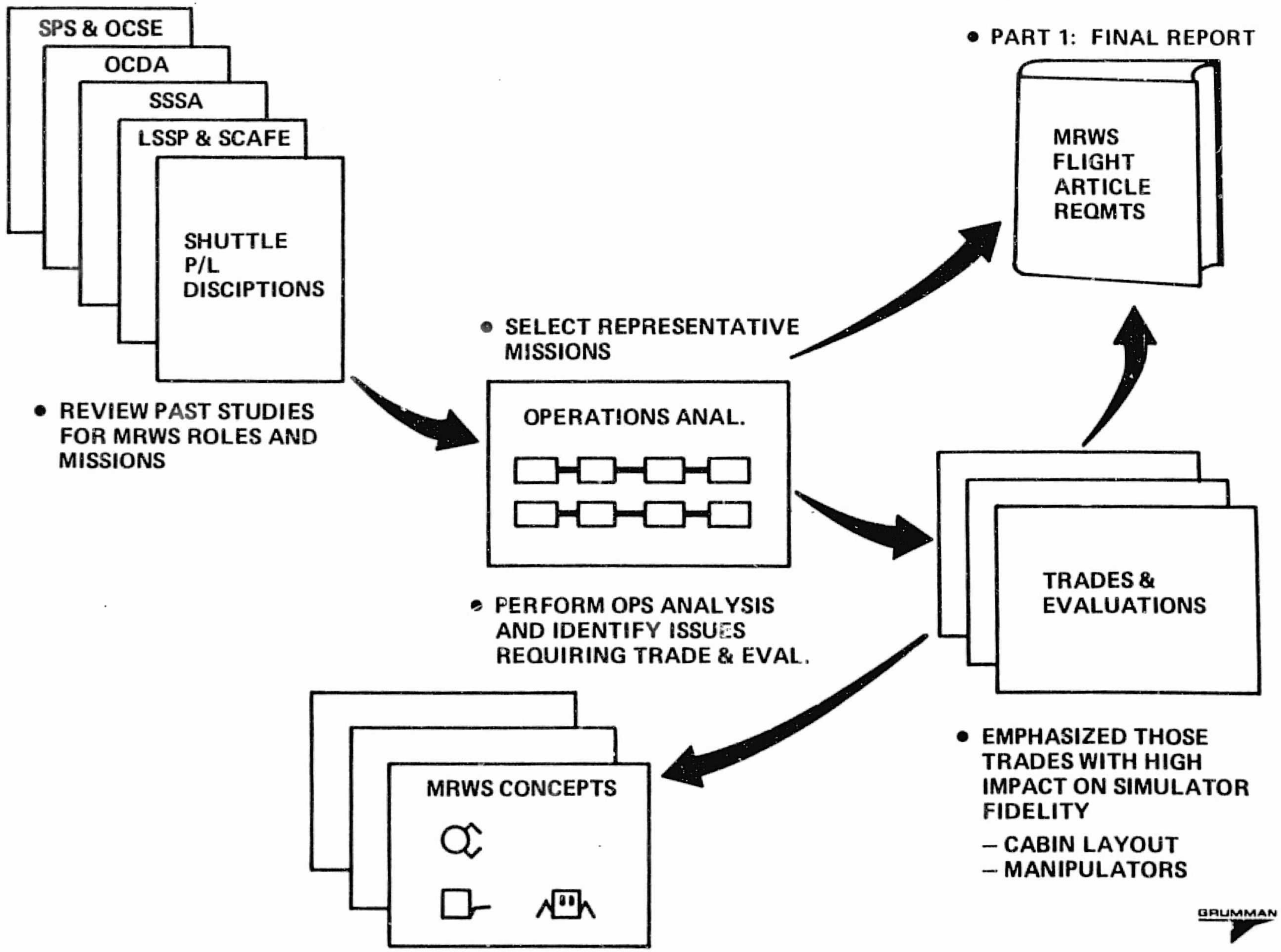
APPROACH TO FLIGHT ARTICLE CONCEPT ANALYSIS

Past Past studies on future initiatives and near term plans were reviewed for MRWS mission applications. Representative missions were then selected and MRWS roles defined by analyzing orbital operations. This analysis surfaced design and operational issues that were used as the basis for performing trade/evaluation studies. We concentrated our efforts on those trades that would have significant impact on determining the design requirements for the simulation MRWS. As a result of this analysis, the MRWS concepts evolved and flight article requirements determined.

APPROACH TO FLIGHT ARTICLE CONCEPT ANALYSIS



MRWS MISSION MATRIX

Future missions were reviewed for possible MRWS applications. The missions logically divided into three time periods. Near term (1982-1985), consisted of those missions supported directly by the Orbiter, such as: Multimission Modular Spacecraft, Long Duration Exposure Facility, Large Space Structure, Space Construction Automated Fabrication Experiment and Initial Space Construction Base. Mid term (1986-1990), utilized the Space Construction Base for assembly of large satellites such as: Microwave Power Transmission Development Article, Photovoltaic Solar Collector Development Article, 100-meter Radiometer and 61-meter Communications Antenna. Far term (1990-2000), concentrated on the Solar Power Satellite construction activities.

Two MRWS roles, fixed closed cherry picker and railed cabin, were found to have limited application. These functions were usually performed by the railed close cabin cherry picker.

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		SCB –OCDA	SPS CONSTRUCTION (PHOTOVOLTAIC)
• FIXED CRANE		SCB –STRONGBACK	SPS CONSTRUCTION (THERMAL)
• RAILED CRANE			SPS CONSTRUCTION (PHOTOVOLTAIC)
• RAILED CABIN			
• FIXED CABIN			SPS CONSTRUCTION (THERMAL)
• FREE FLYER			SPS CONSTRUCTION
• OTV CABIN		GEO. SATELLITE SERVICING	SPS CONSTRUCTION

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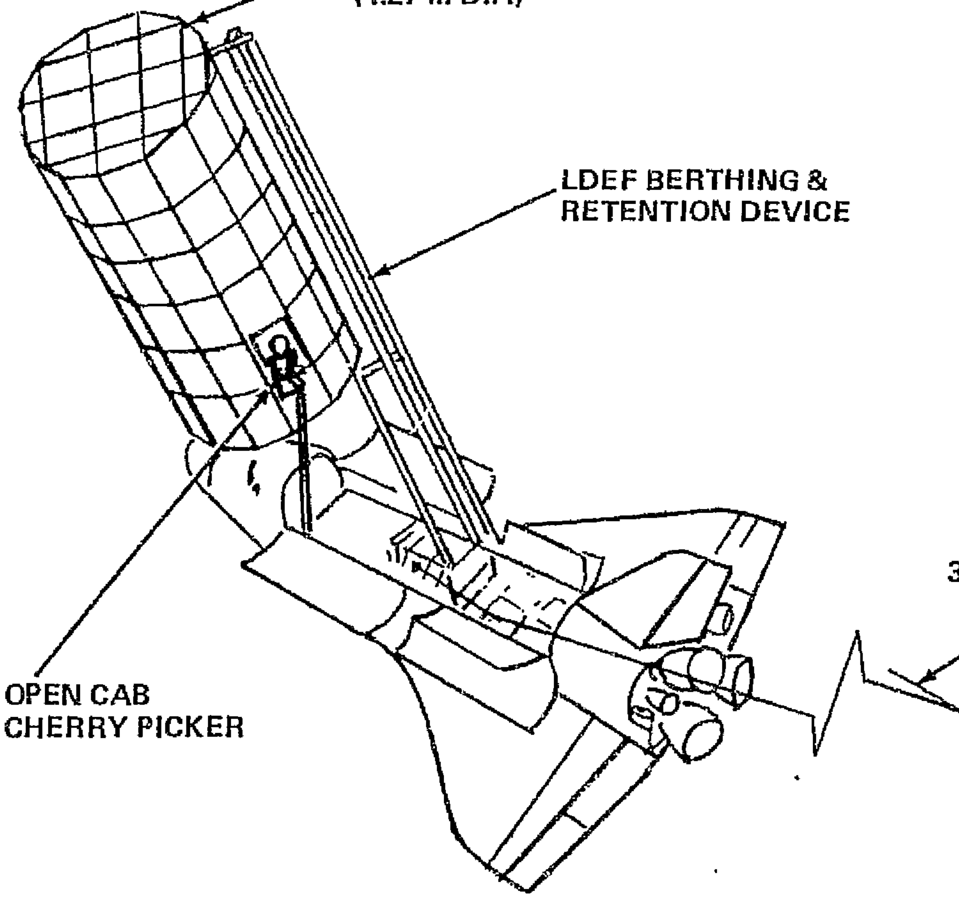
LONG DURATION EXPOSURE FACILITY SUPPORT

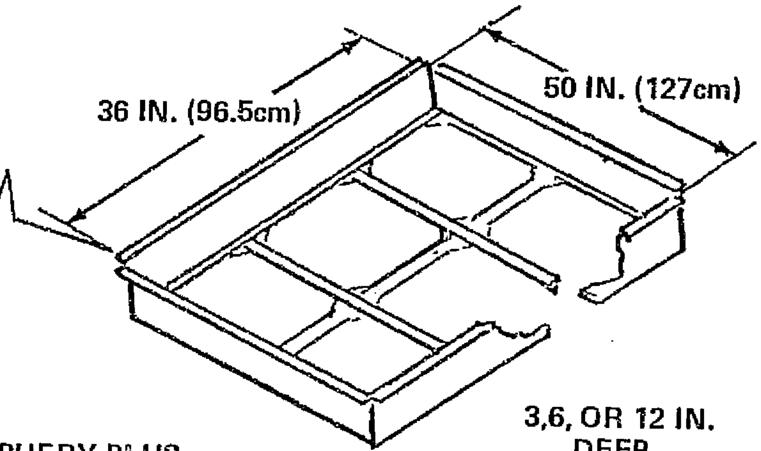
This gravity gradient stabilized facility will remain in low earth orbit for many months, while experiments mounted in trays are conducted. The open platform MRWS mounted on the end of the Orbiter RMS could be used by an EVA astroworker to replace trays, retrieve data and, service experiments. Requirements for astroworker position control of the Orbiter RMS, attachment method to the platform, and illumination and means of handling trays are evident in this mission.

LONG DURATION EXPOSURE FACILITY SUPPORT



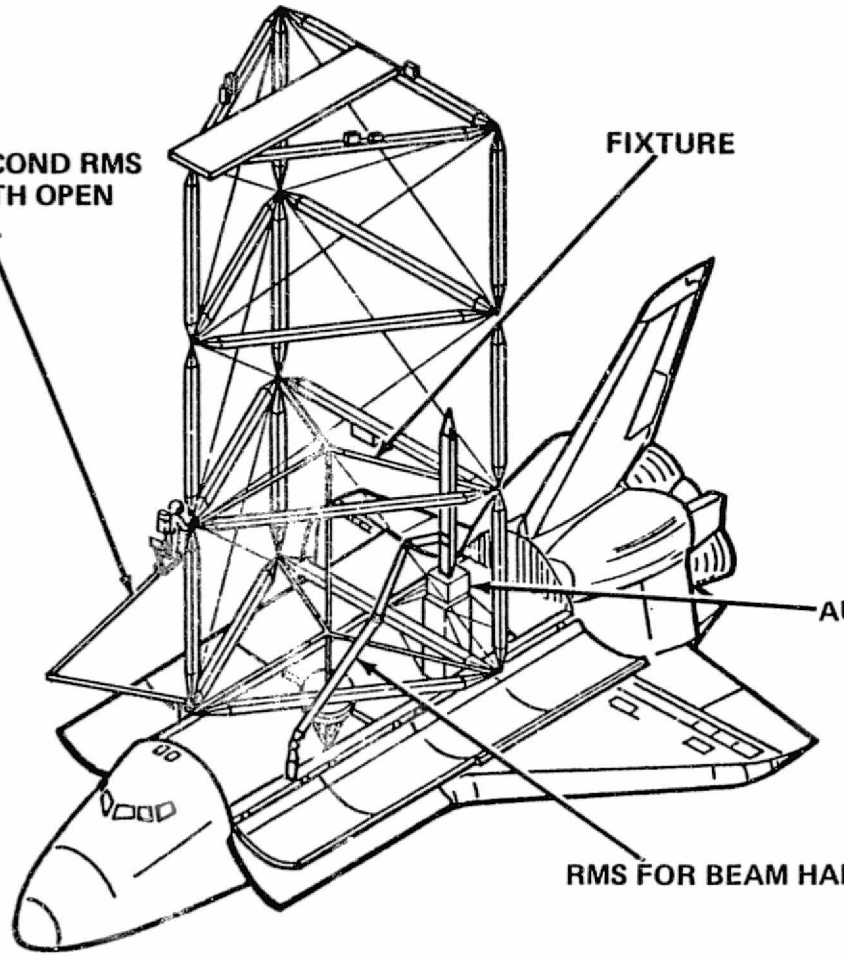
MRWS FUNCTIONS

- RETRIEVE & REPLACE EXPERIMENT TRAYS
- INSPECTION & DATA COLLECTION AT EXPERIMENT TRAYS



The baseline method of building this structure utilizes two astroworkers and the RMS. If a single astroworker used the second RMS open platform cherry picker concept for translation and as a stable platform during assembly tasks, his productivity could be improved. This is possible because translation time is reduced, and work associated with translating minimized, thereby lessening astroworker fatigue. Requirements for structure avoidance are evidenced here requiring joint by joint control of the Orbiter RMS, and means of crew alert when the platform or RMS is moving toward potential impact with the structure.

SUPPORT CONSTRUCTION OF LSS PLATFORM



OPEN CHERRY PICKER FUNCTIONS

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

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OPEN CHERRY PICKER SYSTEM REQUIREMENTS

These requirements were determined as a consequence of analyzing the near term missions. The open platform should be designed for operation by one person and should be able to transport a second astroworker. Controls and displays must be provided on the open platform so that the attached RMS can be maneuvered anywhere within normal travel limits. Selection of MRWS control location is at the Orbiter RMS control station. A stabilizer controlled at the platform should be provided to stabilize the open platform during work activities. Means of obstacle avoidance should be provided. Control of the second orbiter RMS not attached to the MRWS platform is desirable. After coarse positioning of the RMS from the orbiter, the platform astroworker could control final positioning of the second RMS because he has better close in visibility than the orbiter crew. In the event of RMS incapability, to return the crew to the orbiter payload bay, the open platform astroworker must be able to travel along the RMS utilizing suitable hand holes and tether.

OPEN CHERRY PICKER SYSTEM REQUIREMENTS

- MISSION TIME COMPATIBLE WITH STS
- ONE PERSON ACCOMMODATION
- CAPABLE OF TRANSPORTING SECOND PERSON
- COMPATIBLE WITH ORBITER P/L BAY STOWAGE & SRMS INTERFACES
- STOWAGE VOLUME 150 cm X 110 cm X 90 cm
- MRWS CONTROL OF SRMS
- ORBITER SRMS CONTROL SHALL OVERIDE MRWS CONTROL
- ADAPTER TO REACT ASTROWORKER INDUCED LOADS 650 kg & 340 Nm
- HANDLE PAYLOADS 1 m X 2 m X 3 m MASS 200 kg
- TOOL & PART STORAGE 20 cm X 35 cm X 50 cm
- PROVIDE SRMS C&W & OBSTACLE AVOIDANCE
- PROVIDE MEANS OF CONTROLLING SECOND SRMS FROM MRWS
- ILLUMINATION AT WORKSITE 50 F–C
- PROVIDE FOR ON ORBIT MAINTENANCE
- ASTROWORKER SHALL BE CAPABLE OR RETURNING TO ORBITER UNAIDED IN EVENT OF SRMS MALFUNCTION

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ASSEMBLY TIME COMPARISON

Comparison of time to assemble three beams of the LSS platform was made with and without the open cherry picker using underwater simulation as a reference.

Underwater simulation using two astroworkers was used as reference to transport beams from stowage, align and assemble three beam in an LSS fixture. If tethers had been included, the assembly operation time of 45 minutes would be increased. Next, the same operations were performed with a single astroworker during the assembly and the automatic beam machine produced beams and the remote manipulator used to transport the beams to the assembly area. This reduced the estimated time of assembly by approximately 29%. Then the open cherry picker was utilized by one astroworker to assemble the same three beams. Here we see a further reduction in estimated assembly time by 33% for the same operation without the cherry picker. The primary advantages of the open cherry picker is the improvement in astroworker translation time and reduction in fatigue due to translation effort and tether restrictions. Subsequent EVA activities will show a more dramatic improvement in assembly time, 49%, because no time allocation for platform deployment is required.

ASSEMBLY TIME COMPARISON
EVA & WITH OPEN CHERRY PICKER

	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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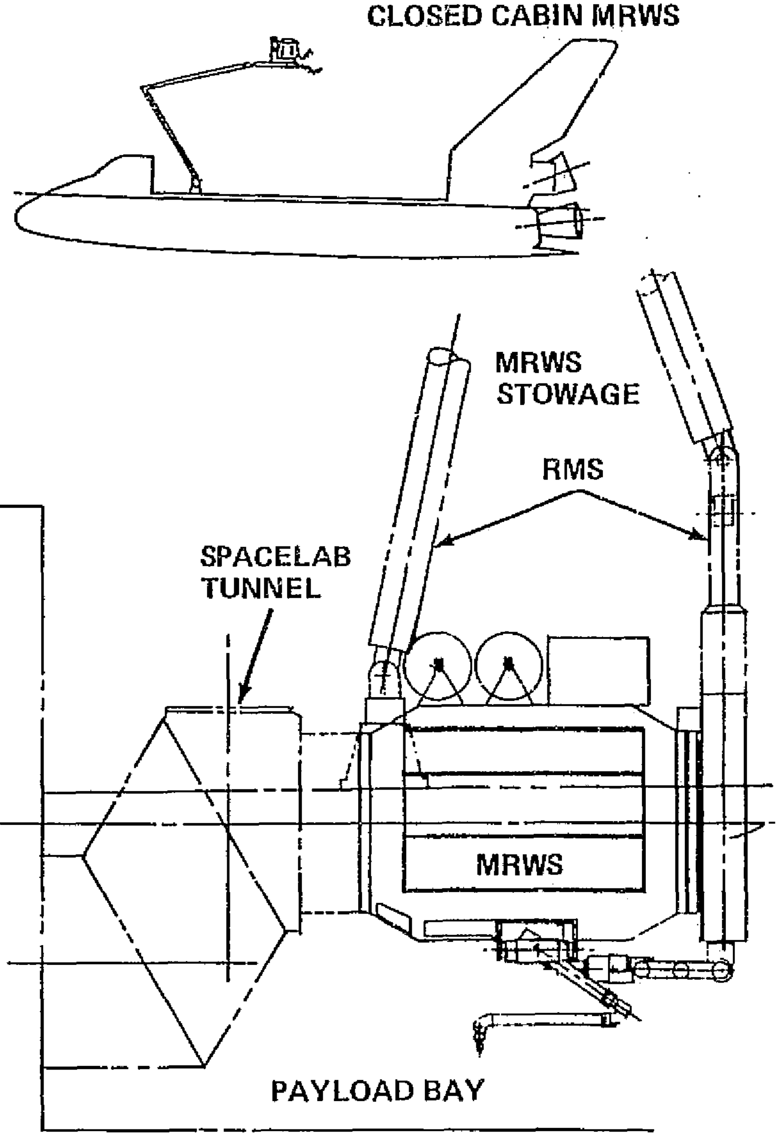
TRANSITION FROM OPEN TO CLOSED CABIN

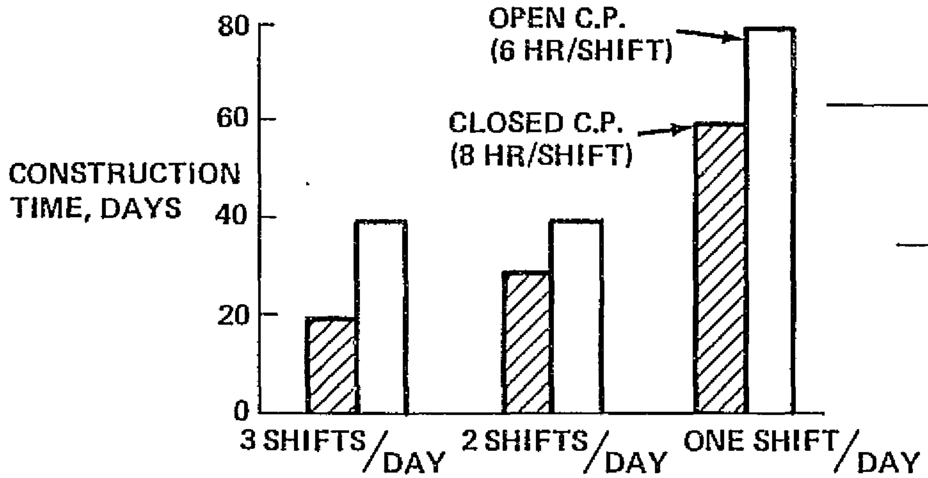
When the open platform constraints shown on the opposite page impact construction operations, the following advantages of a closed cabin MRWS should be utilized: extended on-station work time, improved crew productivity, and reduced hazardous operations. EVA preparations require 3½ hour prebreathing and 1½ hour post EVA activity. For an eleven hour EVA work day, less than six hours is spent on construction tasks. Radiation protection is required in synchronous orbit and low earth orbit activities are impacted by the South Atlantic anomaly. Improvement in low earth orbit operations with a closed cabin over an open platform is illustrated using the construction of the microwave antenna development article as an example. A closed cabin MRWS reduces the time for construction by extending the work shift by two hours; and for three shift operations, the closed cabin further reduces construction time. Third shift EVA is hazardous due to South Atlantic radiation therefore, no advantage is gained by adding a third EVA shift.

TRANSITION FROM OPEN TO CLOSED CABIN

OPEN CABIN CONSTRAINTS:

- GEO. OPERATIONS
- EVA LIMIT 6 HR/DAY
- CREW PRODUCTIVITY
- HAZARDOUS OPERATIONS
- SOUTH ATLANTIC ANOMOLY
  - IMPACT ON MICROWAVE ANTENNA DEVELOPMENT ARTICLE CONSTRUCTION





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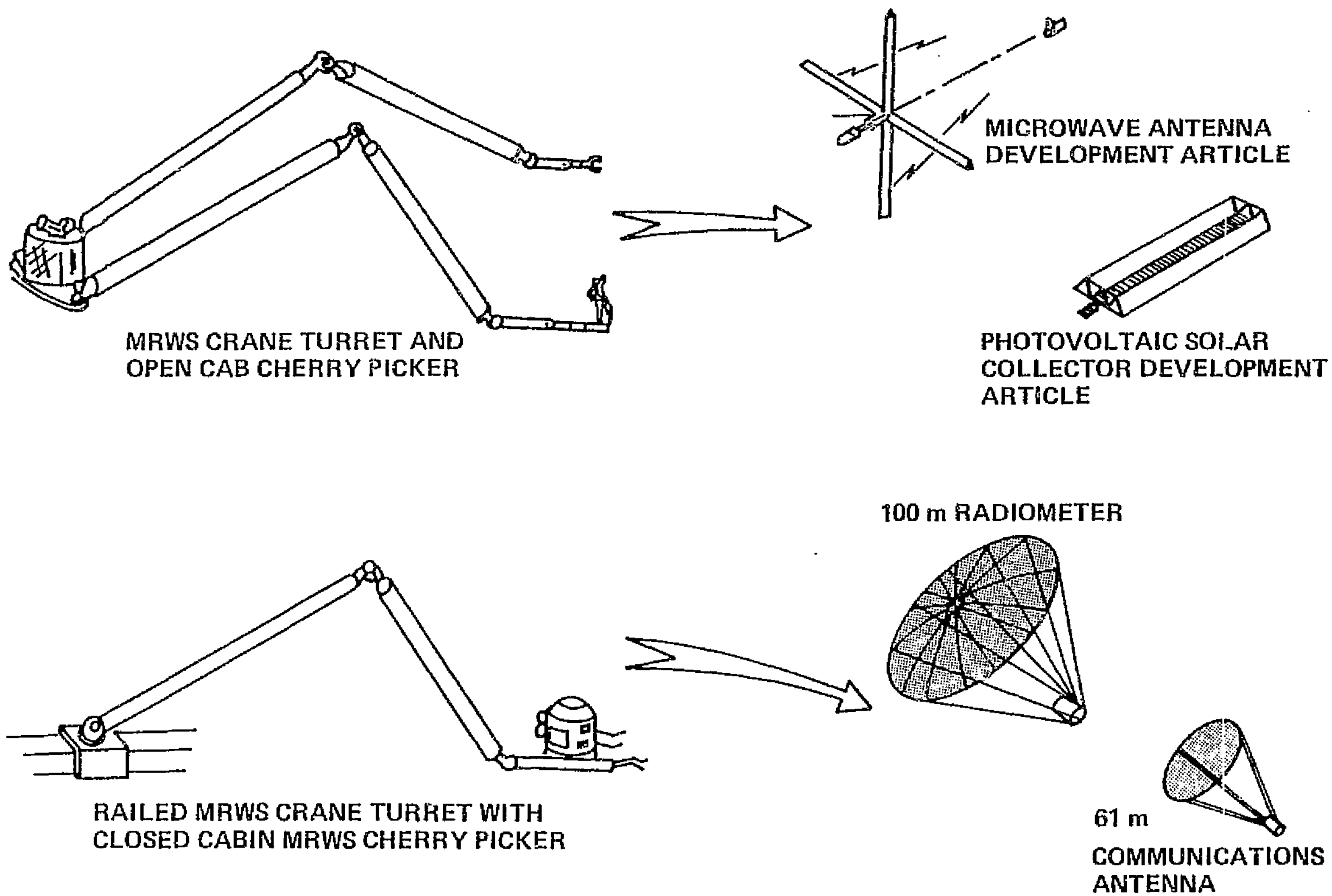
MID TERM REPRESENTATIVE MISSIONS

The initial Space Construction Base will be used to construct a number of different satellites. Four construction scenarios were studied to further define MRWS requirements. The fixed base crane and open cherry picker platform were utilized to build a crossed Microwave Antenna SPS Development Article and 1 MW Photovoltaic Solar Collector SPS Development Article. Components in these construction scenarios are ground-fabricated for orbital assembly. Requirements are established for the crane turret and additional open platform requirements were determined. Two other satellite assembly scenarios studied are the 100-meter Radiometer and the 61-meter Communications Antenna. These satellites were built by a Space Construction Base that has two railed closed cabin cherry pickers mounted on an assembly platform. Again, major components are ground-fabricated; however, the specific assembly tasks to be done are different from those previously studied, but the generic tasks (handle, align, fasten, adjust) are similar. The analysis of these scenarios provided closed cabin MRWS requirements.

MID TERM REPRESENTATIVE MISSIONS



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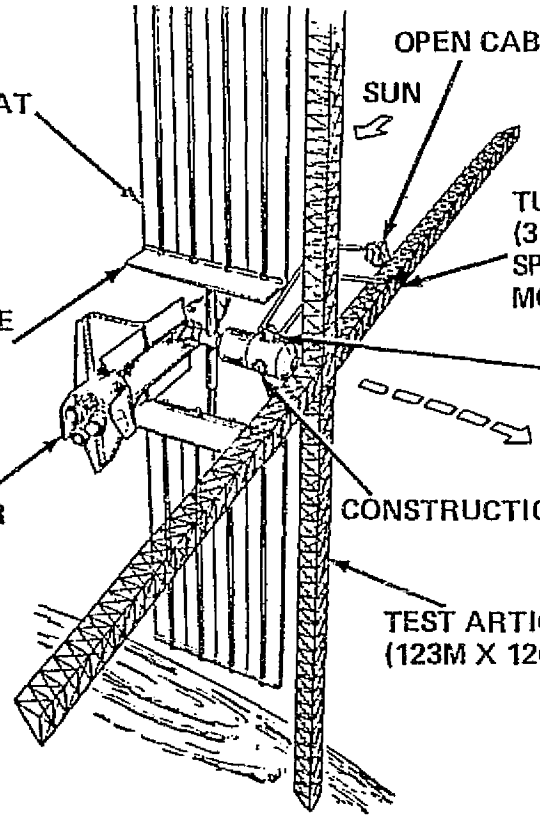
MRWS REQUIREMENTS IN SUPPORT OF SOLAR POWER MICROWAVE ANTENNA DEVELOPMENT

Solar power microwave antenna development article assembly consists of deploying segments of long cross arms which contain waveguides, amplitrons and power cables. Phase control electronics are installed on each segment after deployment. These segments are 4.5 meter in diameter x 15.8 meters long for the vertical arm and 17.6 meters long for the horizontal arm. The crane turret operator is afforded a good view of the crane arm when moving the folded antenna segments. The astroworker in the cherry picker has a better vantage point during the later part of each assembly task. He can place the open platform close to the work and direct or control the positioning of the antenna segments. The final alignment and attachment of each segment is done by the EVA astroworkers. This includes mechanical, electrical power and, signal cable connections.

MRWS REQUIREMENTS IN SUPPORT OF MICROWAVE ANTENNA DEVELOPMENT



ANTENNA OBJECTIVES

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

CRANE TURRET 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

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CRANE TURRET SYSTEM REQUIREMENTS

The crane turret interfaces should be compatible with the Orbiter and Spacelab with respect to operational time, payload stowage, hatch sizes, and environmental control. The turret cab perform a second function by serving as an airlock for the EVA astroworker to egress to the open platform. Subsystem requirements should permit orderly growth to final capability for SPS support. Closed circuit TV is required for crane control and construction supervision purposes.

CRANE TURRET SYSTEM REQUIREMENTS

- INITIAL CRANE TURRET MISSIONS ARE 30 DAYS WITH A REQUIREMENT FOR ON-ORBIT SERVICING. GROWTH TO 10 YRS MISSION WITH ON-ORBIT SERVICING
- THE CRANE TURRET SHOULD BE DESIGNED FOR (SHIRTSLEEVE) OPERATION BY ONE MAN; TWO GAS; 14.7 psi ATMOSPHERE
- THE CRANE TURRET CABIN SHOULD BE INTERFACED TO BASE THRU A 360° ROTARY BEARING. EACH CRANE ARM SHOULD HAVE AN INDEPENDENT AZIMUTH ROTATION
- THE CRANE TURRET SHOULD HAVE AN UPPER AND LOWER ONE METER DIAMETER EGRESS HATCH. THIS ARRANGEMENT PERMITS USE OF THE CABIN AS AN AIRLOCK FOR EGRESS FROM THE CONSTRUCTION MODULE TO THE CHERRY PICKER
- THE CRANE TURRET SHOULD BE DESIGNED WITH AN INDEPENDENT HEAT REJECTION/ECLS SYSTEM FOR GROWTH TO ULTIMATE SPS CONSTRUCTION ROLE
- INTERFACE WITH A PUMP DOWN AIR EVACUATION SYSTEM SHOULD BE CONSIDERED FOR SCB APPLICATION. A BLOW DOWN SYSTEM SHOULD BE USED FOR ULTIMATE APPLICATIONS
- THE CRANE TURRET OPERATOR SHOULD CONTROL ONE CRANE ARM AT A TIME UTILIZING ATCA/TTCA HAND CONTROLLERS
- TWO SCREEN CCTV SYSTEM SHOULD BE PROVIDED
- SUPPORTS AND RESTRAINTS SHOULD BE PROVIDED FOR OPERATOR
- CAB WINDOWS SHOULD BE SIZED FOR MAXIMUM WORK ZONE VISIBILITY
- CONTROLS/DISPLAYS REQUIRED FOR CCTV, ICS, ECLS, EPS AND ILLUMINATION SUBSYSTEMS

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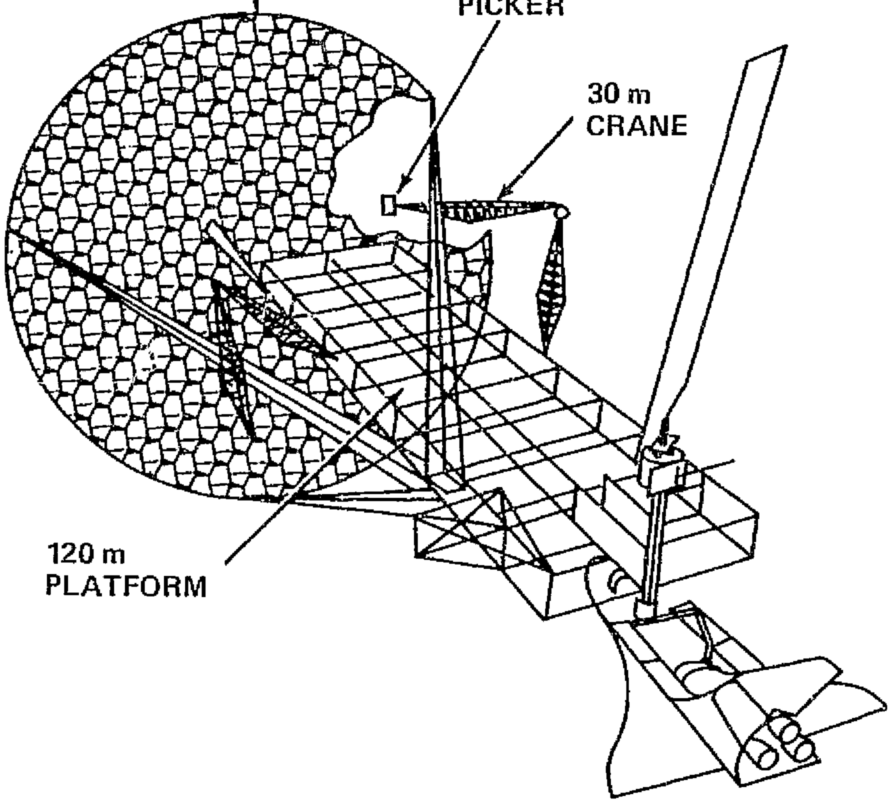
MRWS REQUIREMENTS IN SUPPORT OF COMMUNICATION ANTENNA CONSTRUCTION

Two railed cherry picker MRWS mounted on a platform configuration Space Construction Base were used in the 61 m communications antenna construction scenario. The first task is to mount and align the turn table, and the electronics feed fixtures. Then antenna construction commences with the removal of lens panels from the Orbiter payload bay, transportation to the work site and mounting on the construction turntable. After the lens has been completed, requirements are established for mounting and aligning the electronics feed assembly on its fixture. Support struts are assembled to join the feed structure to the lens. Subsystems must be installed and antenna checkout prior to deployment.

MRWS REQUIREMENTS IN SUPPORT OF COMMUNICATIONS ANTENNA CONSTRUCTION



ANTENNA FUNCTIONS

- MULTI BEAM-HI RESOLUTION COMMUNICATIONS
  - 256 FIXED BEAMS
  - 16 SCANNING BEAMS
  - 110 km RESOLUTION

CLOSED CHERRY PICKER FUNCTIONS

- HANDLE, INSTALL & ALIGN CONSTRUCTION FIXTURES
- HANDLE, INSTALL & ALIGN APERTURE ELEMENTS
- HANDLE, INSTALL & ALIGN FEED ELECTRONICS PACKAGE AND SUPPORT STRUCTURE

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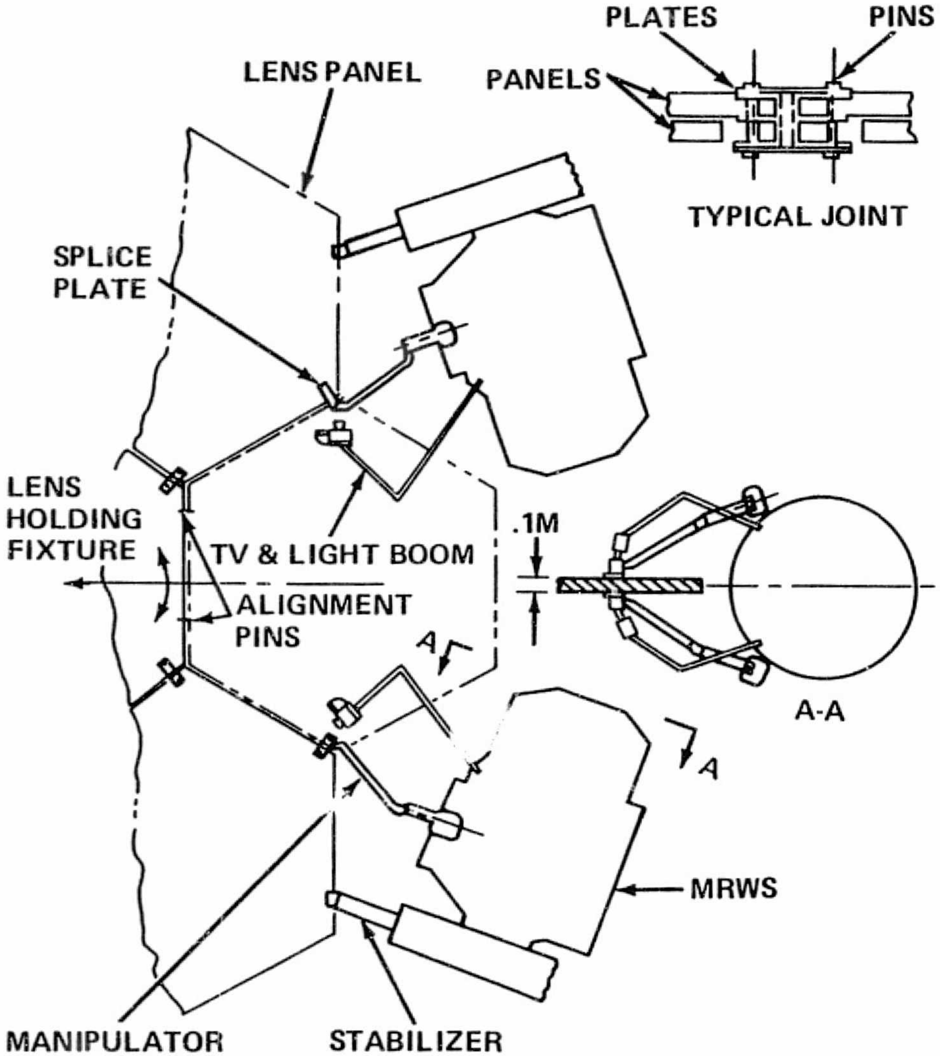
ANTENNA LENS PANEL ASSEMBLY

Many MRWS requirements are evident in this sketch of the 61 m antenna lens assembly. The MRWS manipulators must be capable of handling the 4.5 m diameter lens panels and maneuvering them into position for attachment to other panels. The size and design approach require grapple/manipulator handling points; means of aligning the panels must be determined. It is assumed alignment pins will be provided on one edge of one side and that two attachment points are provided on opposite points of the hexagon panel. The joint shown is typical of ground-based construction approaches. This requires reach-around capability, and piece parts, an undesirable time consuming situation for space construction. Crew visibility needs dictate closed circuit TV and illumination aids.

ANTENNA LENS ASSEMBLY



LENS PANEL CHARACTERISTICS

- 4.5 m DIAMETER, .38 m DEPTH (DEPLOYED)
- 35 kg EACH
- 226 PANELS

MRWS OPERATIONS

- GRAPPLE
  - HANDLE PANELS DURING CRANE MOTION AT 0.5 m PER SECOND
  - INSERT PANELS INTO RETENTION FIXTURE MOUNTED TO ADJACENT PANELS
- MANIPULATOR
  - FASTEN PANEL AT 2 PLACES

TASK TIME

- 10 MIN. TO HANDLE
- 220 MIN. TO FASTEN

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CLOSED CABIN CHERRY PICKER SYSTEM REQUIREMENTS

These requirements compliment those specified for the open cabin cherry picker and the crane turret MRWS and introduce new requirements. Because the cherry picker MRWS operates at some distance from the habitation/operation center, independent power and ECLS subsystems are required. Also, crew safety issues must be addressed, such as life support in the event of loss of cabin integrity and EVA needs when docking is impossible. Dexterous manipulator/grappler requirements are evidenced here and obstacle avoidance needs must be specified. Out-the-window crew visibility, controls, and restraint systems are all driven by the manipulator design and tasks to be performed.

CLOSED CABIN CHERRY PICKER SYSTEM REQUIREMENTS

- ONE PERSON SHIRT SLEEVE
- TWO GAS 14.7 psi ATMOSPHERE
- TWO 8-HOUR SHIFTS/DAY FOR 6 DAYS
- UPPER AND LOWER EGRESS HATCH
- BACKUP FOR LOSS OF CABIN PRESSURE
- $\pm$ 180° CABIN ROTATION
- WINDOW SIZED FOR MAXIMUM VISIBILITY
- TWO SCREEN CCTV
- C&D FOR CCTV, COMM, ECLS, EPS & ILLUMINATION
- SIMULTANEOUS CONTROL OF TWO DEXTEROUS MANIPULATORS
- POWER CONTROLLED STABILIZER
- OBSTACLE AVOIDANCE
- SUPPORT & RESTRAINT FOR OPERATOR
- ELECTRICAL POWER VIA HARDWIRE
- WORKSITE ILLUMINATION
- RF COMMUNICATIONS
- CONTROL SECOND CRANE

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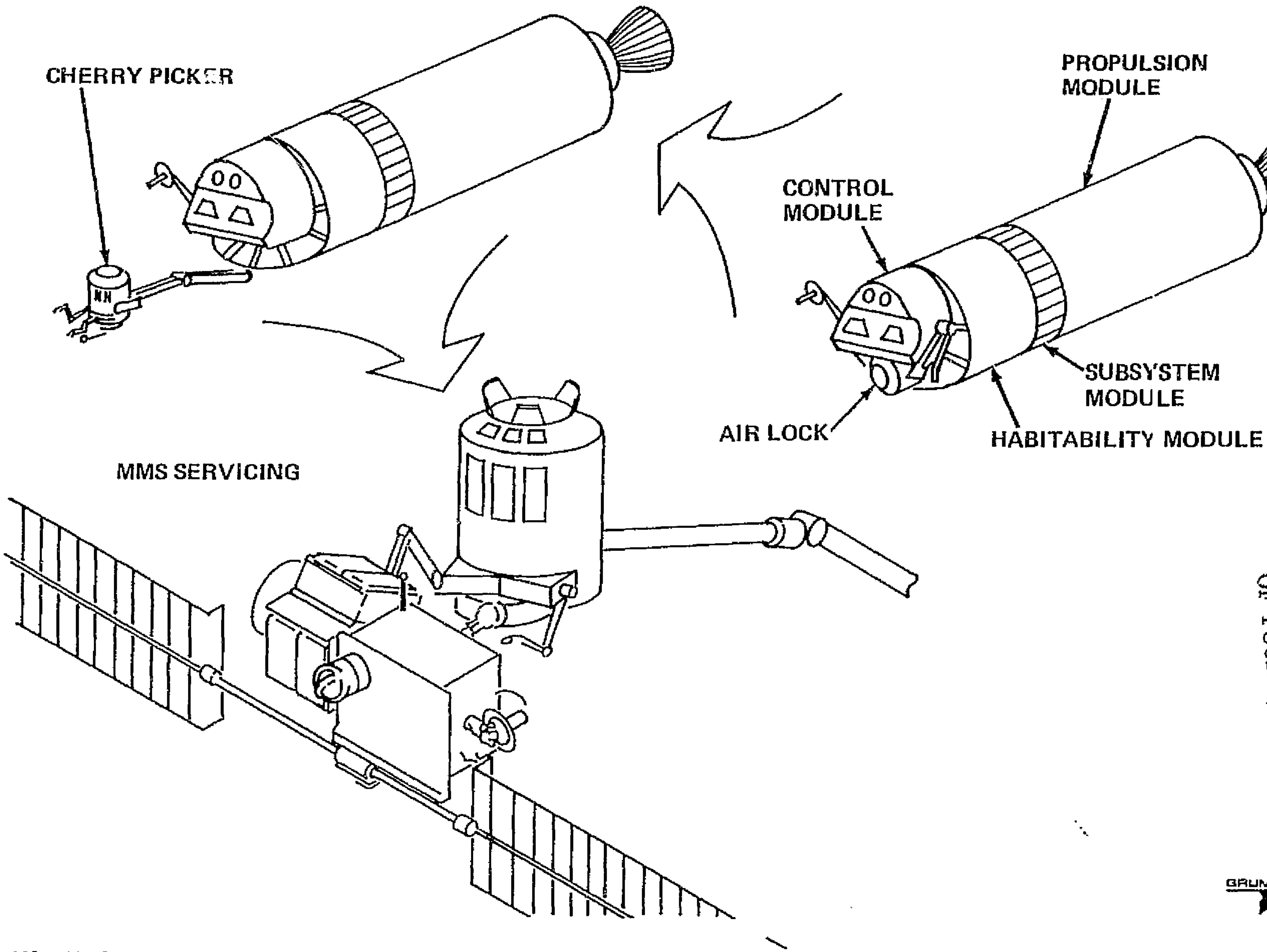
PERSONNEL ORBIT TRANSFER VEHICLE SUPPORT FUNCTIONS

A potential MRWS application as a combined cherry picker and airlock for the Personnel Oribt Transfer Vehicle (POTV) is shown on the opposite page. The POTV, with potential introduction in the late 1980s, is used for geosynchronous sortie missions for repair and retrieval of satellites and for varied construction activities associated with SPS development articles and Public Service Platforms. The MRWS can be utilized as the egress path airlock, for this vehicle as well as a cherry picker for close-in, shirt sleeve operations. The facing page concept shows the use of the MRWS as a cherry picker servicing a geosynchronous based Multi-Mission Spacecraft.

PERSONNEL ORBIT TRANSFER VEHICLE SUPPORT FUNCTIONS



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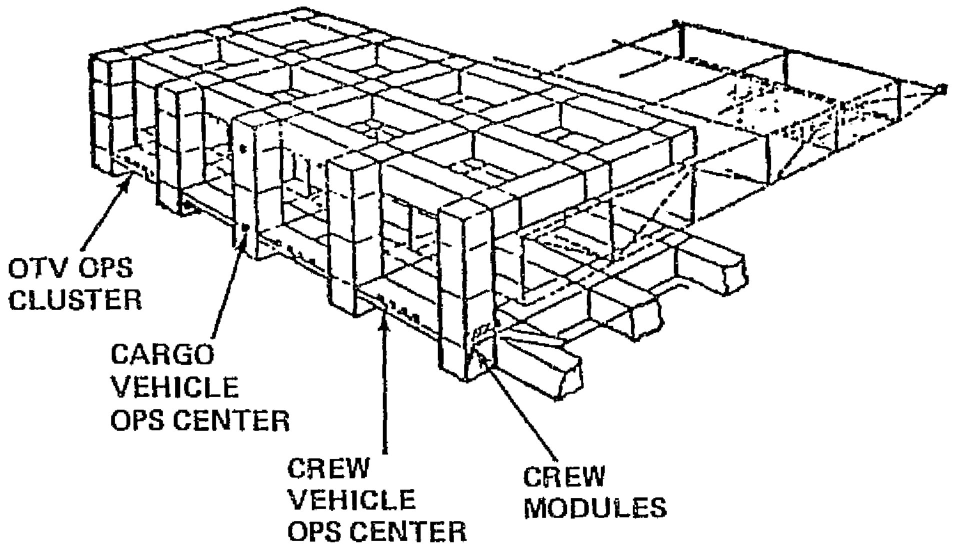
SPS LEO CONSTRUCTION BASE

The JSC Solar Power Satellite Systems studies were reviewed, and the MRWS SPS construction roles listed on the facing page, identified. MRWS cabins have application for each major construction function including base logistics. The cherry picker mounted to crane arms ranging in length between 20 and 250 m has the greatest application while a potentially new application, namely, the use of the MRWS as a fixed-based process control cabin identified. This later MRWS application has no need for manipulative activity but requires significant control and display area for monitoring and controlling the solar array deployment machine, the microwave subarray installer and the large 7.5 m beam fabricators.

The most demanding tasks for manipulative activity involve power bus installation in both the solar array and antenna, and the assembly of the brush system used on the antenna gimbal system.

PHOTOVOLTAIC SPS LEO CONSTRUCTION BASE



MAJOR CONSTRUCTION ELEMENTS CONSIDERED IN MRWS REQUIREMENTS ANALYSIS:

1 – BASE TRANSPORTER
2 – BEAM FABRICATOR
3 – JOINT MACHINE
4 – BUS/SWITCH GEAR INSTALLER
5 – SOLAR ARRAY DEPLOYMENT MACHINE
6 – MICROWAVE SUBARRAY INSTALLER
7 – ANTENNA STRUCTURE ASSEMBLER
8 – ROTARY JOINT ASSEMBLER
9 – POWER CABLE CONNECTIONS
10 – QUICK REPAIR AND RESCUE MODULE

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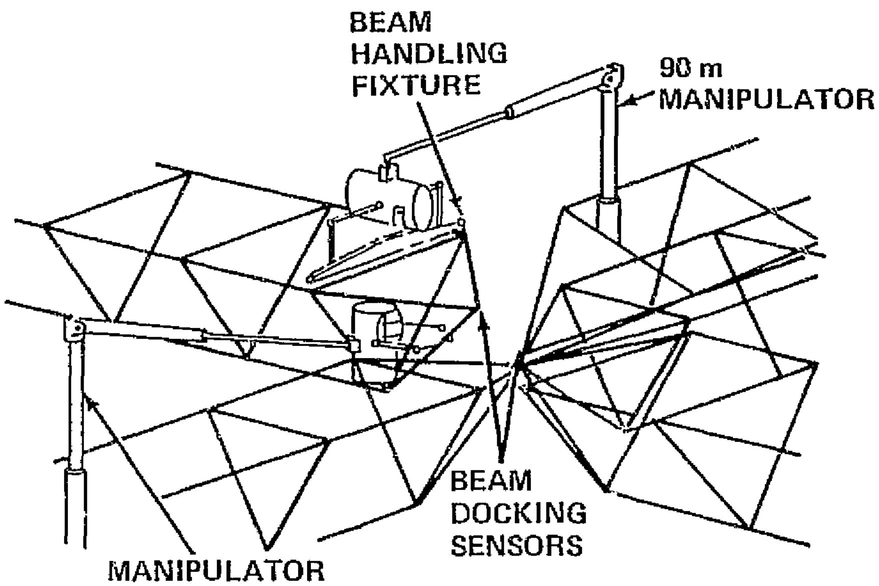
JOINT MACHINES

Cherry picker MRWSs are required to position large beams, align them for joining, and perform the joining operations. This operation levies requirements on the cherry picker crane position accuracy, stabilizer manipulator a end effectors to handle the beams, stabilizer/manipulator position accuracy, joint tool design and, illumination/visibility aids. Analysis of the SPS joint machine operations indicate that approximately 1 hr is required to join and align the 7.5 m deep truss girders at a nodel fitting. The characteristics of the beams being handled and aligned are shown on the opposite page. These beams can range in length between 470 and 816 m and in mass, between 1603 and 4513 kg.

JOINT MACHINES

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



SOLAR ARRAY BEAM CHARACTERISTICS

DEPTH, m	LENGTH, m	MASS, kg
7.5	816	4513
7.5	660	3656
7.5	470	1603

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

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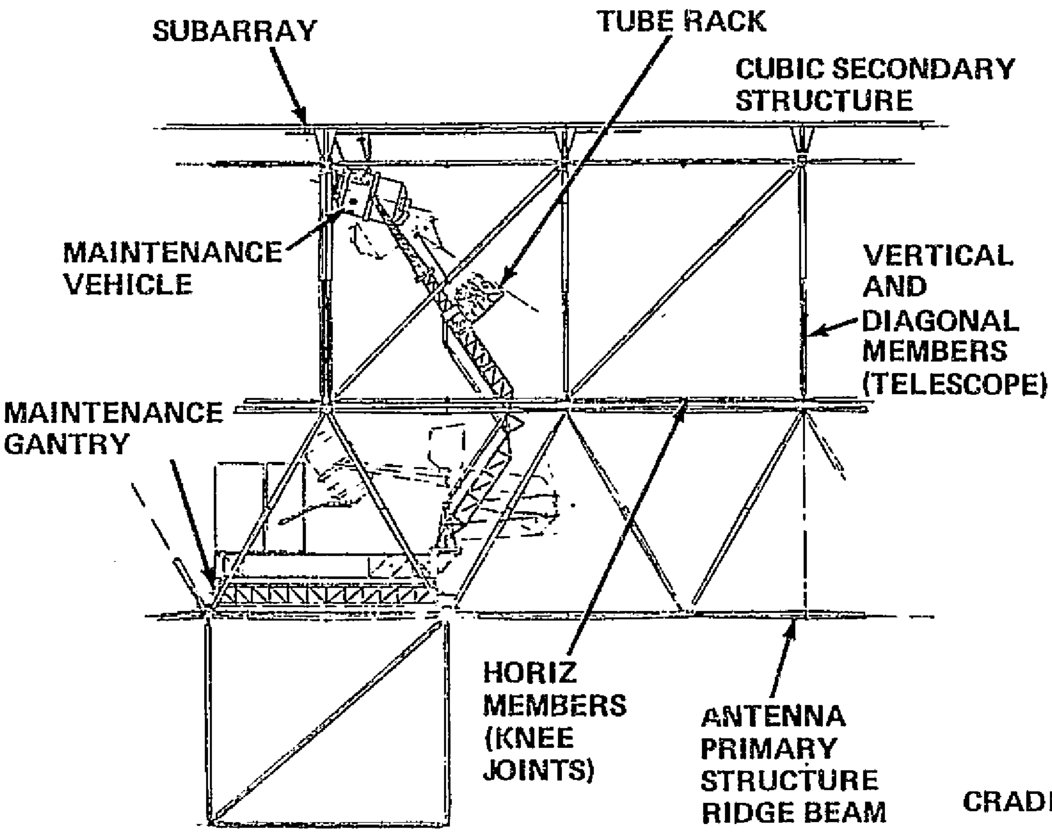
MRWS GEOSYNCHRONOUS MAINTENANCE OPERATIONS

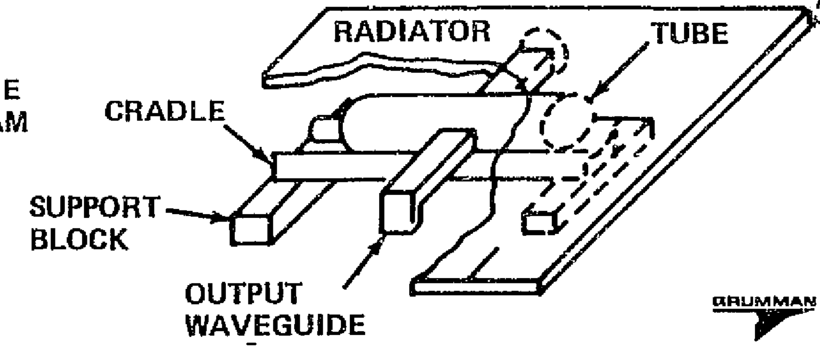
The SPS microwave antenna primary structure is a frame design, forming ridges that allow free unobstructed movement of a maintenance gantry horizontally across the antenna. The maintenance vehicle can move laterally on the gantry and reach up through the secondary structure to the failed klystron tubes. A tube replacement time of 45 minutes is expected which indicates removal and replacement of two structure diagonals, removal and replacement of one klystron tube module, and movement to the next failed klystron tube approximately 20 m away. Manipulator requirements for disconnection of radiator panels, heat pipes, waveguide, signal and power lines must be accomplished prior to tube replacement.

GEOSYNCRONOUS MAINTENANCE OPERATIONS

TUBE REPLACEMENT



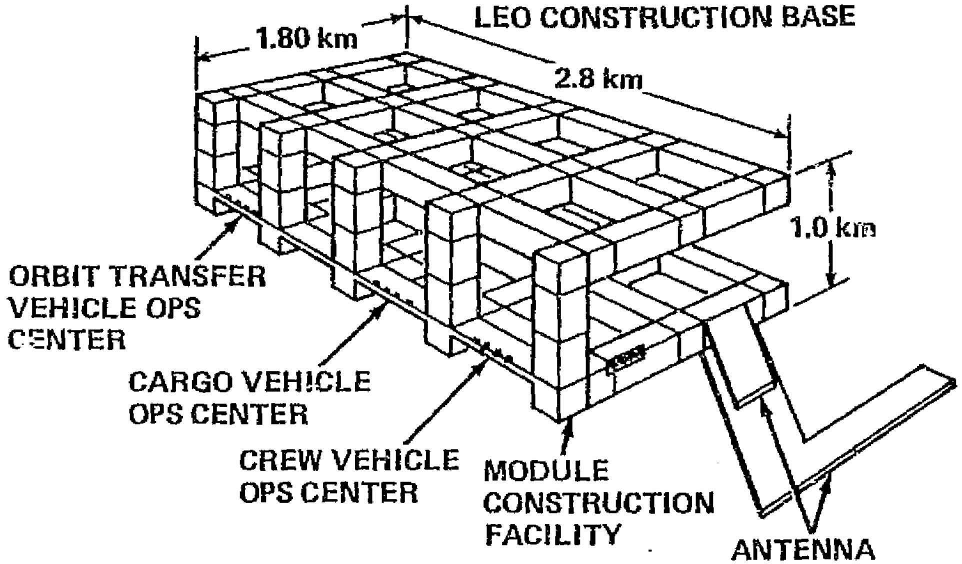
- CONTROL RAILED CARRIAGE ON MAINTENANCE GANTRY
- PROVIDE STORAGE RACK FOR REPLACEMENT SPENT KLYSTRONS
- PERFORM DEXTEROUS TASKS
  - DISCONNECT & RAISE RADIATOR PANELS
  - DISCONNECT HEAT PIPE INTERFACE WITH RADIATOR
  - DISCONNECT WAVEGUIDE INPUT & OUTPUTS
  - DISCONNECT POWER & SIGNAL LINES
  - REASSEMBLE WITH NEW TUBE
  - CHECKOUT

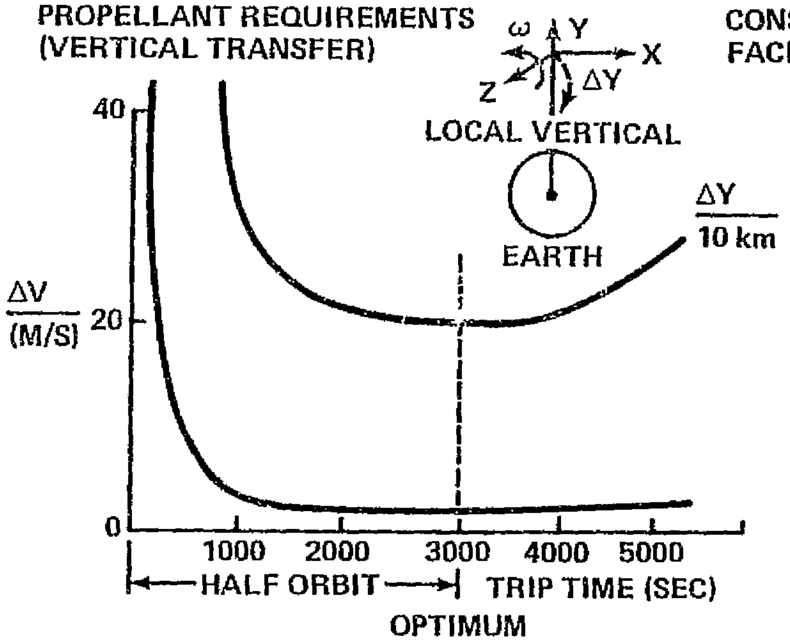


SPS REPAIR/RESCUE SCENARIO

The Free Flyer requirements listed on the opposite page reflect the need for the addition of an RCS system and a GN&C system for orbit transfer, rendezvous, and docking. The ΔV requirements for propulsion system sizing were established by assuming a 10 km Holmann transfer along the local vertical axes of a construction base. Evaluation of flight paths that maintain a fixed position relative to the construction base indicated that propellant requirements become unacceptably high and that orbital transfer and rendezvous is needed along with the complement of computers, rendezvous sensors and inertial systems.

SPS REPAIR/RESCUE SCENARIO





FUNCTIONAL REQUIREMENTS

- QUICK REPAIR
- RESCUE
- DEBRIS COLLECTION
- ASSEMBLY

MRWS FREE FLYER REQUIREMENTS

- TWO TRAVERSES 10 km EACH
- ONE HOUR 5 km OUT-OF-PLANE
- CONTROL AUTHORITY:
  - ROTATIONAL 10°/SEC2
  - TRANSLATION 0.31/SEC2
- RCS: ROTATION & TRANSLATION SAME THRUSTERS
  - MIN. PLUME IMPINGEMENT
  - SIX THREE-THRUSTER CLUSTER
  - PROPELLANT N_2H_4
  - THRUSTERS 5 LBF & 80 LBF
- GUIDANCE: RANGING
- EPS: FUEL CELLS 500 kWh
- C&D: CONTROL, RCS, GUIDANCE, EPS

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GENERIC WORK SITE CHARACTERISTICS FOR SIMULATION

Seven MRWS functions have been identified in previous studies; here we show four, to categorize the generic work site characteristics. The three functions not shown (transport, checkout and monitor) have their requirements incorporated in those illustrated.

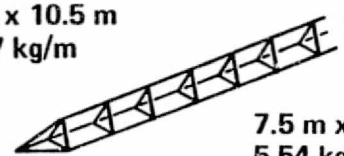
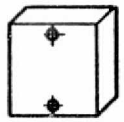
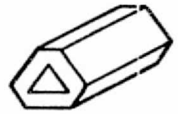
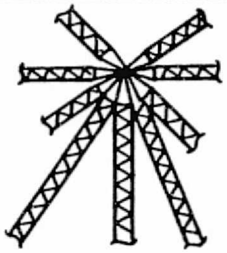
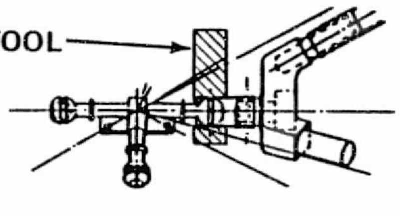
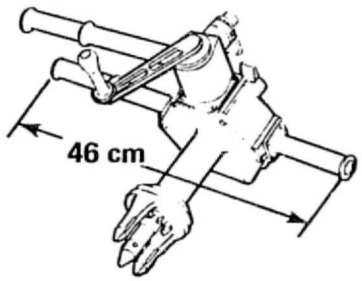
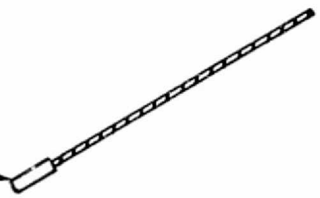
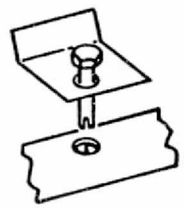
STRUCTURE

Many structures are built with triangular beams as the primary building element. Small one-meter beams are utilized for construction of the LSS platform, while larger 7.5-m beams, 816-meters long, are required for the SPS photovoltaic solar collector. These beams are shown joining at a common nodal fitting, however, other approaches such as lapping one beam to another should also be demonstrated.

HIGH MASS COMPONENTS

High mass components range from the MMS module of 150 kg to the 7.5-m beam machine estimated at 15 000 kg. These are aligned and fastened to the spacecraft structure using either a special purpose tool or the general use MRWS end effector.

GENERIC WORKSITE CHARACTERISTICS FOR SIMULATION

MRWS FUNCTIONS	STRUCTURE	HIGH MASS COMPONENTS	
		MMS MODULE	BEAM BUILDER
HANDLE	1 m x 10.5 m 1.27 kg/m BEAM  7.5 m x 816 m 5.54 kg/m	 0.5 m x 1.2 m x 1.2 m 150 kg	 7.5 m dia x 15 m 15,000 kg
ALIGN	JOINTS  ±7 mm ±8°	MMS MODULE ±5 cm ±3°	BEAM BUILDER GIMBAL MOUNTED
FASTEN	CRIMPING TOOL  ±10 mm	MMS MODULE BOLT FASTEN/RELEASE TOOL 100 FT–LB	 46 cm
ADJUST	CABLES TENSION ADJUSTER 	BEAM BUILDER ATTACHMENT	

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LARGE SURFACE AREA COMPONENTS

The 61-m communications antenna lens assembly was selected from mid term construction activities as a large surface area component to be handled. Lens panels were sized for stowage in the payload bay and must be fitted together, then joined, to form the antenna lens. A second challenging item is the handling of the SPS microwave antenna subarray (rectangular 10 m x 11.5 m). The mass varies from 550 kg to 3000 kg depending on the number of klystrons required to provide correct antenna patterns. Planarity of the antenna surface is accomplished by three jacks on each panel. These must be attached, then adjusted by the MRWS.

SOLAR BLANKET

Solar blanket deployment contrasts with other operations previously discussed in that the blankets are very large and light for their size. The perimeters are attached to the structure or to each other and tensioned to assure flatness. The MRWS must grasp the tensioning device (springs) and attach them to the structure. A gross tensioning device may also be installed, such as a cable snubber that is used to apply initial tension. Some type of seaming operation is also required (velcro) to join the blankets together.

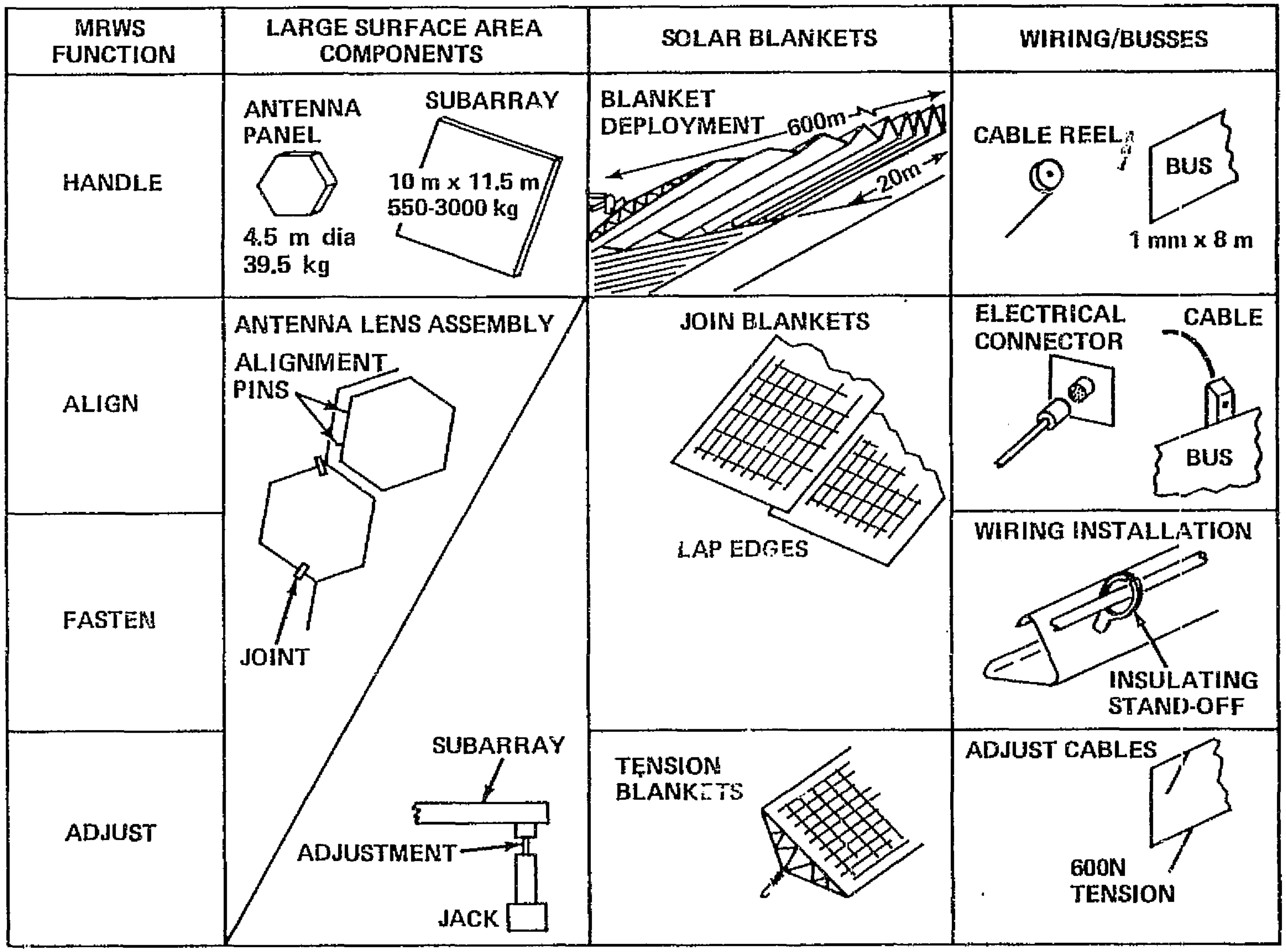
WIRING/BUSSES

Electrical cables must be attached to major components and routed along the structure. The MRWS would be involved in performing operations such as coupling electrical connectors, attaching heavy power cables to busses and installing primary power busses. One power bus approach is to suspend large sheets of aluminum approximately 1 mm thick x 8 m wide in the structure by cables. These sheets are attached electronically to power switches by aluminum conductors.

FLUID/GAS LINES

This task is not illustrated, however, should be included in this simulation tasks. This involves the MRWS in an assembly repair scenario for the thermal SPS. Most heat rejection systems are closed systems and a minimum amount of on-orbit fluid/ gas couplings are required. The thermal SPS radiators require coupling to the power generating equipment, a task that the RMS must perform.

GENERIC WORKSITE CHARACTERISTICS FOR SIMULATION (CONTD)



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MRWS CONSTRUCTION GUIDELINES

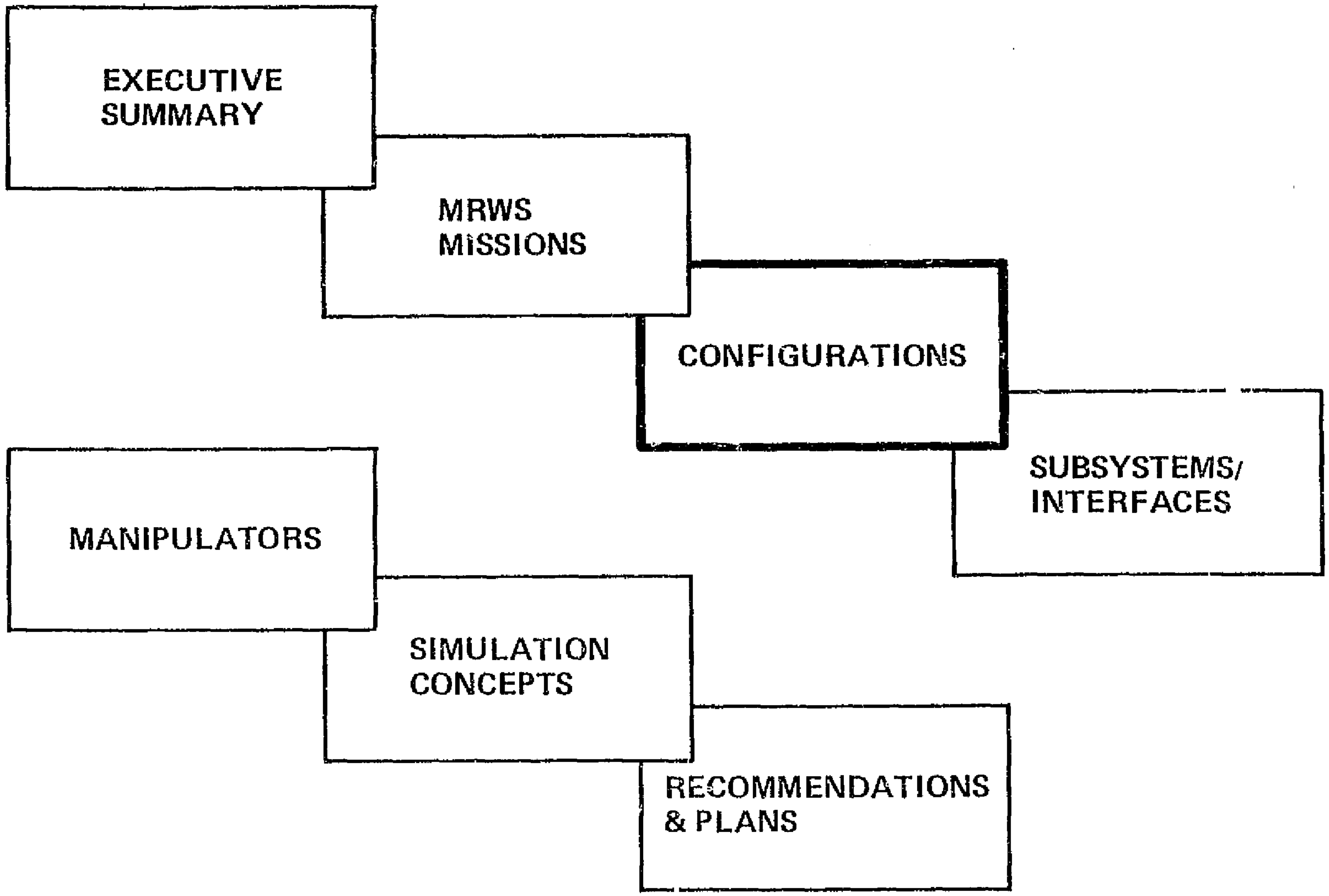
As a consequence of analyzing construction tasks, it became apparent that certain design features should be incorporated to facilitate assembly operations. One sided fastening simplifies assembly because it eliminates reacharound requirements. No loose fittings should be involved in the assembly operations. A second view of operation 90° to normal line-of-sight is very desirable, because there are times when the dexterous manipulator or structure may partially obscure the operation being performed. To minimize the operator concentration required (hence fatigue) the largest latitude in assembly tolerances should be permitted and parts to be mated should have guides to assist the operator.

Manipulator operations conducted in earth environment cannot permit relaxation of a single joint because continuous support of the component being handled is required. However, the balanced g forces of space permit a manipulator or crane joint drive and braking restriction to be removed, permitting alignment of the joint/component by external input, e.g., EVA Astroworker, another manipulator, movement of the manipulator/crane.

MRWS CONSTRUCTION GUIDELINES

- ATTACHMENTS DESIGNED FOR ONE SIDE FASTENING
- ATTACHMENTS CAPTIVE
- TWO VIEWS OF ASSEMBLY
- LARGE ASSEMBLY TOLERANCE
- GUIDED MATING
- UTILIZE ZERO G FOR ALIGNMENT

GRUMMAN


EXECUTIVE SUMMARY
MRWS MISSIONS
CONFIGURATIONS
SUBSYSTEMS/ INTERFACES
MANIPULATORS
SIMULATION CONCEPTS
RECOMMENDATIONS & PLANS

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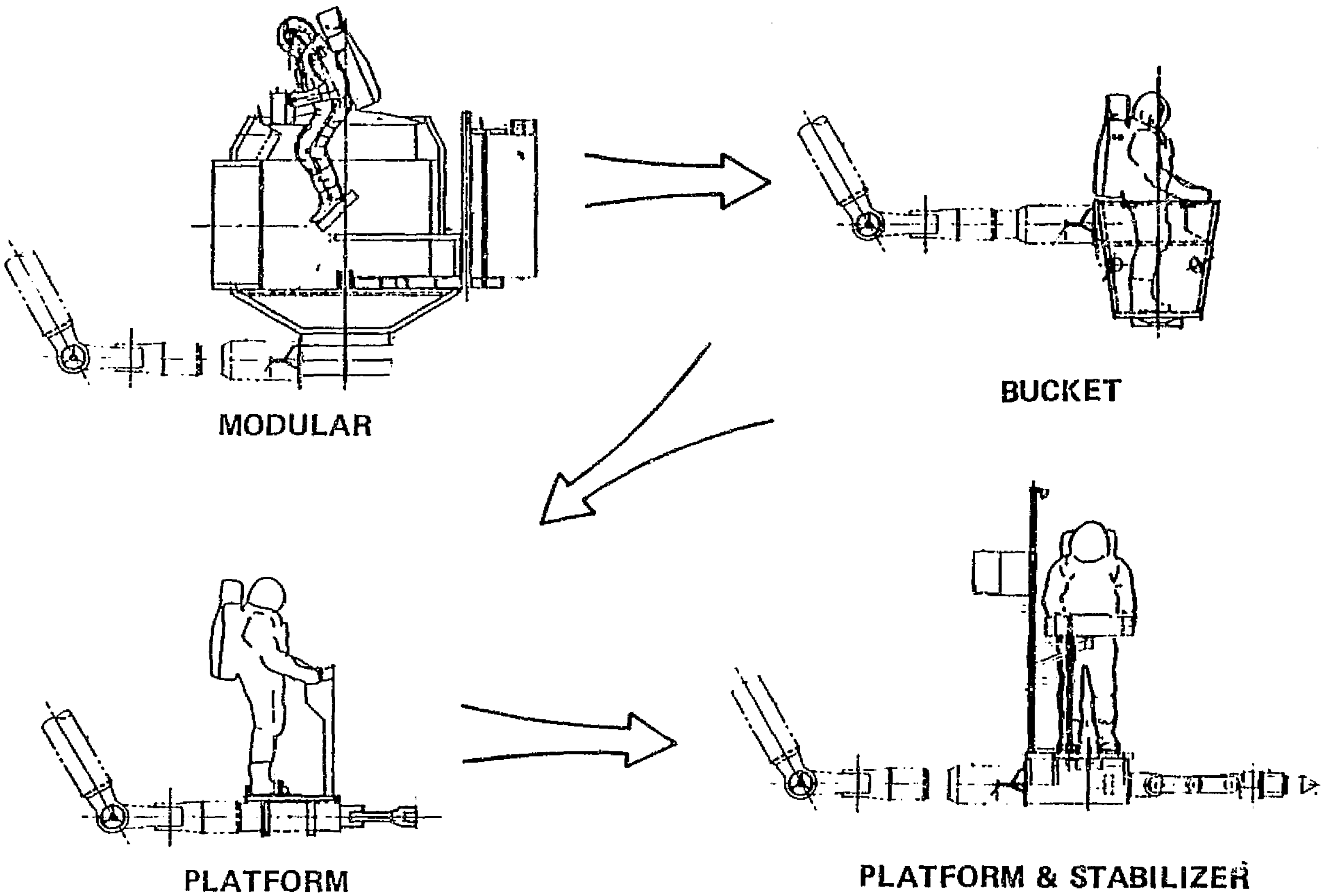
OPEN CAB CHERRY PICKER CONFIGURATION DEVELOPMENT

Two design concepts were pursued in the development of the open cab cherry picker: the modular growth concept and the dedicated vehicle concept.

The modular OCP has the growth potential of being modified at a later date to a closed cabin cherry picker by adding the upper portion of the cab structure to the existing base. This approach does not optimize the reach requirements for the suited astronaut when servicing space hardware. Since the closed cherry picker is a shirt sleeve operation and the OCP is a suited operation, nothing is gained in the development of the growth concept.

The bucket and platform concept was investigated for the dedicated OCP. The bucket design is more restrictive to the suited man than the platform concept whereas the platform design provides more flexibility for adaptation to specific requirements of each space craft being serviced. The dedicated platform concept is being developed as the Open Cherry Picker.

OPEN CAB CHERRY PICKER
CONFIGURATION DEVELOPMENT



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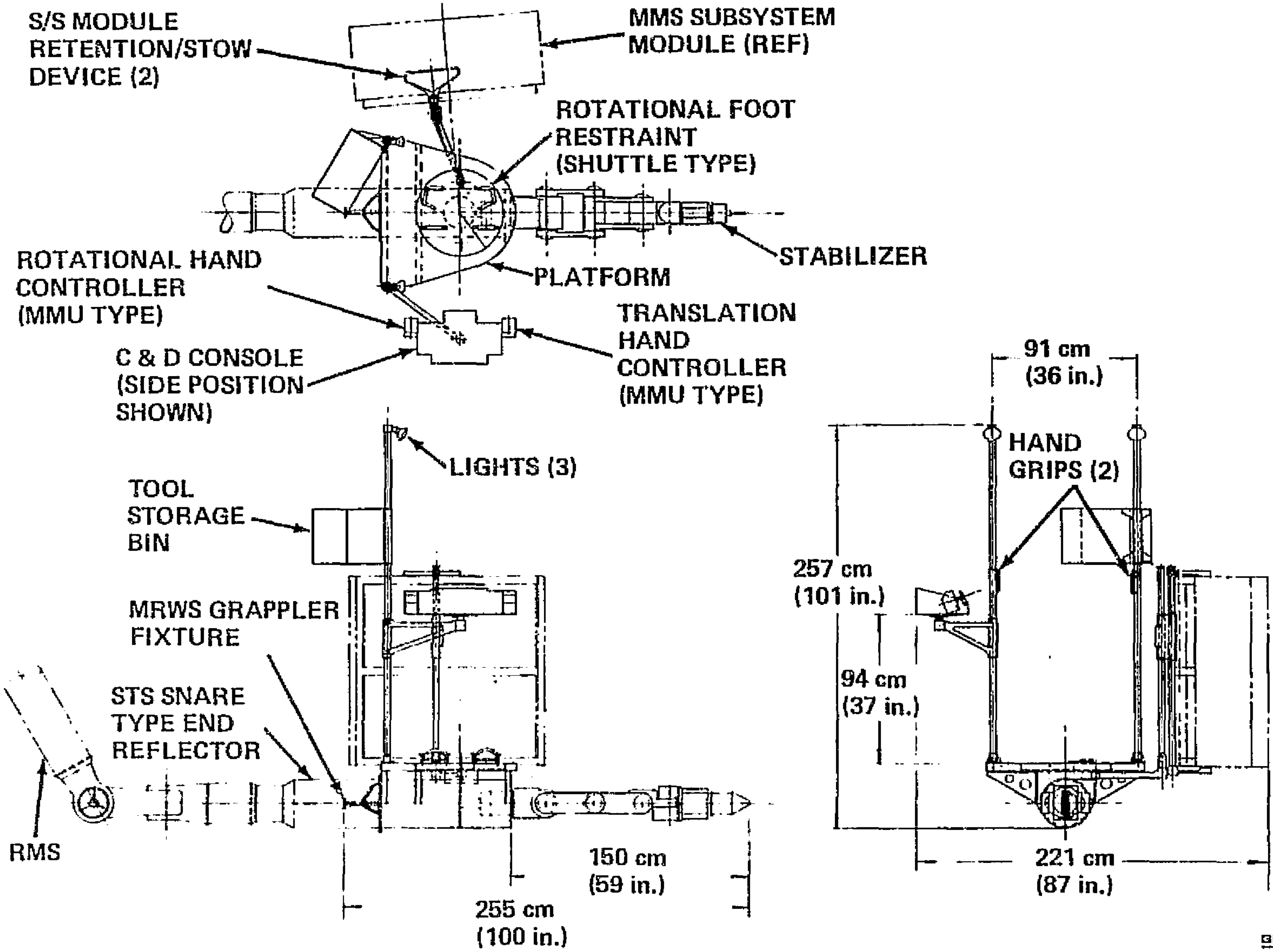
OPEN CAB CHERRY PICKER MRWS CONFIGURATION – SHUTTLE RMS SUPPORT

The open cab cherry picker shown on the opposite page operates from the end of the Shuttle RMS. The mechanical/electrical mating of the OCP and RMS is via a grapple fixture mounted on the OCP which interfaces with the STS snare-type end effectors of the RMS. A small triangular platform provides the base from which the elements of the OCP are mounted. A shuttle-type foot restraint is used to secure an EMU suited astroworker to the OCP. The foot restraint assembly provides 360° of rotation to enhance the astroworkers' accessibility at the worksite. Two vertical stanchions mounted to the fix platform provide support for a tool storage bin, flood lights and a Control and Display console. This console, containing displays and MMU type Attitude and Translation controllers, can be rotated from a rear stow position to a side operating position. Two payload retention/stow devices are provided. Those illustrated are configured to handle the Multimission Modular Spacecraft subsystem modules. The OCP also provides a 6 DOF stabilizer which is mounted at the forward end of the platform and is used to anchor the OCP to the work site.

OPEN CAB CHERRY PICKER MRWS CONFIGURATION
SHUTTLE RMS SUPPORT



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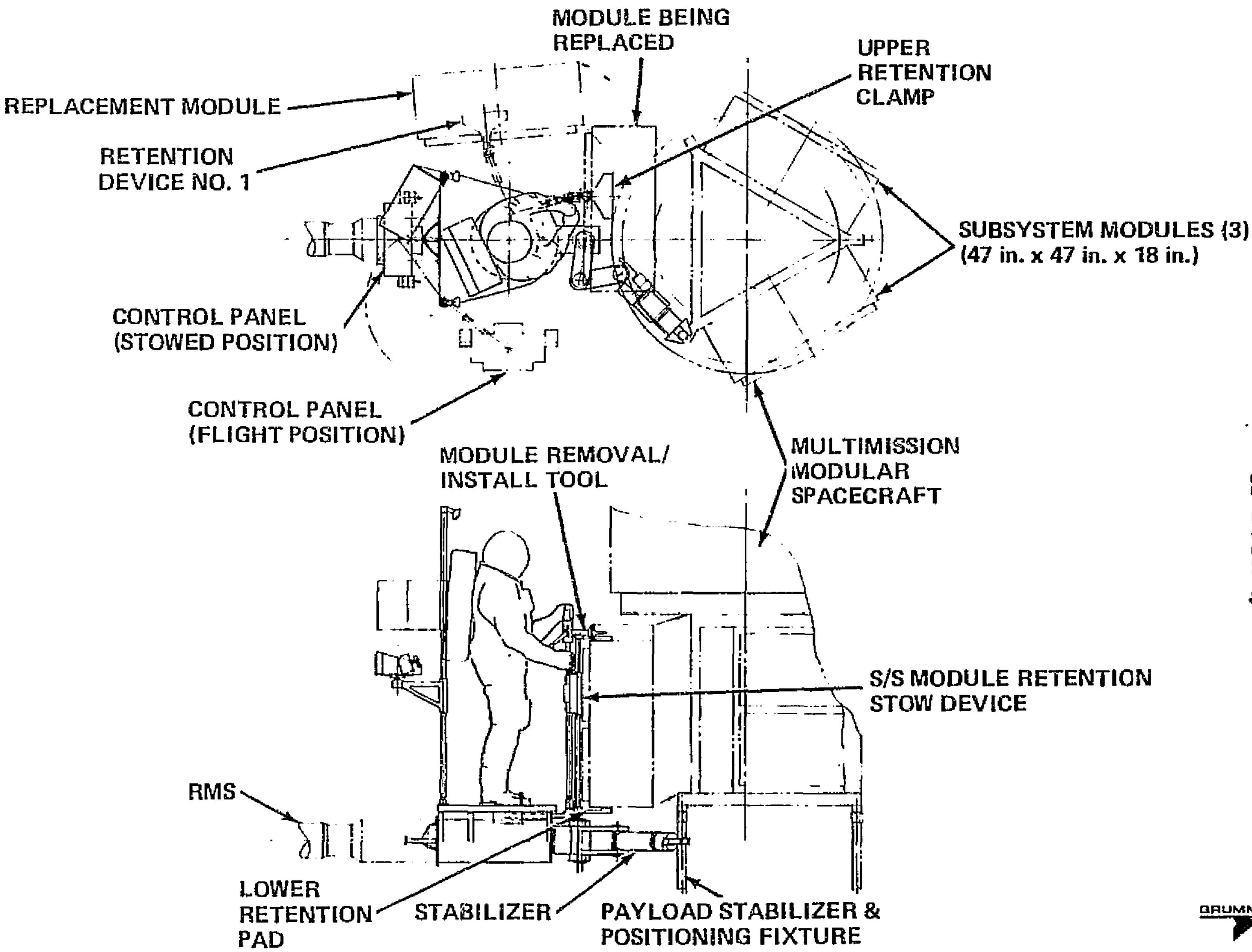
The OCP shown has been configured to service the Multimission Modular Spacecraft. Minor modifications to the OCP module retention/stow device can be made to adapt it to handle components of other space vehicles. In this application a MMS subsystem replacement module is stored in one of two retention devices mounted on the OCP. The astroworker using the control console located at its flight position maneuvers the OCP to the MMS which has been berthed to the payload positioning platform in the orbiter cargo bay. When the OCP is properly positioned at the work site, the astroworker uses the OCP stabilizer to grapple the MMS positioning platform; he then makes the stabilizer rigid which in turn anchors the OCP to the work site. Once anchored, the control console is moved to its stowed position providing the astroworker unobstructed access to the spacecraft. The empty module retention/stow device is moved into place as the astroworker uses the module removal/installation tool stored in the tool bin, removes the spent subsystem module from the spacecraft and places and secures it in the retention/stow device. The spent module is then moved to its stow area by means of the retention/stow device swing arm. The replacement module is then moved into place and the reverse procedure is performed to install the new module. Completing the module installation, the astroworker releases the OCP stabilizer from the positioning platform and the OCP is moved to the cargo bay where the astroworker deposits the spent spacecraft module in the Module Magazine.

OPEN CAB CHERRY PICKER MMS SERVICING



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OPEN CAB CHERRY PICKER MRWS MASS ESTIMATE

The weight estimate for the Open Cherry picker is 192 kg. The structural elements, weighing 35 kg, consist of the platform, bearing tube upright stanchions (2), support structure for the moveable control and display consoles. The mechanical devices, weighing 77 kg, consist of the 6 DOF stabilizer, module retention/stowage devices (2) and the rotational foot restraint rotary bearing. The electrical power supply, weighing 14 kg, consists of three floodlights and the wiring required to interface with the controls and displays. Control & Displays weighing 14 kg, consists of the controls and displays on the console and the MMU controllers. Crew Support weighing 14 kg consist of tool storage bin foot restraints and tethers. A 25% contingency added to these weights provide the total of 192 kg for the open cherry picker.

OPEN CAB CHERRY PICKER MRWS DESIGN 52

MASS ESTIMATE

ITEM	MASS	
	kg	lb
STRUCTURE	(35)	(78)
• PLATFORM	6	15
• BEARING TUBE	19	43
• (2) STANCHIONS	5	10
• CONTROL & DISPLAY CONSOLE & SUPT	5	10
MECHANICAL	(77)	(170)
• STABILIZER	38	85
• BEARING (FOOT RESTRAINT)	5	10
• GRAPPLE FIXTURE	5	10
• (2) RETENTION/STOW DEVICE	29	65
CREW SUPPORT	(14)	(30)
• TOOL STORAGE BIN	4	8
• FOOT RESTRAINT	9	20
• TETHERS	1	2
CONTROLS & DISPLAYS	(14)	(30)
ELECTRICAL POWER SUPPLY	(14)	(30)
• WIRING, ETC	12	25
• LIGHTS	2	5
CONTINGENCY (25%)	(38)	(85)
TOTAL DRY	192	423

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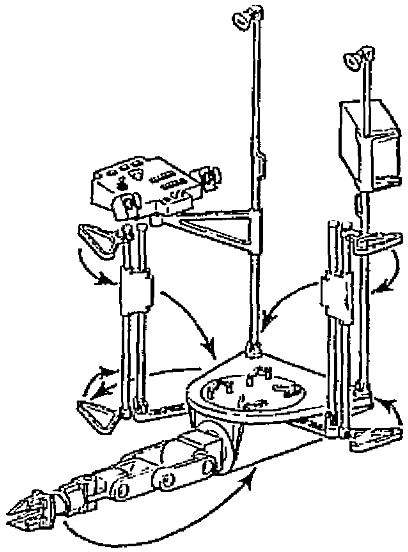
OPEN CHERRY PICKER STOWAGE AND DEPLOYMENT SEQUENCE

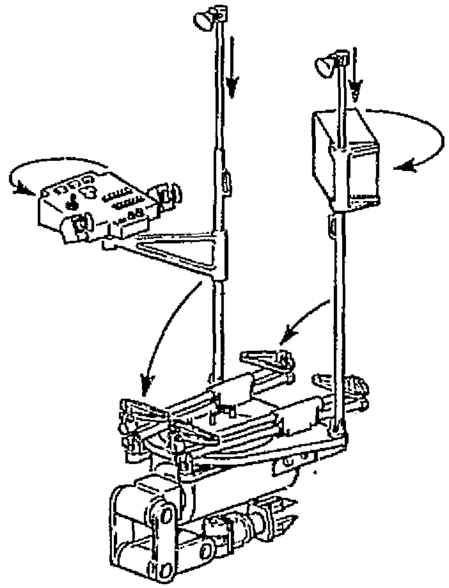
In order to minimize volume required to stow the OCP in the payload bay, a foldup arrangement has been devised. The stabilizer can be folded down and back below the platform. The left hand upright stanchion, with the tool storage bin mounted on it, can telescope down. At this compressed height, the stanchion can rotate down against the top of the platform, the tool bin extending down forward of the platform. In a similar fashion the left stanchion telescopes down to the proper height and then swings down against the platform. The control and display panel extends down, forward of the platform opposite of the tool bin. The module retention devices can also be rotated down to lay flat against the top surface of the platform. The overall size of this folded package is 91 cm high, 106 cm wide and 152 cm long. This compact package can be stowed and supported at the orbiter starboard MMU/FSS station utilizing the existing orbiter hard points.

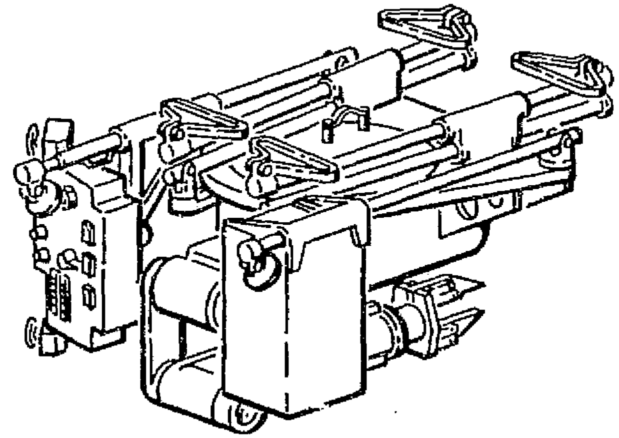
The Shuttle rear station operator can deploy the RMS and engage it with the stowed OCP. The OCP can either be automatically or manually released from its stowed position. The RMS moves the OCP to a suitable location in the payload bay from where the astronaut deploys the elements on the OCP. When fully operational, the astronaut enters the OCP and assumes command of the RMS.

OCP FOLDING SEQUENCE



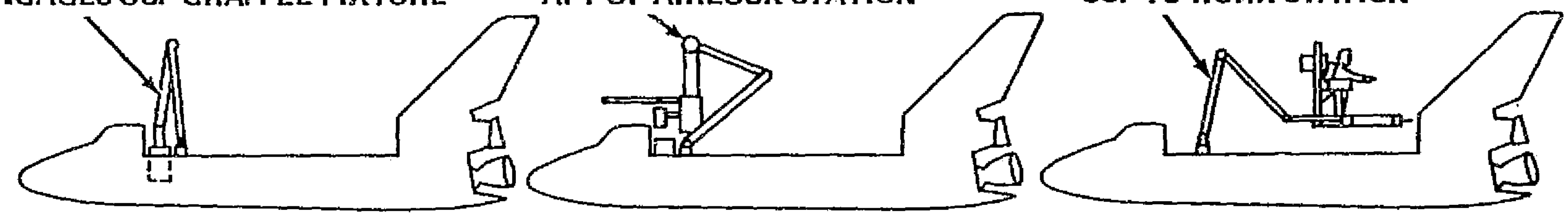
DEPLOYED CONFIGURATION

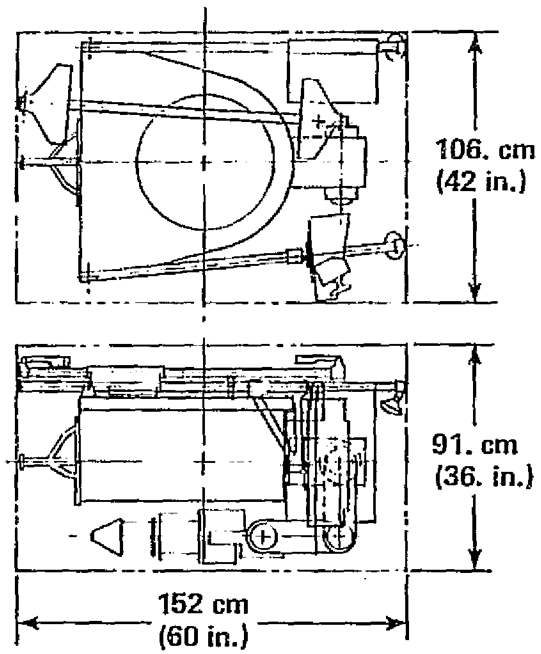




FOLDED CONFIGURATION

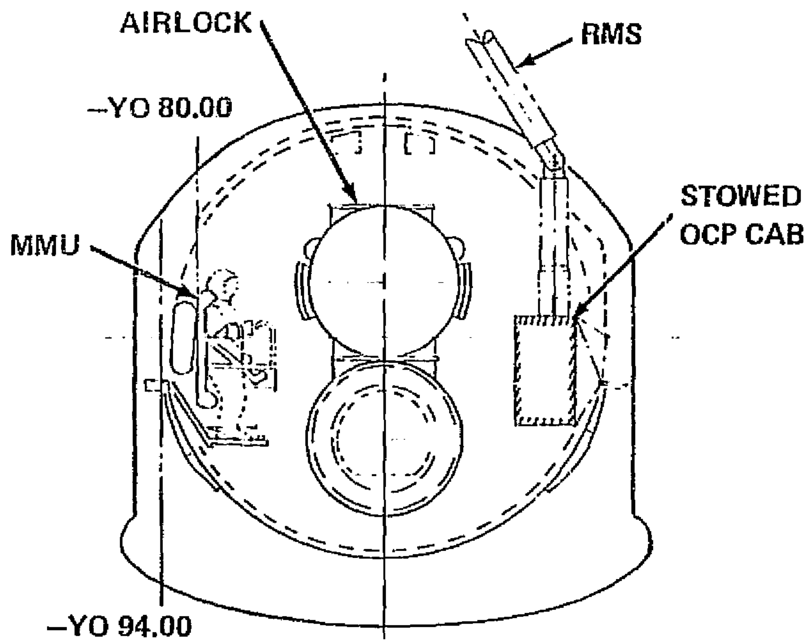
OPEN CHERRY PICKER STORAGE & DEPLOYMENT SEQUENCE





STOWED CONFIGURATION

STOWED VOLUME 1.48 3(52 ft^3)



VIEW LOOKING FORWARD

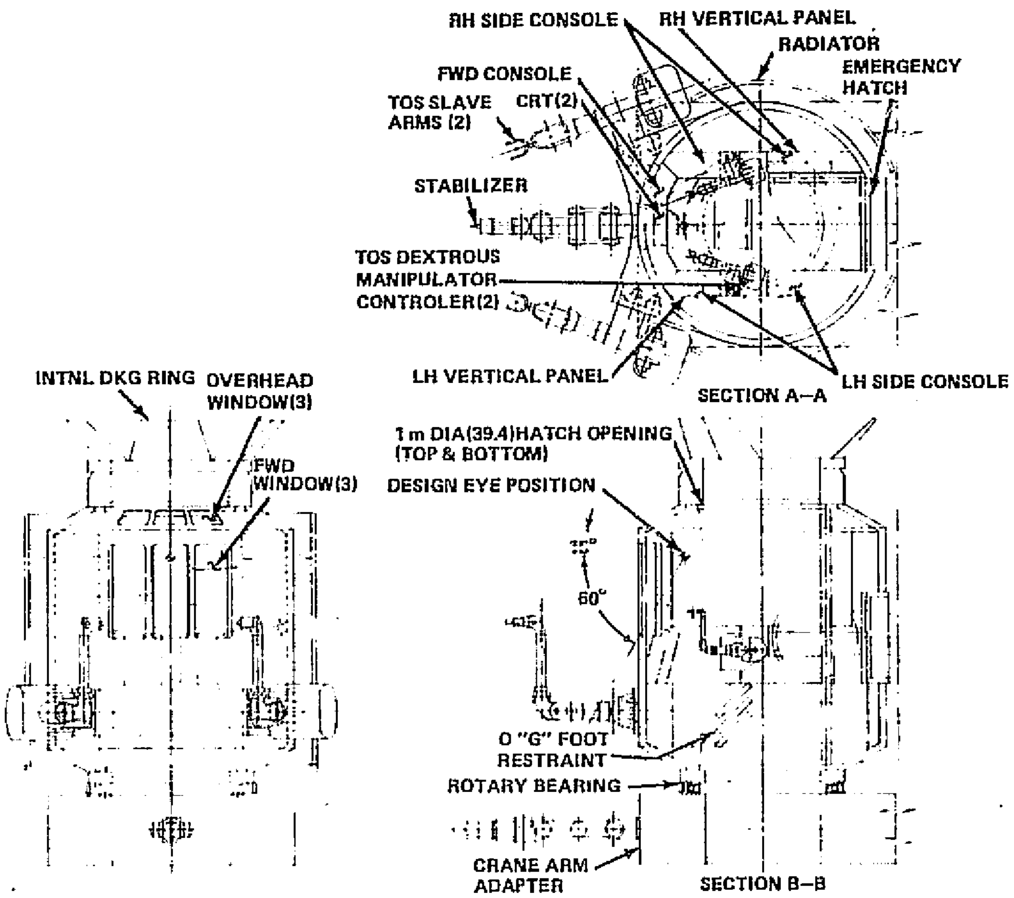
OCP STOWED AT MMU DONNING STA,

X_0 582 - 636

CLOSED CABIN CHERRY PICKER – ONE OPERATOR + ONE RELIEF MAN (1 + 1)

Prior to establishing a one man MRWS, the two-man CP was developed (opposite page). In this configuration one man operated the CP from a forward facing control station, while a second man sat behind him. The second person was considered a relief operator who could take control when the first man tired. The 2-meter diameter cabin contains a control station with forward and side consoles. Two dexterous manipulators, canted 20° inboard, provide control of the two 2-meter slave arms located outside the CP. Two 1-meter diameter hatches, one in the ceiling and one in the floor, provide ingress/egress to the CP. A docking ring on the top center line of the cab provides required interface to home base. The entire cab is mounted to the crane arm adapter by means of a rotary bearing which provides ±180° of rotation. The stabilizer is mounted on the forward part of the crane arm adapter; a third hatch located on the aft wall of the cab can be used for emergency EVA. Two radiator panels, providing 10.3 m^2 of radiating surface, are wrapped around the cab structure.

CLOSED CABIN CHERRY PICKER – ONE OPERATOR & ONE RELIEF MAN (1 + 1)



CABIN I.D.	203(80)–cm(in.)
CABIN HEIGHT	241(95)
OVERALL HEIGHT	385(152)
VOLUME TO IML	7.0(248)–m^3(ft^3)
PRESSURE	1.03(14.7)–kg/cm^2(psi)

WINDOW AREA	m^2(ft^2)
• FWD	0.83(8.9)
• UPPER	0.19(2.0)
TOTAL	1.02(10.9)

DISPLAY AREA	m^2(ft^2)
• FWD CONSOLE	0.15(1.63)
• L/R SIDE CONS	0.42(4.48)
• L/R VERT PANEL	2.52(27.12)
TOTAL	3.09(33.23)

RADIATOR AREA 10.31(111)–m^2(ft^2)

HEAT LOAD	WATTS
• WINDOW	250
• METABOLIC	350
• CO_2 REMOVAL	50
• INTERNAL ELEC	1050
• EXTERNAL ELEC	3113
• AFT EQPT BAY	0
TOTAL	4813

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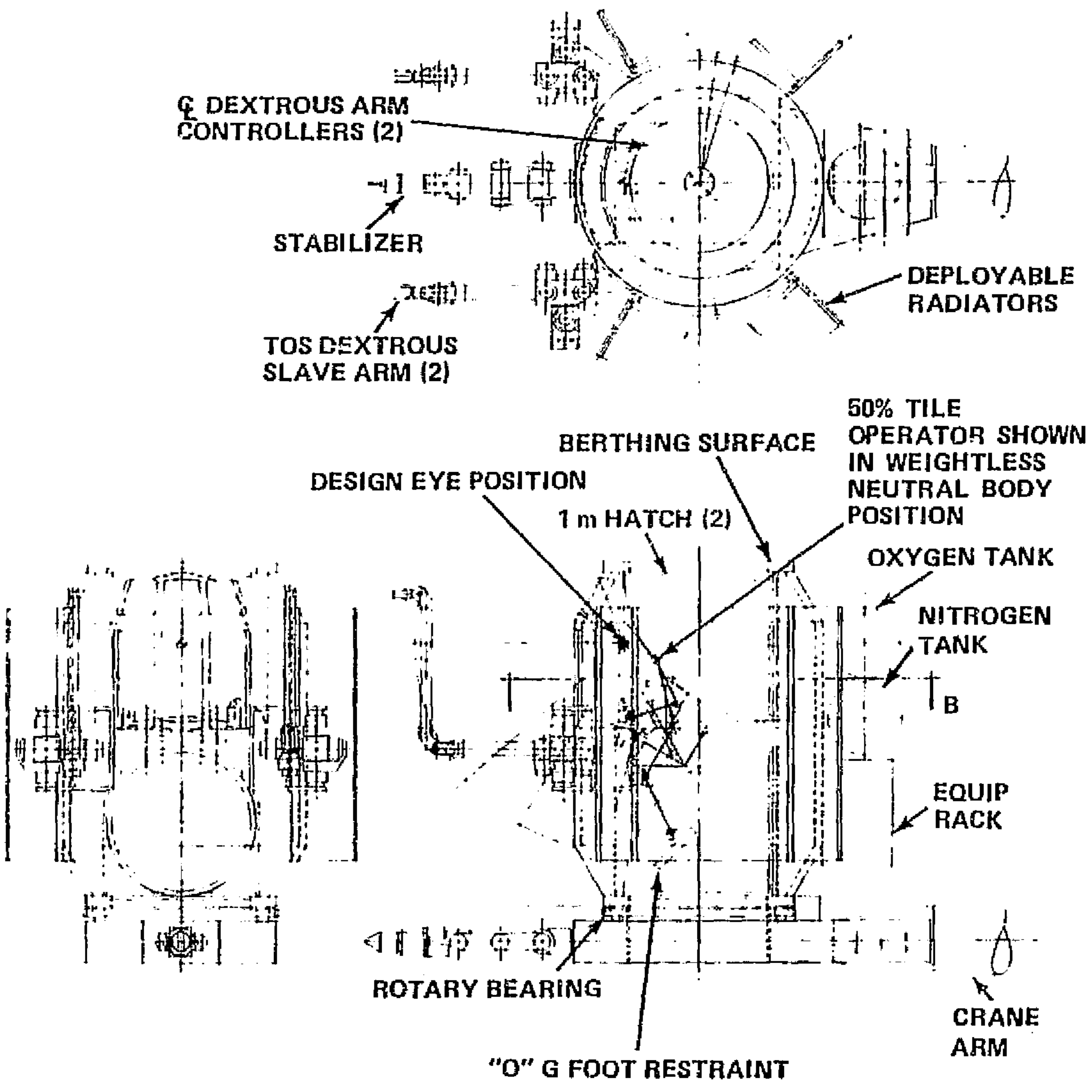
CLOSED CABIN CHERRY PICKER — ONE MAN OPERATION

The closed cabin cherry picker represents the current baseline configuration. This reduced diameter cabin provides for one man operation. The control station geometry is based on the neutral zero g standup body position derived by NASA. The operator stands on an adjustable zero g foot restraint system. By adjusting the foot restraint to the proper height, the full range (5 to 95 percentile) of personnel can be accommodated at the design eye position. By placing the eye close to the window, the glass area is minimized while providing large external viewing. A forward and side console provide required surface area for displays and controls. Control of the 2-meter slave arms on the outside of the cabin is maintained by a 0.6 m master controllers. One-meter diameter hatches are located in the ceiling and floor providing two ingress/egress paths. The entire cab is mounted to the crane arm adapter by means of a rotary bearing which provides ±180° of cab rotation. The stabilizer is mounted to the forward part of the crane arm adapter. Electronic equipment, oxygen, and nitrogen bottles are mounted to the aft external surface of the cab. Curved radiator panels with flat foldout provide 13.4 m^2 of radiating surface area. The curved panels are single sided radiating surfaces while the foldout panels are double-sided radiating surfaces. In addition to these radiators, a radiator panel is mounted to the aft surface of the equipment rack to take care of the externally mounted electronics.

CLOSED CABIN CHERRY PICKER ONE-MAN OPERATION



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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CLOSED CABIN CHERRY PICKER – WEIGHT ESTIMATE

The weight comparison between the (1 + 1) configuration and the one man CP is shown on the opposite page. It can be readily seen that the latter configuration is considerably lighter. The basic structure, windows, supports, and consoles have been reduced in size thereby reducing the structural weight by 19%. The hatch sizes remain the same (1-meter diameter). Additional weight can be saved and improved; internal mobility can be achieved by reducing the hatch diameter. The environmental protection and environmental control system has also been reduced by 19%. In the mechanical subsystem grouping, the weights of the slave and master manipulators and stabilizer remain the same, while the rotary bearing weight decreased due to the selection of a smaller diameter assembly. Selection of a berthing interface in lieu of a docking interface saves 300 kg. Deletion of one crew member and two EMUs saves an additional 215 kg. The totals of 3,007 kg vs 2,148 kg reflect a 29% reduction in vehicle weight.

CLOSED CABIN CHERRY PICKER WEIGHT ESTIMATE

ITEM	(1 + 1) CAB		1–MAN CAB	
	kg	lb	kg	lb
STRUCTURE	(679)	(1496)	(549)	(1210)
• BASIC	296	652	228	502
• HATCHES & WINDOWS	68	150	52	115
• SUPPORTS/CONSOLES	200	440	154	339
• ROBUST ARM INTERFACE	115	254	115	254
ENVIRONMENTAL PROTECTION	(68)	(150)	(55)	(121)
ENVIRONMENTAL CONTROL SYSTEM	(182)	(402)	(150)	(330)
MECHANICAL	(554)	(1222)	(516)	(1137)
• MANIPULATOR–SLAVE	103	226	103	226
• MANIPULATOR–MASTER	62	136	62	136
• STABILIZER	38	85	38	85
• ROTARY BEARING	351	775	313	690
BERTH INTERFACE			(147)	(325)
DOCKING INTERFACE	(442)	(931)		
ELEC POWER SUPPLY/INSTRUMENTATION	(113)	(250)	(113)	(250)
COMM/STAB. & CONTROL	(62)	(138)	(36)	(80)
CONTROLS & DISPLAYS	(91)	(200)	(91)	(200)
CONTINGENCY (25%)	(543)	(1197)	(414)	(913)
TOTAL DRY	2715	5986	2071	4566
CREW	154	340	77	170
EMU	138	304	0	0
TOTAL	3007	6630	2148	4736

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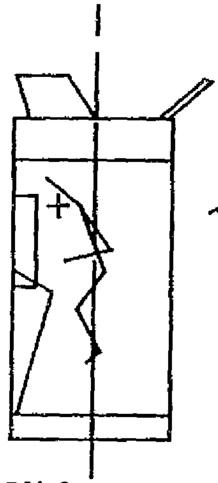
TRADE STUDY – CABIN CONCEPTS

Five options were considered for the closed cockpit cherry picker. Options 1 and 2 are basically a one man MRWS, while options 3, 4, and 5 reflect a two man operation. A timeline analysis of the tasks required by the MRWS indicate that the tasks can be performed sequentially by one man. The one element that has to be resolved is the energy expended by the operator for long periods of time. While the task analysis shows one man operation, the exertion factor might dictate a relief operator. Accordingly, Option 1 has been selected for baseline design, while consideration should be given to Option 3 as an alternate.

With the exception of a second control station and windows located in the aft part of the cabin Option 2 is the same as Option 1. In this fashion one man can operate from two discreet dedicated work stations. The additional windows limit radiator installation and also preclude external mounting of equipment. In addition a rotary bearing located at the bottom of the cab provides ±180° of visibility. It was for these reasons that Option 2 was dropped.

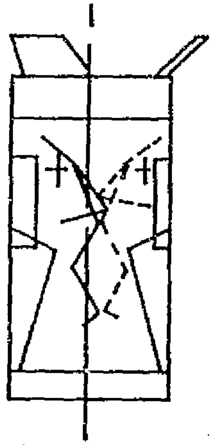
TRADE STUDY – CABIN CONCEPTS



OPTION 1

1-MAN OPERATION
1 CONTROL STATION

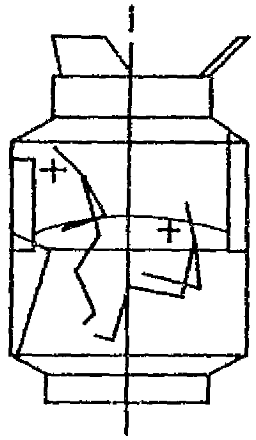
BASELINE



OPTION 2

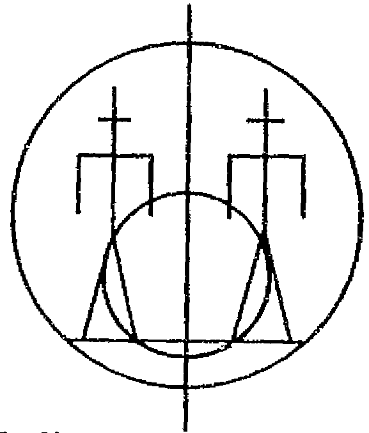
1-MAN OPERATION
2 CONTROL STATIONS

ALT BASELINE



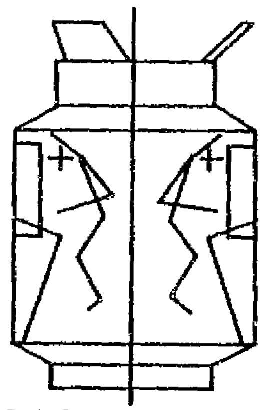
OPTION 3

1-MAN OPERATION
1-MAN RELIEF STATION
1 CONTROL STATION
1 AUXILIARY STATION



OPTION 5

2-MAN SIDE-BY-SIDE OPERATION
2 CONTROL STATIONS



OPTION 4

2-MAN REVERSE TANDEM OPERATION
2 CONTROL STATIONS

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LIFE CYCLE COST EVALUATION OF ONE VS ONE PLUS ONE MAN DESIGN DURING SPS CONSTRUCTION

The accompanying chart depicts the equivalent cost per shift between the one man MRWS and the one plus one man cabin. Based on 50 units, the amortized MRWS cost per 8 hour shift is slightly more for the one plus one cabin. The amortized crew cost for a man in space for a 90 day stay time per shift for the one plus one is double that of the one man unit. The cost of money per shift is the same for both vehicles. Adding up these three factors indicates a MRWS cost per shift of $28,893 for the one plus one and $21,936 for the one man cab. This indicates a cheaper unit cost for the one man MRWS. However if a relative utility factor is applied to these numbers it shows that the one plus one man cabin has a lower cost per shift.

LIFE CYCLE COST EVALUATION OF ONE VS ONE + ONE MAN DESIGN DURING SPS CONSTRUCTION

EVALUATION DATA	COMPARISON		BASIS AND/OR DATA RATIONALE
	1-MAN	1 + 1	
MRWS COST			
WEIGHT	2148 kg	3007 kg	PRELM WEIGHT STATEMENTS
COST ELEMENTS			
RDT&E	$196M	$207M	KOLLE MANNED VEH. COST MODEL WITH 40%
UNIT	$ 46M	$ 49M	NEW TECHNOLOGY
TOTAL	$242M	$256M	
LAUNCH COST	$0.1M	$0.1M	30 $/Eg HLLV LAUNCH COST
AMORTIZED MRWS COST/8 h SHIFT	(a) $6,850	$7,293	10-yr LIFE, THREE 8-h SHIFTS/DAY, RDT&E AMORT OVER 50 UNITS
CREW COST			
$ TO DELIVER MAN TO ORBIT	$0.285M	$0.570M	90-DAY STAY TIME, $20M ÷ 70 MEN
COST TO HOUSE MAN	$1.47M	$2.94M	90-DAY STAY TIME, HABIT MODULE = $60M/MEN/10 yr
AMORTIZED CREW COST/ SHIFT	(b) $6,500	$13,000	(HABIT COST + DELIVERY COST) ÷ (90 DAYS) ÷ (3 SHIFTS)
COST OF MONEY			
$/DAY	$2M	$2M	BOEING STUDY RESULTS
% CONSTRUCTION TIME INVOLVING MRWS	75%	75%	
COST OF MONEY/MRWS	$30,000	$30,000	0.75 x $2M ÷ MRWS
COST/SHIFT	(c) $10,000	$10,000	3 SHIFTS
MRWS COST/SHIFT	$23,350	$30,293	TOTAL (a), (b) & (c)
RELATIVE UTILITY FACTOR	0.65	1.0	1 MAN REQUIRES REST
EQUIV COST/SHIFT	$35,423	$30,293	

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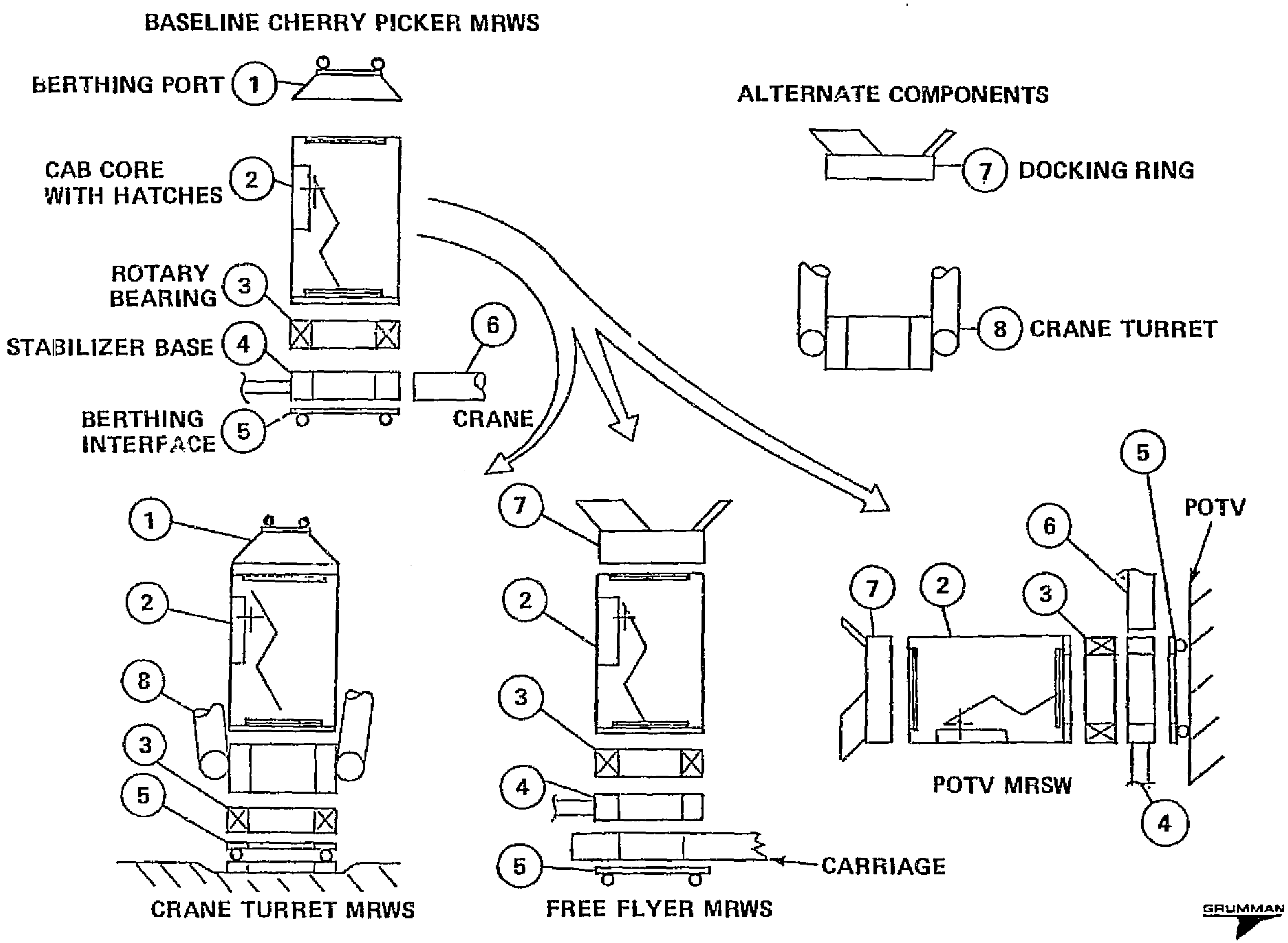
MRWS – GROWTH TRADE

Using Option 1 as the baseline configuration for the closed cab cherry picker, a study was made to determine the growth capability into future MRWS vehicles. The CCP was broken down into six basic structural/functional elements: upper mating interface, cab core with hatches, rotary bearing, stabilizer base/crane turret, and lower berthing interface.

The cab core structure was considered common to the CCP, crane turret MRWS, free flyer MRWS, and POTV airlock. The cab 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 externally mounted equipment. The CCP and crane turret MRWS have a berthing port interface added to the top of the cab core, while the free flyer and POTV MRWS vehicle have a docking ring interface added. All four vehicles have identical rotary bearing and lower berthing interfaces added to the bottom region 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 cab core and rotary bearing.

The controls and displays can be tailored to meet the requirements of each MRWS with minimum impact to the common cab core.

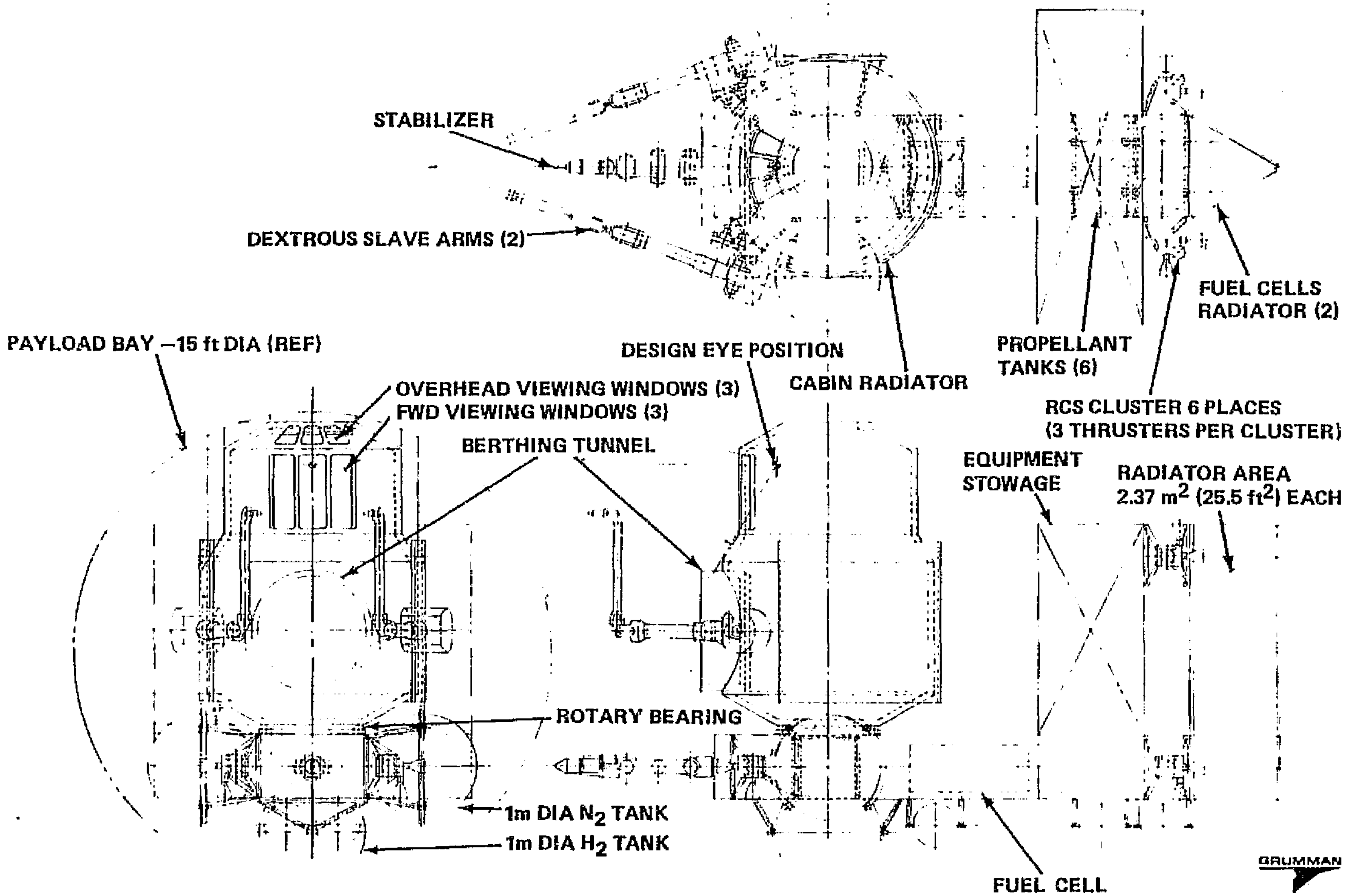
MRWS FUTURE GROWTH TRADE



Although the illustration shown on the opposite page does not depict the current cherry picker cab, basic elements of the free flyer are presented. A cherry picker cab is mounted to a structural frame by means of the rotary bearing, permitting ±180° of cab rotation. The cab has two 2-meter manipulator slave arms mounted to the forward face of the cab and a stabilizer mounted to the forward part of the structural frame. Six clusters of three RCS jets are mounted about the center-of-gravity of the free flyer. Six propellant tanks are mounted on the bottom of the frame as are the three tanks for oxygen, nitrogen and hydrogen. A fuel cell is located in the central part of the structural frame. The radiators for cabin equipment heat loads are mounted to the outside surface of the cherry picker cab, while the radiator for the fuel cells are located at the aft part of the free flyer. The area between the cab and the aft RCS jet pads is to be used for transportation of equipment from one point to another.

It is assumed that an updated drawing of the free flyer will result in a small, lighter and more compact vehicle. It will also show an overhead docking ring rather than the forward berthing port as shown.

FREE FLYER MRWS



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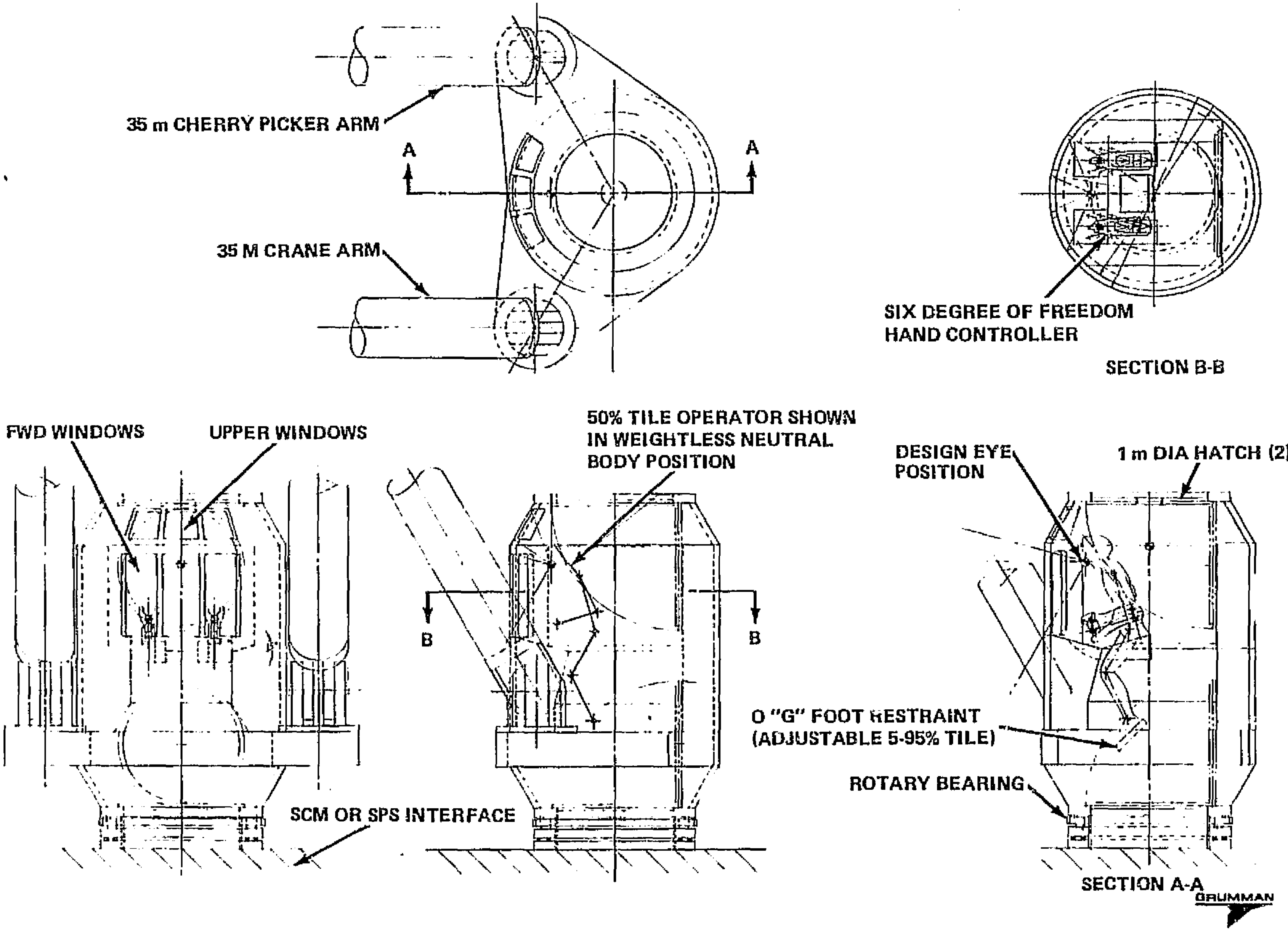
CRANE TURRET MRWS

The crane turret MRWS incorporates the one-man cherry picker cab. The basic difference between this vehicle and the cherry picker is the substitution of the crane arm module for the stabilizer base. On this application, the cab core is mounted directly to the crane arm module which in turn is mounted to the rotary bearing. In this manner, the cab and crane module rotate on the bearing ±180° as one unit. The rotary bearing interfaces with the Space Construction Module (SCM), or Solar Power Satellite (SPS). Ingress to the crane cab is through the rotary bearing and lower hatch. A berthing hatch at the top of the cab provides a matching interface to the cherry picker.

The dexterous manipulator masters in the cherry picker are replaced in this vehicle with two six-degree-of-freedom resolved rate hand controllers. One controller operates the 35-meter crane arm while the other controller operates the 35-meter crane arm for the cherry picker.

CRANE TURRET MRWS DESIGN 200



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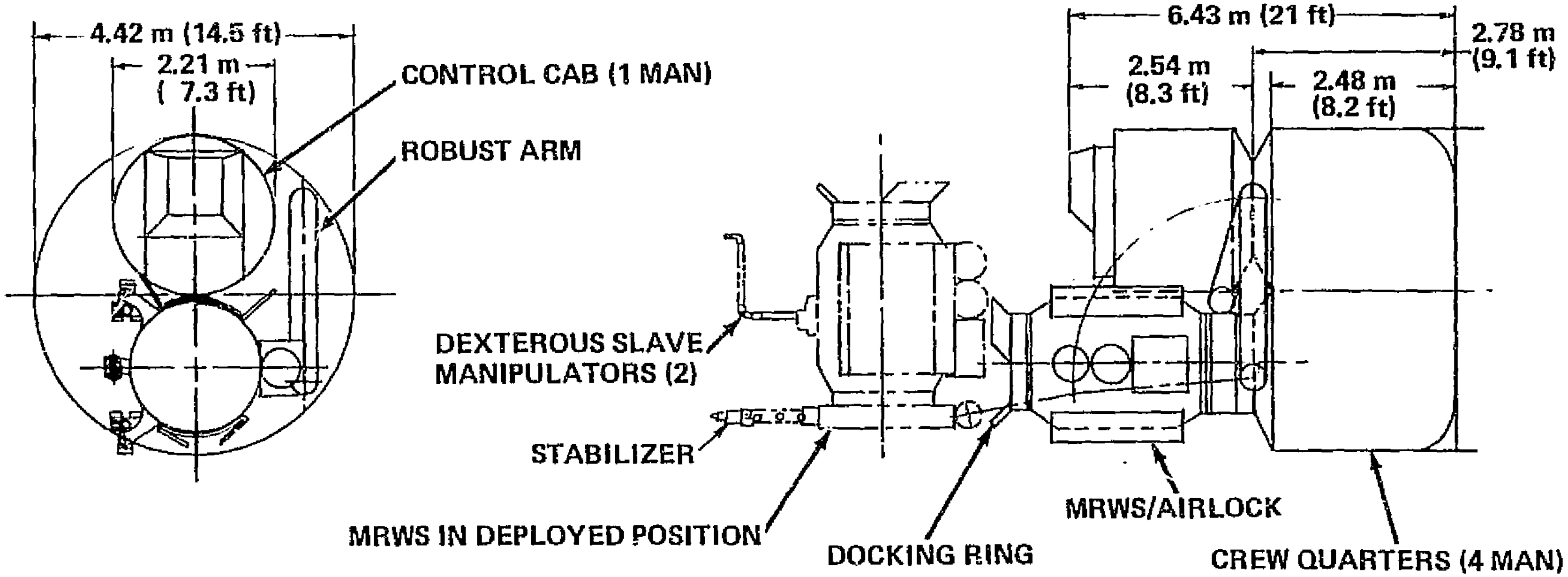
POTV – MRWS/AIRLOCK CONFIGURATION

The baseline MRWS shown here was modified by substituting the docking ring for the berthing port at the top of the cab. For the POTV configuration a control cab and MRWS are mounted to the forward side of the 4.42-meter diameter crew quarters module. In order to package these two modules within the prescribed diameter, the control cab diameter had to be reduced to 2.21 m. Further investigation is required to determine whether a 2-man side-by-side flight station is achievable for this reduced size control cab. For this presentation, the control cab is designated a one man flight station.

The MRWS interfaces with the crew quarters through the berthing port at the bottom of the assembly. In this position the POTV can dock to a base station using the docking ring on the MRWS. Crew transfer from the POTV to the base station is through the MRWS. A robust arm attached to the forward side of the crew quarters module and the stabilizer base, is capable of deploying the MRWS for use as a cherry picker.

POTV-MRWS/AIRLOCK – CONFIGURATION



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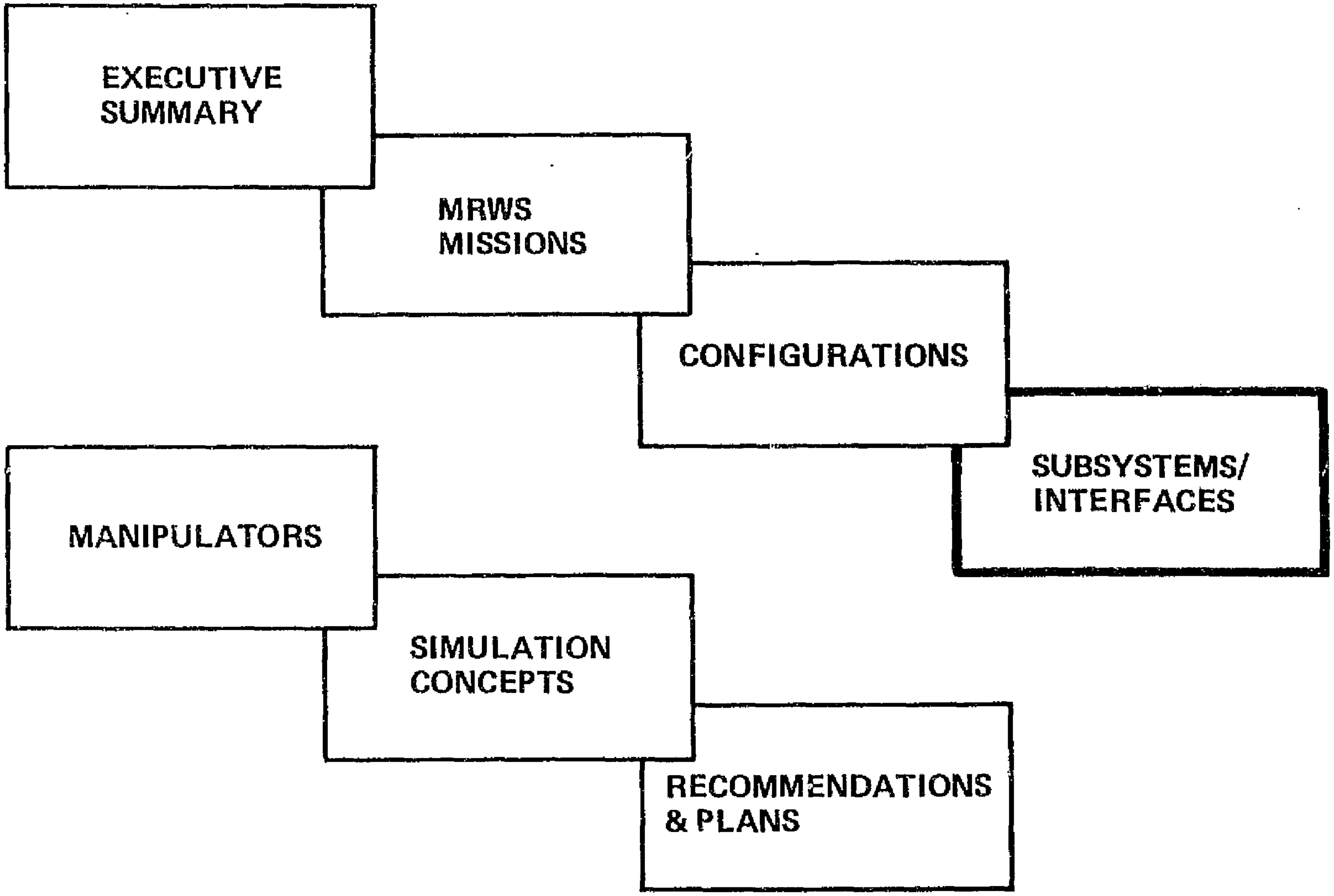
EXECUTIVE SUMMARY
MRWS MISSIONS
CONFIGURATIONS
SUBSYSTEMS/ INTERFACES
MANIPULATORS
SIMULATION CONCEPTS
RECOMMENDATIONS & PLANS

The principal factors of safety for the major structural components are shown in the chart on the opposite page; in addition, an ultimate factor of safety of 2.0 will be used on pressurized tankage.

All primary and secondary structure will be designed for a service life of ten years multiplied by a scatter factor; the factor currently selected is 4.0. However, the sensitivity of structural weight versus the factor will be assessed for values of 2.0, 3.0 and 4.0. The 10 year service life requirement will be used to evaluate the time-dependent characteristics of the structure including meteoroid penetration probability. A safe life design concept will be used which will incorporate fail-safe features by providing adequate fracture-arrest capability and adequate residual strength in any potential damage condition. Effects of flaws and defects on the structure depend on a prior assessment of potential flaw sizes, types and locations that can be reasonably expected to remain undetected by the best available NDE techniques. Fracture mechanics analyses for selected initial flow size will be used to assess life and proof test requirements. Materials will be selected which have good fracture toughness properties and are not susceptible to stress corrosion.

The design loads, static and dynamic, should be calculated for launch and landing conditions in the Shuttle and for space operations in orbit.

MRWS STRUCTURAL REQUIREMENTS

- FACTORS OF SAFETY
  - PRIMARY STRUCT: YIELD LOAD = 1.2 X LIMIT LOAD; ULTIMATE = 1.5 X LIMIT LOAD
  - CABIN PRESSURE STRUCT: ULTIMATE = 2.0 X MAXIMUM RELIEF VALVE PRESSURE
  - WINDOWS, DOOR, ETC. ULTIMATE = 3.0 X MAXIMUM RELIEF VALVE PRESSURE
- SERVICE LIFE 10 YEAR WITH SCATTER FACTOR = 4.0
- STRUCTURE WILL BE DESIGNED FOR SAFE LIFE INCORPORATING FAIL-SAFE FEATURES
- FRACTURE MECHANICS ANALYSES WILL BE USED TO ASSESS FLAW GROWTH, LIFE AND PROOF TEST REQMTS
- FRACTURE RESISTANT MATERIALS WILL BE USED, I.E., 2024-T851 PLATE, 2024-T81 SHEET
- LAUNCH AND LANDING LOADS MOUNTED IN ORBITER BASED ON JSC 07700, VOL XIV
- SPACE OPERATIONS WILL CONSIDER DOCKING/BERTHING, PRESSURE, RMS/ROBUST ARM, EQUIPMENT/COMPONENT HANDLING
- LUNAR MODULE CABIN STRUCT. CONCEPTS AND SEALING TECHNIQUES WILL BE USED

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MRWS RADIATION PROTECTION

The missions defined for the open cabin and closed cabin cherry pickers are shown in the table on the opposite page. The open cabin design mission covers the range 28.5° to 57° inclination at altitudes of 500 km to 1600 km with 6 hour shifts for a maximum of 14.5 days per crew member. The close cabin design missions vary from 28.5° to 31° at altitudes of 350 km to 478 km. Shift periods are 6 to 10 hours up to 54 days per crew member, assuming two different crew members per shift. One mission at GEO also includes a 54 day mission.

The figures show existing available data for LEO and GEO. The EVA data is based on no passage through the South Atlantic anomaly. The shuttle nominal EVA suit thickness is 0.1 gm/cm^2. The data shows that all the 28.5° inclination orbits up to 560 km are below the daily allowable percentage dose limit for 30 days. The 57° at 560 km and 1600 km require further investigation; these missions are 6 hour shifts of 2 days and one day per crew member respectively. The missions also have to be investigated for possible avoidance of the South Atlantic anomaly by proper scheduling of the EVA.

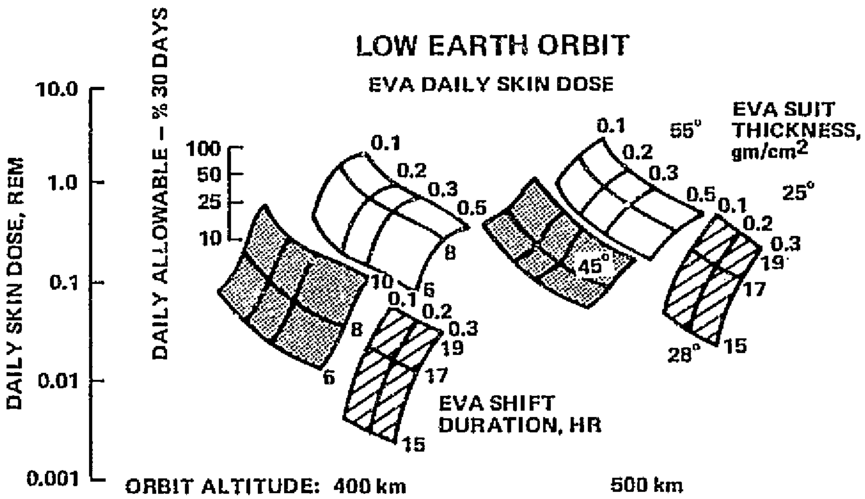
The close cabin missions at LEO present no problem since the orbits do not exceed 31° at an altitude of 478 km.

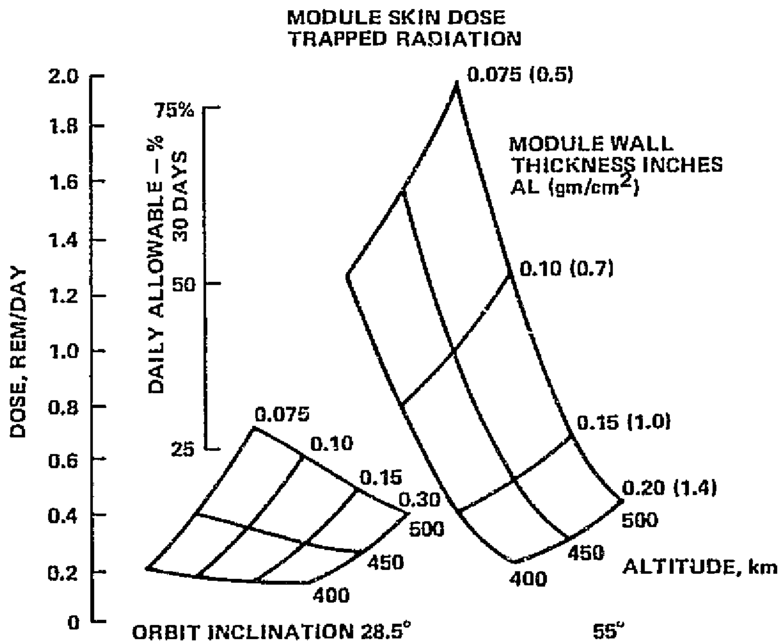
The higher dose rates in geosynchronous orbit are caused by a higher intensity electron and associated bremstrahlung environment and the effective absence of geomagnetic shielding against solar flare particles and cosmic rays. The figure also illustrates the average daily dose from trapped electron and bremstrahlung behind a range of aluminum thicknesses. To achieve a reduction in the daily skin dose to about 2 rems, approximately 300 mils of aluminum are required. The same shielding protection can be obtained by combining aluminum and a heavy material such as tantalum. As seen, a 20 mil layer of tantalum combined with 400 mils of aluminum reduces the dose by a factor of 10.

For both LEO and GEO it is recommended that an adequate warning system be used to permit the crew to enter a "storm shelter" during solar flare activities.

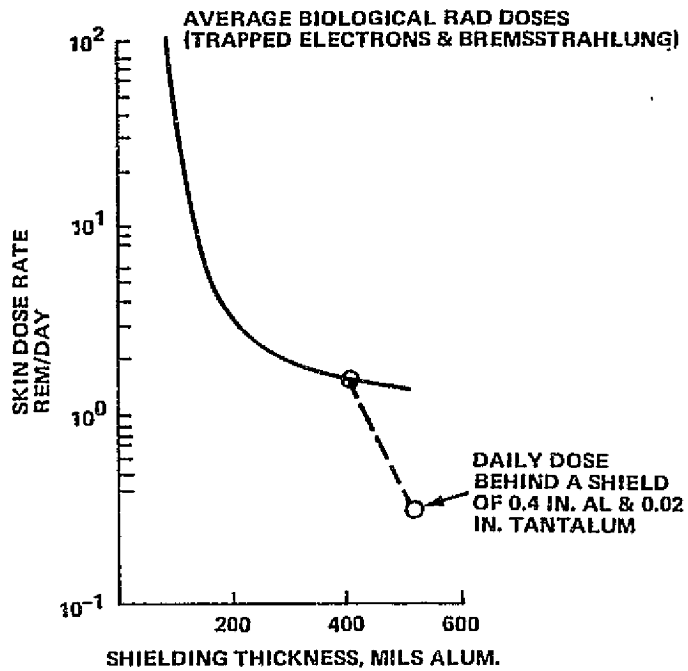
MRWS RADIATION PROTECTION

LOW EARTH ORBIT





GEOSYNCHRONOUS ORBIT



PARAMETER \ CONFIGURATION	OCP		CCP
INCLINATION, DEG	28.5 – 57	28	0 – 31°
ALTITUDE, km	500 – (1600)	350 – 400	LEO & (GEO)
MAX DAILY EXPOSURE DURATION OVER 30 DAYS, HR	6	8	10

ISSUE: SOUTH ATLANTIC ANOMOLY IMPLICATIONS

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As noted, the cabin structure should be studied for several methods of construction. The design should incorporate many of the structural concepts and sealing features used on the Lunar Module Ascent Stage cabin. The preferred structure is an integrally stiffened machined skin with machined frames.

A trade study should be made to assess the potential weight saving by designing the cabin structure for a nominal cabin operating pressure of 8 psi vs 14.7 psi. The effect of varying scatter factor values in designing for the required service life should also be studied to assess the potential weight variation.

The radiation protection issue requires additional studies which will establish whether the open or closed cabin design can be used for the LEO missions; the key points are: will the EVA suit prevent (1) the exceedance of the allowable dosage for the high orbits and (2) limit the crew work shift periods because of the South Atlantic anomaly. In addition, for the GEO close cabin configuration, the protection system should optimize the weight through use of aluminum combined with tantalum.

Definition of crew safety and mission success reliability requirements are needed to optimize the meteoroid protection system.

STRUCTURAL DESIGN – TRADE STUDIES & OPTIONS

WEIGHT TRADES	OPTIONS
CABIN WEIGHTS	• EXTERNAL SKIN SUPPORTED BY FRAMES AND HAT SECTION STIFFENERS • EXTERNAL SKIN SUPPORTED BY CONTINUOUS CORRUGATED SHEET AND FRAMES • HONEYCOMB WITH FRAMES √ • INTEGRALLY STIFFENED MACHINED SKINS & MACHINED FRAMES
CABIN PRESSURE	INTERNAL CABIN PRESSURE 8 psi VS 14.7 psi
SERVICE LIFE SCATTER FACTOR	STUDY EFFECT OF SCATTER FACTOR = 2.0, 3.0, 4.0
RADIATION PROTECTION OPEN CABIN VS. CLOSED CABIN AT LOW EARTH ORBIT	FOR LEO MISSIONS: STUDY CREW OPERATIONS & TIMELINES FOR AVOIDANCE OF SOUTH ATLANTIC ANOMALY IN OPEN CABIN; √ CLOSED CABIN PREFERRED
RADIATION PROTECTION CLOSED CABIN AT GEO	OPTIMIZE CABIN WALL PROTECTION REQUIREMENT BY COMBINING ALUMINUM AND TANTALUM
METEOROID PROTECTION	EXTABLISH CREW SAFETY & MISSION SUCCESS RELIABILITY REQMTS; OPTIMIZE BUMPER SKIN AND CABIN WALL SKIN THICKNESS

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CONCLUSIONS & RECOMMENDATIONS

The more significant issue which requires resolution is the extent of which the open cabin concept can be used to perform the low earth orbit missions. As noted, the dosage incurred during EVA in the higher orbits and passage through the South Atlantic. Anomaly must be calculated to establish whether the exposure levels are within acceptible limits.

The recommended trade studies should be carried out in order to optimize the design.

STRUCTURAL DESIGN

CONCLUSIONS & RECOMMENDATIONS

- STRUCTURE DESIGNED FOR SAFE LIFE WITH FAIL-SAFE FEATURES
- USE INTEGRALLY STIFFENED MACHINED SKINS
- 30% REDUCTION IN PRODUCTIVITY FOR OCP DUE TO SOUTH ATLANTIC ANOMALY
- FAVOR CLOSED CABIN CHERRY PICKER TO AVOID SOUTH ATLANTIC ANOMALY AT LEO; CLOSED CABIN IS REQUIRED AT GEO
- USE "STORM SHELTER" DURING SOLAR FLARE ACTIVITY

ISSUES TO BE RESOLVED

- PERFORM RECOMMENDED TRADES
- DETERMINE RADIATION EFFECT OF SOUTH ATLANTIC ANOMOLY
- 1600 km ORBIT EVA EFFECTS
- ESTABLISH CREW SAFETY AND MISSION SUCCESS RELIABILITY REQUIREMENTS FOR METEOROID PROTECTION

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SUBSYSTEM REQUIREMENTS – CONTROLS & DISPLAYS

The requirements developed for the OCP stress the use of the existing Shuttle Remote Manipulator System (SRMS) with certain functions jointly available to the astronaut on the platform and the SRMS operator in the Orbiter. The OCP must include caution and warning (C&W) functions, stabilizer controls and functions associated with the payload handling mechanisms.

The CCP, Crane and Free Flyer have many common functional requirements (e.g., CCTV controls) as indicated. The C&D design approach has emphasized the CCP cabin with required modifications identified for the crane and free flyer. Minimization of cabin volume requires that the C&D panels have minimum depth and power while opposing human factors considerations require operator visibility of critical displays and the external work volume through the window. Lunar Module displays were used where applicable to establish panel areas but integrated flat panel technology was incorporated for alphanumeric and graphic displays to reduce panel area and depth.

Final resolution of the C&D design requires evaluation of candidate concepts by simulation.

SUBSYSTEM REQUIREMENTS – CONTROLS & DISPLAYS

OCP	CCP	CRANE	FREE FLIER
SIMPLE FUNCTIONS: • SRMS CONTROL • C&W • GRAPPLER CONTROL • PAYLOADS HANDLING	• DEXTEROUS MANIP. MASTER CONTROLLER (2) • C.P. ARM CONTROLLER	• CRANE CONTROLLER • CRANE END EFFECT CONTROLS • CRANE SWITCHING & STATUS DISPLAY {	• TRANSLATION & ROTATION CONTROLLERS • RCS SWITCHING & STATUS • RADAR CONTROL • ATTD/ATTD RATE • RANGE/RANGE RATE • VELOCITY COMPONENTS • POSITION COORDINATES • DEXTEROUS MANIP. MASTER CONTROLLER(2) • STABILIZER CONTROL
	• STABILIZER • ALPHANUM./GRAPHIC • KEYBOARD • CAUTION & WARNING • MASTER STOP • CCTV CONTROL • EXTERIOR LIGHTS • EPS CONTROL • CIRCUIT BREAKERS • ENVIRON CONTROL • AUDIO • INTERIOR LIGHTS	SIMILAR TO CCP	SIMILAR TO CCP
MAXIMUM USE OF SRMS PANELS	CCP MODS FOR CRANE & FREE FLIER		

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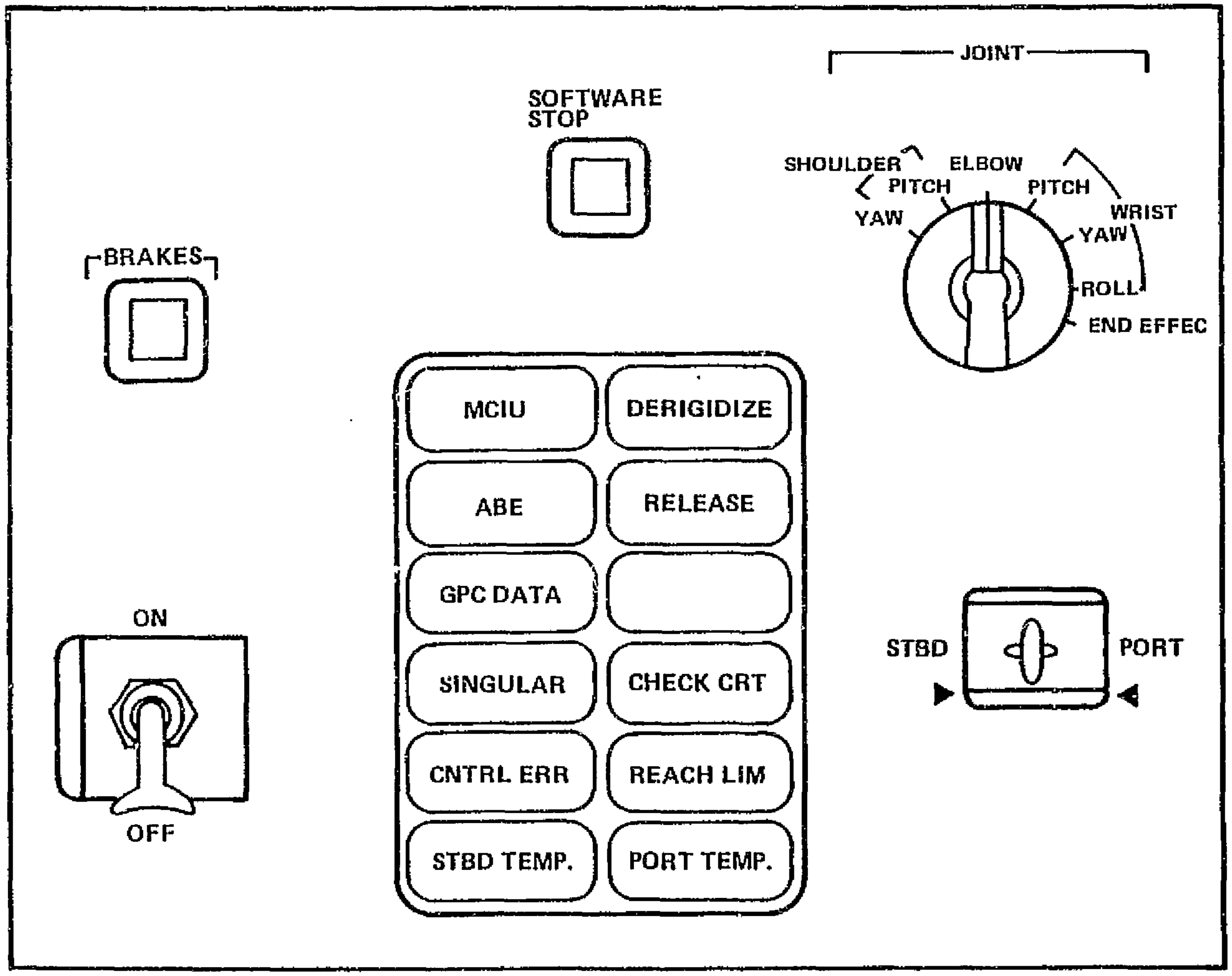
OCP PROPOSED D&C PANEL

The control and displays will be similar to those used in the Orbiter. However most of the Orbiter D&C panel parameters are not required at the OCP. It is proposed therefore that a very simple D&C panel be used which will contain caution indications together with a brake command switch, an arm selection switch (port or starboard), a joint selection switch and, a single drive switch.

The hand controllers will have the same functions as the Rotational Hand Controller and Translational Hand Controller in the Orbiter but the movement and force characteristics will require an increase as the CP operator will be constrained by his EVA suit.

OPEN CHERRY PICKER

CONTROLS & DISPLAYS PANEL (SIMPLE)



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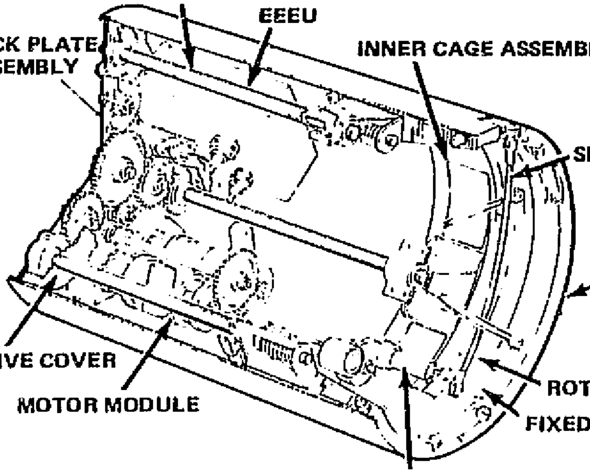
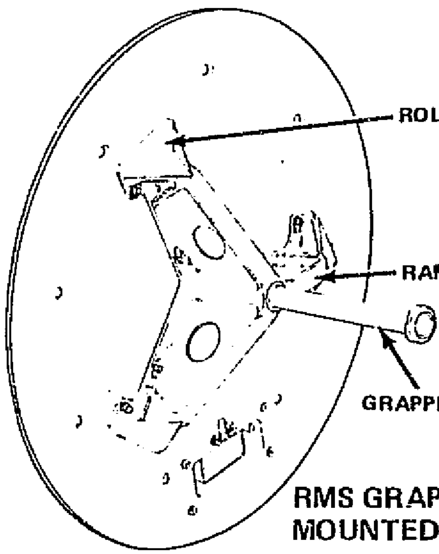
OCP/RMS INTERFACE DEFINITION

The mechanical and electrical interface between the Shuttle Remote Manipulator System (RMS) and OCP is provided by the snare type end effector on the end of the RMS with the grapple fixture attached to the OCP platform. Capture of the grapple fixture is accomplished by manipulating the snare in such a way that the grapple pin enters the open end of the snare. The snare ring drive motor tightens the enclosed cables and snares the grapple pin. Rotation of the end effector ring causes the three snare cables to close on the grapple, centering it and capturing the OCP platform. Operation of the ball screw and nut withdraws the cables pulling the grapple fixture into full contact and a keyed orientation with respect to the end effector. Further operation tensions the cables rigidizing the contact and mating the electrical connector establishing the complete interface.

OCP/RMS MECHANICAL INTERFACE DEFINITION



SNARE TYPE RMS END EFFECTOR



RMS GRAPPLE FIXTURE MOUNTED ON OCP

– PROVIDE MECH/ELECTRICAL/SIGNAL INTERFACE
– RMS GRAPPLE MRWS

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
- 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

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ORBITER/SEE/SPEE WIRING

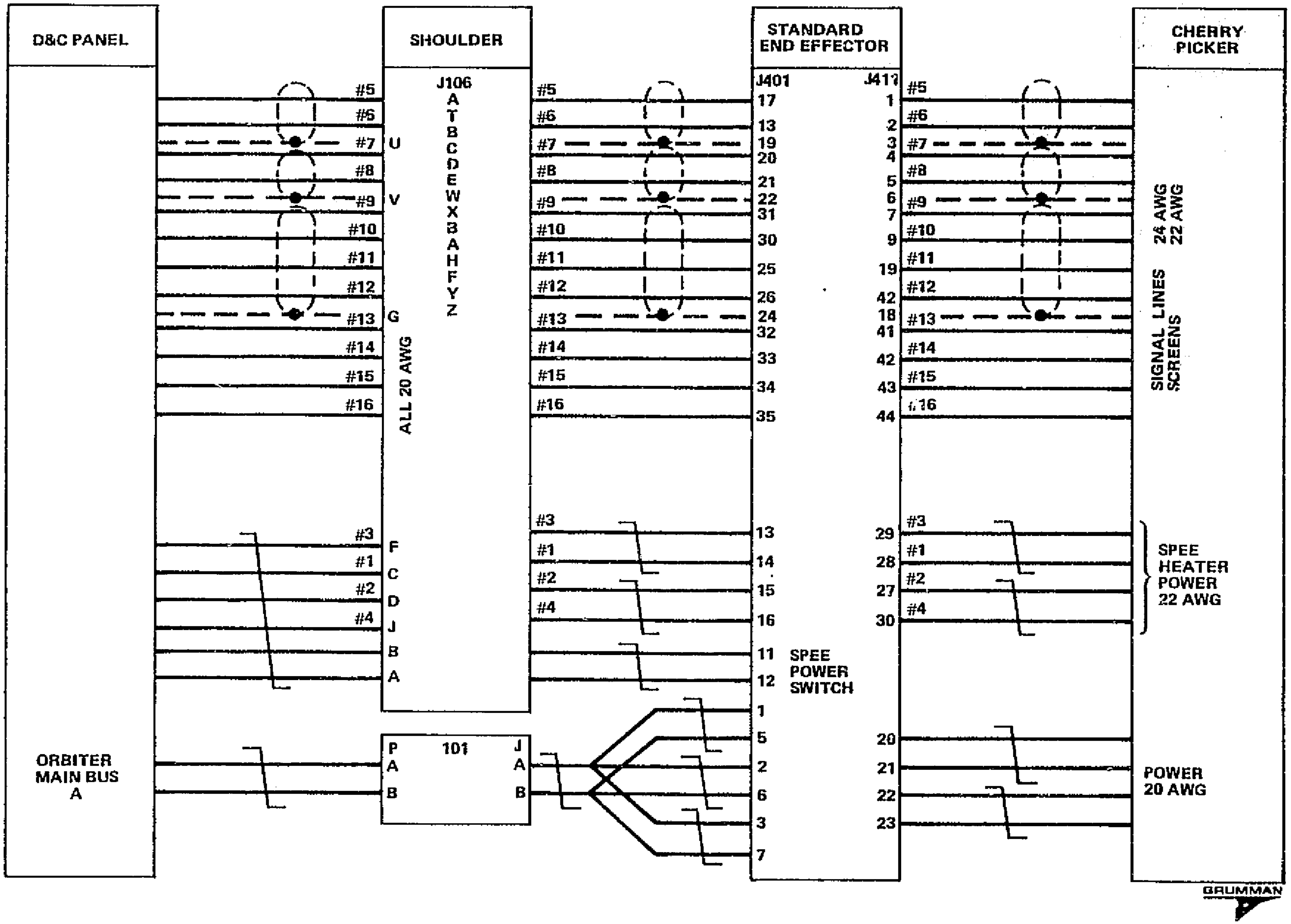
The OCP will be treated as a Special Purpose End Effector (SPEE). The SRMS has dedicated wiring for any SPEE and it is proposed that this wiring be utilized.

The wiring incorporated at present is shown in this illustration. This shows the number of conductors and wire sizes from the rear of the Orbiter D&C panel through to the SPEE.

The wiring comprises twelve signal lines which are distributed in two twisted shielded pairs, one shielded quadruple and four single conductors. Cable cores are available for heater power to the SPEE which could be used for signal lines if heater power were not required.

The power to the SPEE is switched at the Standard End Effector by a signal generated in the Orbiter. Maximum power available for the SPEE is 150 watts through the power cables and 100 watts for the heater power. The estimate for power for the D&C panel and the hand controllers excluding heater power is 40 watts.

ORBITER/SEE/SPEE WIRING



OCP/ORBITER BLOCK DIAGRAM

The SRMS system block diagram is shown on the opposite page. The D&C subsystem of the SRMS provides, in conjunction with the Orbiter CRT Display and Keyboard, the essential interface between the SRMS Operator and the subsystems of the Remote Manipulator. The Manipulator Control Interface Unit (MCIU) controls the flow of data to and from the D&C panel, the General Purpose Computer (GPC) and the Arm Based Electronics (ABE).

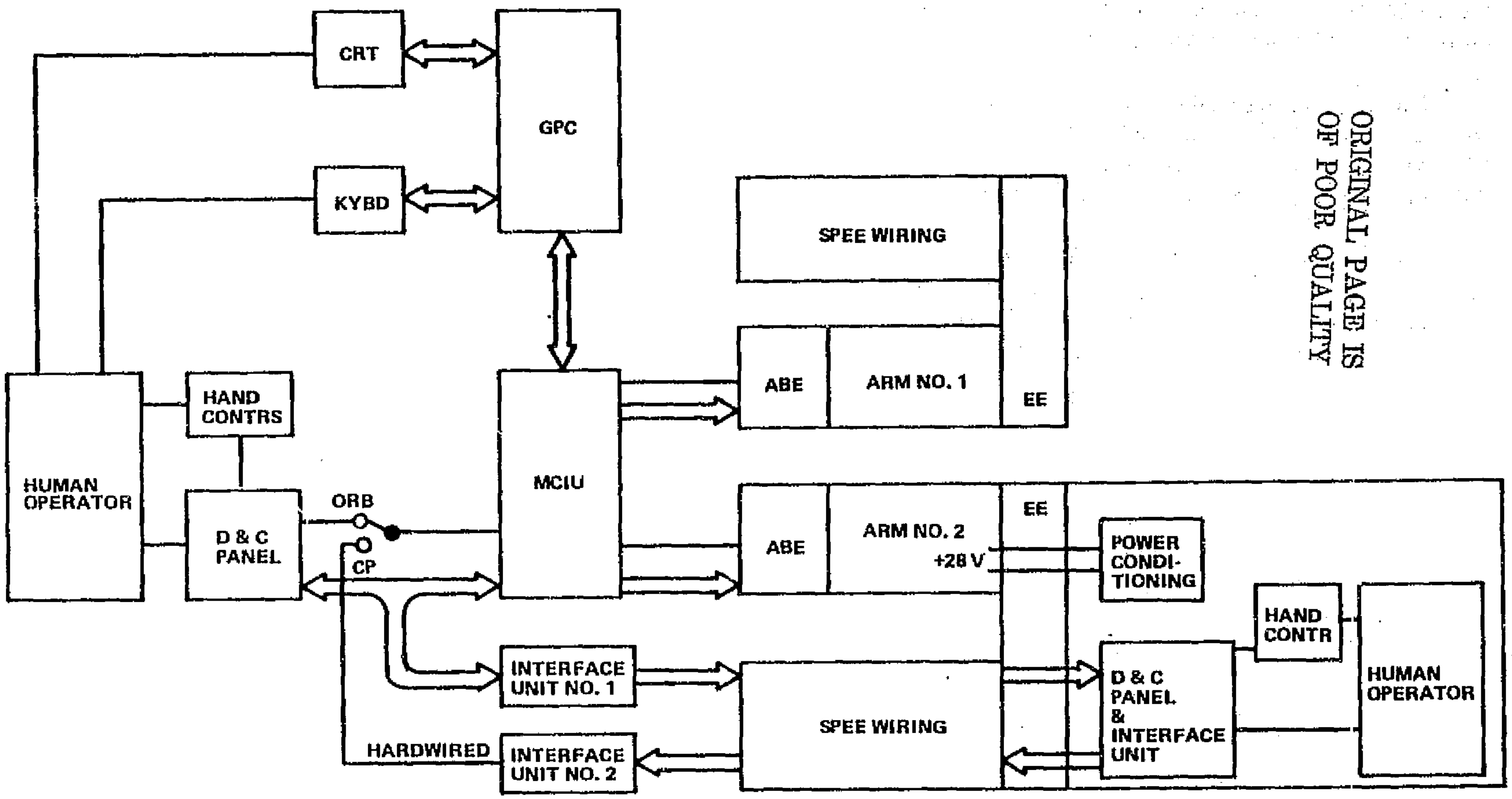
The main data flow between the MCIU and the D&C is accomplished using serial buses (MCIU data and D&C response bus). The exceptions to this data are the rate command signals from the hand controllers. These signals of x, y, z, roll, pitch and yaw rate command are hardwired into the MCIU.

The signals required by the OCP for monitoring are all available on the D&C panel to the MCIU data bus. Therefore, by introducing interface unit No. 1 between this data bus and the proposed OCP data bus it will be possible to obtain the required signals at the OCP D&C panel.

The command inputs to the system will be generated at the OCP D&C panel and transmitted down the data bus to interface Unit No. 2. The output of interface unit No. 2 will then be applied to the MCIU.

Selection of the CP or Orbiter control station is only made at the Orbiter.

OCP/ORBITER BLOCK DIAGRAM



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SUBSYSTEM OPTIONS – CONTROLS AND DISPLAYS

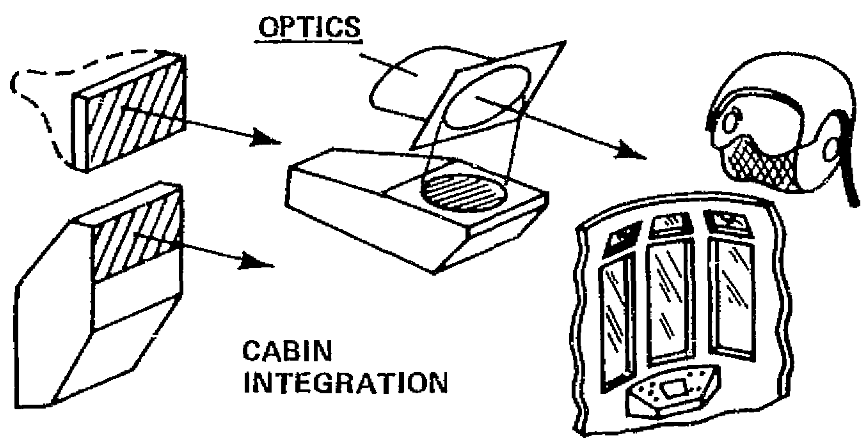
The integration of different display functions in a single element was investigated as an area which can greatly reduce total C&D volume and power. Display technology options were assessed to establish a baseline approach which best meets the MRWS requirements including moderate advances in state-of-the-art display capabilities. Displays are divided into two parts: the display device which generates the image and the display optics that transport the image to the observer's eye.

The device is generally either electron beam addressed or matrix addressed. The former uses a moving electron beam to generate the image while the latter uses coincident current techniques similar to computer core addressing methods. The CRT and the first four matrix addressed panels were selected for further evaluation. A comparison of the two devices indicates power and reliability advantages with the matrix panels but more versatility in display capability with the CRT.

The display optics either require viewing of a display surface (direct, ported and projected optics) or use optical techniques to superimpose the information on the scene viewed by the person. Direct, ported and helmet-mounted optics were selected as candidates for use in the MRWS. Heads-up approaches were ruled out because the window arrangement and work region geometry of the MRWS is considered unsuitable when viewing is not restricted to a particular direction.

SUBSYSTEM OPTIONS – CONTROLS & DISPLAYS

DEVICE COMPARISON	
MATRIX ADDRESSED FLAT PANEL	CATHODE RAY TUBE
LOW POWER	MULTICOLOR AVAILABLE
LOW VOLTAGE	MORE GREY SHADES
LESS VOLUME – DEPTH	HIGHER RESOLUTION
HIGHER RELIABILITY	LOWER COST (?)
LONGER LIFE	NO ERASING MODE
SOFT FAILURE	WIDE SELECTION OF FORMAT SIZES
INHERENT MEMORY	
UNIFORM RESOLUTION	MATURE TECHNOLOGY
INSTANT ON/OFF	ADDRESSING EASY
LOW DISTORTION	



CCP APPROACH

- MINIMIZE CABIN VOLUME, PANEL DEPTH, PWR
- VISIBILITY – WINDOWS, STATUS, C&W, CCTV
- CONVENIENCE – CONTROLLERS
- COMBINATION OF LUNAR MODULE PLUS INTEGRATED PANELS

DEVICE TECHNOLOGY

- ELECTRON BEAM ADDRESSED
  - – CRT
  - – LIGHT VALVE PROJECTOR
- MATRIX ADDRESSED FLAT PANEL
  - – PLASMA
  - – LED
  - – LIQUID CRYSTAL
  - – ELECTRO LUMINESCENT
  - – MAGNETIC PARTICLE

OPTICS TECHNOLOGY

- DIRECT
- PORTED
- HEADS UP
- HELMET MOUNTED
- PROJECTED

DISPLAYS AND CONTROLS – SELECTED APPROACH

Electroluminescent flat panel technology was selected for the alphanumeric/graphic display primarily becuase of its low power and high performance which makes it very attractive for displaying subsystem status information, caution and warnings and, task descriptions for orbital activities. A computer entry keyboard operates in conjunction with this panel for verifying data input values. Specific information displayed at any given time is determined according to a priority interrupt system with caution and warning parameters as necessary.

A conventional direct display black and white TV was chosed as baseline for video information (CCTV) because of its reasonable power level and proven state of development. Color TV is not warranted at this time but is worthy of evaluation by simulation. A baseline C&D panel arrangement has been developed but final selection will be the result of evaluation of alternate designs by simulation.

DISPLAYS & CONTROLS – SELECTED APPROACH

- ELECTROLUMINESCENT FLAT PANEL DISPLAY FOR ALPHANUMERIC/GRAPHIC (50 W AVG PWR)
  - SUBSYSTEM STATUS
  - CAUTION & WARNING
  - TASK DESCRIPTIONS
- CONVENTIONAL DIRECT DISPLAY B&W TV
- BASELINE PANEL SELECTION

ISSUES TO BE RESOLVED

- SIMULATION: KEY TO CONTROLS & DISPLAYS INTEGRATION
  - COLOR TV EVALUATION
  - PANEL ARRANGEMENT
  - HELMET-MOUNTED DISPLAY EVALUATION
  - CCTV CAMERA LOCATION TRADES

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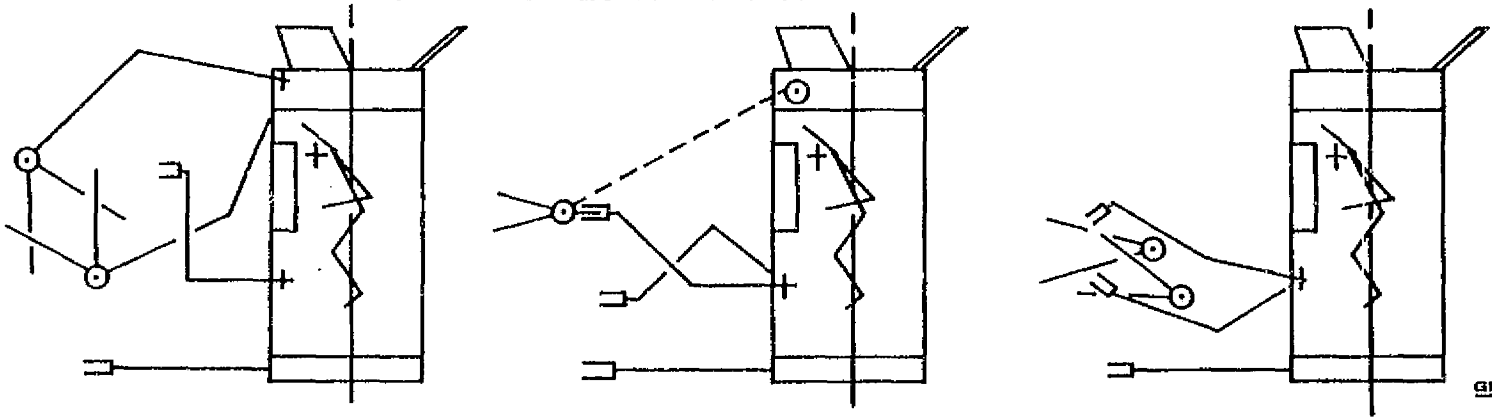

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SUBSYSTEM REQUIREMENTS – ENVIRONMENTAL CONTROL/LIFE SUPPORT (ECLS)

The basic design requirements for the ECLS subsystem are listed. These assume the equivalent of continuous one man operation for seven days in a closed cabin pressurized to one atmosphere. ECLS requirements are essentially the same for all versions of the closed cabin MRWS. Open cherry picker operations require the standard pressure suit as with any EVA.

To minimize storage volume, consumables are stored in 3300 psi composite tanks similar to those used on the shuttle. Total storage volume for the O_2, N_2 and emergency O_2 tanks is 6.4 ft^3.

The ECLS radiator is sized to reject 1447 watts of interior cabin heat resulting from metabolic, subsystem, and external sources.

SUBSYSTEM REQUIREMENTS – ENVIRONMENTAL CONTROL/ LIFE SUPPORT (ECLS)

OCP	CCP	CRANE	FREE FLYER
STANDARD EVA REQMTS	← PRESSURIZED CABIN →		

- PRESSURIZED FREE VOLUME 168 FT^3
- ENVIRONMENT (O_2/N_2) 14.7 PSIA
- TEMPERATURE 75 - 85° F
- HUMIDITY (DEW PT) 45 - 60° F
- RECHARGE 7 DAYS
- METABOLIC (3 - 8 H SHIFTS, 1-MAN CONTINUOUS)
  - AVG LOAD 1200 BTU/H
  - PEAK LOAD 1600 BTU/H
  - CO_2 GENERATION 5.0 LB/DAY
  - H_2O GENERATION 14-20 LB/DAY
- CONSUMABLES

CONSUMABLES	OXYGEN	NITROGEN
– LEAKAGE (LB/DAY)	0.4	1.6
– METABOLIC (LB/DAY)	4.2	–
– 2 REPRESS (LB)	7.5	30.0
TOTAL (LB)	39.7	41.2
– 3300 PSI TANK (IN)	20	–
– EMERGENCY O_2 (LB)	20	–
TANK (IN)	15.5	–

- CABIN INTERIOR HEAT LOAD

CABIN INTERIOR HEAT LOAD	
– METABOLIC (1200 BTU/H)	350 W
– CO_2 REMOVAL	50
– ELECTRICAL	822
– SOLAR INPUT (WINDOWS)	255
TOTAL	1447 W

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SUBSYSTEM OPTIONS – ECLS

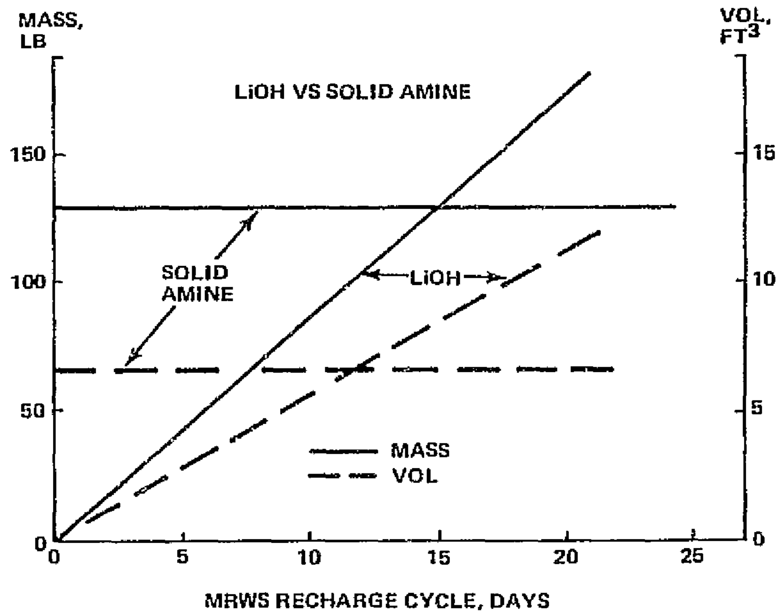
Results of several ECLS trade studies are summarized. The standard STS pressure suit, which includes all services in a self-contained backpack, is adequate for EVA in the open cherry picker, and imposes no new development costs. Other possibilities include use of a small backpack plus a carry-on pack or carry-on hose which connects to MRWS services. Both provide better mobility and redundancy than the standard suit, but introduce additional suit development or MRWS design complications.

A regenerable solid amine system, which is currently under development for the Shuttle, was selected for CO_2 removal as the best of several candidates. As seen on the opposite page, Li OH is smaller and lighter for relatively short periods. However, the mission weight/volume panalties of multiple expendable cartridges are unacceptable for the high-use MRWS. The other systems require GSE, service supplies and/or bake-out routines, all of which are unneccessary with the solid amine system. The selected system also provides inherent humidity control which permits an elevated inlet coolant temperature, thereby minimizing required radiation area.

A simple, single fluid (FC-40) thermal transport system was selected since the coolant circuits within the cabin are small, and damage potential is low.

To conserve space and reduce cabin heat loads, all equipment which need not exist in the pressurized volume is mounted in an aft equipment bay. Since sufficient radiator surface is available to passively cool this equipment, no additional coolant loops are require in this area.

SUBSYSTEM OPTIONS – ECLS



- HUMIDITY CONTROL MAINTAINED VIA SOLID AMINE BED; PERMITS INCREASED INLET COOLANT TEMPERATURE; RESULTS IN 10% REDUCTION IN RADIATOR AREA (85 ft^2 VS 95 ft^2)

AFT EQUIPMENT BAY

- ELECTRICAL LOAD 228 W
- PASSIVE HEAT REJECTION @ AVG RADIATOR TEMP 155° F
- REQUIRED RADIATOR AREA 5.2 ft^2
- AVAILABLE AREA (AFT EQUIPMENT BAY REAR SURFACE) 6.3 ft^2

*HAMILTON STANDARD TRADE STUDY

- BACKPACK CONCEPTS
  - √ – SELF CONTAINED
  - – CARRY-ON PACK
  - – CARRY-ON HOSE
- CABIN CONCEPTS
  - – CO_2 REMOVAL SYSTEM*
    - – LiOH
    - – MOLECULAR SIEVE
    - – HYDROGEN DEPOLARIZED CONCENTRATOR (HDC)
    - √ – REGENERABLE SOLID AMINE
  - – RADIATORS (HX CONFIG)
  - – EQUIPMENT LOCATION
    - – INTERNAL
    - – EXTERNAL

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SUBSYSTEM REQUIREMENTS – ELECTRICAL POWER

Power requirements for each version of the MRWS are summarized. Electrical loads for the open cherry picker and for all emergency modes are well under one MRW. Total load for the closed cabin MRWS ranges from 3 to 4 kw.

Two recharge concepts were considered: a seven day continuous operating regime and a nine hour (eight hour shift plus one hour contingency) supply in which expendables one replaced energy shift. The result is widely different energy requirements, tens of kilowatt hours for the nine hour recharge cycle and hundreds of kilowatt hours for the seven day cycle.

SUBSYSTEM REQUIREMENTS – ELECTRICAL POWER

	OCP	CCP	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	298/142
TOTAL	250 (MAX)	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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Fixed base systems could be powered via hardwire directly from the base.

Stored energy systems are the only practical power source candidates for a non-fixed base MRWS. Interference and blockage eliminates solar panels and radioisotape dynamic power systems require excessive radiator area.

Of the various battery options, nickel cadmium appears to be the best compromise from a performance/cost standpoint. Although promising lower weight and longer life, the metal-hydrogen batteries are not yet proven and impose a large volume penalty. The silver compound systems are lighter and smaller, but have limited cycle life and pose voltage regulation and recharge problems.

Existing and advanced Shuttle fuel cells were considered with cryogenic and gaseous reactant storage. Gaseous storage requires simpler installation and controls, but high storage pressures must be used to realize a significant volumetric advantage over batteries.

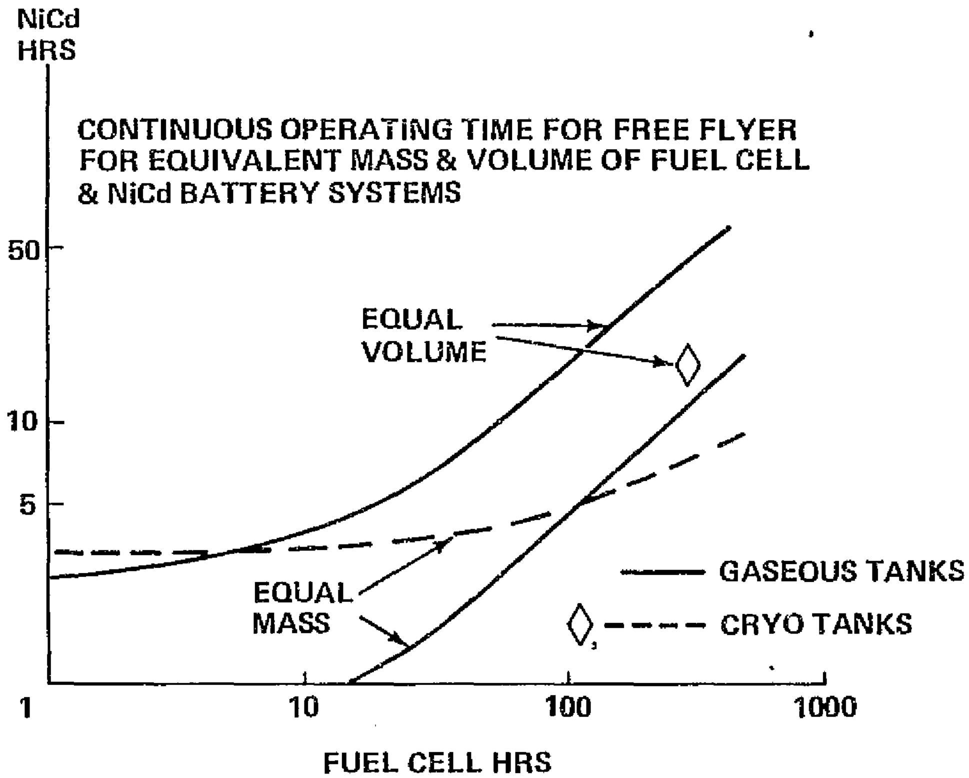
The illustration depicts the substantial weight and volume advantage afforded by fuel cells over NiCd batteries. For the same mass, fuel cells can operate about 20 times longer than batteries at a given load, and 8-10 times longer at equal volume. The values shown reflect advanced NiCd batteries, advanced Shuttle fuel cells with (1) existing Shuttle cryogenic tanks and (2) tailored 3300 psi composite tanks.

Based on specific mass/volume, batteries could only be considered for the short (9 hr) recharge cycle regime, whereas fuel cells one attractive for seven or more days of continuous operation.

The advanced Shuttle fuel cell provides about twice the life and operates at a higher temperature than the existing system. Radiator areas for the advanced fuel cell are comparable to those required for NiCd batteries.

Use of the Shuttle fuel cell can also accomodate MRWS power levels up to 7-12 kw, providing wide design/mission flexibility.

SUBSYSTEM OPTIONS – ELECTRICAL POWER



- ENERGY SOURCES

√ – STORAGE

– SOLAR COLLECTOR

– RADIOISOTOPE DYNAMIC PWR SYS

– FACILITY PWR

- ENERGY STORAGE APPROACHES

– BATTERIES

√ o NiCD

o NiH_2

o AgH_2

o AgZu

o AgCd

– FUEL CELL

o SHUTTLE

o ADVANCED SHUTTLE

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CONCLUSIONS/RECOMMENDATIONS – ISSUES TO BE RESOLVED

Fixed-base MRWS versions can be powered directly via hardwire. For mobile versions of the MRWS, fuel cells provide the greatest flexibility and long continuous service. There is some question however, of the advisability of storing hydrogen at very high pressure. This could dictate use of the more complicated cryogenic reactant storage. Should installation/control of the cryogenic system prove undesireable, NiCd batteries could be a backup, but permit only short work intervals between recharge. All emergency requirements can be satisfied with a small NiCd battery.

A simple, single loop cooling system is recommended for the closed cabin MRWS, together with the most attractive solid amine system. A LiOH CO_2 removal system could be considered as a ready backup should the solid amine system be unavailable.

Consumable storage volumes one based on use of 3300 psi tanks similar to those used on the Shuttle. Additional volume could be saved if higher storage pressure was used. Composite 5000 psi tanks are being developed and might be considered for MRWS.

Greater mobility and consumable redundancy could be achieved with a modified pressure suit for the open cherry picker. The cost/availability of this suit should be investigated for possible inclusion in later MRWS missions.

The issue of recharge time, maintenance difficulty/frequency, mission effectiveness and cost must be addressed through an optimization study before firm requirements one established for consumable/electrical energy storage. For example, the desireability of long, continuous operation with fuel cells must be compared to the use of simpler, longer life batteries and the cost of replacement and recharge.

MRWS EPS/ECLS

CONCLUSIONS/RECOMMENDATIONS

- STORED ENERGY SYSTEMS ARE THE ONLY REASONABLE EPS CANDIDATES
- HIGH PRESS OR CRYO FUEL CELL SYSTEM PERMITS MUCH LONGER CONTINUOUS OPERATION THAN BATTERIES – USE GASEOUS SYSTEM FOR ALL BUT FIXED-BASE MRWS
- NICD BATTERIES BEST CHOICE FOR EMERGENCY POWER. (1 kWh) AND AS FUEL CELL BACKUP (8 hr RECHARGE)
- USE SIMPLE, SINGLE-LOOP COOLANT SYSTEM
- USE SOLID AMINE CO_2 REMOVAL SYSTEM (LIOH BACKUP)

ISSUES TO BE RESOLVED

- HIGH PRESSURE H_2 STORAGE
- 5000 psi STORAGE OF CONSUMABLES
- AVAILABILITY OF SOLID AMINE SYSTEM
- AVAILABILITY OF PREFERRED PRESSURE SUIT (OPEN CHERRY PICKER)
- RECHARGE CYCLE/MAINTENANCE COST OPTIMIZATION

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SUBSYSTEM REQUIREMENTS – PROPULSION & ACS (FREE FLYERS)

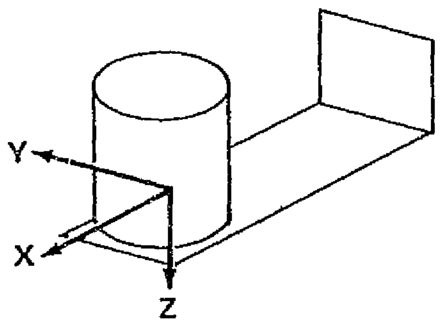
A free flyer operating period of 10 hours was developed based on a rescue mission which consisted of a 10 km translation across a large space structure with a required delta ΔV of 40 m/sec. It has been assumed that 25% of the operating period is spent free flying with the MRWS physically attached to the structure at the worksite during the remaining time. Stationkeeping at a distance of 5 km above or below (worst case) the structure cg for one hour requiring a continuous 10.8 lbf thrust level. The attitude control deadband of 0.1 deg was selected to provide thrust vector orientation and to reduce grappling dynamics.

Rotational and translational control authority levels were selected based on astronaut experience with Lunar Module flights. Corresponding control thrust levels were developed for a typical free flyer configuration indicating the need for 80 lbf thrusters to provide the desired levels of control authority.

Thruster configuration development should stress the avoidance of adverse plume effects and must not interfere with cabin motion. The configuration selected should be capable of providing satisfactory control with changes in cg location due to payload handling.

SUBSYSTEM REQUIREMENTS – PROPULSION & ACS (FREE FLYER)

- OPERATING PERIOD: 10 HRS, 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, 180° EACH @ 1 DEG/SEC
- "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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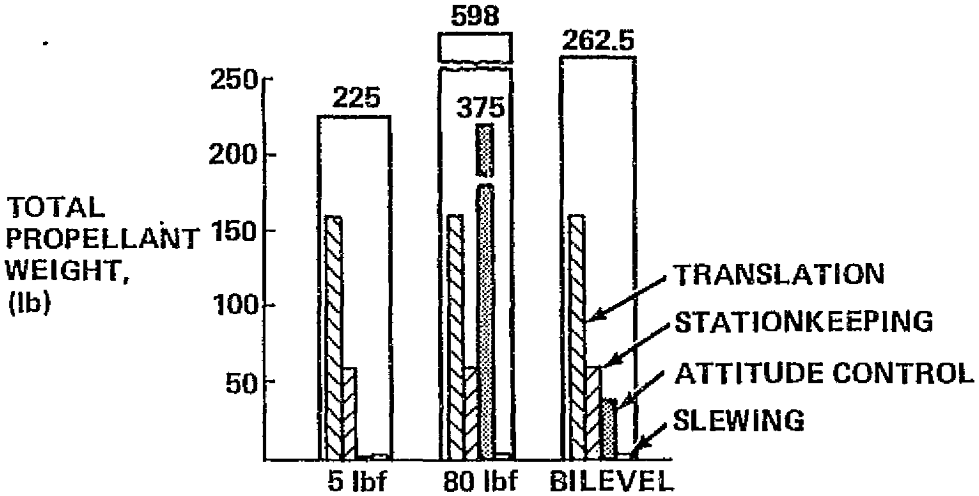
The need for a propulsion system for translation and stationkeeping is apparent. Two key options are: the thrust level and the thruster configuration. Propellant (N_2H_4) consumption is a major consideration in the case of the former, in addition to the desired control authority level discussed earlier. This is apparent in the diagram which shows the propellant quantity for the reference mission for three thruster systems: 5 lbf thrusters with unacceptably low control authority, the optimum 80 lbf thrusters and a hybrid dual - thrust system where 80 lbf thrusters are used for all translation but only for 10% of the rotation control; the remainder is provided by 5 lbf thrusters. The attitude control propellant is seen to be a major factor which effects propellant requirements. This portion varies from 2.5 lb/min for 80 lbf thrusters to 0.01 lb/min for 5 lbf thrusters for the specified 0.1 deg deadband.

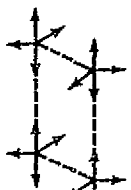
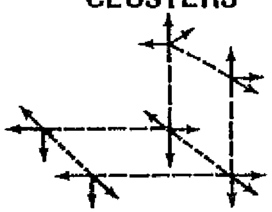
Integrated thruster configurations providing both attitude and translation control were evaluated for two basic thruster groupings: quad clusters, four thrusters at a point, and triple clusters (three thrusters at a point). The former requires four clusters for full control while the latter requires six. Comparison of the two concepts shows desirable advantages with the triple clusters such as avoidance of plume effects in the forward, upper quadrant of the vehicle which is the primary zone where manipulator work is conducted. The four-thruster always require at least one set of thrusters to be mounted on the cabin is considered a significant disadvantage because of interference with the manipulators, radiators and work region.

SUBSYSTEM OPTIONS – PROPULSION & ACS

PROPELLANT CONSUMPTION



THRUSTER CONFIGURATIONS

CONCEPT	ADVANTAGES	DISADVANTAGES
QUAD CLUSTERS 	• MIN THRUSTERS (16) • SIMPLE FIRING LOGIC	• MAX CABIN IMPING • SENSITIVE TO CG MOVEMENT OUT OF PLANE • CABIN MOUNT REQUIRED
TRIPLE CLUSTERS 	• MIN PLUMES IN WORK VOLUME • MIN MANIPULATOR IMPINGEMENT • ADAPTABLE TO CG LOCATION SHIFTS	• MAX THRUSTERS (18) • COMPLEX SELECTION LOGIC

- PROPULSION REQUIRED
- RCS VS MOMENTUM MGMT
- THRUST LEVELS

	deg/sec^2	ft/sec^2
5 LBF	0.6	0.05
80 LBF	10.0	0.3
√ HYBRID	(10.0) (0.6)	0.3

- TANK SIZING
- THRUSTER CONFIGURATION
  - √ – QUAD CLUSTERS
  - – TRIPLE CLUSTERS

CONCLUSIONS/RECOMMENDATIONS

The major results of the Propulsion & Attitude Control Subsystem Analysis are indicated in this chart. Momentum management via reaction wheels or control moment gyros was ruled out because of the limited free flying time in the mission with extended periods spent attached to the work site where the subsystem is inactive. The need for a propulsion system for translation and high torque/low power requirements suggest an integrated translation/rotation control approach using the same thrusters. Monopropellant hydrazine (N_2H_4) was selected for the indicated reasons with a bilevel thrust approach using 80 lbf and 5 lbf thrusters to reduce limit cycle propellant consumption. The recommended system consists of six triple clusters of bilevel thrusters and four multi/mission modular spacecraft (MMS) tanks.

The refinement of free flyer requirements is a major issue to be resolved including evaluation of alternate missions and MRWS configuration characteristics. Free flyer design guidelines should be established in more detail and the selected subsystem approach should be optimized for the final vehicle configuration. The impact of rendezvous and docking requirements on the propulsion & ACS design should be evaluated and a particular approach selected. The effect of maintenance and resupply considerations on subsystem selection may change the conclusions reached in the analysis to date.

PROPULSION & ACS

CONCLUSIONS/RECOMMENDATIONS

- MOMENTUM MANAGEMENT RULED OUT
  - SHORT DURATION/FREQUENT DOCKING
  - PROPULSION NEEDED FOR TRANSLATION
  - HIGH TORQUE FOR CONTROL AUTHORITY
  - POWER SENSITIVE
- INTEGRATED TRANSLATION & ROTATION CONTROL
- MONOPROPELLANT HYDRAZINE (N_2H_4) SELECTED
  - HIGH THRUST
  - MODERATE I_{SP}
  - THRUSTERS & TANKS AVAILABILITY
  - ACCEPTABLE PLUME EFFECTS
- BILEVEL THRUST APPROACH
- FOUR 16.5 IN. DIA MMS TANKS (283 LB PROPELLANT)
- SIX TRIPLE CLUSTERS

ISSUES TO BE RESOLVED

- ALTERNATE FREE FLYER MISSION SCENARIOS
- CONTROLLABILITY REQMTS FOR FREE FLYER MISSION
- TANK SIZING VS CONFIGURATION CHARACTERISTICS
- RENDEZVOUS & DOCKING REQMTS
- MAINTENANCE/RESUPPLY CONSIDERATIONS

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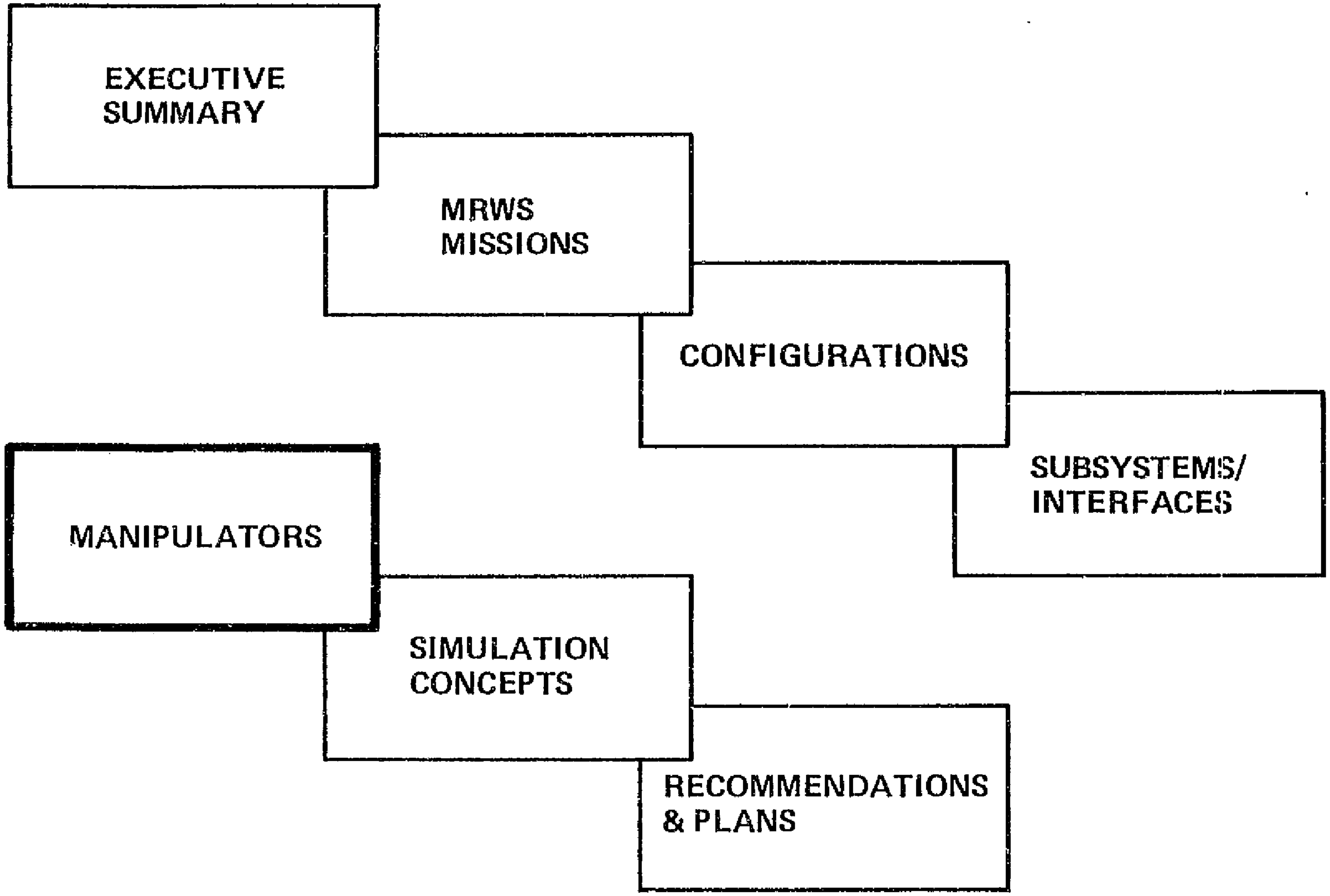

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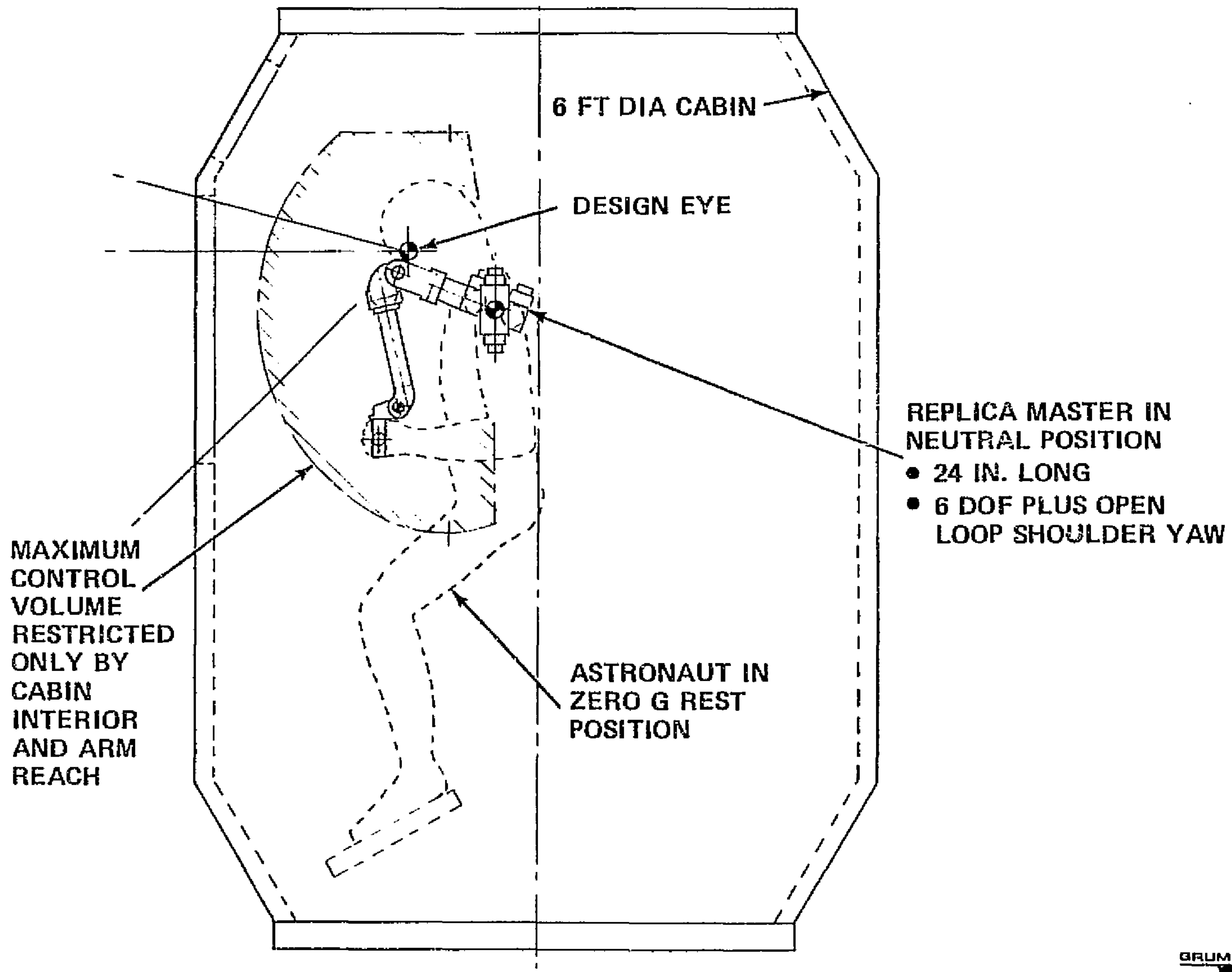
MASTER CONTROL CONFIGURATION

A configuration of a full reach 6 DOF plus shoulder yaw controller in lieu of a controlled volume indexed controller is shown on the opposite page. Included is the orientation of an Astronaut in a zero g rest position relative to the design eye, the cabin and windows, the adjustable foot restraint platform, the master controller (one for each arm), and the maximum control volume which is restricted by Astronaut arm reach, and the cabin interior walls, consoles, etc.

MASTER CONTROL CONFIGURATION



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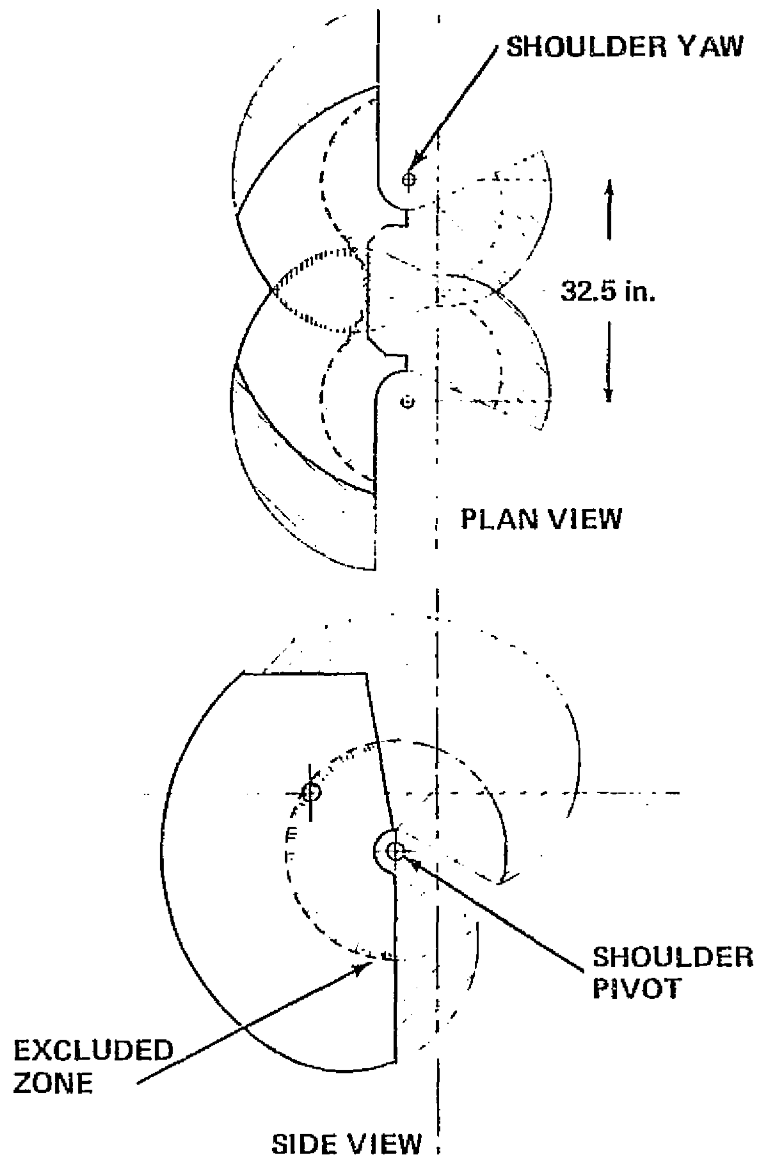
MASTER CONTROL VOLUME

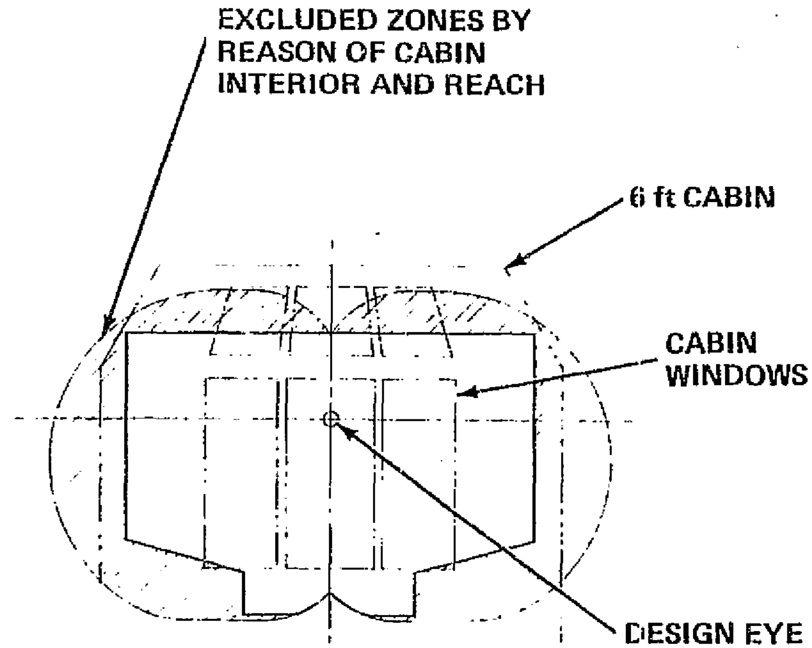
Three views of the Master Controller volume capabilities with the restrictions imposed when installed in the cabin and used by the astronaut are shown on the opposite page.

It is envisioned that a four bar linkage for support of the yaw pivot will permit the astronaut to manually position and lock the pivot location for three specific reasons:

- Provide clearance for cabin hatch opening
- Provide additional room for the astronaut during free flyer operation
- Provide personalized adjustment and increased outboard reach capabilities with an off-center-line Astronaut.

MASTER CONTROL VOLUME





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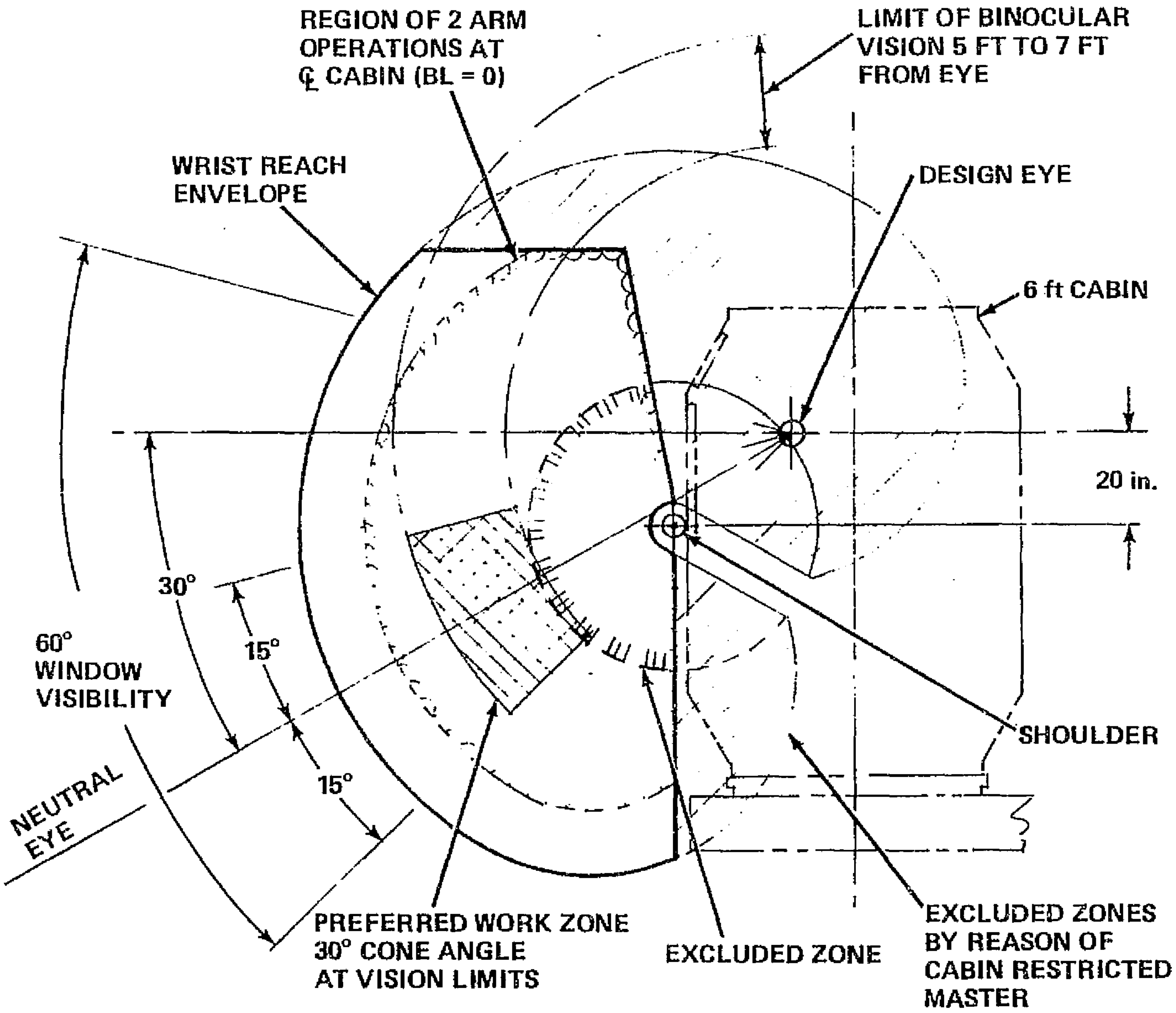
SLAVE WORK VOLUME – SIDE VIEW

The relationship of the cabin, design eye, forward vision, and preferred work zone relative to the 6 DOF plus shoulder yaw slave manipulator is, depicted on the opposite page. The manipulators shoulder position, two arm operation at the centerline of cabin, and the available work volume with the restrictions imposed by the master control system are shown.

SLAVE WORK VOLUME – SIDE VIEW



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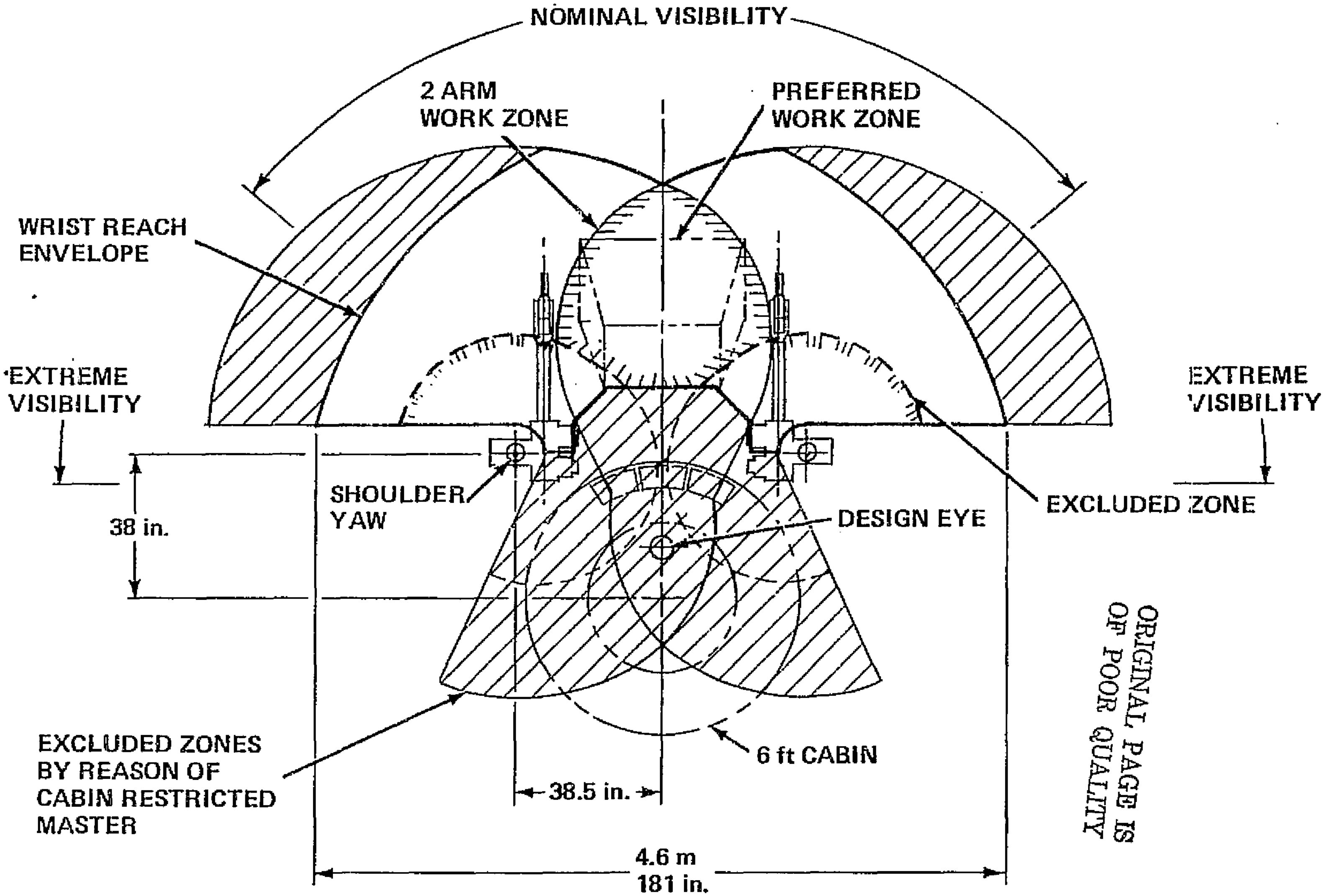
SLAVE WORK VOLUME – TOP VIEW

The opposite page shows the relationship of the cabin, design eye, nominal visibility, extreme visibility, and preferred work zone relative to the slave manipulator shoulder yaw pivots, two-arm work zone, and the available work volume with the restrictions imposed by the master control system.

The maximum spread reach of 181 in. can be individually increased on each side depending on the Astronaut's positioning of the master shoulder yaw pivot in the cabin.

SLAVE WORK VOLUME – TOP VIEW



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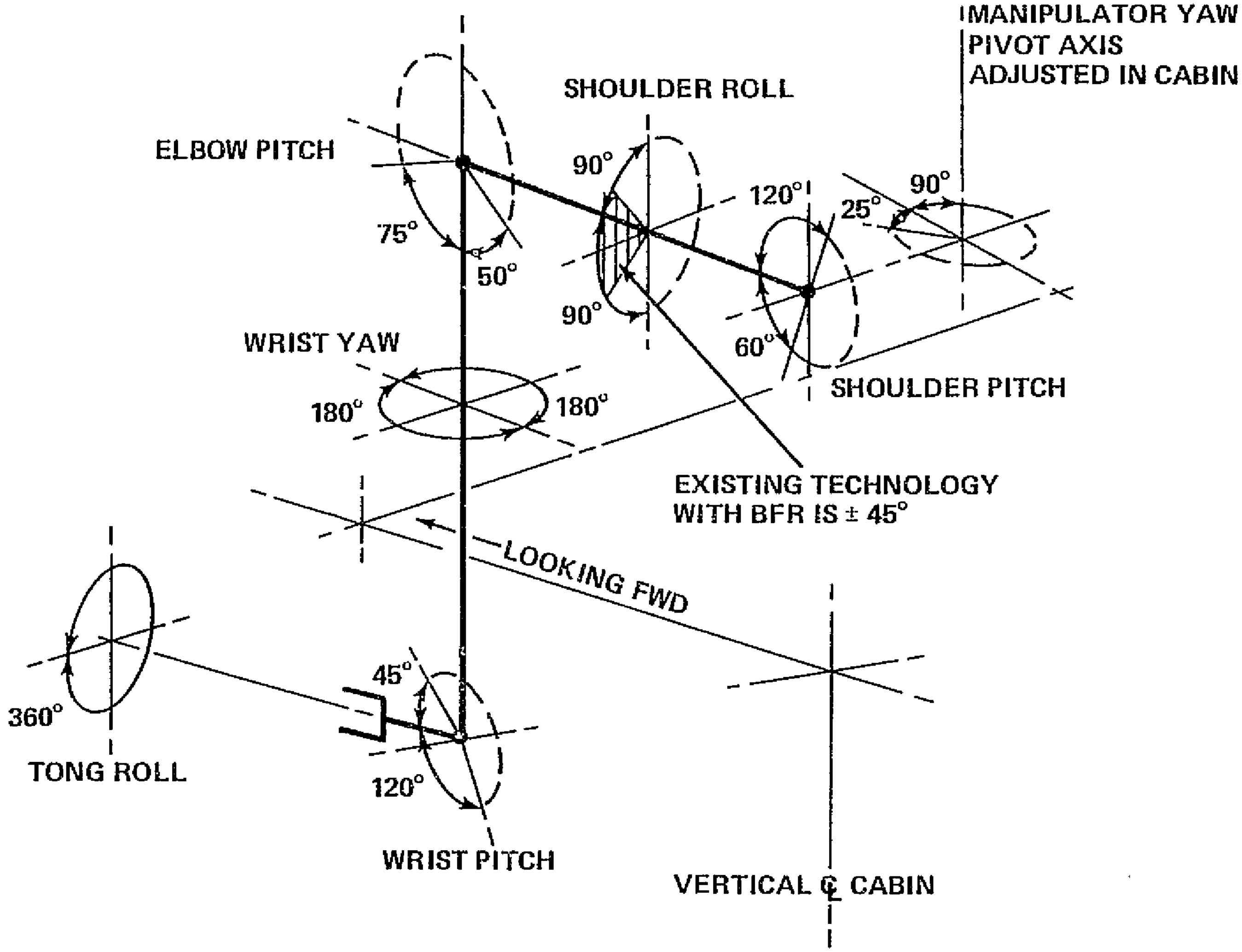
1852-126V-5

RECOMMENDED SLAVE ARM KINEMATICS

The recommended slave arm DOF and limits of motion are displayed. Wrist roll and yaw are both 360° motions for maximum versatility. Consequently, wrist pitch can be less than 90°. The 165° range shown is compatible with state-of-the-art (SOA) technology and enhances efficiency for some operations. Total shoulder pitch of 180° is selected to provide the maximum working zone for the arm. By limiting elbow pitch to an angle less than 180°, an indeterminate arm position (a singularity) is avoided (the case when forearm and upper arm are approximately parallel). Elimination of this singularity removes control problems near that position, particularly when indexing and coordinate transformations are used. To provide a larger working volume, shoulder roll requirements are enlarged from the current SOA of ±45° to the maximum available with bilateral force reflection (BFR); the goal is ±90° in shoulder roll. The seventh DOF is shoulder yaw which is not a BFR motion. The 90° motion permits two dexterous arms to handle wide bodies. The 25° yaw motion is based upon the geometry of a particular MRWS installation.

RECOMMENDED SLAVE ARM KINEMATICS



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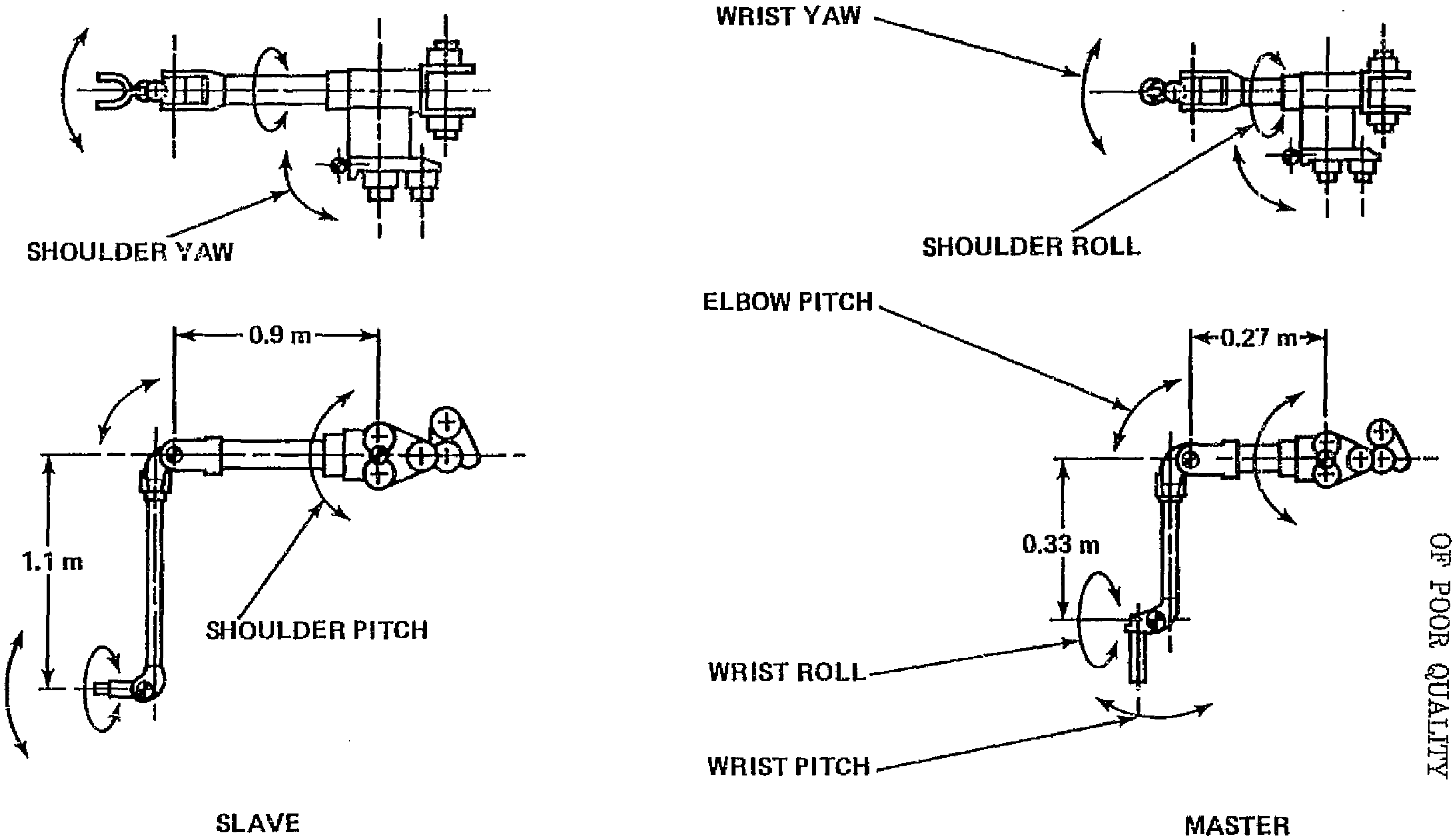
1852-079V-5

DEXTEROUS MANIPULATOR ARRANGEMENT

A replica master slave arrangement is recommended which implies similarity of geometry and orientation between master and slave. However, two differences are planned. Reduce operator fatigue by using a pistol grip for the master handle instead of the single DOF CRL tong. The other difference is in control of slave yaw motion. To position a body at an arbitrary attitude and position, 6 degrees-of-freedom (DOF) are required. Conversely, the position of the control handle will uniquely determine the position of a 6 DOF master. However, to simulate the dexterity of a human arm, 7 DOF (in rotation) are required of a slave arm. Either the master must operate with 7 DOF and the resulting position indeterminancy, or 1 DOF must be removed from the master and placed on a separate control dial or switch, or an additional constraint be made between operator and master (e.g., a forearm "sleeve"). Based upon unsatisfactory experiments with controllers with more than 6 DOF and a desire to leave the operator unencumbered, we recommend removing shoulder yaw from the master.

DEXTEROUS MANIPULATOR ARRANGEMENT



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1852-080V-5

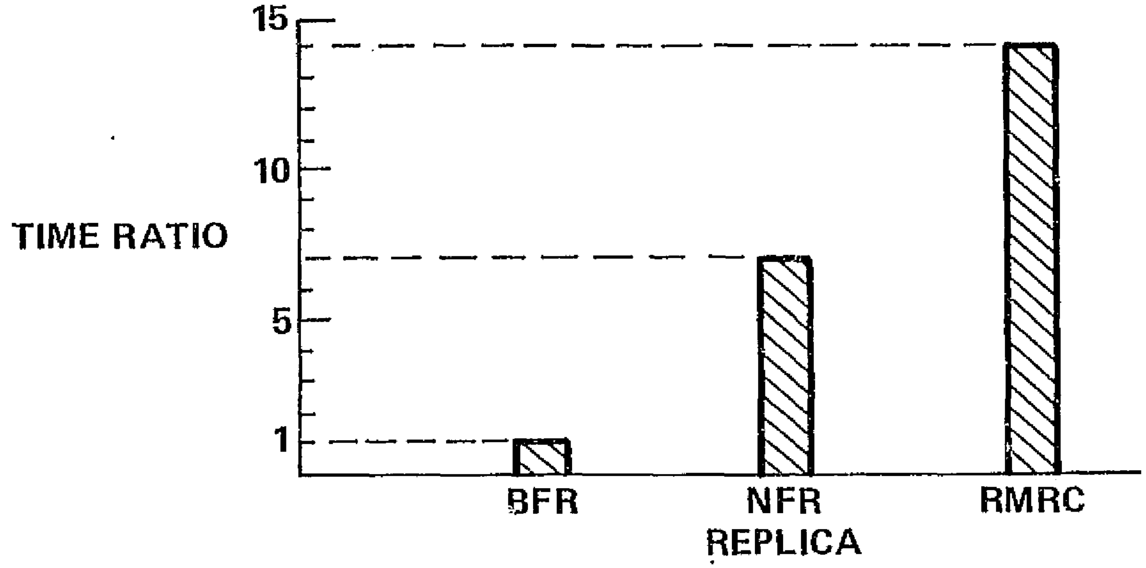
SUPPORTING EVIDENCE FOR PRODUCTIVITY

The approximate relative efficiency between three control modes is shown on the opposite page. Bilateral force reflection (BFR) is the most efficient and is used as the standard for time comparisons. NFR Replica is a position control device which uses master/slave control with a 1:1 ratio. It is nonforce-reflecting and relies only on visual cues for operator feedback. Resolved motion rate control (RMRC), utilizes a 6 DOF hand controller to establish the direction of motion and tip speed of a slave arm.

The tests which form the basis for the displayed data were not optimized for either space tasks or the comparison which is presented here. On some, dissimilar manipulators were used for comparing task times. On others, an insufficient number of tests were conducted; none of the test sequences were related to space construction.

However, all known tests results indicate a significant advantage in task efficiency for BFR. Its nearest competitor, NFR, requires about seven times more time for average tasks. Since productivity is a compelling parameter for fabrication of future very large space structures, it is recommended that BFR be evaluated in an MRWS simulation laboratory.

SUPPORTING EVIDENCE FOR PRODUCTIVITY DECISION
SUMMARY RELATIVE TASK TIMES



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VERTUT ET AL, "CONTRIBUTIONS TO DEFINE A DEXTERITY FACTOR FOR MANIPULATOR," PROC. OF 21ST CONFERENCE ON REMOTE SYSTEMS TECHNOLOGY 1973

NEVIS ET AL, "THE MULTIMODED REMOTE MANIPULATOR SYSTEM," FIRST CONFERENCE ON REMOTELY MANNED SYSTEMS, 1972

FLATAU, "TASK TIME COMPARISON OF THREE MANIPULATOR CONTROL MODES, BFR, UNILATERAL AND RATE CONTROLLED," 1969 AND 1978, UNPUBLISHED

FLATAU ET AL, "SOME PRELIMINARY CORRELATION BETWEEN CONTROL MODES OF MANIPULATOR SYSTEMS AND THEIR PERFORMANCE INDICES," FIRST CONFERENCE ON REMOTELY MANNED SYSTEMS, 1977

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1852-082V-5

BFR VS NON-BFR: TEST RESULTS OF 3-12-78

These data were obtained by Carl Flatau in his own laboratory. Since available time was extremely limited, each task was performed only four times. Consequently, a large quantity of data scatter is evident. The general conclusion is that BFR was 6.7 times more efficient than NFR Replica for these tasks.

BFR VS NON-BFR: TEST RESULTS OF 3-12-78

TASK	TEST RESULTS IN SECONDS				TASK TIME RATIO: NFR/BFR
	BFR		NFR		
	MEAN* TIME	STD DEV	MEAN* TIME	STD DEV	
1. REMOVE PIN (3/8 in. dia. 0.0005 in. FIT)	4.0	0.6	31.0	8.9	7.8
2. PUT PIN DOWN	1.2	0.9	4.75	1.5	4.0
3. PICK UP PIN (VISION OBSTRUCTED)	1.5	1.0	26.2	15.6	17.5
4. REINSERT PIN	8.0	0.9	48.0	6.1	6.0
5. PICK UP T HANDLE ALLAN WRENCH	1.8	1.0	19.8	1.6	11.0
6. INSERT IN SCREW (VISION OBST)	3.4	1.6	50.2	12.8	8.0
7. TURN WRENCH 3½ REV	9.0	0.5	56.3	11.3	6.3
8. RETURN WRENCH	3.0	0.7	26.5	6.7	8.8
9. GRAB AIR IMPACT WRENCH	1.3	0.8	9.3	8.7	7.2
10. PLACE ON BOLT	1.5	0.5	6.8	5.3	4.5
11. SCREW DOWN	1.0	0.2	7.3	11.5	7.3
12. REMOVE	1.0	0.3	3.5	5.6	3.5

AVERAGE RATIO = 6.75; STD DEVIATION OF RATIO = 2.2

*TESTS USED 2 OPERATORS; EACH OPERATOR PERFORMED EACH TASK 2 TIMES

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1852-081V-5

RECOMMENDED LABORATORY MANIPULATOR SYSTEM

Two identical dexterous arms are the familiar anthropomorphic arrangement. People are accustomed to working with two hands. Although a human hand has 21 degrees-of-freedom (DOF), one handed tasks are difficult and time-consuming. A typical dexterous arm hand has 1 DOF (3 at most). Consequently, greater efficiency is anticipated with two handed dexterous arm activity.

The velocity ratio at the tip of both arms results from the ratio of slave length to master length. The maximum recommended tip speed is based upon observation limits of the human eye. Speeds higher than 0.75 m/s are not perceived accurately.

Slave maximum tip force is based upon a requirement to connect/disconnect a hydraulic fitting. This requirement was established in a previous study. Maximum master tip force will be a compromise between adequate BFR capability and operator fatigue. The recommended range is suggested as a starting point for simulator tests.

The recommended values for accuracy, resolution, deadband, master friction and BFR sensitivity are current state-of-the-art for BFR manipulator systems.

The manipulator system should have the capability of evaluating various types of indexing systems. Indexing may be required to improve operator productivity. A relatively inexpensive test series is recommended to establish a need for indexing. The effect of different shoulder locations (for master and/or slave) on productivity and access should be examined during laboratory tests.

RECOMMENDED LABORATORY MANIPULATOR SYSTEM

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

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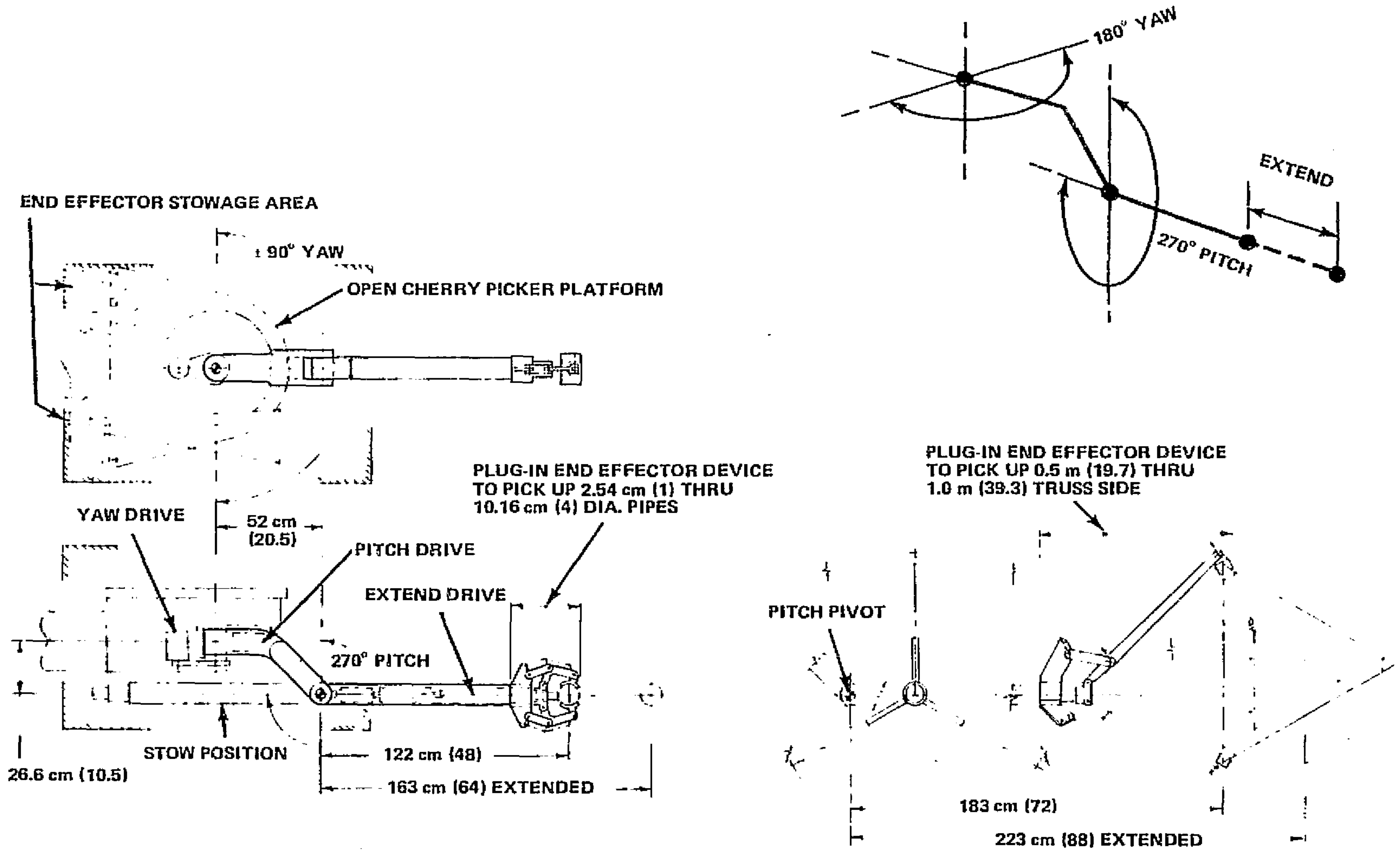
THREE DEGREE-OF-FREEDOM STABILIZER

The opposite page shows the concept for a 3 DOF electromechanical manipulator which is attached to the bottom of the OCP and is used to grasp a portion of the worksite as a stabilizing device.

The link attached to the OCP is driven ±90° in yaw, parallel to the astronaut's platform. The second link is driven 270° in pitch to permit horizontal positioning under the platform, for Shuttle Bay Storage, and up to a vertical orientation in front of the astronaut for end effector installation or removal. This link incorporates a powered extension of 16 in. The end of this link is compatible for the attachment of a family of end effectors. Two such effectors are shown; one to pick up pipes between 1 to 4 in. in diameter and another to pick up triangular trusses between 0.5 to 1 m on a side. The end-effectors are stowed under the platform when not in use.

THREE-DEGREE-OF-FREEDOM STABILIZER



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TYPICAL STABILIZER SYSTEM

The opposite page specifies the minimum design requirements for the stabilizer system. Three items are expanded as follows:

- One stabilizer satisfies the results of a previous tradeoff study on the use of multi-stabilizers

- Open loop-type control used for end effector grip and for each DOF is controlled by individual two-position hold/neutral switches located on the OCP control console

- The length designated reflects the pipe end effector configuration. Each end effector design will impact the overall length and must be considered to ensure the astronaut is within reach of the worksite task.

TYPICAL STABILIZER SYSTEM

• NUMBER OF STABILIZERS	1
• TYPE OF CONTROL	OPEN LOOP
• CONTROL DEVICE	DOF SWITCHES (TWO POSITION HOLD/ NEUTRAL)
• LENGTH	1.2 TO 1.6 m
• DEGREES OF FREEDOM (DOF)	3
• DEXTERITY	S (Y) E (P) W (E)
• MAX TIP FORCE (LOCKED)	40 LB
• MAX TIP MOMENT (LOCKED)	≈ 1000 IN.-LB
• ACCURACY/RESOLUTION	± 1 cm/± 2 mm
• STABILIZER ARRANGEMENT	
– POWER	ELECTROMECHANICAL
– TRANSMISSION	PROXIMITY DRIVE
– COUNTERWEIGHTS	NO
• FAIL-SAFE LOCKS AT POWER LOSS	YES

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1852-098V-5

PROS AND CONS OF 3 DOF

Some advantages and disadvantages of using a 3 DOF stabilizing manipulator are listed on the opposite page.

It should be noted, that even with the additional DOF provided by the RMS, these DOF are not wholly additive to the 3 DOF stabilizer, because the DOF that are important are those relative to the astronaut's worksite task and the stabilizer end effector.

A properly configured 6 DOF device would eliminate the disadvantages stated, due to its ability to orient the end effector to any position on the worksite. To accomplish the same degree of capability with a 3 DOF device would require specifically designed, single or multiple pickup points.

It is recommended that the concept of a family of end effectors be used to enhance a wide range of pickup capability and force distribution with a 6 DOF manipulator.

PROS AND CONS OF 3 DOF

DISADVANTAGES

- LIMITED DOF RESTRICTS ORIENTATION AND/OR CREWMAN'S REACH TO WORK SITE UNLESS SPECIFIC STABILIZATION POINTS ARE PROVIDED
- STOWING REQUIREMENTS AND DOF LIMITS REACH CAPABILITY RANGE (SHORT TO LONG)
- STOWING END EFFECTORS INCREASES CREWMAN TASKS
- NOT AN OFF-THE-SHELF ITEM

ADVANTAGES

- PLUG-IN END EFFECTOR CONCEPT PROVIDES WIDE RANGE OF PICK-UP CAPABILITIES AND FORCE DISTRIBUTION
- LOW NUMBER OF ACTUATORS
  - 3 MOTION 1 GRIP AGAINST 6 MOTION 1 GRIP FOR PAR TYPE

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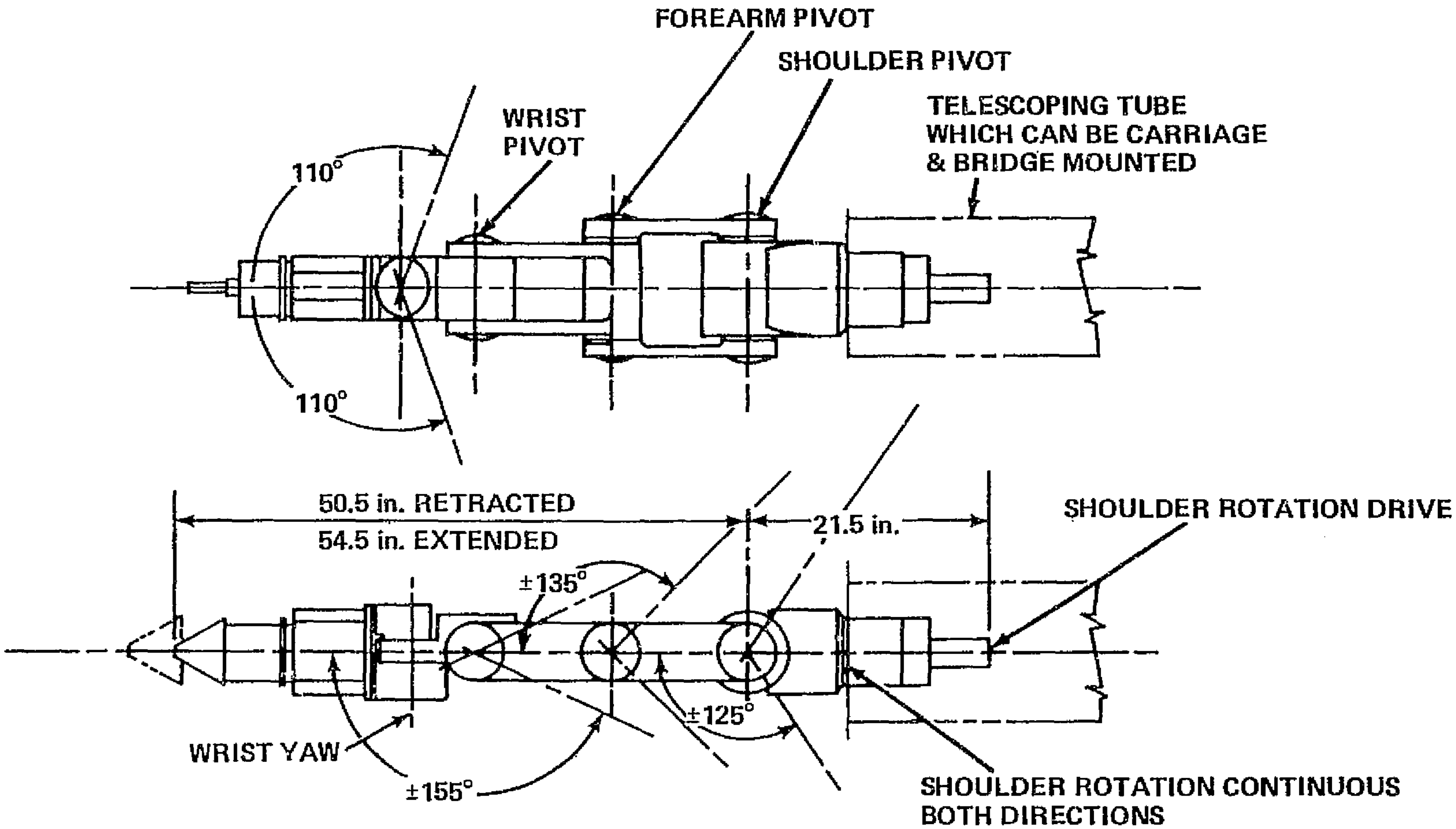
1852-097V-5

OFF-THE-SHELF-STABILIZER

The properties of an off-the-shelf 6 DOF manipulator with a jaw end effector are described on the opposite page. The PAR 3000 used throughout industry is approximately 5 ft. long, has a tip load of 150 lbs and weighs approximately 170 lbs. This device uses an open loop control system with toggle switches provided for each axis. This system may be the ideal starting point for lab evaluation of the stabilizer because it provides the flexibility to select the number of degree-of-freedom and can be purchased with either a tip extension or base extension feature.

OFF-THE-SHELF STABILIZER



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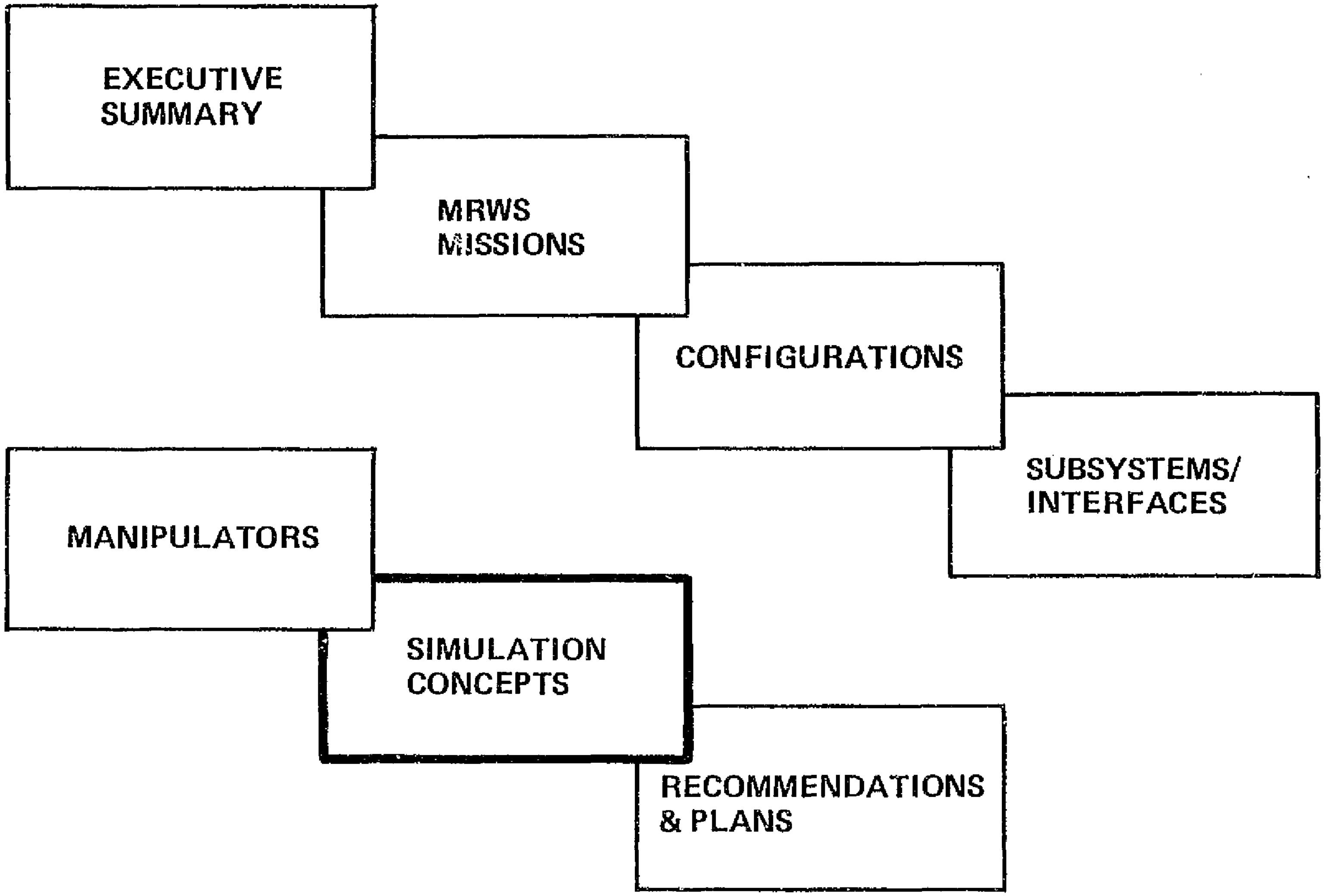
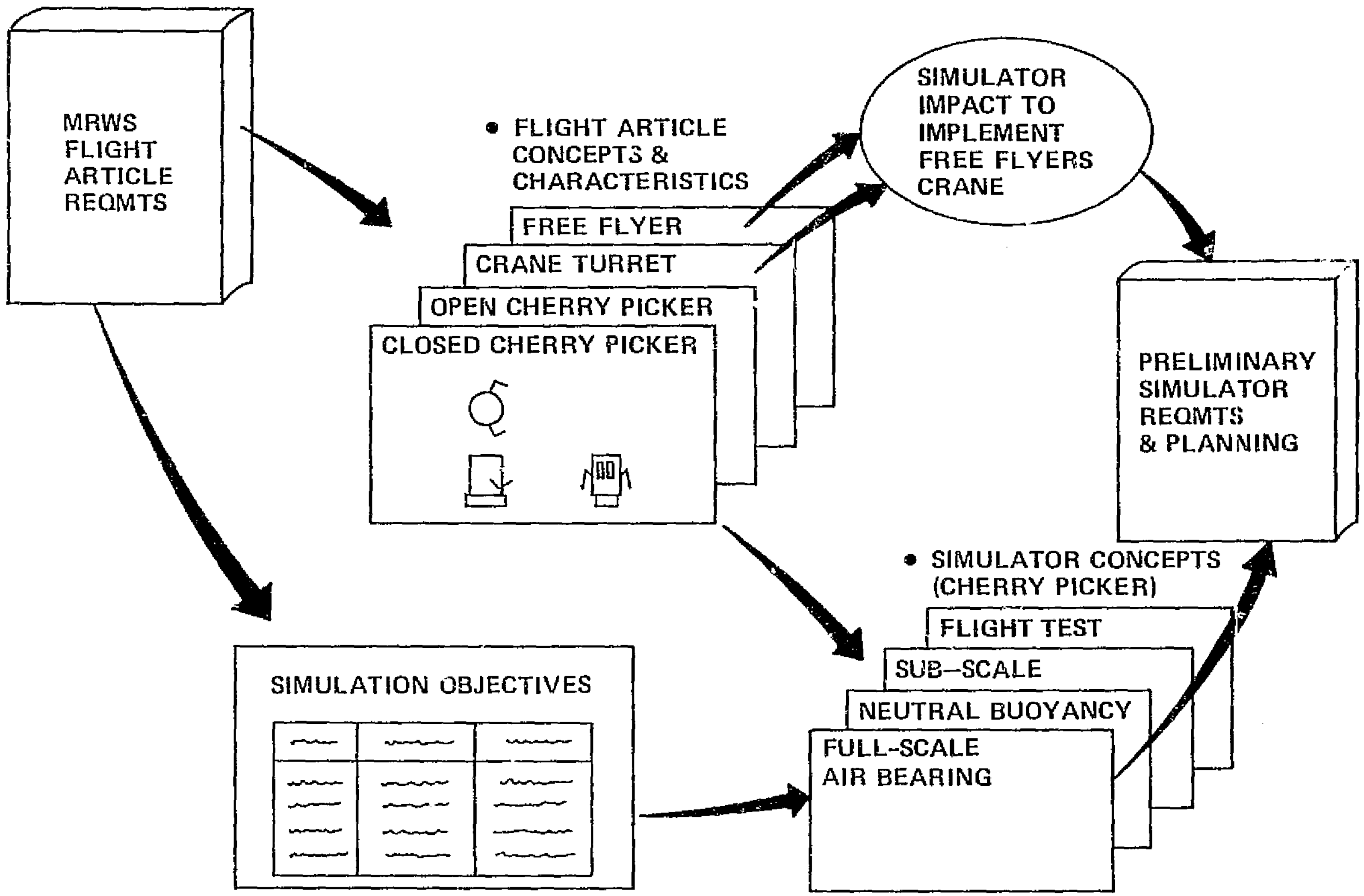

EXECUTIVE SUMMARY
MRWS MISSIONS
CONFIGURATIONS
SUBSYSTEMS/ INTERFACES
MANIPULATORS
SIMULATION CONCEPTS
RECOMMENDATIONS & PLANS

SIMULATOR REQUIREMENTS DEFINITION APPROACH

The results of design efforts and requirements analysis on the MRWS flight article are used to formulate simulator test objectives. This is then used as the basis for defining DTA and simulator system concepts. The objectives are broken up into five major categories.

Zero g simulator design concepts emphasize the utilization of a full-scale open cherry picker on the air bearing table; however, consideration is also given to neutral buoyancy, sub-scale, and flight test evaluations.

SIMULATOR REQUIREMENTS DEFINITION APPROACH



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SIMULATION OBJECTIVES CATEGORIES

Simulator objectives are collected under five categories on data sheets. Considerations is given to work site configurations when establishing these preliminary simulator recommendations. Typical simulator evaluations are indicated for the five categories.

For example, a typical cabin design factor for simulation is the relationship between work duration output and errors, for a spectrum of space construction tasks and operators. At a subsystem design level, simulation can address the metabolic workload the designer should consider. This requirement can be assessed by measuring heart rate, respiration, and plain temperature.

SIMULATION OBJECTIVES: CATEGORIES

CATEGORY 1 – CABIN DESIGN FACTORS

- WORK DURATION
- METABOLIC LOAD
- DISPLAYS
- VIEWING
- LIGHTING (INTERNAL)
- MEN & CONSOLES

CATEGORY 2 – EQUIPMENT DESIGN FACTORS

- MANIPULATOR REQUIREMENTS
- CONTROLLERS
- CCTV UTILIZATION
- GRAPPLER REQUIREMENTS
- END EFFECTOR DESIGN
- EQUIPMENT/TOOL STOWAGE

CATEGORY 3 – PROCEDURES DEVELOPMENT

- COMPONENT HANDLING
- STRUCTURAL JOINING & ALIGNING
- CONSTRUCTION EQUIPMENT SERVICING
- FIXTURE INSTALLATION
- SUBSYSTEM INSTALLATION
  - ELECTRONIC
  - POWER
  - FLUID

CATEGORY 4 – MAN/MACHINE INTERFACE FACTORS

- WORKSITE ACCESSIBILITY
- WORK TASK ACCESSIBILITY
- WORK SITE CONFIGURATION
- LIGHTING & VISIBILITY
- FATIGUE/TASK DURATION
- LEARNING CURVE

CATEGORY 5 – CONSTRUCTION BASE INTERFACE FACTORS

- DESIGN LOADS
- RESCUE OPERATION
- CREW TRANSFER
- COMM/POWER/SIGNAL INTERFACE

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SIMULATOR DESIGN CONSIDERATIONS

There are three main zero g areas of interest that will be considered in the design of the DTA for simulating orbital operations. First, the crew activities at the work-site will be analyzed to define the best simulation approach that will produce the required answers to the problems uncovered in the analysis phase. Second, the dexterous interaction between the MRWS manipulators and any free floating work site or work object will be considered and simulation approaches, such as neutral buoyancy (balloon), servo controller and air bearing supports recommended where necessary to resolve particular problems. Third, in mechanizing the manipulator itself a three phased evolutionary approach will be considered. This involves:

- a laboratory bench test
- an open cherry picker with a single manipulator mounted on it
- a closed cherry picker with the final version of the manipulator system being used in the simulation studies to define the requisite time lines

SIMULATOR DESIGN CONSIDERATIONS

- CREW ACTIVITIES
- INTERACTION BETWEEN MRWS MANIPULATORS & FREE FLOATING, UNGRAPPLED, WORK SITE OR WORK OBJECT
- MANIPULATOR MECHANIZATION

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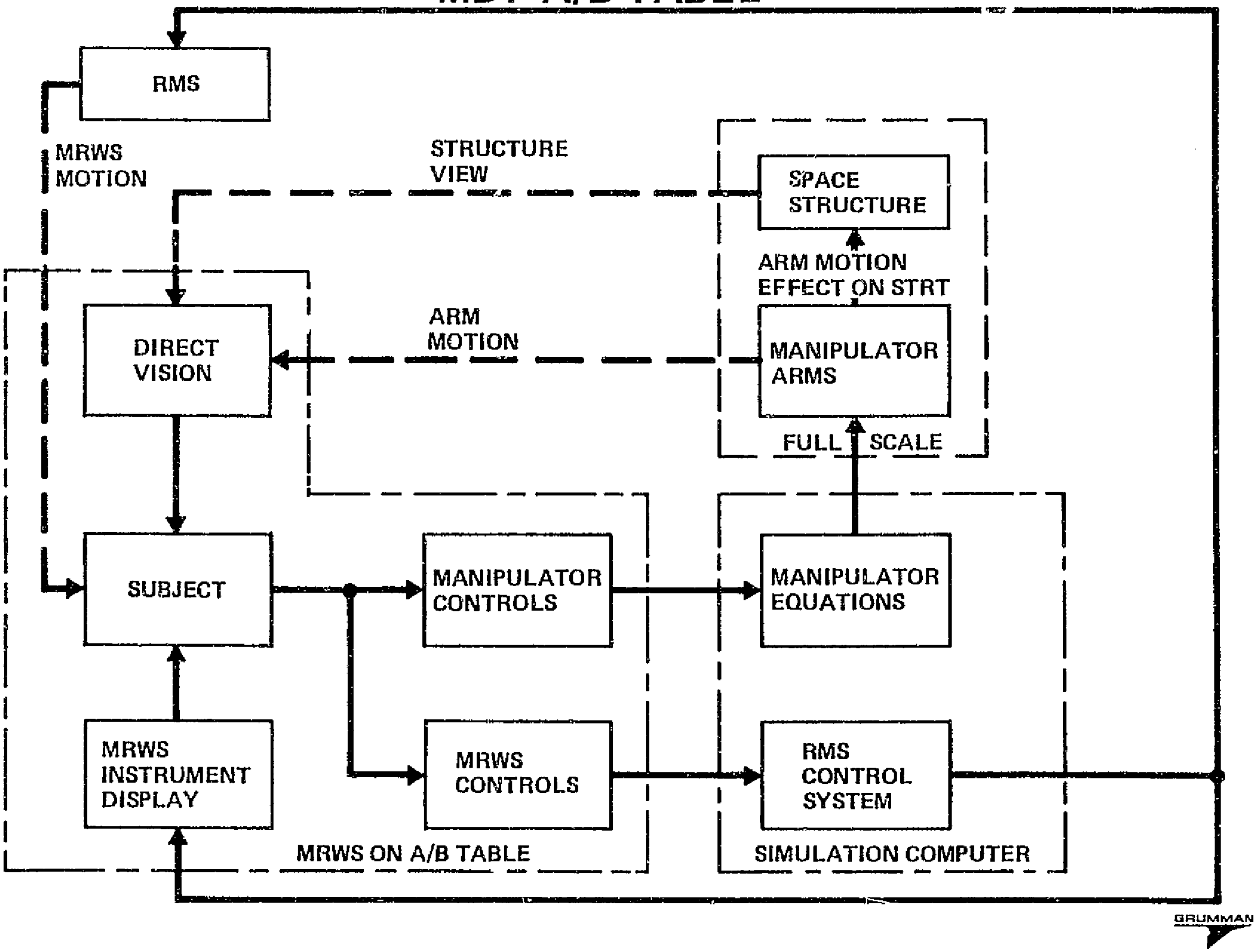
MRWS SIMULATION CONFIGURATION

The block diagram for a typical higher fidelity full-scale MRWS-DTA simulation configuration utilizing the JSC MDF air bearing table is shown in the opposite page. It represents an evolutionary step from the near term open cherry picker configuration to the full-scale closed MRWS-DTA that will provide laboratory capabilities for simulating the closed cherry picker and constrained travel of the free flyer.

BASIC MRWS SIMULATION CONFIGURATION UTILIZING MDF A/B TABLE



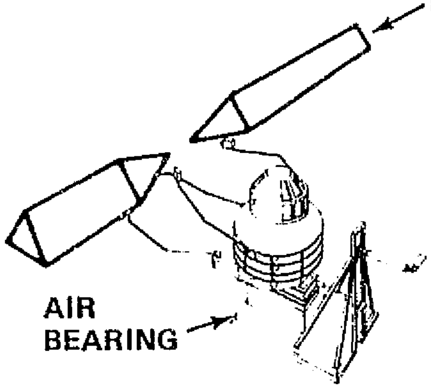
WORK SITE 6 DOF NEUTRAL BUOYANCY (BALLOON)

Many construction tasks, in particular SPS construction, involve large and massive elements. Using balloons to produce neutral buoyancy, the natural reaction between the manipulator and work site can be simulated for zero g conditions. The relative advantage of this approach can be summarized as follows:

- Real world fidelity – fair; only a section of a large structure can be used and it is filled with a balloon and structural inertial simulating devices
- Flexibility – poor; each structural configuration has its own balloon shape and correct inertia
- Total degrees-of-freedom – nine; three from the DTA plus six from structure
- Cost – low; only balloons and sections of structures are needed.
- Complexity – simple; i.e., it requires no servo mechanization
- Availability – fair; structures and balloon shapes can be fairly readily fabricated

WORK SITE SIX DOF NEUTRAL BUOYANCY (BALLOON)

TASKS	COMMENTS
• TRANSPORT 6 DOF; CARRY MATL FROM ONE PLACE TO ANOTHER	3-DIMENSIONAL OBSTACLE AVOIDANCE; DIFFICULTY MODELLING MASS, INERTIAS & DYNAMICS & GEOMETRY.
• HANDLE – 12 DOF REQD; MANIPULATE ITEM WITH SPECIFIED PLACEMENT REQMTS	3-DIMENSIONAL MANIPULATION; DIFFICULTY MODELLING AS ABOVE
• ALIGN – 12 DOF REQD; POSITION & VERIFY AS SPECIFIED PRIOR TO FASTENING	3-AXIS ALIGNMENT CAPABILITY
• FASTEN – 12 DOF REQD; JOIN, CONNECT OR ATTACH WITH SPECIFIC ACTION REQUIRED	ALL-AXIS TOOL EFFECTS DEPENDENT ON MODELLING
• ADJUST – 12 DOF REQD; REPOSITION PREVIOUSLY FASTENED ITEM BY APPLYING FORCE THROUGH OTHER ELEMENT	FULL CAPABILITY



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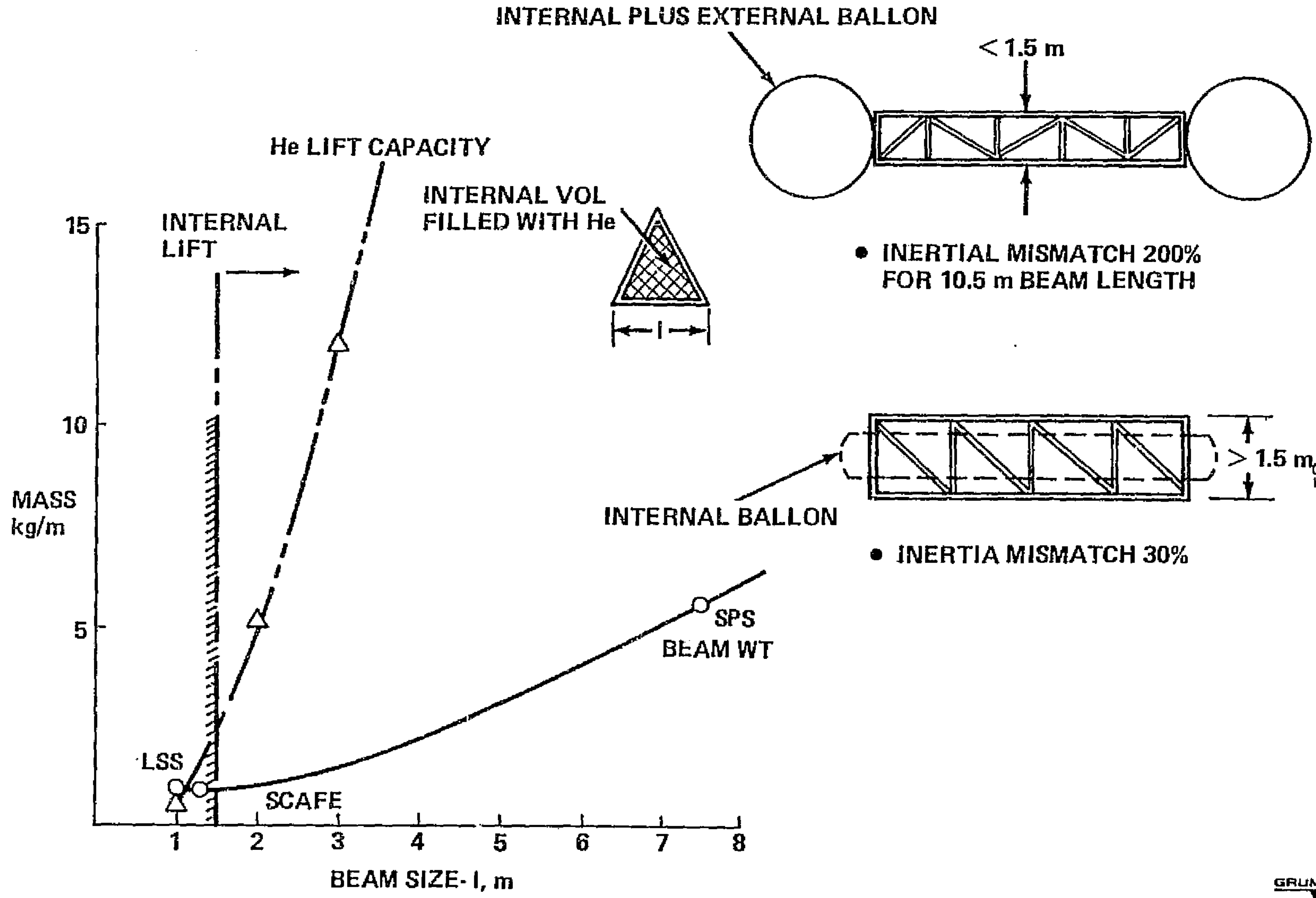
HELIUM FILLED BEAMS

Another method of simulating zero g is to use the neutral buoyancy concept. The beam is made neutrally buoyant in air by supporting it with a helium-filled balloon. In order to minimize inertia mismatch, the balloon should be located in the internal volume of the beam. As shown on the opposite page, the weights per meter of three typical construction beams are plotted. The LSS and SCAFE beams are 1 m and the SPS is a 7.5 m beam. The lifting capacity is plotted for each beam if we assume the entire internal volume of the beam is filled with helium. As can be seen from the plot, the internal volume of a 1-meter beam is not large enough to hold enough helium to support its weight; a 1-meter beam would have to be supported with external helium-filled balloons. This would result in an inertia mismatch of 200% for 10.5-meter long LSS beam. The larger beams can accommodate an internal balloon and the resulting mismatch in inertia would only be 30%.

HELIUM-FILLED BEAMS



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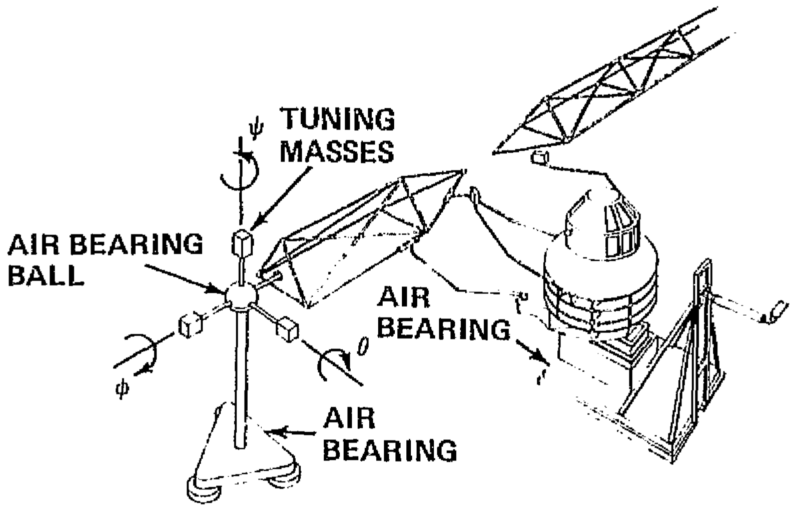
WORK SITE 5 DOF NATURAL REACTION SIMULATOR (ZERO G)

Another concept, using an air bearing frame to support the structure and a full-scale MRWS on the air bearing table can be used to simulate zero g conditions, to determine the natural reaction between the manipulator and work site. The relative advantage of this approach can be summarized as follows:

- Real world fidelity – fair; only a section of a large structure can be used with structural inertia compensation
- Flexibility – fair; different structural configurations can be mounted to the air bearing support frame
- Total degrees-of-freedom –eight; three from the DTA plus five from the structure
- Cost – low/moderate; although initially moderately expensive, once fabricated it can be reused for different simulation configurations
- Complexity – moderate; requires air supply and air bearing ball
- Availability – fair; one support structure available; it can be fairly readily modified for a new configuration.

WORK SITE FIVE DOF NATURAL REACTION SIMULATOR (ZERO-G)

TASKS	COMMENTS
• TRANSPORT 6 DOF; CARRY MATL FROM ONE PLACE TO ANOTHER	PLANAR MOTION WITH OBSTACLE AVOIDANCE. $I_{z'}$ MASS AND DYNAMICS MODELLED
• HANDLE – 12 DOF REQD; MANIPULATE ITEM WITH SPECIFIED PLACEMENT REQMTS	PLANAR MANIPULATION WITH X & Y DYNAMIC COUPLING OF INERTIAS CAN BE REPRODUCED
• ALIGN – 12 DOF REQD; POSITION & VERIFY AS SPECIFIED PRIOR TO FASTENING	PLANAR ALIGNMENT ONLY
• FASTEN – 12 DOF REQD; JOIN, CONNECT OR ATTACH WITH SPECIFIC ACTION REQUIRED	Z AXIS TOOL EFFECTS NOT SIMULATED
• ADJUST – 12 DOF REQD; REPOSITION PREVIOUSLY FASTENED ITEM BY APPLYING FORCE THROUGH OTHER ELEMENT	NO Z ADJUSTMENT



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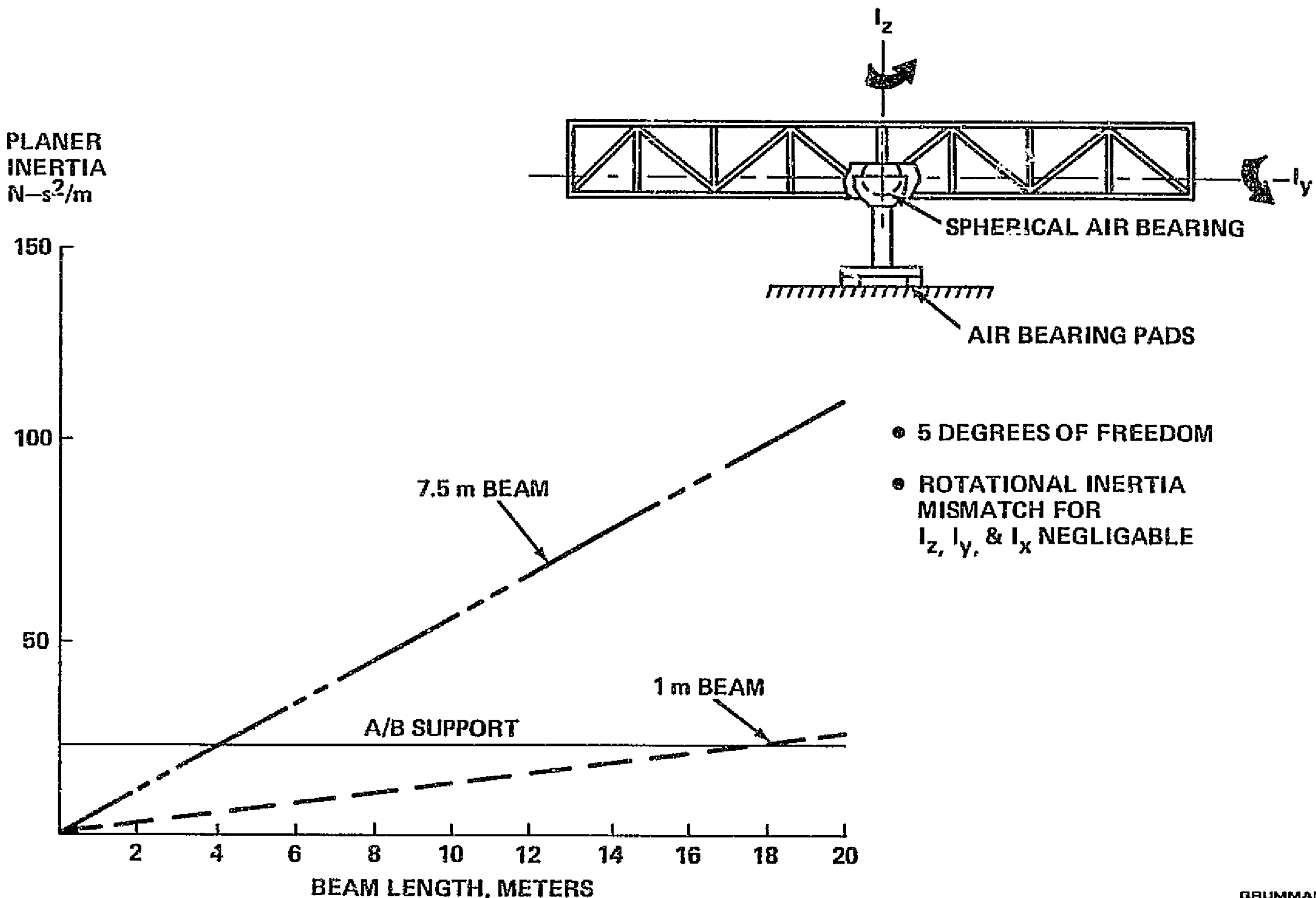
AIR BEARING SUPPORT BEAM INERTIA FIDELITY

One of the basic methods proposed for simulating zero g is the use of air bearings. A spherical air bearing is mounted to the beam so that the center of rotation of the bearing is at the center of mass of the supported beam. The rotational inertia of the beam is much larger than the rotational inertia of the spherical steel bearing. A 6-inch diameter steel ball will have an inertia of 0.053 N-m/s^2 where as a one meter LSS beam, 10.5 meters long will have a rotational inertia of 122 N.m/s^2 about the Z-axis.

The spherical air bearing is supported by a fixture which floats on air bearing pads. The planer inertia of the air bearing support as shown in the graph is 23 N-m/s^2 and is independent of supported beam length. The graph also shows planer inertia of a 1 meter and 7.5 meter beam vs length. The inertia of the air bearing support has a large effect on the inertia fidelity of the one meter beam, but its impact on the inertia of the 7.5 meter beam is diminished as the length of the beam is increased.

AIR BEARING SUPPORT BEAM INERTIA FIDELITY



- 5 DEGREES OF FREEDOM
- ROTATIONAL INERTIA MISMATCH FOR I_z, I_y, & I_x NEGLIGABLE

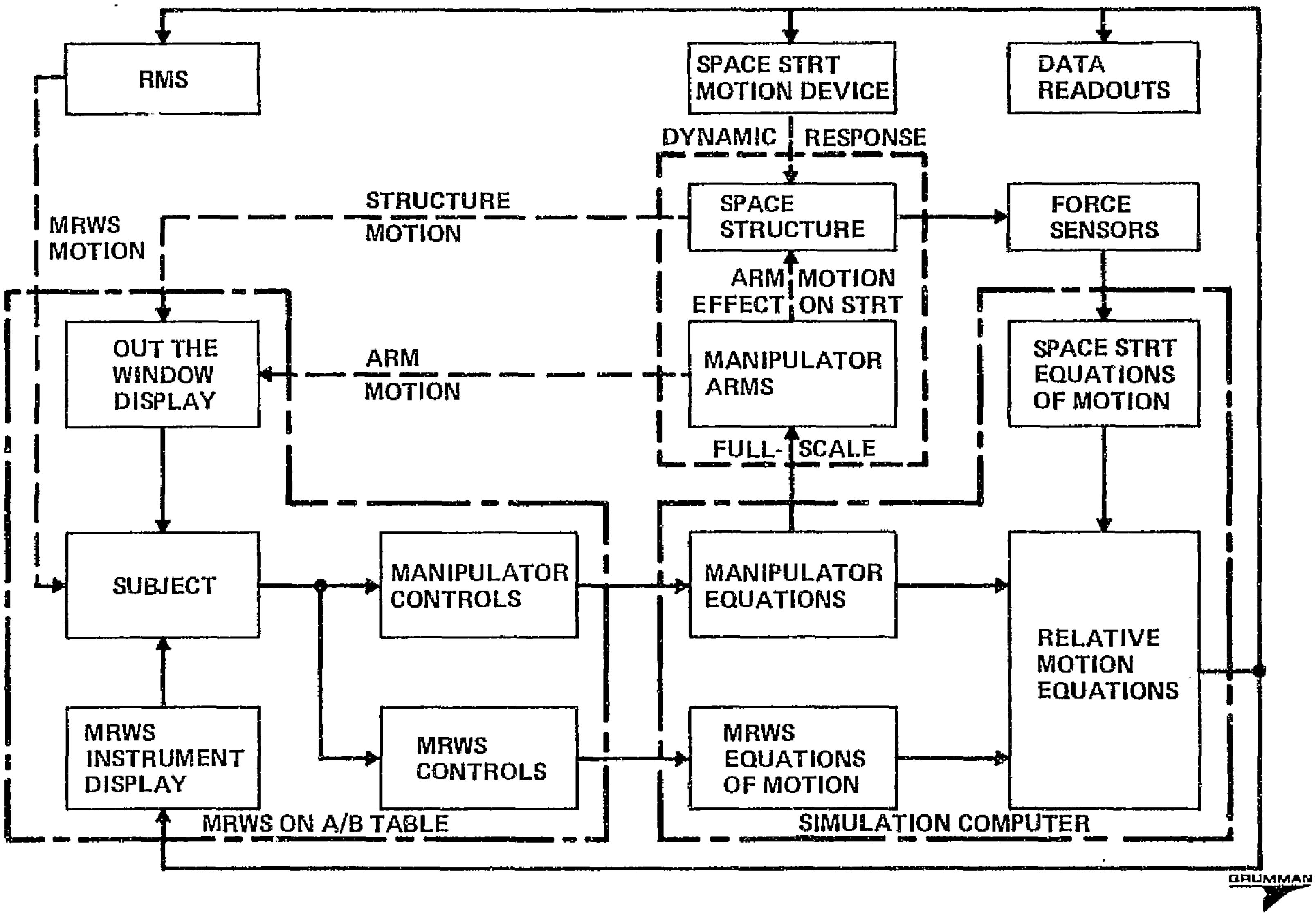
MRWS SIMULATION MDF AIR BEARING TABLE

The majority of work sites and structural elements will be anchored into a construction fixture, or grappled; for those that remain free floating there are three basic methods for simulating zero g:

- Natural reaction using neutral buoyancy (balloon).
- Natural reaction using air bearings that can reproduce MRWS/target motion with 6 to 10 degrees of freedom (DOF).
- Servo-driven target with 6 DOF motion base and a computer model of the space dynamics to yield the full 12 DOF.

The block diagram for a typical full-scale MRWS-DTA simulation configuration utilizing the JSC MDF air bearing table is shown on the opposite page. It represents the near term open cherry picker information flow.

TYPICAL HIGH FIDELITY MRWS SIMULATION CONFIGURATION UTILIZING MDF A/B TABLE



WORK SITE 6 DOF SERVO DRIVEN SIMULATOR (ZERO G)

The ultimate in fidelity for simulating the zero g dynamic responses between the manipulator and the work site is a servo driven structure to support the work site in a 6 DOF motion base and a computer model representing the relative 6 DOF motions between the manipulator and work site. The relative advantages of this approach can be summarized as follows:

- Real world fidelity – excellent; although only a section of a large structure is used, the relative motions in the area of interest can be reproduced, depending upon the complexity of the math model, with a high degree of accuracy

- Flexibility – excellent; different structural configurations can be mounted on the servo driven support and the math model relatively easily reprogrammed.

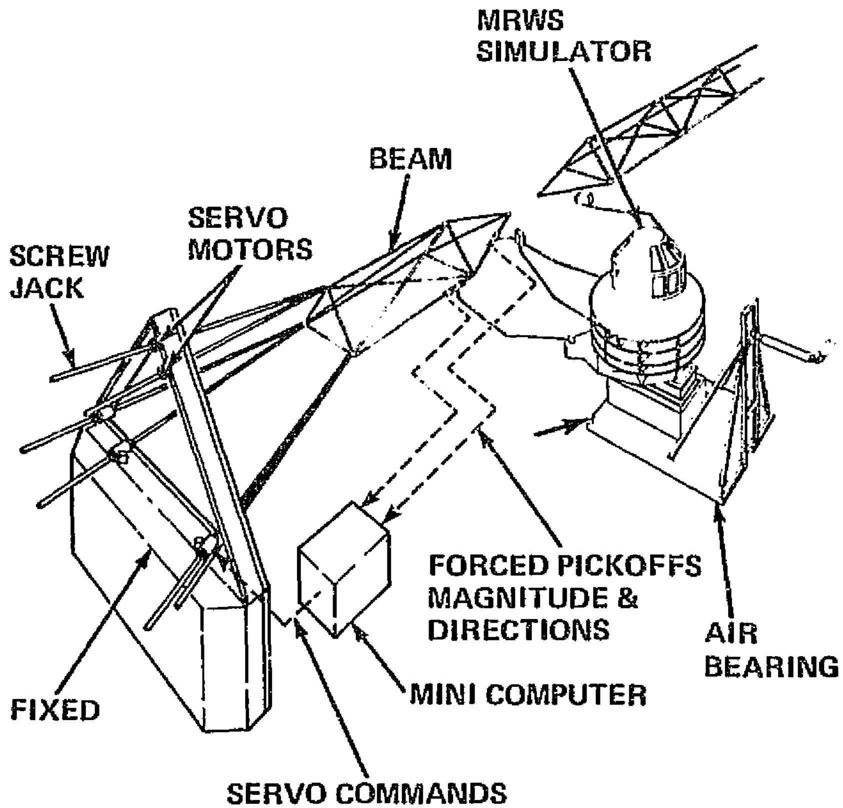
- Cost – moderate/high; although initially moderately to high cost, once fabricated it can be revised for different simulation configurations

- Complexity – high; requires servo and computer interfaces

- Available – fair; once servo driven support structure is available, it can be fairly modified for new configurations

WORK SITE SIX DOF SERVO DRIVER SIMULATOR (ZERO-G)

TASKS	COMMENTS
• TRANSPORT 6 DOF; CARRY MATL FROM ONE PLACE TO ANOTHER	LIMITED LARGE TRANSLATIONAL MOTION; SIMULATED MASS, INERTIAS & DYNAMICS
• HANDLE – 12 DOF REQD; MANIPULATE ITEM WITH SPECIFIED PLACEMENT REQMTS	LIMITED LARGE TRANSLATIONAL MOTION; SIMULATED MASS, INERTIAS & DYNAMICS
• ALIGN – 12 DOF REQD; POSITION & VERIFY AS SPECIFIED PRIOR TO FASTENING	3-AXIS ALIGNMENT CAPABILITY
• FASTEN – 12 DOF REQD; JOIN, CONNECT OR ATTACH WITH SPECIFIC ACTION REQUIRED	ALL-AXIS TOOL EFFECTS SIMULATED
• ADJUST – 12 DOF REQD; REPOSITION PREVIOUSLY FASTENED ITEM BY APPLYING FORCE THROUGH OTHER ELEMENT	FULL CAPABILITY



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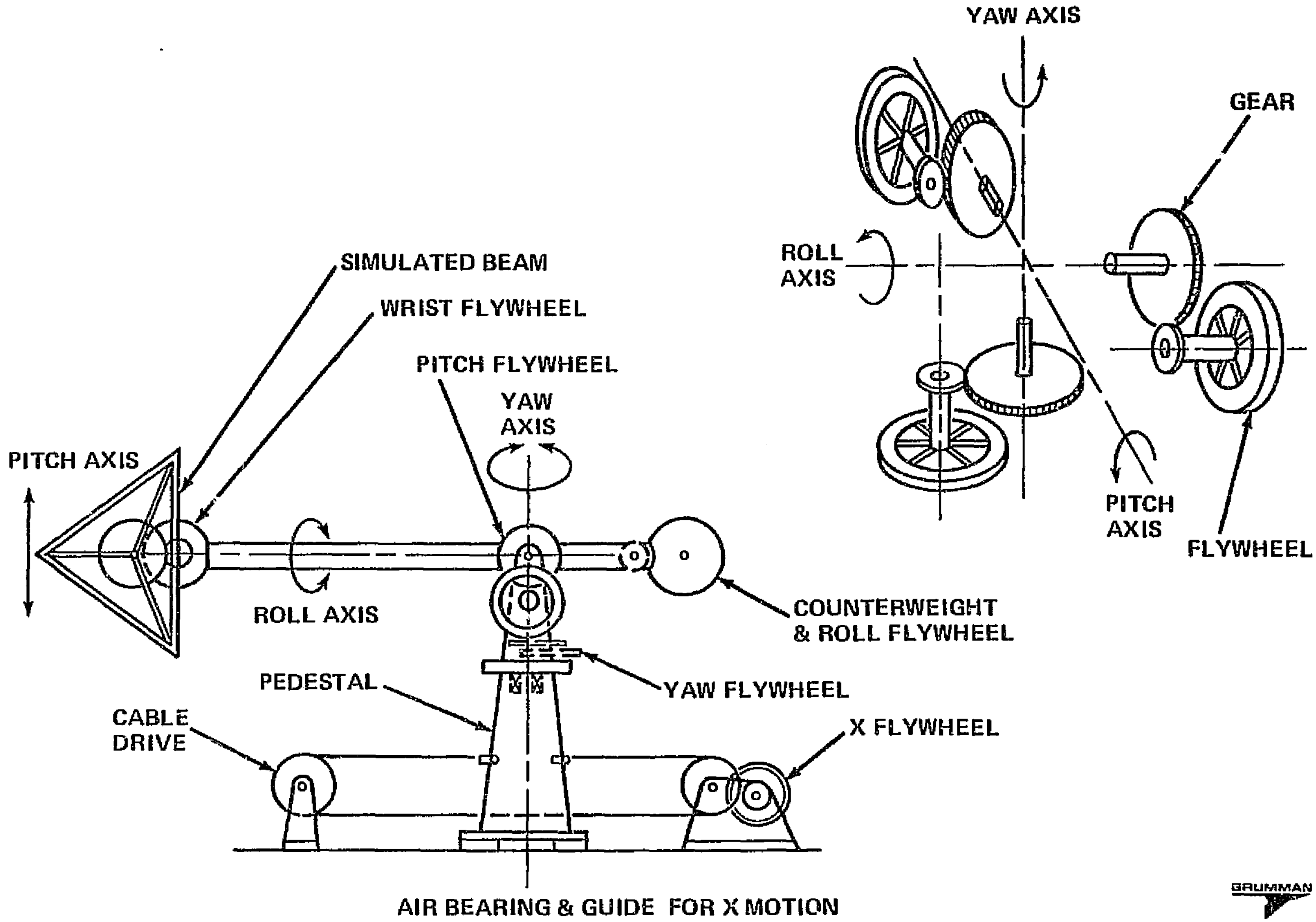
5 DOF ZERO G MASS INERTIA SIMULATOR

The usual methods of simulating zero g, air bearing, neutral buoyancy and cable suspension are limited by the size of the mass that must be supported. For heavier masses a technique shown on the opposite page could be used. A simulated beam much lighter than the real beam is attached to the end of a fairly long arm and suspended in a 3 DOF gimbal. A counterweight is added at the opposite end of the arm to counterbalance the simulated beam and arm. The gimbal is mounted to a pedestal which is floating on an air bearing floor. The pedestal is restrained to move in the X direction only and is attached by cable to a gear train and flywheel. The three gimbal shafts are also attached to a gear train and flywheel as shown. A fifth degree-of-freedom is obtained by attaching a gear train and flywheel to the end of the arm so that the simulated beam can pivot around its center of mass. The original inertias are then simulated by driving a flywheel at an increased speed through a gear train. The flywheel can be small since the reflected inertia at the end of the arm varies as the gear ratio squared and arm length squared. The mass of the flywheel can be easily changed when simulating wide ranges of inertia. The pitch and yaw rotations must be restricted to small angles so that the motion of the simulated beam at the end of the long arm is essentially linear.

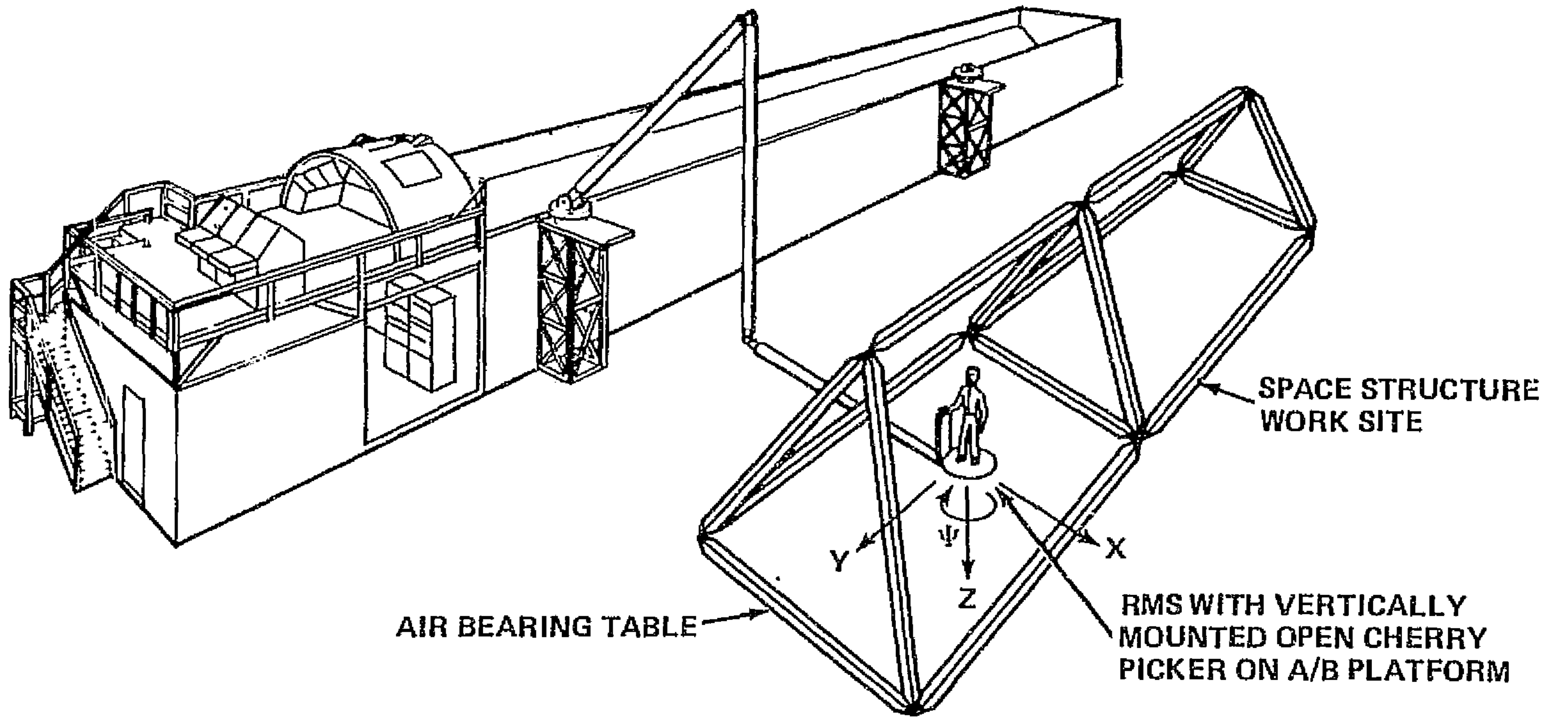
5 DOF ZERO G MASS INERTIAL SIMULATOR



VERTICALLY MOUNTED OPEN CHERRY PICKER SIMULATION CONCEPT

The near term open cherry picker zero g simulation concept for evaluations involving the three decoupled degrees-of-freedom of planer translations and rotation using the SSC MDF airbearing table is shown diagrammatically on the opposite page. Considerations are also being given for the utilization of an astronaut harness (Peter Paw-type rig) to suspend the subject in a side position with the equivalent 90° rotation of the base of the cherry picker to allow the subject to use the foot restraints for torque transmission to the RMS. This approach will allow for two additional degrees-of-freedom, one translation and one rotation, with one redundant translation that could be used for correlation purposes.

VERTICALLY MOUNTED OPEN CHERRY PICKER SIMULATION CONCEPT FOR EVALUATIONS INVOLVING 3 DOF MOTION (X, Y, Ψ)



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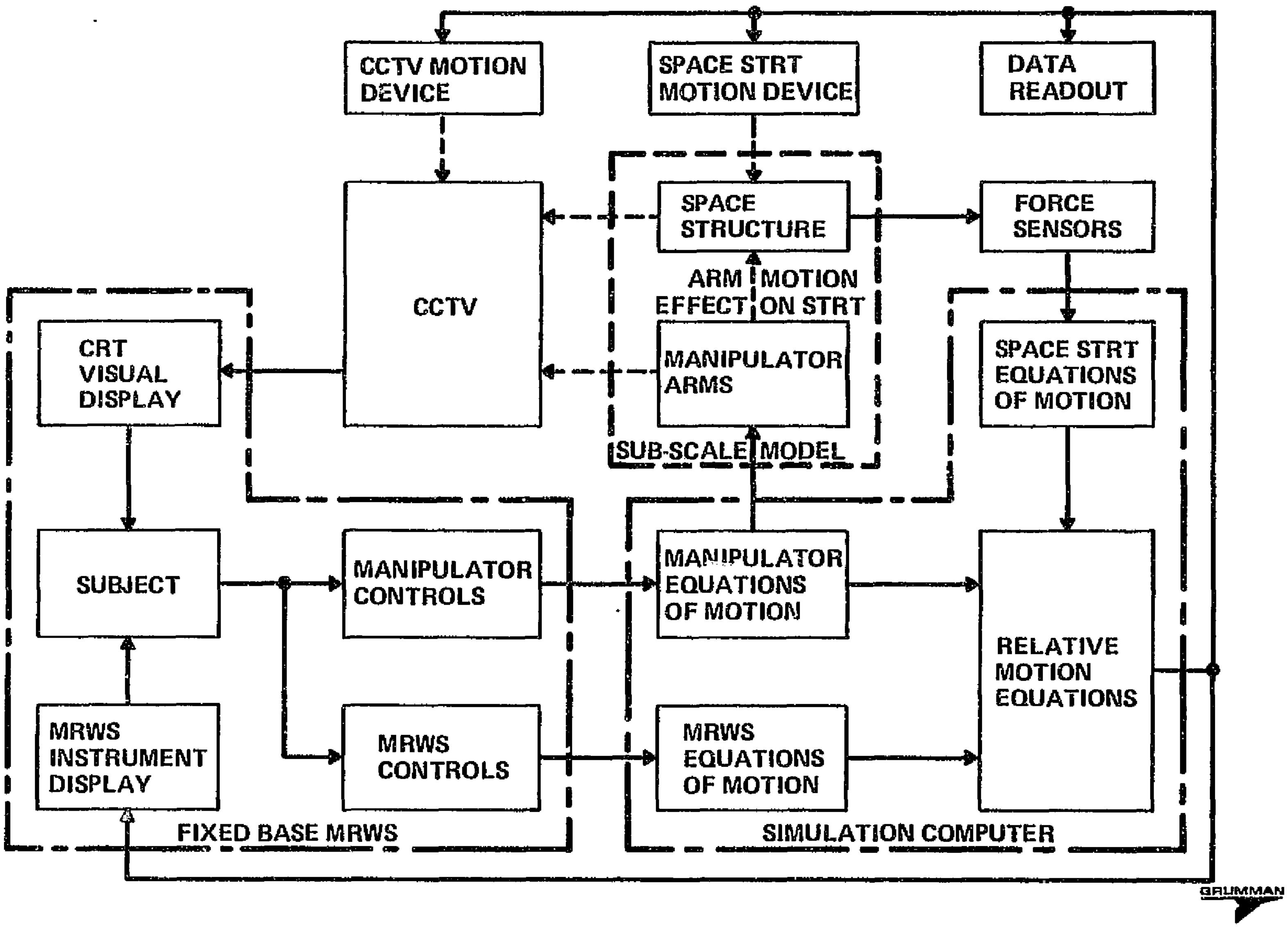
TYPICAL MRWS SUB-SCALE MODEL CONSTRUCTION SIMULATION CONFIGURATION

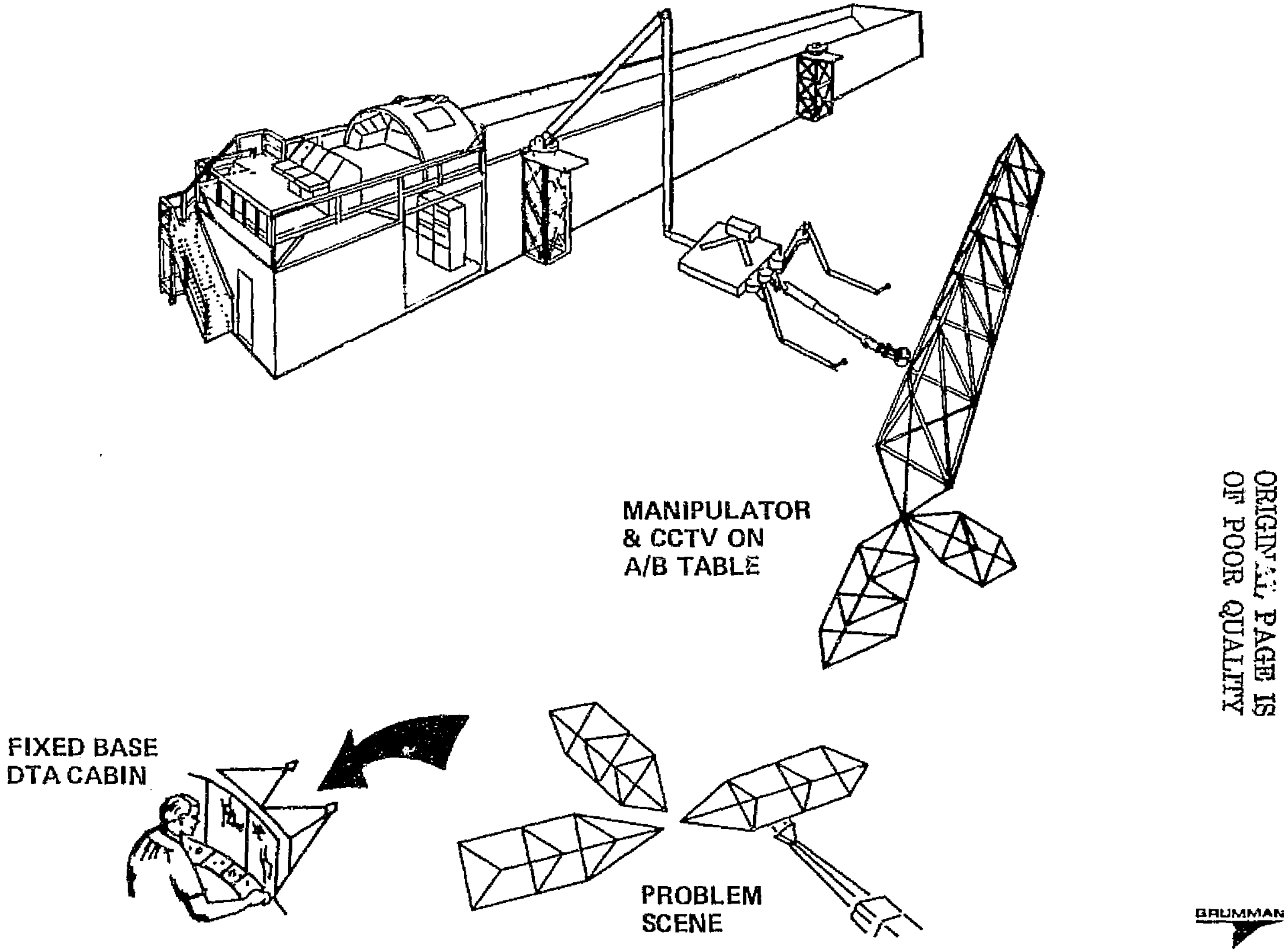
The block diagram for a typical MRWS-DTA simulation of large space structure work site utilizing the JSC MDF air bearing table is shown on the opposite page. It represents the ultimate evolutionary step that will provide laboratory capabilities for zero g simulations of the full gamit of MRWS configurations. Conceptually, the full-scale DTA will be used as a fixed base simulator with out-the-window cues being presented to the subject by CRT displays through a CCTV system. The camera of the CCTV, mounted on a JSC-MDF airbearing platform, represents the subject's eye. Computer-driven sub-scale manipulators and construction site motions are used to develop the correct relative out-the-window visual cues that are used by the subject to perform the space construction task. Force sensors, such as strain gauges, are used to measure the reaction forces on the structure and the equivalent proportional forces are used in the computations to calculate the relative motions between the simulated MRWS and the work site.

TYPICAL MRWS SUB-SCALE MODEL CONSTRUCTION SIMULATION CONFIGURATION



It is presently envisioned that the ultimate MRWS-DTA zero g simulation will also involve sub-scale modelling techniques because of the enormity of the space structure worksites. The opposite page conceptually shows the JSC-MDF in its final evolutionary configuration utilizing a computer driven RMS to move an air bearing platform containing a CCTV camera representing the pilot's eye point over the air bearing platform containing the sub-scale modelled worksite structures.

CLOSED CHERRY PICKER SUB–SCALE MODEL SIMULATION



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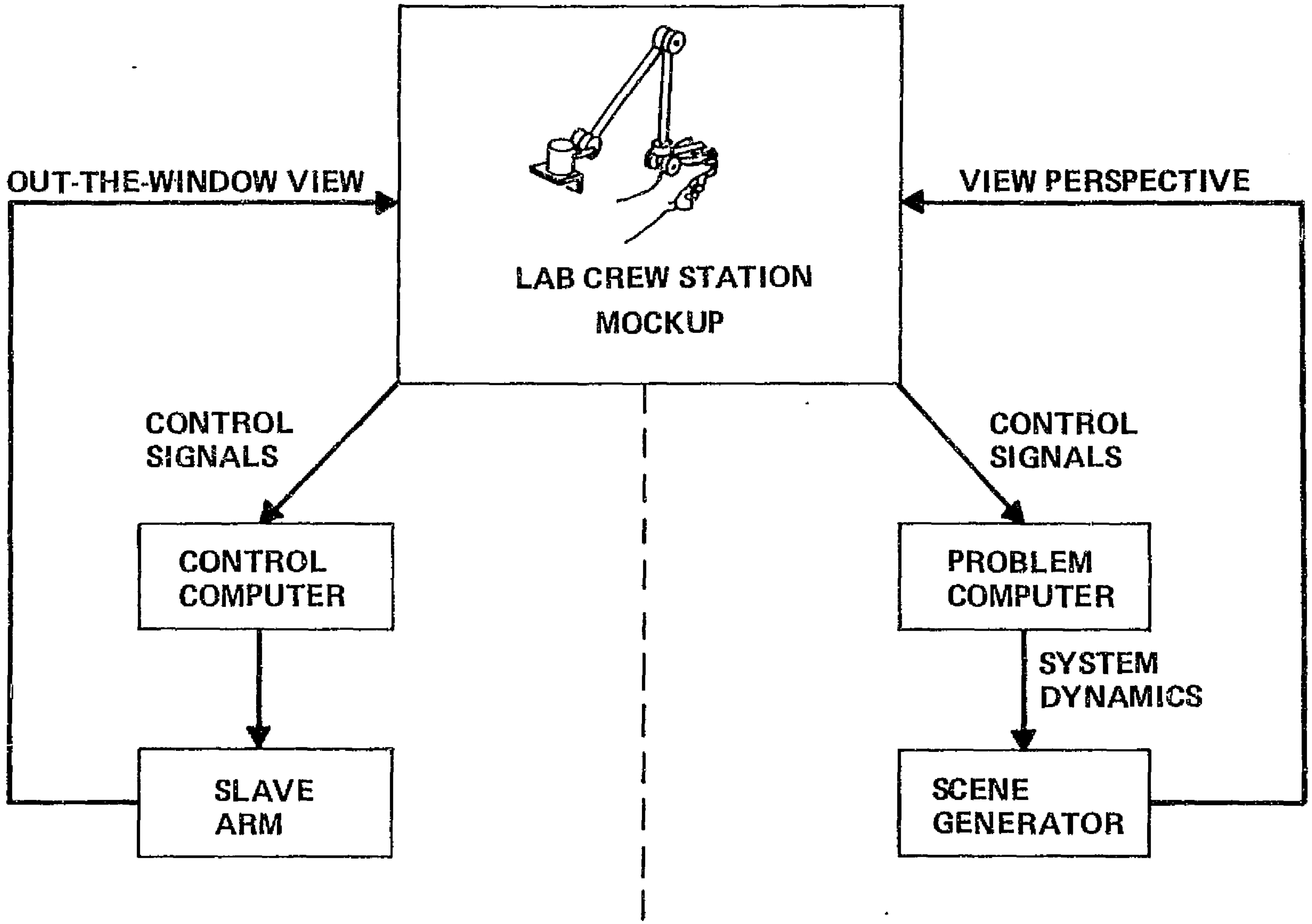
LABORATORY SIMULATION CONCEPTS

In order to develop design requirements for the manipulator at an early stage in the design of the DTA, a three phased evolutionary approach is being considered. This involves first, a laboratory bench test, then, the open cherry picker with a single manipulator system mounted on it and last the closed cherry picker with the final version of the manipulator system being used in the simulation studies to define the required timelines.

For the laboratory (bench test) simulation concept (shown on the opposite page), two viable approaches are possible, involving hardware or software techniques. The software technique uses computer aided, scene generated simulations that functionally duplicate the hardware simulation. The hardware simulations utilize a mechanical manipulator system for the design requirements study. The hardware simulation concept, because of cost and off-the-shelf components is being considered as the best approach to quickly develop preliminary design requirements for the manipulator before final committment must be made.

LABORATORY SIMULATION CONCEPTS

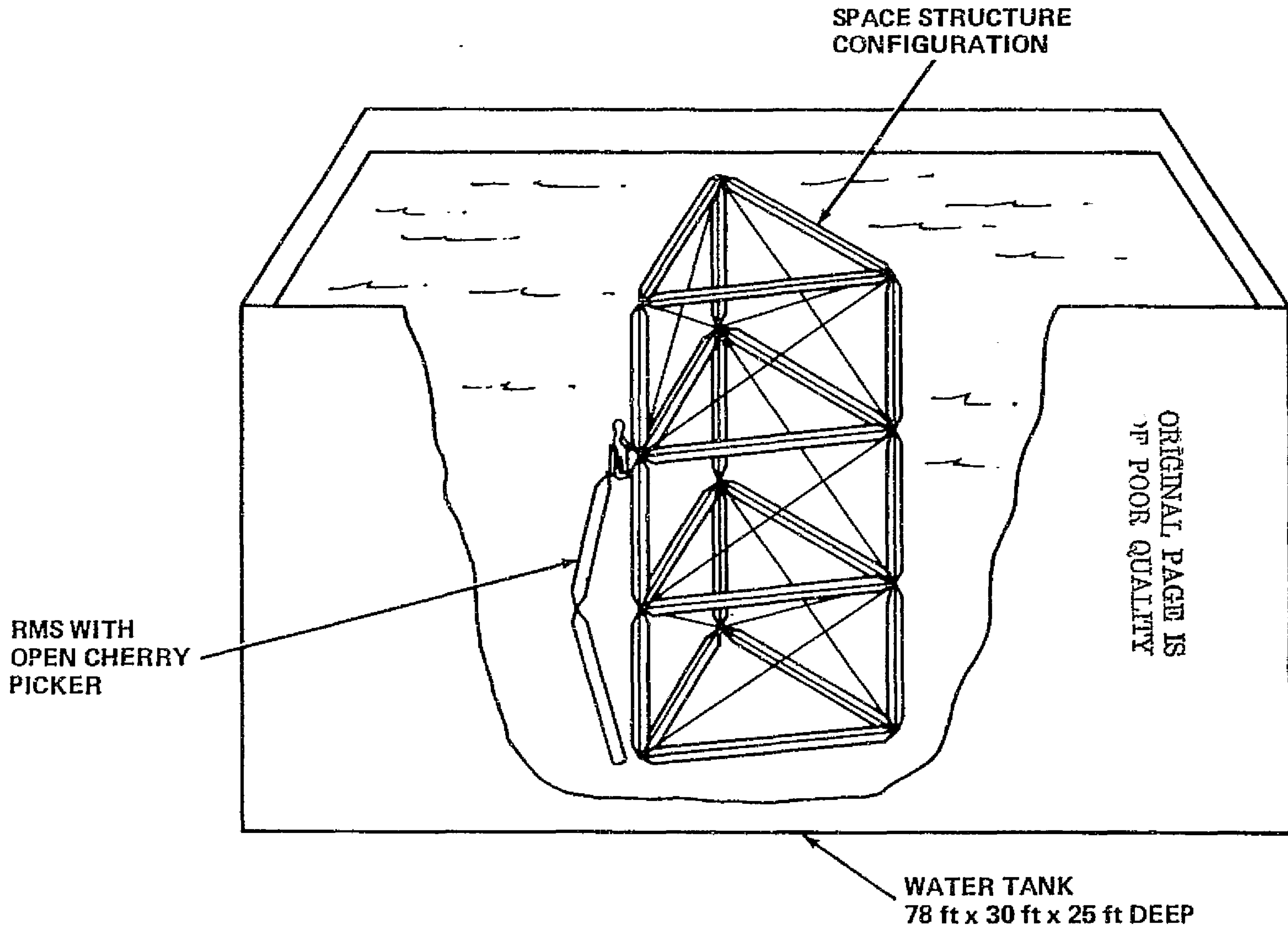


A/B EQUIPMENT SIMULATIONS OR SCENE GENERATED SIMULATIONS

NEUTRAL BUOYANCY WATER TANK

A neutral buoyancy facility could be used for the three-dimensional work site simulation. The basic system would include mockups of a hydraulically (water) actuated neutrally buoyant RMS with an open cherry picker, space structure configuration, stabilizer arm and two or three neutrally buoyant cargo modules of various shapes and sizes; although this method is limited by difficulties in achieving neutral buoyancy, limited mass capabilities, various damping and visual problems; it is felt that it should provide useful data for correlation purposes with the three-dimensional high fidelity air bearing table evaluation.

NEUTRAL BUOYANCY 3-D PART TASK WORKSITE SIMULATION FOR DATA CORRELATION PURPOSES



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ZERO G MANIPULATOR MECHANIZATION CONCEPTS

The following issues arise from the design of the MRWS dexterous manipulators that have to be resolved by simulation:

- Data on productivity on typical tasks using different control modes
- Effect of manipulator to controller ratio on productivity
- Effect of the various indexing methods on productivity

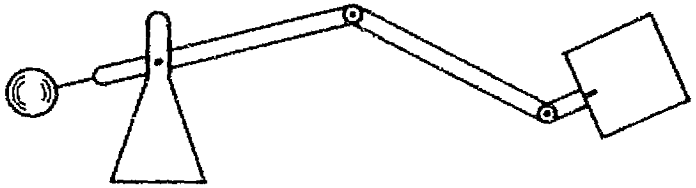
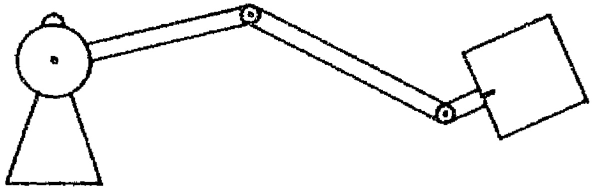
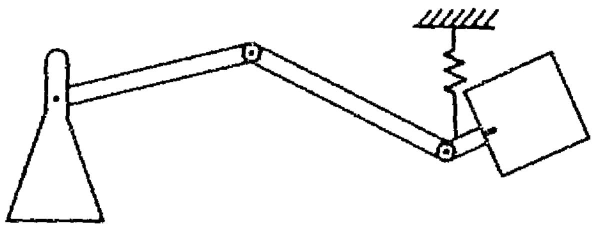
Much of the simulation work can be done without simulating Zero G conditions throughout. However, after the results have been obtained further effects of complete zero G conditions should be investigated. On top of this a number of issues must be resolved which require zero G simulation. These include:

- Determination of optimal force range on master controller
- Determination of appropriate thermal duty cycle for zero g manipulator operation
- Verification of capacities specified

These simulation requirements require that gravitational components be cancelled while retaining the mass and inertial effects of the objects in six, or at least five, DOF.

Three possible mechanizations for zero g manipulator simulations are presented on the opposite page with appropriate comments regarding each concept.

ZERO-G MANIPULATOR MECHANIZATION CONCEPTS

CONCEPT	COMMENTS
 COUNTERBALANCE	• COUNTERBALANCE ADDED FOR EACH WEIGHT • USE OF ACTUAL WEIGHT – MUST INCREASE CAPACITY OF MANIPULATOR • COUNTERBALANCE SENSITIVE TO GRASP POSITION • NO ZERO G BALANCE WHEN NOT IN CONTACT WITH WEIGHT
 COMPUTER CANCELLATION	• COMPLEX S/W • WEIGHT LIMITED TO MANIPULATOR CAPACITY • FOR LARGER WEIGHTS USE NEUTRAL BUOYANCY BALLOONS • OVERSIZE MOTORS
 CABLE SUSPENSION	• CHEAP • WEIGHT LIMITED TO MANIPULATOR CAPACITY • CONSTRAINED MOTION • OVERSIZE MOTORS

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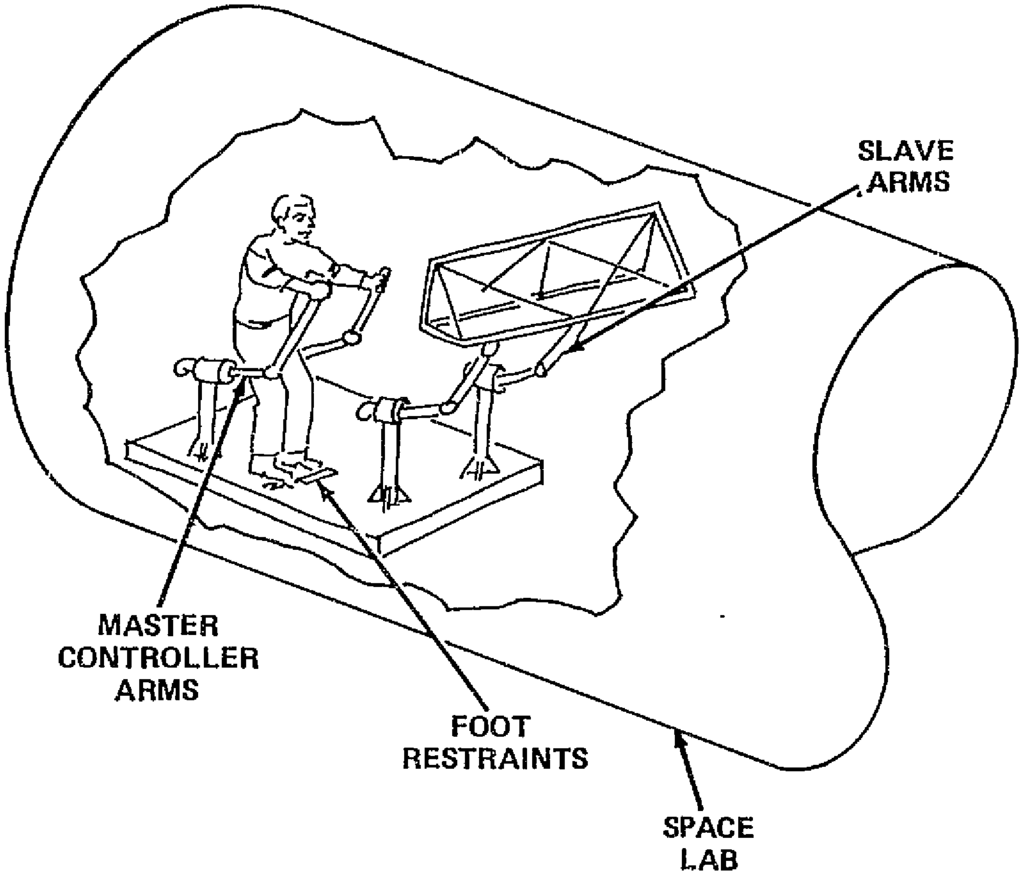
FLIGHT TEST PROGRAM

Although the dexterous manipulator for zero g usage will follow an orderly earth-bound development progression, it is possible to utilize the STS for a flight test program to verify in true zero g conditions the various pieces of hardware designed under simulated zero g conditions. The Space Laboratory Life Sciences Module could be used in the final acceptance testing of the manipulator system under controlled laboratory-type shirt sleeve environment, while the OCP could be used for acceptance testing of the stabilizer system.

FLIGHT TEST PROGRAM



- OPEN CHERRY PICKER VERIFIES:
  - STABILIZER CONCEPTS & UTILIZATION
  - RMS CONTROL MODES
  - ASTROWORKER RESTRAINS SYSTEM
- SPACE LABORATORY LIFE SCIENCES MODULE
  - ZERO G VERIFICATION OF MANIPULATOR H/W.
  - FATIGUE/TASK DURATION
  - COMPONENT JOINING

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FREE FLYER SIMULATION OBJECTIVES

Rescue and crane repair roles were identified for the Free Flyer during our mission and trade study analyses. The various issues that must be resolved by simulation are shown on the opposite page. The cabin design factors such as controls/displays, visibility, metabolic workload, and men/consoles must be evaluated during the simulation program. The requirements for the Guidance and Control subsystems must be determined. The vehicle translational and rotational accelerations and rates must be established. Various guidance techniques for the Free Flyer Control System will be evaluated. The simulation program will establish any requirements for CCTV and determine the illumination necessary at the work site. The stabilizer design must be verified that it adequately locks and holds the Free Flyer to the work site structure or disabled crane. For the rescue or repair roles, operational procedures must be developed. Rescue routes and procedures using the PRS must be established from the disabled vehicle to the Free Flyer. The need for any auxiliary rescue equipment for the Free Flyer will be established.

FREE FLYER SIMULATION OBJECTIVES

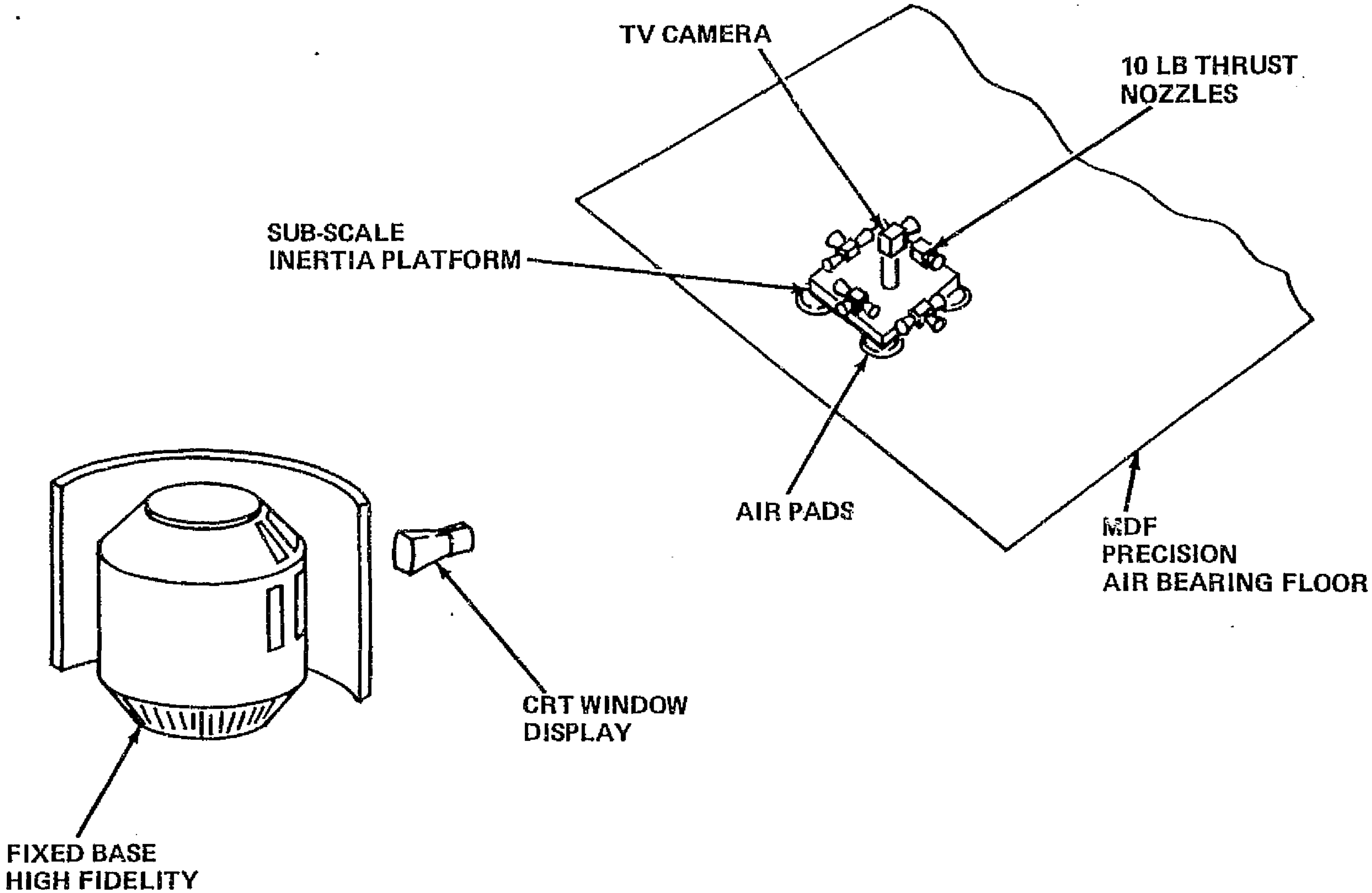
- EVALUATE CABIN CONFIGURATION FOR
  - CONTROLS/DISPLAYS
  - VISIBILITY
  - METABOLIC WORKLOAD
  - MEN/CONSOLES
- DETERMINE REQUIREMENTS FOR GUIDANCE AND CONTROL SUBSYSTEM
  - VEHICLE TRANSLATION AND ROTATIONAL ACCEL AND RATES
  - GUIDANCE TECHNIQUES
- DETERMINE LIGHTING AND VISIBILITY REQUIREMENTS
- EVALUATE STABILIZER DESIGN
- ESTABLISH RESCUE OPERATIONAL PROCEDURES
- DEVELOP REPAIR OPERATIONAL PROCEDURES

GRUMMAN

FREE FLYER SUB-SCALE SIMULATION

The simulation concept proposed for the Free Flyer is shown on the opposite page. Since the initial part of the Free Flyer rescue and repair missions involves translating large distances thru the construction site, a sub-scale simulation is proposed. A sub-scale inertia platform containing ten pound thrust nozzles and TV camera is supported by air pads on the MDF precision air bearing floor. The platform 3 DOF is controlled by the test subject from a fixed base, high fidelity cab with an out-the-window CRT display. Air for the thrust nozzles, air pads, and electrical wires are hard lined to the platform.

FREE FLYER SUB-SCALE SIMULATION



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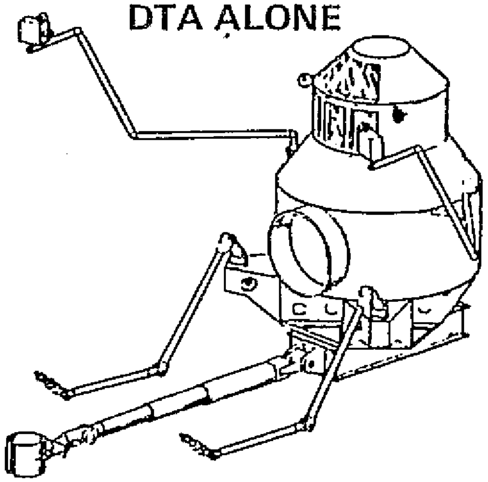
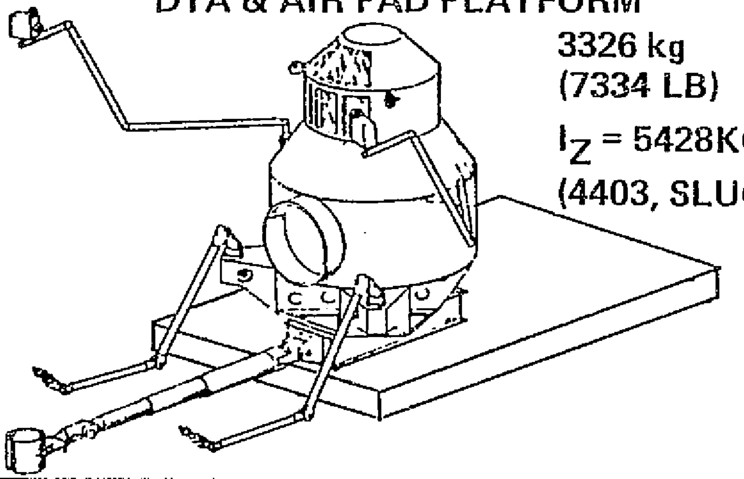
FREE FLYER DTA CONTROL AUTHORITY REQUIREMENTS

A full-scale simulation is proposed for the Free Flyer to determine the requirements for the flight vehicles when operating at the worksite. The Free Flyer DTA will have a high fidelity cab, stabilizer, and manipulator subsystems. CCTV and illumination lights will be mounted to the cabin. The DTA will be supported by air pads on the large MDF air bearing floor. Thrust nozzles will be mounted to DTA to duplicate vehicle dynamics in 3 DOF. If air pads are mounted to the DTA instead of mounting the DTA on the MDF air pad platform, a substantial saving in thrust nozzle size will be realized. This reduction in air requirements would substantially reduce the tank size required if an air storage supply system is mounted to the DTA instead of using a hard line.

DTA CONTROL AUTHORITY REQUIREMENTS

	REQUIRED THRUST LEVEL *(LBF)		
	LINEAR ACCEL.	ANGULAR ACCEL.	
	$0.3\ ft/sec^2$	$5\ deg/sec^2$	$10\ deg/sec^2$
DTA ALONE  1512 KG (3334 LB) $I_Z = 1755\ kg\text{-}m^2$ ($1294\ SLUG\text{-}FT^2$)	31	23	46
DTA & AIR PAD PLATFORM  3326 kg (7334 LB) $I_Z = 5428 KG\text{-}M^2$ ($4403,\ SLUG\text{-}FT^2$)	62	71	142

*1.5m MOMENT ARM

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SPACE CRANE SIMULATION OBJECTIVES

The various issues that resulted from our mission and trade studies analysis and that will have to be resolved by simulation are shown on the opposite page. The various cabin design factors such as visibility, controls/displays and metabolic workload will have to be evaluated by simulation. The effectiveness of the end effector design to capture and grasp beams during transporting, positioning and aligning will have to be determined. The effects of crane arm stiffness on the controlability of the crane arm will also have to be evaluated. Various construction operational procedures will have to be developed that coordinate the various constructions activities of the crane and the OCP. Man/Machine interface factors such as fatigue/task duration, lighting, and visibility requirements must be determined. The ability of the open cherry picker operator to control both the crane arm and the cherry arm simultaneously during the aligning and joining of beams must be assessed.

SPACE CRANE SIMULATION OBJECTIVES

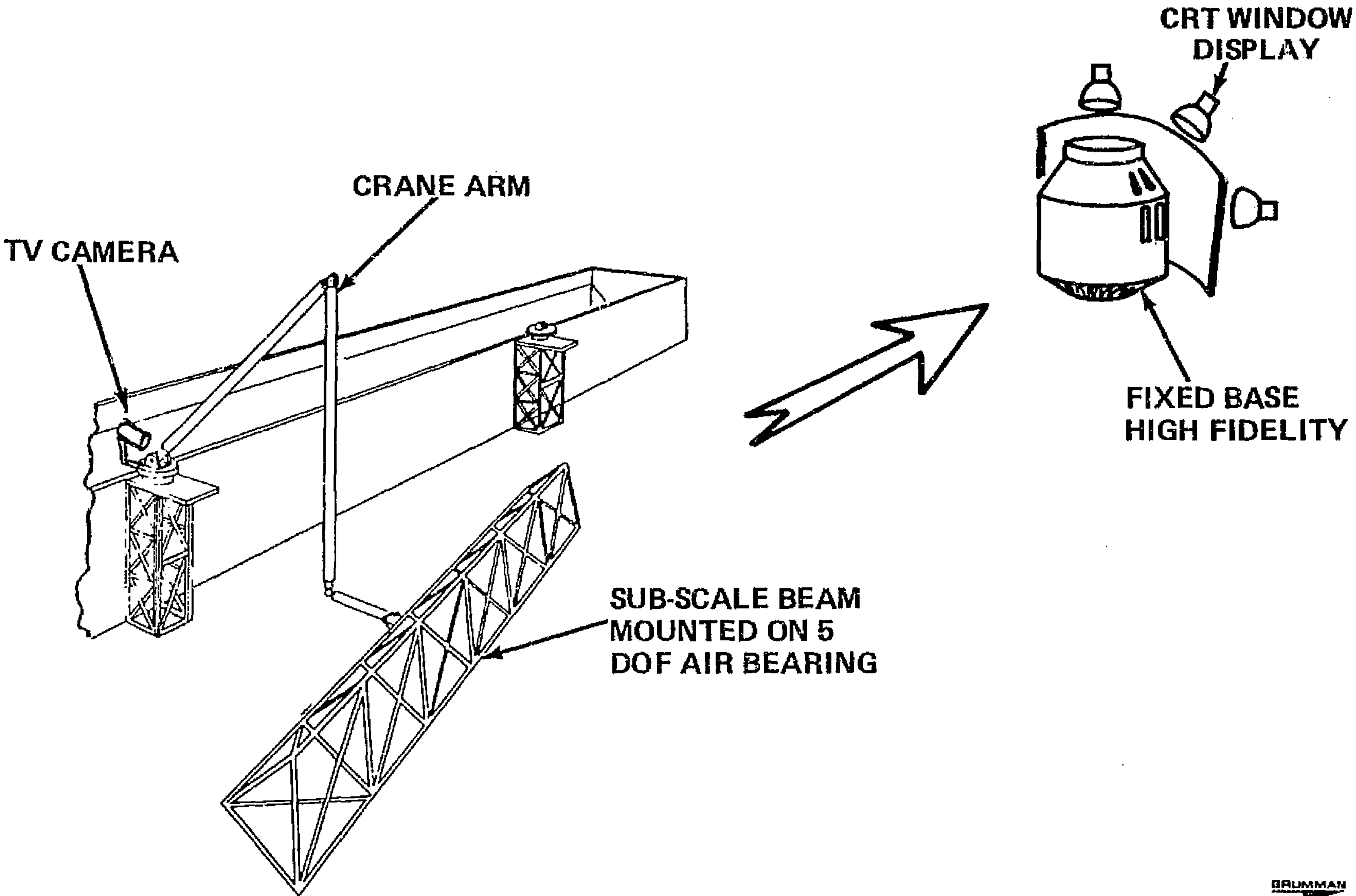
- EVALUATE TURRET CONFIGURATION FOR
  - VISIBILITY
  - CONTROLS/DISPLAYS
  - METABOLIC WORKLOAD
- EVALUATE END EFFECTOR DESIGN
- EFFECT OF CRANE STIFFNESS ON CONSTRUCTION TASKS
- DEVELOP CONSTRUCTION OPERATIONAL PROCEDURES
- DETERMINE FATIGUE/TASK DURATION
- EVACUATE LIGHTING AND VISIBILITY REQUIREMENTS
- DETERMINE ABILITY OF OCP ASTROWORKER TO CONTROL TURRET CRANE ARM AND OCP CHERRY PICKER ARM SIMULTANEOUSLY

GRUMMAN

SPACE CRANE SUB-SCALE SIMULATION

A proposed simulator concept is shown on the opposite page for the space crane. The various roles identified for the space crane from the mission analysis involve handling and moving large masses great distances. Due to the size limitations of MDF facility a sub-scale simulation approach is proposed. The MDF-RMS would be utilized as the space crane. A TV camera will be mounted to a rotatable fixture with the RMS base. The camera would be located at the approximate location of the turret crane operators eyeball. Sub-scale beam models will be mounted on 5 DOF air bearing support system floated on the large MDF air bearing floor. The RMS will be controlled by the test subject from a fixed base high fidelity cab with out-the-window CRT display.

SPACE CRANE SUB-SCALE SIMULATION



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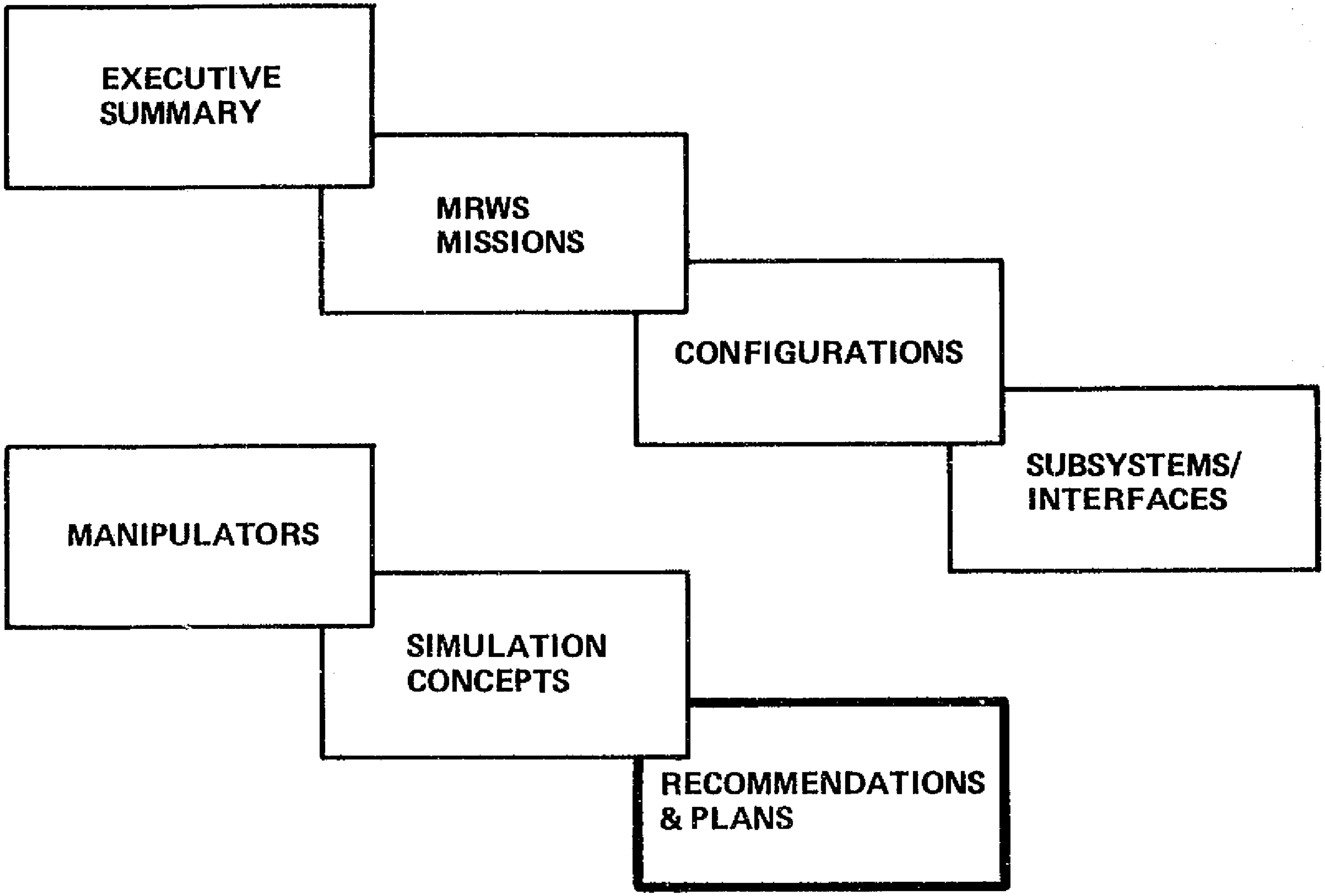

EXECUTIVE SUMMARY
MRWS MISSIONS
CONFIGURATIONS
SUBSYSTEMS/ INTERFACES
MANIPULATORS
SIMULATION CONCEPTS
RECOMMENDATIONS & PLANS

GRUMMAN

MRWS CHERRY PICKER PROGRAM

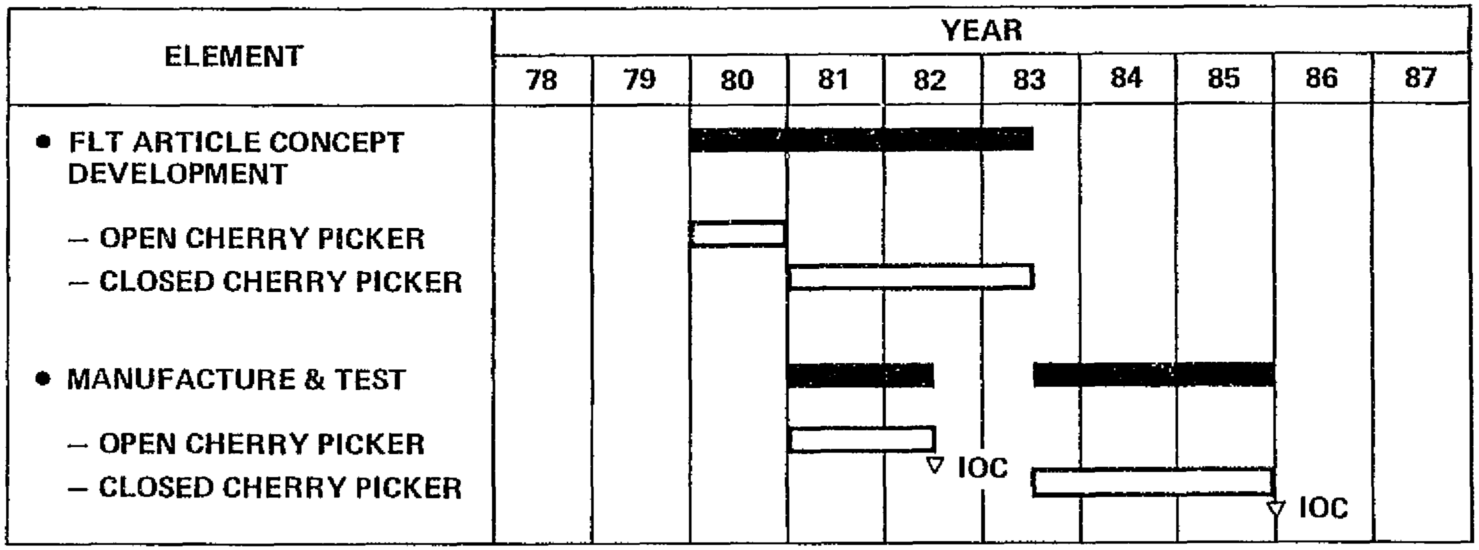
The opposite page summarizes a schedule for the MRWS flight article development. Concept development of the open cherry picker (OCP) begins in 1980 followed by fabrication and test in 1981 and 1982. The IOC is scheduled for mid 1982 to phase with planned construction R&D activity.

The closed cherry picker (CCP) concept development starts in 1982 and runs for two years. This is followed by a 2½ year manufacturing and test phase that meets a mid 1986 IOC. Mission planning indicates that the CCP would best be introduced when the initial construction base is deployed. At this time, multiple shift operations are envisioned that will benefit from a CCP.

The crane turret could also be introduced in 1986 if the mode of construction selected for the initial construction base involve the dual use of a crane and cherry picker.

Mission analysis indicates the need for the POTV airlock in the later half of the 1980s and the need for the MRWS free flyer when the SPS construction effort is initiated beyond 1990.

MRWS CHERRY PICKER PROGRAM



RELATED MRWS ROLES

ROLE	IOC
• CRANE TURRET	1986
• FREE FLYER	1990s
• POTV AIRLOCK	LATE 1980s

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SIMULATOR PROGRAM OPTIONS

Two simulator program options have been studied that provide a growth in simulator capability over the next five years. The first approach shown on the opposite page is centered around a concept of modular buildup of the Development Test Article so that both the open cherry picker and closed cherry picker can be evaluated using the same hardware. In the second option, two dedicated DTAs are fabricated with the first a high fidelity version of the open cherry picker and the second a high fidelity article of the closed cherry picker.

Program Option 1 stresses modularity, in which the lower sections of the DTA are used in open cherry picker simulation. After two years of operation, as an open cherry picker, the upper sections of the DTA including the supporting controls and displays are added for simulating closed C.P. functions.

Program Option 2 emphasizes early development of the open cherry picker by fabricating a DTA that is functional and geometrically the same as the expected flight article. This is followed by fabrication of a closed cherry picker that is not compromised by open cherry picker functions.

DTA PROGRAM OPTIONS

PROGRAM 1: MODULAR DESIGN WITH PHASED GROWTH

- INITIATE PROGRAM WITH OPEN CHERRY PICKER SIZED FOR GROWTH TO CLOSED CABIN CHERRY PICKER

PROGRAM 2: TWO-STEP PROGRAM WITH INTEGRAL DESIGNS

- INITIATE PROGRAM WITH HIFIDELITY OPEN CHERRY PICKER
- FOLLOW-UP WITH HIFIDELITY CLOSE CABIN CHERRY PICKER

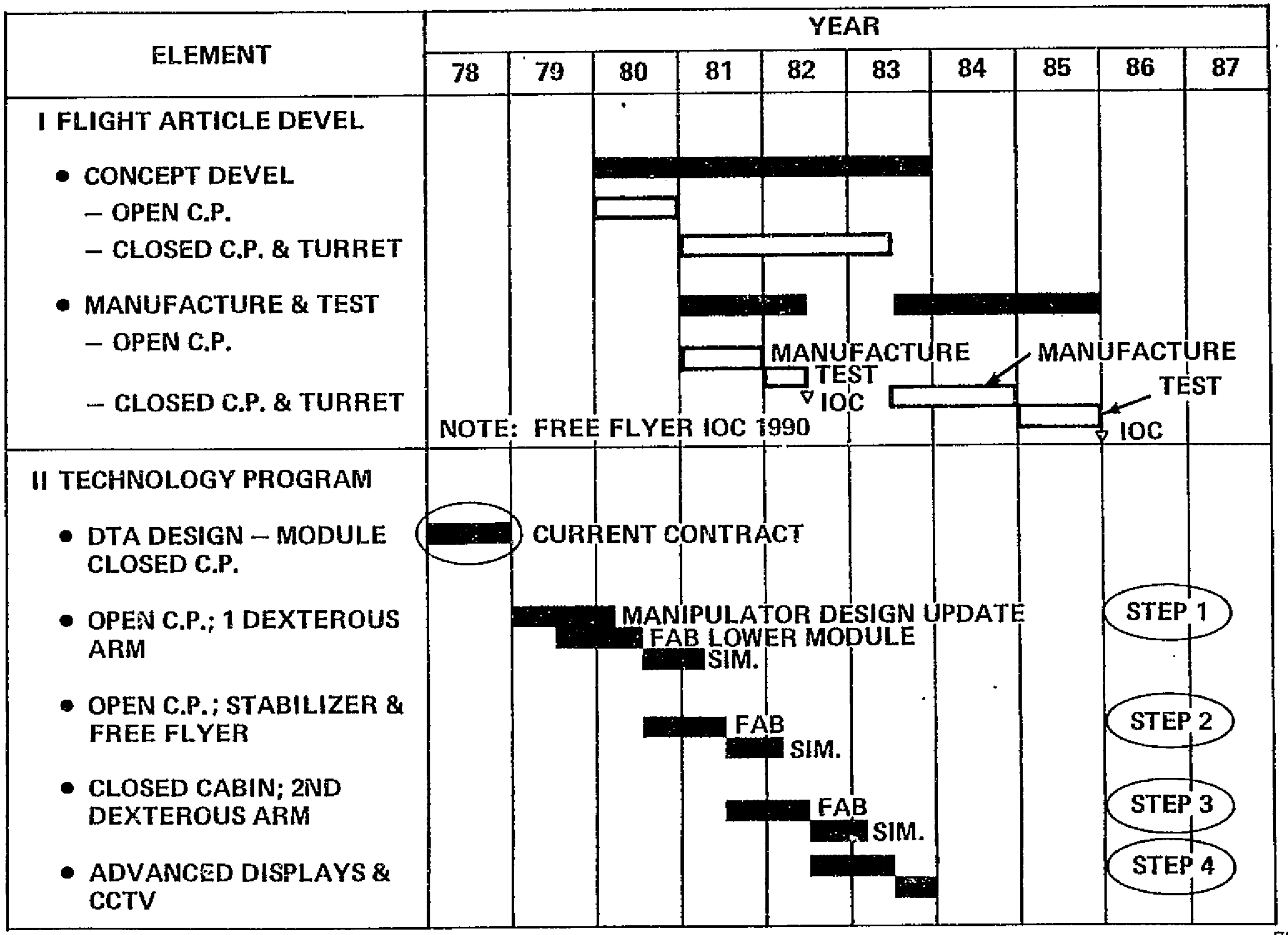
GRUMMAN

PROGRAM 1: DEVELOPMENT SCHEDULE

A summary of the schedule for DTA development and how the simulation activity supports the flight development is shown on the opposite page. Based on mission analysis of MRWS flight article requirements, an open cherry picker operated from the end of the Shuttle RMS is needed by mid 1982 or earlier to support automated payload servicing and construction R&D activities. It is anticipated that the closed cherry picker and crane turret will be phased into operation when the initial construction base is deployed in 1986.

The design of a closed cherry picker DTA that can be assembled in modules is performed in 1978 under the current contract. The lower module representative of the open cherry picker is fabricated in 1979 as is one dexterous manipulator. Testing of the OCP is then performed in 1980 in support of flight article concept development. A stabilizer and a jet system is added in 1980 and testing of free flyer operations in a open cabin configuration is performed in 1981. In 1981, the upper DTA structure is added as well as a second dexterous manipulator and testing performed in 1982. Advanced controls and displays are added in 1982 through 1983 in time to support concept development of the closed cherry picker flight article.

PROGRAM 1: DEVELOPMENT SCHEDULE



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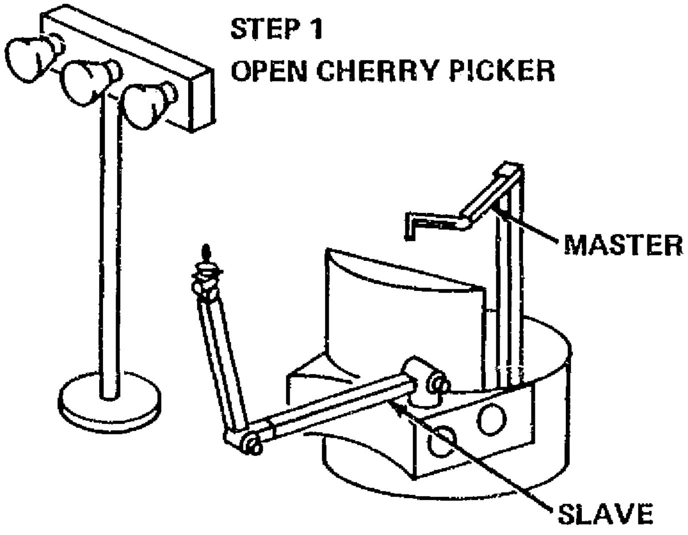
DEVELOPMENT TEST ARTICLE: PROGRAM 1 STEPS

The first set in Program 1 is to fabricate the lower module of the closed cherry picker and mount to it, one dexterous master/slave manipulator. With this configuration, open cherry picker operations can be initiated as well as studies involving the geometry of the manipulator master. Foam core cabins can be utilized to determine the impact of cabin volume limitations on manipulator productivity before the upper portions are fabricated.

Other test objectives that can be addressed with this concept are listed on the opposite page. Such tests as measuring metabolic load, work duration, lighting, and construction-related procedures can be made.

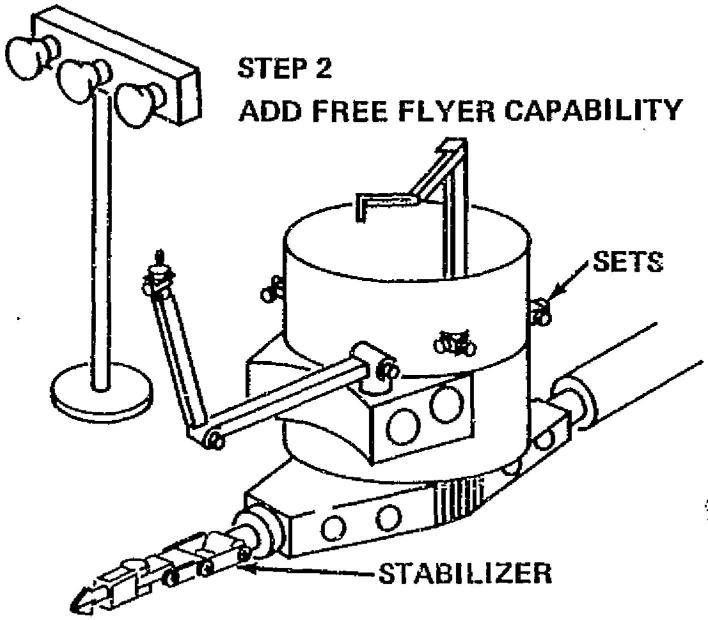
In Step 2, jets, control electronics and a gas system are added to the open cherry picker as is the stabilizer module. Testing can be expanded to include development of procedures for utilizing the stabilizer in both the open cherry picker and free flyer modes. Simulation results in this step are needed to finalize the design of the stabilizer.

DEVELOPMENT TEST ARTICLE: PROGRAM 1 STEPS



TEST TO DETERMINE:

- METABOLIC WORKLOAD WITH & W/O SPACE SUIT
- WORK DURATION
- REQUIRED LIGHTING
- WORKSITE LOCATION/MANIPULATOR LOCATION
- BEAM ASSEMBLY TIMELINE
- TIMELINES TO PERFORM ALIGNMENT, ADJUSTMENT & HANDLE TASKS



DTA MODIFICATION

- ADD
  - STABILIZER
  - THRUSTERS
  - CONTROL ELECTRONICS

TEST TO DETERMINE:

- METABOLIC WORKLOAD FOR OPERATING STABILIZER
- TRACKING ACCURACY REQUIREMENTS USING STABILIZER
- METHODS FOR SNARING, DESPINING, ETC
- FREE FLYER OPERATIONS

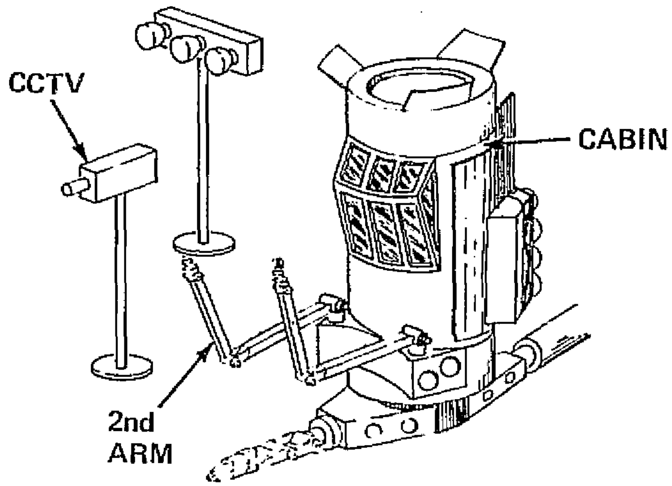
The last two steps in Program 1 are summarized on the opposite page; a second dexterous manipulator and the full cabin are added. Floor-mounted CCTV cameras and cabin monitors are aslo added. Metabolic work load data can now be refined for two manipulator arm operations. The approach to design of the CCTV system can also be addressed.

In step 4, the lessons learned in the previous activities are embodied into a DTA update of controls and displays including the manipulator master controllers.

DEVELOPMENT TEST ARTICLE: PROGRAM 1 STEPS

STEP 3

CLOSED CHERRY PICKER



DTA MODIFICATION

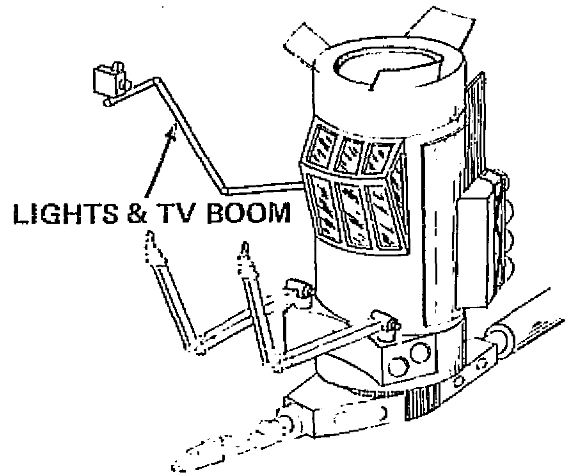
- ADD
  - TOP HAT
  - SECOND DEXTEROUS ARM
  - NEW REPLICA'S
    - ALSO DRIVES STABILIZER
  - CCTV

TEST TO DETERMINE:

- METABOLIC WORKLOAD USING 2 ARMS
- TIMELINES TO FASTEN, ALIGN, & ADJUST
- CRANE ARM STIFFNESS REQUIREMENTS
- TV MONITOR LOCATIONS
- WINDOW GEOMETRY

STEP 3

ADVANCED CONTROLS & DISPLAYS



DTA MODIFICATION

- ADD
  - EXTERNAL FLOOD LIGHTS
  - BOOM MOUNTED LIGHTS & STEREO TV
  - INTEGRATED DISPLAYS & CONTROLS

TEST TO DETERMINE:

- EFFECTS OF STEREO TV ON ASSEMBLY OPERATIONS
- ASSEMBLY DISPLAY REQUIREMENTS & FORMATS

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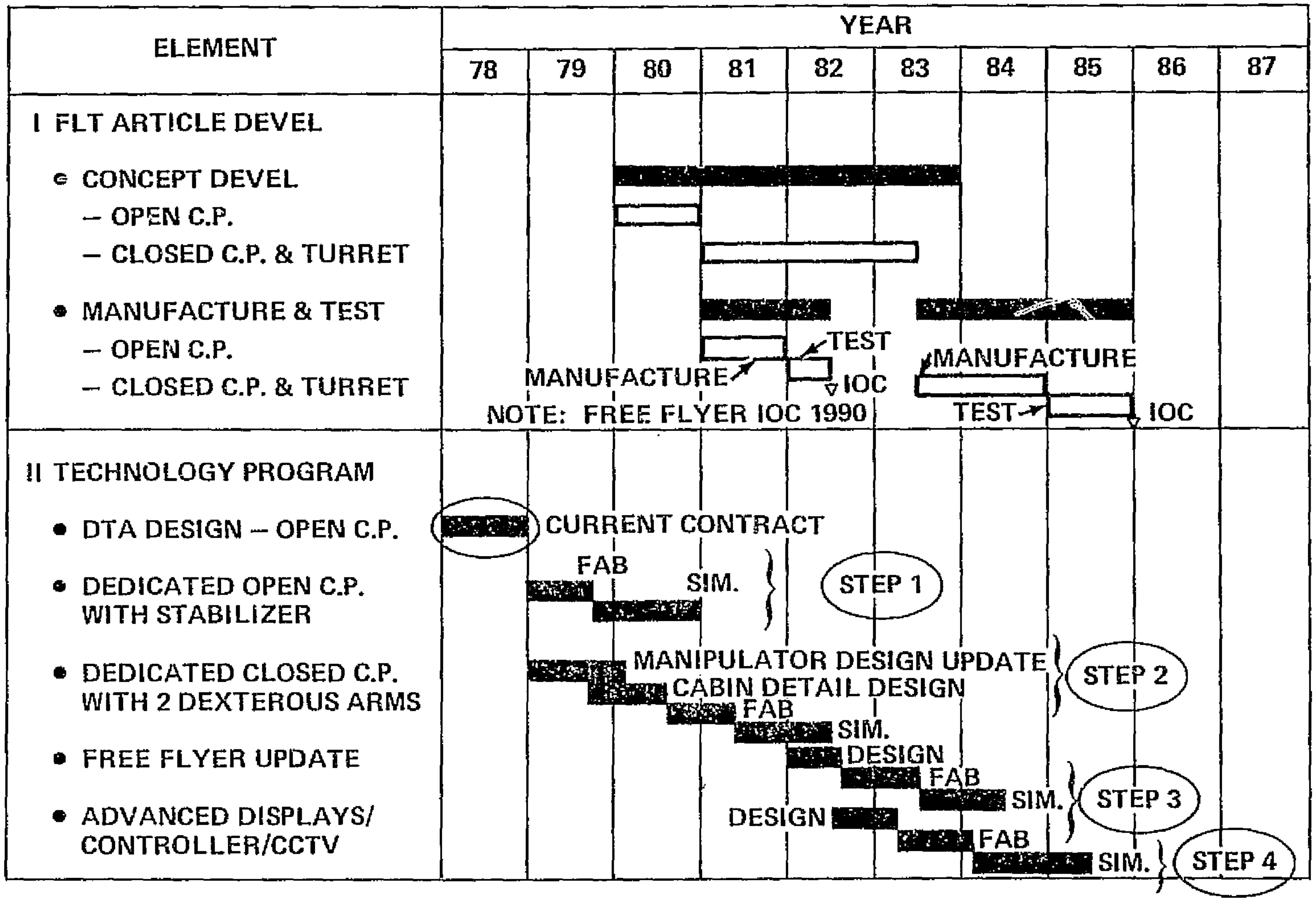
PROGRAM 2: DEVELOPMENT SCHEDULE

The opposite page summarizes the steps in Program 2 and how the simulation program phases with the flight article development and manufacture. Design of a dedicated open cherry picker is performed under the current contract and built in the first nine months of 1979. Open cherry picker testing is then performed into 1980 to support OCP concept development. Manipulator design and fabrication are also performed in 1979 and utilized in a bench test mode in 1980 while design and fabrication of the closed cherry picker is being performed. Testing of the CCP is initiated in 1981 and reconfigured in 1982 to perform free flyer testing. Advanced controls and displays are added and tested in 1983 in time to support CCP concept development.

PROGRAM 2: DEVELOPMENT SCHEDULE



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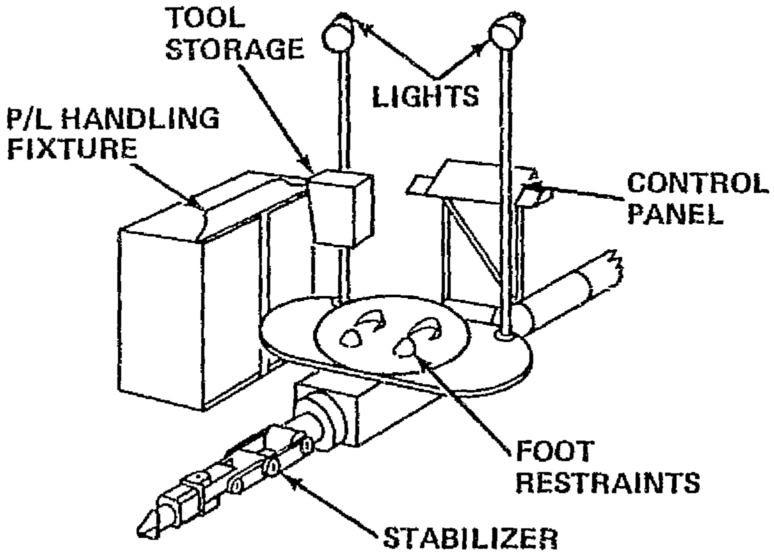
Program 2 begins with deployment of a dedicated high fidelity open cherry picker including the stabilizer and special handling fixtures. Test to determine approaches to the OCP/SRMS control interface and the stabilizer operations should be emphasized. Other key design parameters that impact flight article arrangement are the design loads and lighting requirements.

In step 2 of this program, a dedicated closed cherry picker including two dexterous manipulators are added to the MDF. The stabilizer used in the OCP tests can be interchanged with the newer closed cherry picker. Included with the illustration on the opposite page is a list of typical tests that can be performed.

DEVELOPMENT TEST ARTICLE: PROGRAM 2 STEPS

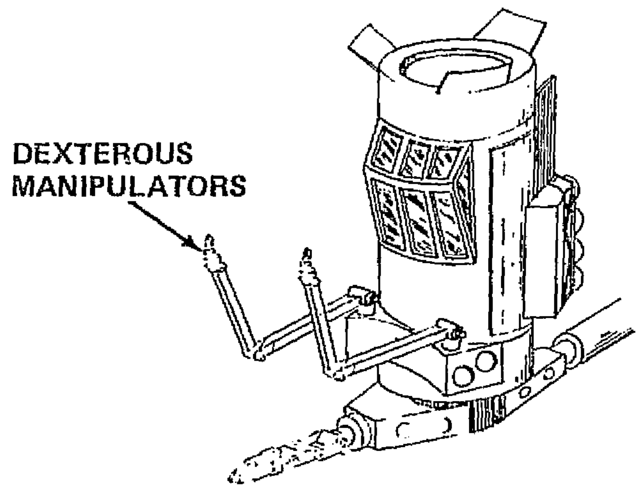
STEP 1
DEDICATED OPEN CHERRY PICKER



TEST TO DETERMINE:

- RMS CONTROL APPROACH INCLUDING OBSTACLE AVOIDANCE
- DESIGN LOADS
- PARALLEL OCP/RMS OPERATIONS
- SUBSYSTEM INSTALLATION PROCEDURES
- STRUCTURAL ASSEMBLY PROCEDURES
- LIGHTING REQUIREMENTS
- WORK DURATION & TIMELINES

STEP 2
DEDICATED CLOSED CABIN CHERRY PICKER



TEST TO DETERMINE:

- DEXTEROUS MANIPULATOR PERFORMANCE USING MASTER VARY
  - MASTER FORCE
  - MASTER INDEXING SCHEMES
- HUMAN FACTORS
  - METABOLIC WORK LOAD
  - WORK DURATION
- WORKSITE FACTORS
  - ACCESSIBILITY
  - MANIPULATOR LENGTH
- STABILIZER OPERATIONS/DESIGN LOADS
- LIGHTING REQUIRED
- STRUCTURAL ASSEMBLY PROCEDURES
- SUBSYSTEM INSTALLATION PROCEDURES

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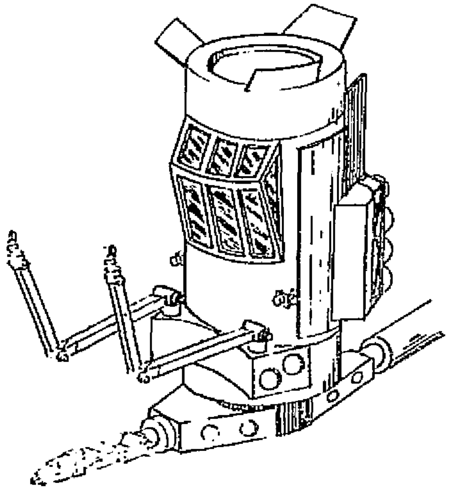
DEVELOPMENT TEST ARTICLE: PROGRAM 2 STEPS

Hardware and testing requirements for Steps 3 and 4 in Program 2 are summarized on the opposite page. In Step 3, jets, control electronics and gas system are added to meet requirements for free flyer simulation. Advanced controls and displays are added to the system in Step 4.

DEVELOPMENT TEST ARTICLE: PROGRAM 2 STEPS

STEP 3

ADD FREE FLYER CAPABILITY



DTA MODIFICATIONS

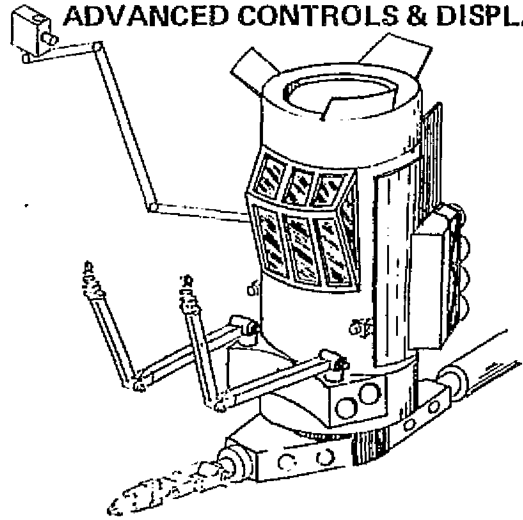
- ADD
  - THRUSTERS
  - CONTROL ELECTRONICS

TEST TO DETERMINE:

- STABILIZER OPERATIONS DURING FREE FLIGHT
- MANIPULATOR OPERATIONS DURING FREE FLIGHT
- AUTO STATION KEEPING GUIDANCE REQUIREMENTS
- RESCUE OPERATIONS

STEP 4

ADVANCED CONTROLS & DISPLAYS



DTA MODIFICATIONS

- ADD
  - EXTERNAL FLOOD LIGHTS
  - BOOM MOUNTED LIGHTS & STEREO TV
  - INTEGRATED CONTROLS & DISPLAYS
  - ADVANCED MANIPULATOR CONTROLLER

TEST TO DETERMINE:

- EFFECTS OF STEREO TV ON ASSEMBLY OPERATIONS
- ASSEMBLY DISPLAY REQUIREMENTS & FORMATS
- PRODUCTIVITY WITH ADVANCED CONTROLLER

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RECOMMENDATIONS

Program 2, which emphasizes early development of the open cherry picker, meets flight article development requirements better than Program 1. The high fidelity makeup of the open cherry picker DTA in this program should provide more timely technology data to meet a 1982 IOC.

The one year period prior to introduction of the closed cherry picker should be used to design and fabricate the dexterous manipulators. A survey of available BFR manipulators showed that none were available with the geometries and features needed for high fidelity simulation. Though the technology exists, the survey recommends that a new design be sought for MDF operations with a plan for delivery by the end of 1979.

The key piece of equipment to be purchased for simulator start-up is the stabilizer. Devices are available with 6 DOF that could meet initial testing requirements. More analysis must be done to determine if a new design stabilizer may be more beneficial to the program.

As a way of reducing cost for the closed cabin DTA, design and fabrication should be performed using skunk work procedures where fabrication is performed with release of top level informal drawings. If a formal drawing, then build sequence is used, a program slip of one year may result.

RECOMMENDATIONS

- SELECT PROGRAM 2 AND EMPHASIZE OPEN CHERRY PICKER
  - SUPPORTS NEAR-TERM APPLICATIONS
  - BETTER CHANCE OF DERIVING "FLYABLE" HARDWARE FROM TECHNOLOGY PROGRAM
  - BETTER PHASING BETWEEN MANIPULATOR DEVELOPMENT & CABIN FABRICATION
  - FREE-FLYER SAFER WITH CLOSED CABIN
- INITIATE PURCHASE OF ADAPTER BY END OF YEAR
- INITIATE DESIGN AND FAB OF DEXTEROUS MANIPULATORS FOR DELIVERY IN LATE 1979 (4 mo DESIGN, 9 mo FAB)
- FABRICATE CLOSED CABIN CHERRY PICKER AS DRAWINGS ARE RELEASED (SKUNK WORKS APPROACH) STARTING IN LATE 1979

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