MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE

NASA CR- 160465

FINAL REPORT — VOLUME II
SIMULATION REQUIREMENTS
AND
APPENDIX A
OPEN CHERRY PICKER DEVELOPMENT TEST ARTICLE SPECIFICATION

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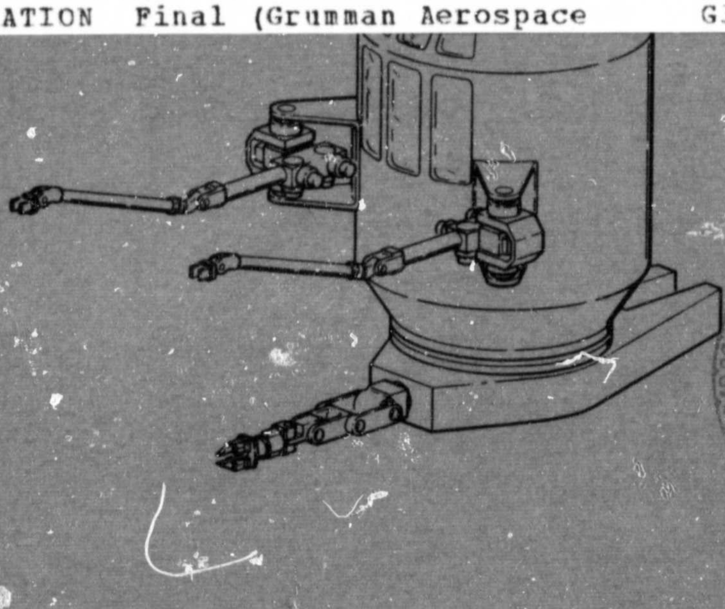

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MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE

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OPEN CHERRY PICKER DEVELOPMENT TEST ARTICLE SPECIFICATION

Prepared for
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Report NSS-MR-RP008

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CONTENTS

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ILLUSTRATIONS

ILLUSTRATIONS (contd)

TABLES

ACRONYMS

BFR	Bilateral Force Reflecting
C&D	Controls and Displays
CCP	Closed Cabin Cherry Picker
CCTV	Closed Circuit Television
CRT	Cathode Ray Tube
CT	Crane Turret
DOF	Degrees-of-Freedom
DMS	Dexterous Manipulator System
DTA	Development Test Article
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
GEO	Geosynchronous Orbit
HEAO	High Energy Astronomy Observatory
JSC	Johnson Space Center
LDEF	Long Duration Exposure Facility
LEO	Low Earth Orbit
LSS	Large Space Structure
MDF	Manipulator Development Facility
MMS	Multi-Mission Modular Spacecraft
MMU	Manned Maneuvering Unit
MRWS	Manned Remote Work Station
OCP	Open Cherry Picker
OCSE	Orbital Construction Support Equipment

ACRONYMS (contd)

POTV	Personnel Orbital Transfer Vehicle
PRS	Personnel Rescue System
SCAFE	Space Construction Automated Fabrication Experiment
SPS	Solar Power Satellite
SRMS/RMS	Shuttle Remote Manipulator System
STS	Space Transportation System

Section 1

INTRODUCTION

The Space Transportation System (STS) will remove many of the constraints of payload volume and mass that can be launched into orbit. It will also transport to orbit up to seven astronauts that can significantly enhance operations in terms of payload handling, satellite servicing, scientific observation, and structural assembly. Many diverse support equipments will be required. However, for efficient and cost-effective orbital operations, commonality of equipment is a prime requisite. The Manned Remote Work Station (MRWS) is the most universal element exemplifying this concept. To establish a technology base for development of the MRWS, this report defines the objectives and development requirements for a simulation program to be conducted at the Lyndon B. Johnson Space Center (JSC) Manipulator Development facility.

An MRWS mission scenario, broken down into the three time phases (Figure 1), was selected as the basis for analysis of the MRWS flight article requirements and concepts. The results of this effort are presented in Volume I Requirement Document (NSS-MR-RP008). This report, containing the mission roles for the three time phases, supporting tradeoff and evaluation studies, was used to identify key issues requiring simulation. The MRWS can operate from the end of the Shuttle Remote Manipulator System (SRMS/RMS) in the early 1980's and perform such operations as support of Spacelab experiments, servicing and repair of satellites, and construction R&D. In the mid 1980's the MRWS will become an integral part of the Orbital Service Module (or Initial Space Construction Base) and perform the tasks of assembling large antenna and solar power technology satellites. The eventual use of the MRWS will be in support of constructing the Solar Power Satellite in the 1990's.

The MRWS is therefore envisioned as a universal crew cabin that can support space operations in the multiple roles outlined in Figure 2. These roles will include use as a Crane Turret, an Open or Closed Cherry Picker, Free Flyer, Railed Work Station, and Personnel Orbit Transfer Vehicle Airlock. Each of these MRWS mission roles has been identified during the Orbital Construction Support Equipment (OCSE) studies (NAS9-15120) as being essential to the assembly of the Solar Power Satellite.

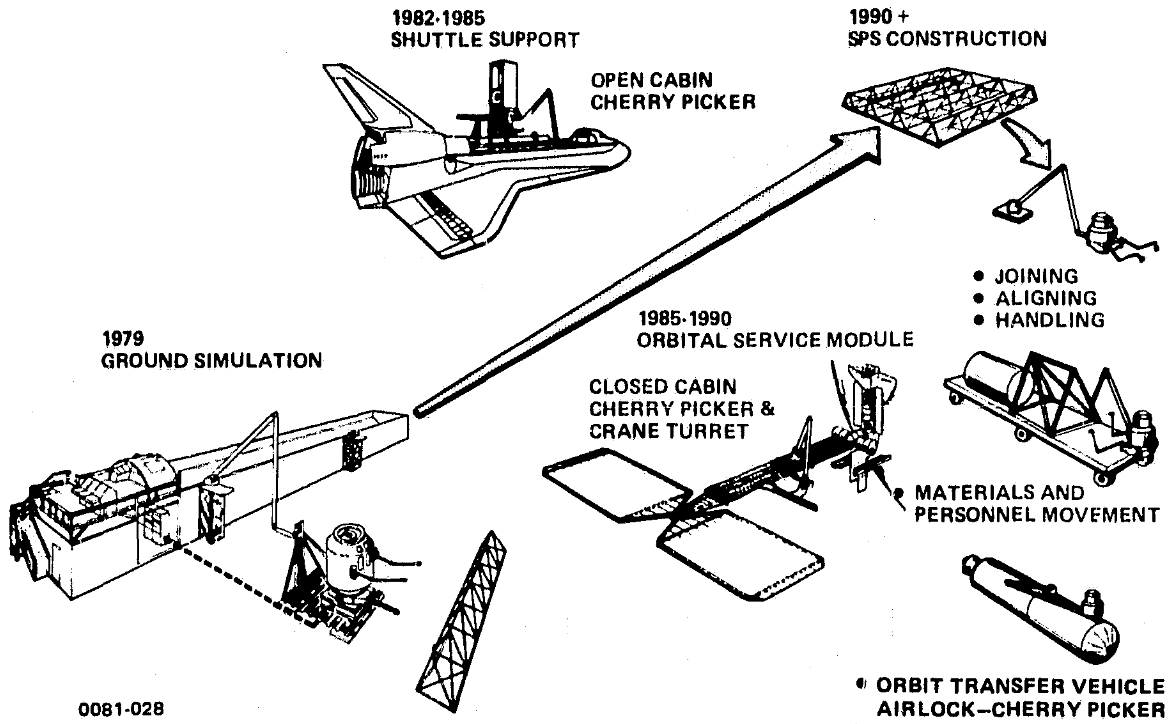

Figure 1. Orbital Construction Support Equipment Development Universal Manned Remote Work Station

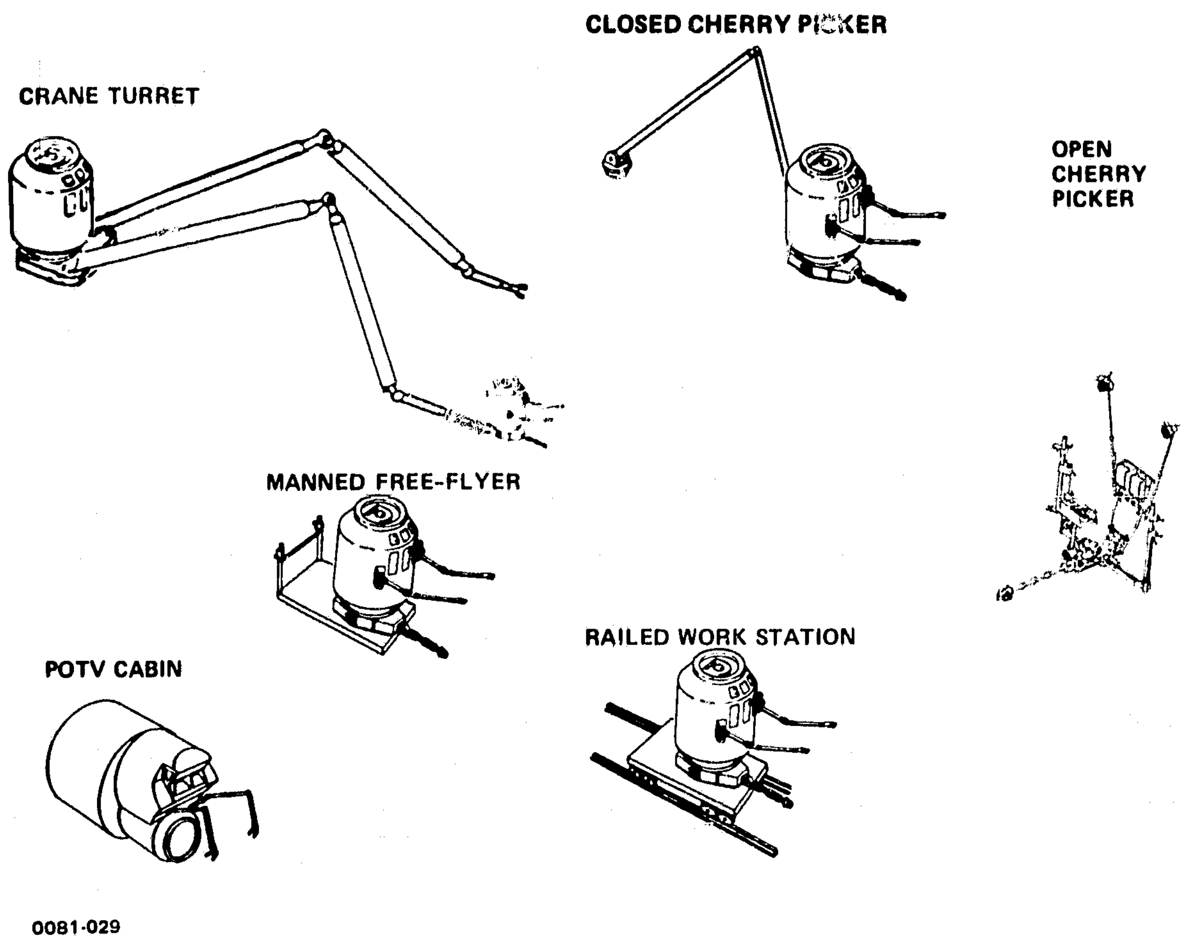

Figure 2. MRWS Multirole Concept in Support of Large Space Systems

Table 1 is a mission matrix that relates the various MRWS operating roles to the missions they perform during the three time phases: near-term, 1982 - 1985; mid-term, 1986 - 1990; and far-term, 1991 - 2000 +. The near-term operations can be performed with an open cabin version of the cherry picker. Requirements for this time phase have been derived from the mission descriptions for automated payloads and two studies (NAS8-32390 and NAS9-15310), related to construction R&D operations directly from the Orbiter. MRWS requirements for the mid-term have been derived from two studies related to the initial construction base operations, namely, the Orbital Construction Demonstration Study (NAS9-14916) and the Space Station Systems Analysis Study (NAS9-14958). These studies identified the need for a closed cabin cherry picker and the crane turret. The basis of far term MRWS requirements are the results of the OCSE studies (NAS9-15120) and the Solar Power Satellite Systems Definition Study (NAS9-15196).

The MRWS development will be supported by an MRWS simulator, the Development Test Article (DTA). The DTA will be located in the Manipulator Development Facility (MDF) Building 9A at JSC. The MRWS Simulator utilizes various MDF systems, subsystems, and equipment required to produce a high fidelity zero-g simulation capability on the air bearing floor. A grappling fixture mounted on top of the air-bearing platform containing the DTA is used in conjunction with the RMS and end effector to maneuver the platform over the air bearing floor for a simulation of the movement of the MRWS in a weightless environment. The DTA has three degrees-of-freedom (3-DOF) in the plane of the air bearing floor.

The primary functions of the DTA are to:

- Serve as a design tool for the MRWS, including the complete man-machine interface evaluation
- Develop and evaluate the Dexterous Manipulator System (DMS) requirements
- Develop and evaluate the stabilizer requirements
- Assist in crew training for large space structure construction activities.

The DTA drive system consists of a 50-ft, hydraulically actuated manipulator arm, activated and monitored at the test director's console and operated either from the MDF operator's console (in the manual augmented mode or direct drive mode) or from the replica controller (in the replica mode) or from the DTA (see Figure 3).

TABLE 1

MRWS MISSION MATRIX

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

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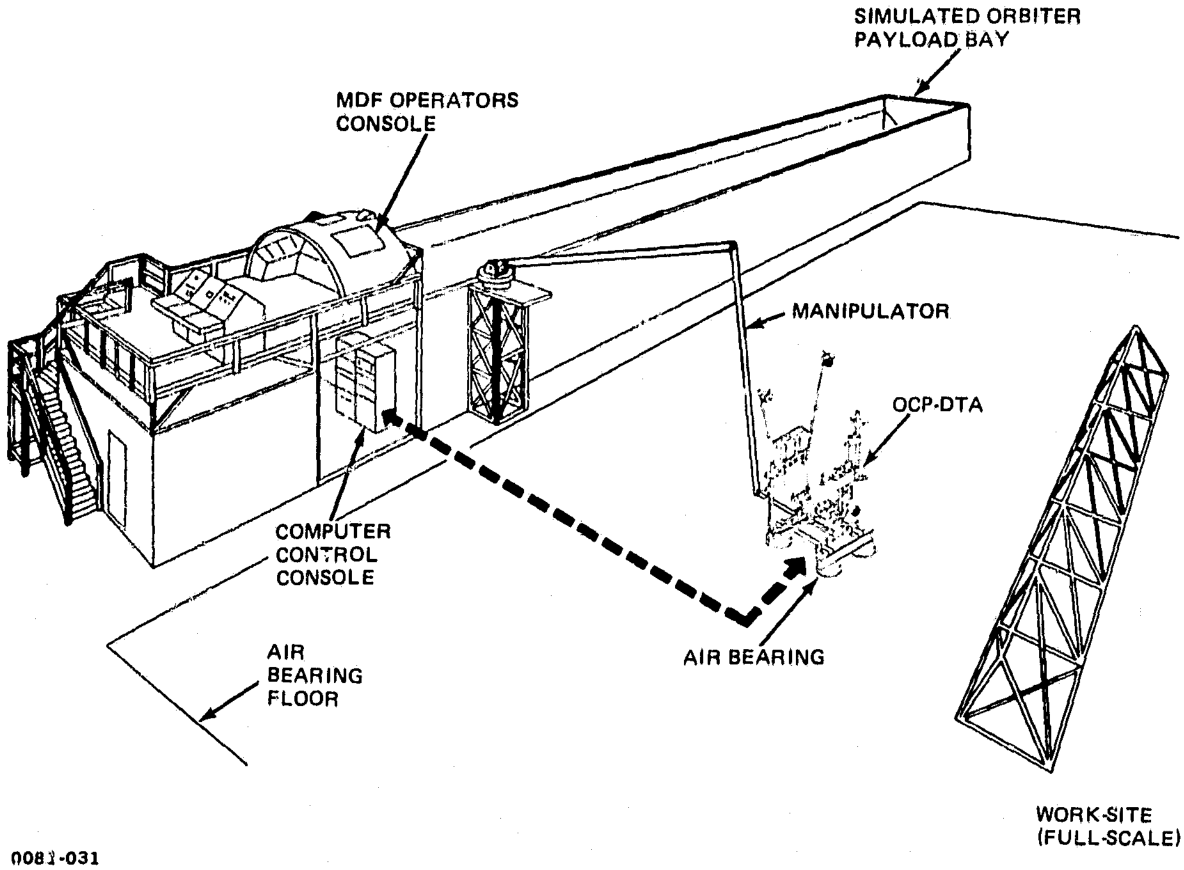

Figure 3. Open Cherry Picker Simulation Concept Using JSC MDF

As conceptually diagrammed in Figure 4, the MRWS Flight Article Requirement Document was used to identify key issues requiring simulation. These issues were then formulated into simulation objectives which were analyzed for the type of simulator needed to meet the objectives.

Section 2 of this document presents the simulator objectives that were developed from the analysis of the MRWS Flight Article Requirements Document. Section 3 summarizes the various simulation concepts that were considered during the preliminary simulator requirements and planning phase of the DTA design. The DTA design guidelines are presented in Section 4 and Appendix A is the Open Cherry Picker DTA specification.

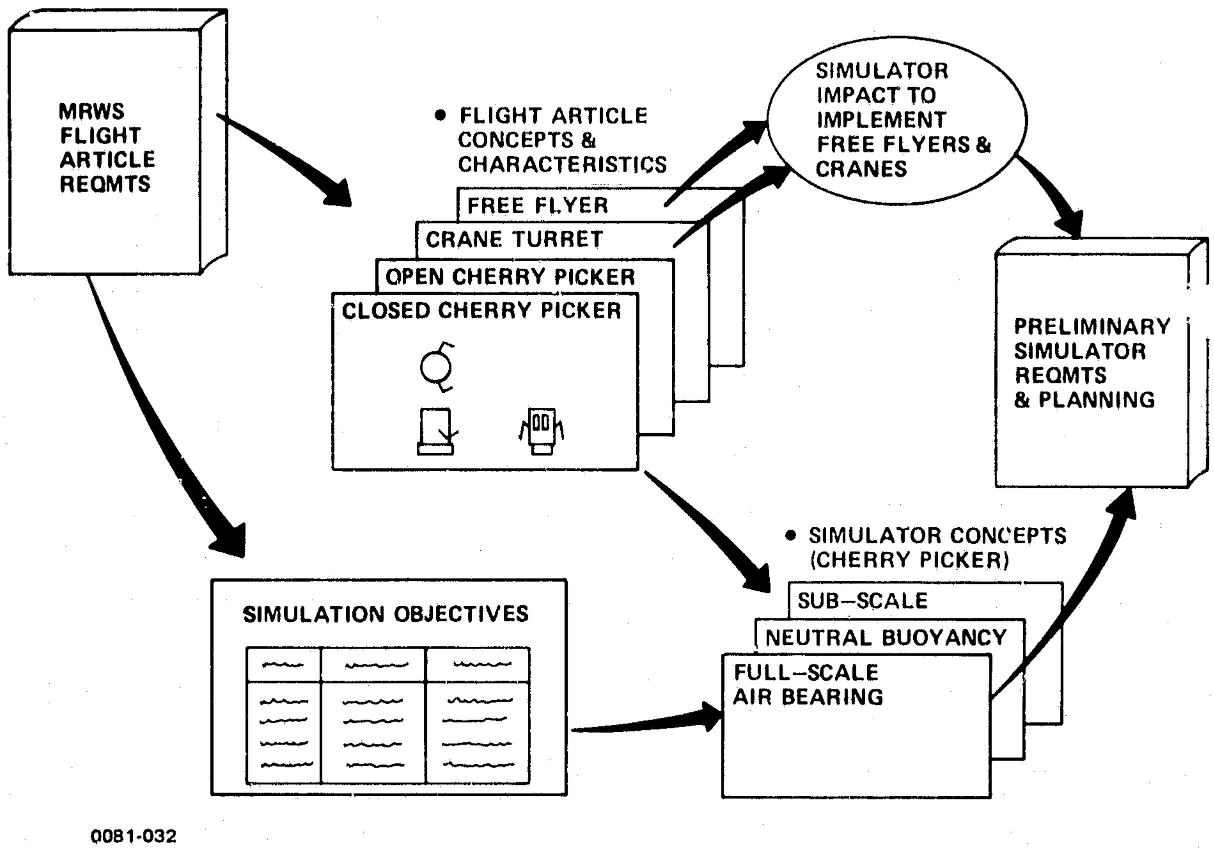

Figure 4. MRWS Simulator Requirements Definition Approach

Section 2

SIMULATION OBJECTIVES

2.1 INTRODUCTION

Volume I, the Manned Remote Work Station Flight Article Requirements Document NSS-MR-RP008, was the basic reference used to identify the MRWS system and subsystem simulation objectives. For each of these time phases: near-term, 1982 - 1985; mid-term, 1986-1990; and far-term, 1991 - 2000+, the multiple mission support roles of the MRWS were analyzed and the key issues requiring simulation were identified and grouped under five categories for each configuration:

- Category 1 - Cabin design factors
- Category 2 - Equipment design factors
- Category 3 - Procedures development
- Category 4 - Man/machine interface factors
- Category 5 - Construction base interface factors.

This section presents the DTA simulation objectives, in tabular form, for the key issues requiring simulation for each mission and MRWS configuration considered in the MRWS Flight Article Requirement Document (Volume I).

2.2 DTA SIMULATION OBJECTIVES

The simulation objectives for the DTA, based on the five categories (Figure 5) were developed for the MRWS configurations and roles indicated in Table 2. Approximately 22 different MRWS roles were identified and preliminary simulation objectives established requiring the use of the DTA for solving the man/machine interface problem. Tables 3 through 10 present in succinct fashion the various simulation objectives identified from the mission analysis, for each of the MRWS configurations identified. The tables identify the simulation objectives and the particular mission and the simulation concepts that could be used to resolve these key issues. The various simulation concepts are discussed in Section 3.

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

- WORK-SITE 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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Figure 5. Simulation Objectives: Categories

TABLE 2

MRWS ROLES

MISSION TIME PHASE	MRWS CONFIGURATION	MISSIONS
NEAR-TERM 1982-1985	• OPEN CHERRY PICKER	• MMS SERVICING • LDEF SERVICING • LSS PLATFORM • SCAFE • POWER MODULE/CONSTRUCTION MODULE PLACEMENT • SPACE TELESCOPE
MID-TERM 1986-1990	• OPEN CHERRY PICKER • CRANE TURRET • CLOSED CABIN CHERRY PICKER	• TA 1 CONSTRUCTION • TA 2 CONSTRUCTION • TA 1 CONSTRUCTION • TA 2 CONSTRUCTION • 100-m RADIOMETER • 61-m RADIOMETER
FAR-TERM 1991-200+	• CLOSED CABIN CHERRY PICKER	• SPS – TRANSPORTER – BEAM MACHINE CONTROL CAB – JOINT MACHINES – SOLAR ARRAY BLANKET DEPLOYER – BUS BAR INSTALLER – ANTENNA CONSTRUCTION – GIMBAL DRIVE CONSTRUCTION – SUBSYSTEM INSTALLER – GEO BERTHING CONTROL CAB – GEO MAINTENANCE – TUBE REPLACEMENT
	• FREE FLYER	• SPS – CRANE REPAIR – RECEIVE
	• POTV	• GEO MMS SERVICING

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TABLE 3

SIMULATION CONCEPTS

IDENT.	CONCEPT
A	FIXED BASE, FULL-SCALE HIGH FIDELITY DTA, SUB-SCALE WORK-SITE
B	SIX DOF SERVO DRIVER SIMULATOR
C	MRWS MOCK-UP (WOOD, CARDBOARD, FOAMCORE)
D	TERRESTRIAL CHERRY PICKER (CONSTRUCTION EQUIPMENT)
E	THREE DOF AIR BEARING (MDF FACILITY)
F	NEUTRAL BUOYANCY – WATER TANK
G	FLIGHT TEST – KC135 AIRPLANE ZERO G MANEUVER
H	SPACE TEST-SHUTTLE

0081-035

TABLE 4

OPEN CHERRY PICKER — NEAR-TERM
(SHEET 1 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS					SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		LSS	SCAFE	LDEF	INITIAL CONST BASE	MMS	
CATEGORY I: CABIN DESIGN FACTORS							
METABOLIC WORKLOAD	• MEASURE HEART RATE, PERSPIRATION & SKIN TEMP OF ASTROWORKER WHILE PERFORMING CONSTR TASKS	√	√	√	√	√	B,D,E,F,G,H
DISPLAYS	• EVALUATE THAT DISPLAYS ARE ADEQUATE TO PERFORM VARIOUS CONSTR TASKS	√	√	√	√	√	B,C,E
	• EVALUATE DISPLAY LIGHTING	√	√	√	√	√	"
	• TYPES & FORMAT OF DATA DISPLAYED ARE ADEQUATE TO KEEP ASTROWORKER INFORMED OF OCP AND RMS OPERATION STATUS	√	√	√	√	√	"
CREW/CONSOLES	• EVALUATE LOCATION, SIZE & STOWED POSITION OF CONSOLE DURING CONSTR TASKS	√	√	√	√	√	B,C,E
	• EVALUATE POSITIONS OF CONSOLE WHEN CONTROLLING SHUTTLE RMS	√	√	√	√	√	"
RESTRAINTS	• EVALUATE ADEQUACY OF FOOT RESTRAINTS IN RESTRAINING ASTROWORKER DURING CONSTR TASKS & IN THAT THEY DO NOT RESTRICT HIS MOBILITY & REACH	√	√	√	√	√	B,C,D,E,F,G,H
	• DETERMINE WHETHER EXTRA BODY RESTRAINS ARE REQUIRED	√	√	√	√	√	"
CATEGORY II: EQUIPMENT DESIGN FACTORS							
STABILIZER REQMTS	• VERIFY PERFORMANCE OF ONE STABILIZER SUB-SYSTEM IN GRAPPLING WORK-SITE & STABILIZING OCP DURING CONSTR TASKS	√	√	√	√	√	B,C,E

0081-036(1)

TABLE 4

OPEN CHERRY PICKER — NEAR-TERM
(SHEET 2 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: LSS	SCAFE	LDEF	INITIAL CONST BASE	MMS	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
	● VERIFY PERFORMANCE OF VARIOUS END EFFECTOR DESIGNS	√	√	√	√	√	B,C,E
EQUIPMENT/TOOL STORAGE BIN	● CHECK ACCESSIBILITY OF STORAGE BIN TO ASTRO-WORKER DURING CONSTR TASKS	√	√	√	√	√	B,C,E
	● EVALUATE METHODS OF RETENTION OF TOOLS IN BIN	√	√	√	√	√	"
CONTROLLERS	● EVALUATE ABILITY OF EVA ASTROWORKER TO CONTROL OCP-RMS USING ONE OR TWO HAND CONTROLLERS	√	√	√	√	√	B,D,E,F
	● FEASIBILITY OF CONTROLLING TWO RMS WITH ONE SET OF HAND CONTROLLERS	√	√	√	√	√	"
	● EVALUATE USE OF INDIVIDUAL SWITCHES FOR CON-TROLLING THE RMS	√	√	√	√	√	"
	● FEASIBILITY OF CONTROLLING THE STABILIZER WITH THE RMS HAND CONTROLLER	√	√	√	√	√	"
WELD TOOL DESIGN	● DETERMINE WELDING PROCEDURES FOR JOINING CROSSBEAMS		√				B,D,E,F,G,H
	● VERIFY, WELDING TOOL DESIGN BY EVALUATION OF ASTROWORKER'S ABILITY TO PERFORM WELDING TASKS		√				"
ASSEMBLY TOOLS & FIXTURES	● ASSESS REQMTS FOR BOLT INSTALL TOOL, LATCHES, P/L HAND HOLDS, AUTOMATIC ALIGNING FIXTURES, DEPLOYMENT MECHANICS	√	√	√	√	√	B,D,E,F,G,H
PAYLOAD HANDLING DEVICES	● EVALUATE DEVICES FOR HANDLING & INSTALLING VARIOUS PAYLOADS	√	√	√	√	√	B,D,E,F,G,H

0081-036(2)

TABLE 4

OPEN CHERRY PICKER — NEAR-TERM
(SHEET 3 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: LSS	SCAFE	LDEF	INITIAL CONST BASE	MMS	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY III: PROCEDURES DEVELOPMENT							
COMPONENT & SUBSYSTEM HANDLING, ALIGNMENT & INSTALLATION	• DEVELOP PROCEDURES FOR HANDLING, ALIGNING & INSTALLING VARIOUS COMPONENTS & SUBSYSTEMS USING VARIOUS TOOLS, FIXTURES & P/L HANDLING DEVICES	√	√	√	√	√	B,D,E,F,G,H
SERVICING AUTOMATIC FABRICATION EQUIPMENT	• DEVELOP PROCEDURES FOR SERVICING & MAINTAINING AUTOMATIC BEAM FABRICATION MACHINE	√	√				B,C,D,E,F
BEAM ALIGNMENT & ASSEMBLY	• DEVELOP PROCEDURES FOR ALIGNING & JOINING 1-m BEAMS	√	√				B,D,E,F
MODULE ASSEMBLY	• ESTABLISH PROCEDURES FOR ALIGNING & BERTHING MODULES, BOLTING GIMBAL FITTINGS, ASSEMBLY & INSTALLING CRANE ARMS				√		B,C,D,E,F
COMPONENT DEPLOYMENT & LOCKUP	• ESTABLISH PROCEDURES FOR DEPLOYMENT OF TELESCOPING CYLINDERS, RADIATOR & SOLAR PANELS				√		B,C,D,E,F
WIRING INSTALLATION & CONNECTIONS	• DEFINE PROCEDURES FOR INSTALLING & CONNECTING	√	√		√		B,E,F,G
INSTRUMENT TRAYS	• ESTABLISH PROCEDURES FOR REMOVAL & INSTALLATION OF EXPERIMENT TRAYS IN SATELLITE			√		√	B,D,E,F

008?-036(3)

TABLE 4

OPEN CHERRY PICKER — NEAR-TERM
(SHEET 4 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: LSS	MISSIONS: SCAFE	MISSIONS: LDEF	MISSIONS: INITIAL CONST BASE	MISSIONS: MMS	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY IV: MAN/MACHINE INTERFERFACE FACTORS							
FATIGUE/TASK	• DETERMINE TASK TIME LINES FOR VARIOUS CONSTR TASKS	√	√	√	√	√	B,D,E,F,G
	• ESTABLISH FATIGUE LIMITS VS TASK DURATION						
OBSTACLE AVIODANCE	• DETERMINE ASTROWORKER'S OBSTACLE AVOIDANCE ABILITY AS FUNCTION OF WORK-SITE/WORK TASK CONFIGURATIONS	√	√	√	√	√	B,D,E,F
	• ESTABLISH REQMTS FOR AUTOMATIC OBSTACLE AVOID-ANCE SYSTEM IF REQUIRED	√	√	√	√	√	"
LIGHTING REQMTS	• DETERMINE ILLUMINATION REQMTS, AT WORK-SITE/ WORK TASK	√	√	√	√	√	C,E
	• EVALUATE EFFECTS OF LIGHT/DARK ORBIT CONDITIONS	√	√	√	√	√	"
CATEGORY V: CONSTRUCTION BASE INTERFACE FACTORS							
OPERATION OF BOTH SHUTTLE RMS ARMS	• DETERMINE ABILITY OF ASTROWORKER TO CONTROL BOTH RMS's DURING WORK TASKS	√	√	√	√	√	B,D,E,H
	• EVALUATE ADEQUACY OF DISPLAYS/CONTROLLERS	√	√	√	√	√	"
PREPARATION OF STOWED OCP FOR OPERATIONAL USE	• ESTABLISH ASTROWORKER'S TASKS TO REMOVE, DEPLOY & CHECKOUT OCP IN SHUTTLE & MATE WITH RMS	√	√	√	√	√	C,E,H

0081-036(4)

TABLE 4

OPEN CHERRY PICKER — NEAR-TERM
(SHEET 5 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS					SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		LSS	SCAFE	LDEF	INITIAL CONST BASE	MMS	
RESCUE OPERATIONS	• ESTABLISH RESCUE PROCEDURES FROM DISABLED OCP BACK TO SHUTTLE	√	√	√	√	√	B,C,D,E,F,G,H
	• VERIFY ADEQUACY OF RESCUE EQUIPMENT, HAND & FOOT HOLDS	√	√	√	√	√	"
RMS—ARM STIFFNESS	• EVALUATE EFFECTS OF RMS—ARM STIFFNESS ON CONTROLLABILITY OF RMS AND EFFECTS OF ASTROWORKER-INDUCED LOADS ON THE RMS	√	√	√	√	√	B,D,E,F,H

0081-036(5)

TABLE 5

OPEN CHERRY PICKER — MID-TERM
(SHEET 1 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: MICROWAVE TRANS. DEVEL ARTICLE (TA-1)	MISSIONS: PHOTOVOLTAIC SOLAR COLLECTOR DEV ARTICLE (TA-2)	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY I: CABIN DESIGN FACTORS				
METABOLIC WORKLOAD	• MEASURE HEART RATE, RESPIRATION & SKIN TEMP OF ASTROWORKER WHILE PERFORMING CONSTR TASKS	√	√	A,B,D,E,F
DISPLAYS	• EVALUATE THAT DISPLAYS ARE ADEQUATE TO PERFORM VARIOUS CONSTR TASKS	√	√	"
	• EVALUATE DISPLAY LIGHTING	√	√	A,B,C,D,E
	• TYPES & FORMAT OF DATA DISPLAYED ARE ADEQUATE TO KEEP ASTROWORKER INFORMED OF OCP OPERATION STATUS	√	√	"
CREW/CONSOLES	• EVALUATE LOCATION, SIZE & STOWED POSITION OF CONSOLE DURING CONSTR TASKS	√	√	A,B,C,D,E,F
	• EVALUATE POSITIONS OF CONSOLE WHEN CONTROLLING CRANE ARM	√	√	A,B,C,D,E,F
RESTRAINTS	• EVALUATE ADEQUACY OF FOOT RESTRAINTS IN RESTRAINING ASTROWORKER DURING CONSTR TASKS & IN THAT THEY DO NOT RESTRICT HIS MOBILITY & REACH	√	√	B,C,D,E,F,G
	• DETERMINE WHETHER EXTRA BODY RESTRAINTS ARE REQUIRED	√	√	"
CATEGORY II: EQUIPMENT DESIGN FACTORS				
STABILIZER REQMTS	• VERIFY PERFORMANCE OF ONE STABILIZER SUBSYSTEM IN GRAPPLING WORK-SITE & STABILIZING OCP DURING CONSTR TASKS	√	√	B,C,E

0081-037(1)

TABLE 5

OPEN CHERRY PICKER — MID-TERM (SHEET 2 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: MICROWAVE TRANS. DEVEL ARTICLE (TA-1)	MISSIONS: PHOTOVOLTAIC SOLAR COLLECTOR DEV ARTICLE (TA-2)	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
	• VERIFY PERFORMANCE OF VARIOUS END EFFECTOR DESIGNS	√	√	B,C,E
EQUIPMENT/TOOL STORAGE BIN	• CHECK ACCESSIBILITY OF STORAGE BIN TO ASTROWORKER DURING CONSTR TASKS	√	√	B,C,E,F
	• EVALUATE METHODS OF RETENTION OF TOOLS IN BIN	√	√	"
CONTROLLERS	• EVALUATE ABILITY OF EVA ASTROWORKER TO CONTROL OCP CRANE ARM USING ONE OR TWO HAND CONTROLLERS	√	√	A,B,D,E
	• FEASIBILITY OF CONTROLLING BOTH CRANE ARMS WITH ONE SET OF HAND CONTROLLERS	√	√	"
	• EVALUATE USE OF INDIVIDUAL SWITCHES FOR CONTROLLING CRANE ARM	√	√	"
	• FEASIBILITY OF CONTROLLING THE STABILIZER WITH THE CRANE HAND CONTROLLER	√	√	"
ASSEMBLY TOOLS	• VERIFY PERFORMANCE & HANDLING OF BOLT TORQUING TOOLS, PAYLOAD UNLOCKING TOOLS, BEAM DEPLOYMENT LOCKS, ASSEMBLY FIXTURE CLAMPING DEVICES	√	√	B,D,E,F,G,H
PAYLOAD HANDLING	• EVALUATE DEVICES FOR HANDLING & INSTALLING VARIOUS PAYLOADS	√	√	B,D,E,F
CCTV	• ACCESS THE NEED FOR CCTV AS AN AID TO DIRECT VIEWING OR AS MONITORING EVA ASTROWORKER FROM CONSTR BASE	√	√	A,B,C,E

0081-037(2)

TABLE 5

OPEN CHERRY PICKER — MID-TERM (SHEET 3 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: MICROWAVE TRANS. DEVEL ARTICLE (TA-1)	MISSIONS: PHOTOVOLTAIC SOLAR COLLECTOR DEV ARTICLE (TA-2)	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY III: PROCEDURES DEVELOPMENT				
TRANSPORTING & HANDLING	• DEVELOP OPERATIONAL PROCEDURES FOR HANDLING & TRANSPORTING BEAMS & FRAMES	√	√	A,B,D,E,F
	• ESTABLISH INTERFACE BETWEEN OCP ASTRO-WORKER & TURRET CRANE OPERATOR	√	√	"
SUBSYSTEM INSTALLATION	• DETERMINE PROCEDURES FOR INSTALLATION OF WAVE GUIDES AMPLITRONS & WIRE CONNECTORS, PHASE CONTROL ELECTRONICS	√		B,C,D,E,F,G,H
WIRING INSTALLATION	• DEVELOP PROCEDURES FOR ELECTRICAL WIRING OF SOLAR PANEL FRAMES TO MICROWAVE ANTENNA		√	B,C,D,E,F
FRAME/BEAM DEPLOYMENT & LOCKUP	• ESTABLISH BEAM/FRAME DEPLOYMENT & LOCK-UP PROCEDURES	√	√	A,B,D,E,F
BEAM/FRAME ALIGNMENT & JOINING	• DERIVE PROCEDURES FOR ALIGNING & JOINING BEAMS/FRAMES TOGETHER	√	√	B,C,D,E,F,G,H
CATEGORY IV: MAN/MACHINE INTERFACE FACTORS				
FATIGUE/TASK DURATION	• DETERMINE TASK TIME LINES FOR VARIOUS CONSTR TASKS	√	√	A,B,D,E,F,G,H
	• ESTABLISH FATIGUE LIMITS VS TASK DURATION	√	√	"
OBSTACLE AVOIDANCE	• DETERMINE ASTROWORKER'S OBSTACLE AVOIDANCE ABILITY AS FUNCTION OF WORK-SITE/WORK TASK CONFIGURATIONS	√	√	A,B,C,D,E,F

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TABLE 5

OPEN CHERRY PICKER — MID-TERM (SHEET 4 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: MICROWAVE TRANS. DEVEL ARTICLE (TA-1)	MISSIONS: PHOTOVOLTAIC SOLAR COLLECTOR DEV ARTICLE (TA-2)	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
	• ESTABLISH REQMTS FOR AUTOMATIC OBSTACLE AVOIDANCE SYSTEM IF REQUIRED	√	√	A,B,C,D,E,F
LIGHTING REQMTS	• DETERMINE ILLUMINATION REQMTS AT WORK SITE/WORK TASK	√	√	A,B,C,D,E
	• EVALUATE EFFECTS OF LIGHT/DARK ORBIT CONDITIONS	√	√	"
CATEGORY V: CONSTRUCTION BASE INTERFACE FACTORS				
OPERATION OF BOTH CRANE ARMS	• DETERMINE ABILITY OF ASTROWORKER TO CONTROL BOTH CRANE ARMS DURING WORK TASKS	√	√	A,B,D,E,F
	• EVALUATE ADEQUACY OF DISPLAYS/ CONTROLLERS	√	√	"
PREPARATION OF STOWED OCP FOR OPERATIONAL USE	• ESTABLISH ASTROWORKERS TASKS TO REMOVE, DEPLOY & CHECK/OUT OCP ON CONSTR MODULE & MATE WITH CRANE ARM	√	√	C,D,E
RESCUE OPERATIONS	• ESTABLISH RESCUE PROCEDURES FROM DISABLED OCP BACK TO CONSTR MODULE	√	√	C,D,E,F,G,H
	• VERIFY ADEQUACY OF RESCUE EQUIPMENT, HAND & FOOT HOLDS, ETC	√	√	C,D,E,F,G,H
CRANE ARM	• EVALUATE EFFECTS OF CRANE ARM STIFFNESS ON CONTROLLABILITY OF CRANE ARM & EFFECTS OF ASTROWORKER INDUCED LOADS ON THE CRANE ARM	√	√	A,B,D,E

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TABLE 6

CRANE TURRET — MID-TERM (SHEET 1 OF 3)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		TA-1	TA-2	
CATEGORY I: CABIN DESIGN FACTORS				
TURRET CONFIGURATION	• EVALUATE BOTH A FIXED OR TOTATABLE CONFIGURATION FOR VARIOUS CONSTR TASKS	√	√	A, B, C, D, E
VISIBILITY	• VERIFY WINDOW AREA IS ADEQUATE FOR COMPLETE VISIBILITY OF CONSTR AREA	√	√	A, B, C, D, E
METABOLIC WORKLOAD	• MEASURE HEART RATE, RESPIRATION & SKIN TEMP OF OPERATOR WHILE PERFORMING CONSTR TASKS	√	√	A, B, D, E,
DISPLAYS	• EVALUATE DISPLAYS FOR TYPES & FORMAT OF DATA PRESENTED SO OPERATOR IS INFORMED OF CRANE TURRET OPERATIONAL STATUS	√	√	A, B, C, D, E
LIGHTING	• VERIFY INTERIOR LIGHTING IS ADEQUATE FOR BOTH LIGHT & DARK ORBIT CONDITIONS	√	√	C, E
CREW/CONSOLES	• EVALUATE LOCATION & SIZE OF CONSOLES	√	√	A, B, C, D, E
RESTRAINTS	• EVALUATE FOOT RESTRAINTS	√	√	C, D, E, F, G
	• DETERMINE WHETHER EXTRA BODY RESTRAINTS ARE REQUIRED	√	√	"
CATEGORY II: EQUIPMENT DESIGN FACTORS				
CONTROLLERS	• EVALUATE VARIOUS TYPES OF HAND CONTROLLERS TO CONTROL CRANE ARM; ONE 6-DOF CONTROLLER, INDIVIDUAL SWITCHES, TWO CONTROLLERS	√	√	A, B, D, E
	• DETERMINE CONTROLLER NECESSARY TO CONTROL OCP-CRANE ARM FROM TURRET	√	√	"

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TABLE 6

CRANE TURRET — MID-TERM (SHEET 2 OF 3)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS TA-1	MISSIONS TA-2	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CCTV	• DETERMINE REQMTS FOR CCTV AS AN AID TO DIRECT VIEWING FOR TURRET CRANE OPERATOR	√	√	A, B, C, D, E
END EFFECTOR	• VERIFY END EFFECTOR DESIGN FOR GRASPING & ALIGNMENT OF VARIOUS CONSTR COMPONENTS & SUBASSEMBLIES	√	√	B, D, E, F, G
CRANE ARM CHARACTERISTICS	• EVALUATE CRANE ARM STIFFNESS, VELOCITY, TIP FORCE & POSITION ACCURACY ON CONTROLLABILITY OF CRANE ARM FROM THE CRANE TURRET	√	√	A, B, D, E, F
CATEGORY III: PROCEDURES DEVELOPMENT				
TRANSPORTING, HANDLING, ALIGNMENT & JOINING	• DEVELOP PROCEDURES FOR VARIOUS CONSTR TASKS	√	√	A, B, C, D, E, F
	• ESTABLISH INTERFACE PROCEDURES BETWEEN TURRET OPERATOR & ASTROWORKER IN OCP FOR CONSTR TASKS	√	√	"
CATEGORY IV: MAN/MACHINE INTERFACE FACTORS				
FATIGUE/TASK DURATION	• DETERMINE TIME LINES FOR VARIOUS CONSTR TASKS	√	√	A, B, D, E
	• ESTABLISH FATIGUE LIMITS VS TASK DURATION	√	√	
OBSTACLE AVOIDANCE	• DETERMINE TURRET OPERATOR'S OBSTACLE AVOIDANCE ABILITY AS FUNCTION OF WORK-SITE/WORK TASK CONFIGURATIONS	√	√	A, B, D, E
	• ESTABLISH NEED FOR AUTOMATIC OBSTACLE AVOIDANCE TECHNIQUES	√	√	"
LIGHTING REQMTS	• DETERMINE WORK-SITE AREA ILLUMINATION REQMTS DURING LIGHT/DARK ORBIT CONDITIONS	√	√	A, B, C, D, E

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TABLE 6

CRANE TURRET — MID-TERM
(SHEET 3 OF 3)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		TA-1	TA-2	
CATEGORY V: CONSTRUCTION BASE INTERFACE FACTORS				
RESCUE OPERATIONS	• ESTABLISH RESCUE PROCEDURES NECESSARY FROM DISABLED OCP BACK TO CONSTR MODULE	√	√	B, C, D, E
FREPARATION OF STOWED OCP FOR OPERATIONAL USE	• ESTABLISH CRANE OPERATOR TASKS TO REMOVE, DEPLOY & CHECK OUT OCP FROM CONSTRUCTION MODULE & MATE WITH CRANE ARM	√	√	C, D, E

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TABLE 7

CLOSED CABIN CHERRY PICKER — MID-TERM (SHEET 1 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: 100-m RADIOMETER	MISSIONS: 61-m ANTENNA	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY I: CABIN DESIGN FACTORS				
VISIBILITY	• VERIFY THAT WINDOW AREA IS ADEQUATE FOR COMPLETE VISIBILITY OF CONSTRUCTION AREA	√	√	A, B, C, E
METABOLIC WORKLOAD	• MEASURE HEART RATE, RESPIRATION & SKIN TEMP OF OPERATOR WHILE PERFORMING CONSTR TASKS	√	√	A, B, D, E
DISPLAYS	• EVALUATE DISPLAYS FOR TYPES & FORMAT OF DATA PRESENTED SO OPERATOR IS INFORMED OF MRWS OPERATIONAL STATUS	√	√	A, C, E
LIGHTING	• VERIFY INTERIOR LIGHTING IS ADEQUATE FOR BOTH LIGHT & DARK ORBIT CONDITIONS	√	√	A, C, E
MEN/CONSOLES	• EVALUATE LOCATION & SIZE OF CONSOLES	√	√	A, B, C, D, E
RESTRAINTS	• EVALUATE FOOT RESTRAINTS	√	√	C, D, E, F, G
	• DETERMINE WHETHER EXTRA BODY RESTRAINTS ARE REQUIRED	√	√	"
CATEGORY II: EQUIPMENT DESIGN FACTORS				
CONTROLLERS	• EVALUATE VARIOUS TYPES OF HAND CONTROLLERS TO CONTROL CHERRY PICKER ARM: ONE 6-DOF CONTROLLER, INDIVIDUAL SWITCHES, TWO CONTROLLERS	√	√	A, B, D, E, F
	• DETERMINE WHETHER STABILIZER CAN BE CONTROLLED BY USE OF CHERRY PICKER ARM CONTROLLERS	√	√	"
	• EVALUATE CONTROLLER FOR CHERRY PICKER ARM BASE TRANSLATIONAL CONTROL	√	√	"

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TABLE 7

CLOSED CABIN CHERRY PICKER – MID-TERM (SHEET 2 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS: 100-m RADIOMETER	MISSIONS: 61-m ANTENNA	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
MANIPULATOR REQMTS	• VERIFY THAT MANIPULATOR SLAVE/MASTER CAN PERFORM THE VARIOUS CONSTR TASKS	√	√	B, D, E, F, H
	• EVALUATE THE VARIOUS END EFFECTORS REQUIRED	√	√	"
STABILIZER REQMTS	• EVALUATE THE VARIOUS STABILIZER DESIGNS & VERIFY THAT ONE STABILIZER CAN STABILIZE THE MRWS	√	√	B, D, E, F, G
	• DETERMINE ADEQUACY OF GRAPPLE FITTINGS ON VARIOUS PAYLOADS	√	√	"
	• VERIFY END EFFECTOR DESIGN	√	√	"
CCTV	• DETERMINE REQMTS FOR CCTV: NUMBER CAMERAS, LOCATION, ETC	√	√	C, D, E
	• EVALUATE USE OF COLOR TV	√	√	"
	• SIZE & NUMBER OF MONITORS	√	√	"
EQUIPMENT/TOOL STORAGE	• OPTIMIZE LOCATION & SIZE OF BINS FOR ASSEMBLY PARTS & TOOLS IN RELATION TO MANIPULATOR SLAVE ARMS & ASTROWORKER'S VIEW	√	√	C, E
CHERRY PICKER ARM REQMTS	• EVALUATE EFFECT OF ARM STIFFNESS, VELOCITY, TIP FORCE & POSITION ACCURACY ON CONSTR TASKS	√	√	A, B, D, E
TOOLS/CHECKOUT EQUIPMENT	• EVALUATE PERFORMANCE OF VARIOUS ASSEMBLY & CHECKOUT TOOLS & EQUIPMENT THAT ARE REQUIRED FOR VARIOUS CONSTR TASKS	√	√	B, D, E, F, G, H

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TABLE 7

CLOSED CABIN CHERRY PICKER — MID-TERM (SHEET 3 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		100-m RADIOMETER	61-m ANTENNA	
CATEGORY III: PROCEDURES DEVELOPMENT				
FIXTURE INSTALLATION	● DEVELOP DEPLOYMENT, HANDLING, ALIGNMENT & ATTACHMENT (FASTEN) PROCEDURES FOR: — TURNTABLE SUPPORT STRUCTURE — RIB FABRICATION MODULE — TIP MODULE — ANTENNA HUB — BOOM MANIPULATOR	√		A, B, C, D, E, F
SUBSYSTEM INSTALLATION	● DETERMINE INSTALLING, PROCEDURES, CONNECTING & CHECKOUT FOR: — POWER BUS — CABLING — TENSION STAYS	√		A, B, D, E, F, H
STRUCTURAL JOINING & ALIGNING	● EVALUATE DEPLOYMENT & ATTACHMENT OF LARGE AREA: — ANTENNA REFLECTIVE MESH — SOLAR BLANKET	√		B, D, E, F, G, H
FIXTURE INSTALLATION	● DEVELOP DEPLOYMENT, HANDLING, ALIGNMENT & ATTACHMENT (FASTEN) PROCEDURES FOR: — TURNTABLE SUPPORT STRUCTURE — SUBSYSTEM MODULE — LENS RIM DISPENSER — SOLAR ARRAY		√	A, B, C, D, E, F
SUBSYSTEM INSTALLATION	● DETERMINE INSTALLING CONNECTING & CHECKOUT FOR: — POWER BUSES — DOCKING INTERFACES — TENSION TIES		√	A, B, D, E, F, H
STRUCTURAL JOINING & ALIGNING	● EVALUATE TRANSPORTATION, FASTENING, HANDLING & ATTACHMENT (FASTENING) TECHNIQUES FOR: — MULTI-BEAM ANTENNA CONFIGURATION — SUBSYSTEM MODULE STRUTS		√	B, D, E, F, G, H

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TABLE 7

CLOSED CABIN CHERRY PICKER – MID-TERM (SHEET 4 OF 4)

SIMULATION OBJECTIVES	DESCRIPTION	MISSIONS		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		100-m RADIOMETER	61-m ANTENNA	
CATEGORY IV: MAN/MACHINE INTERFACE FACTORS				
WORKSITE/WORKTASK ACCESSIBILITY	• DETERMINE CLEARANCES, MANIPULATOR SLAVE REACH & GRAPPLER REACH FOR VARIOUS WORK-SITE CONFIGURATIONS	√	√	B, C, D, E, F
LIGHTING & VISIBILITY	• ASSESS REQMT FOR WORK-SITE ILLUMINATION DURING LIGHT & DARK ORBIT CONDITIONS	√	√	A, B, C, E
FATIGUE/TASK DURATION	• ESTABLISH TIME LINES FOR VARIOUS CONSTR TASKS	√	√	A, B, D, E, F, G
	• EVALUATE FATIGUE VS WORK TASK PRODUCTIVITY	√	√	"
CATEGORY V: CONSTRUCTION BASE INTERFACE FACTORS				
CREW TRANSFER	• VERIFY CREW TRANSFER PROCEDURES FROM CONSTR PLATFORM TO MRWS	√	√	C, D, E, F
RESCUE OPERATION	• DETERMINE RESCUE PROCEDURES TO RECUE ASTROWORKER IN DISABLED MRWS	√	√	A, C, D, E, F
ROTATING BOOM	• DETERMINE INTERFACES BETWEEN MRWS CP & ROTATING BOOM ON CONSTR BASE	√	√	A, B, D, E
CARGO TRANSFER	• DETERMINE INTERFACES BETWEEN CARGO TRANSFER FROM ORBITER TO WORK-SITE & MRWS	√	√	A, C
COMM/POWER/SIGNAL	• DETERMINE RESUPPLY OF MRWS CONSUMABLE PROCEDURES	√	√	C

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TABLE 8

CLOSED CABIN CHERRY PICKER — FAR-TERM
(SHEET 1 OF 6)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION									SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		TRANSPORTER	BEAM MACHINE	JOINT MACHINE	SOLAR BLANKET DEPLOYER	BUS BAR INSTALLER	ANTENNA CONST.	SUBSYSTEM INSTAL.	GEO BERTHING	GEO MAINTENANCE	
CATEGORY I: CABIN DESIGN FACTORS											
VISIBILITY	● VERIFY WINDOW AREA IS ADEQUATE FOR COMPLETE VISIBILITY OF CONSTR AREA	√	√	√	√	√	√	√	√	√	A, B, C, D, E, F
METABOLIC WORKLOAD	● MEASURE HEART RATE, RESPIRATION & SKIN TEMP OF OPERATOR WHILE PERFORMING CONSTR TASKS	√	√	√	√	√	√	√	√	√	A, B, D, E, F, H
DISPLAYS	● EVALUATE DISPLAYS FOR TYPES & FORMAT OF DATA PRESENTED SO OPERATOR IS INFORMED OF MRWS OPERATIONAL STATUS	√	√	√	√	√	√	√	√	√	A, B, C, D, E
LIGHTING	● VERIFY INTERIOR LIGHTING IS ADEQUATE FOR BOTH LIGHT & DARK ORBIT CONDITIONS	√	√	√	√	√	√	√	√	√	C, E
MEN/CONSOLES	● EVALUATE LOCATION & SIZE OF CONSOLES	√	√	√	√	√	√	√	√	√	A, B, C, D, E
RESTRAINTS	● EVALUATE FOOT RESTRAINTS	√	√	√	√	√	√	√	√	√	C, D, E, F, G
	● DETERMINE WHETHER EXTRA BODY RESTRAINTS ARE REQUIRED	√	√	√	√	√	√	√	√	√	"

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TABLE 8

CLOSED CABIN CHERRY PICKER — FAR-TERM
(SHEET 2 OF 6)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION: TRANSPORTER	BEAM MACHINE	JOINT MACHINE	SOLAR BLANKET DEPLOYER	BUS BAR INSTALLER	ANTENNA CONST.	SUBSYSTEM INSTAL.	GEO BERTHING	GEO MAINTENANCE	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY II: EQUIPMENT DESIGN FACTORS											
CONTROLLERS	● EVALUATE VARIOUS TYPES OF HAND CONTROLLERS (TWO CONTROLLERS, ONE 6-DOF CONTROLLER, INDIVIDUAL SWITCHES) FOR CONTROLLING:										A, B, D, E, F
	— SELF-PROPELLED RAILED MRWS	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	— CONSTR CRANE ARM	✓					✓	✓	✓		
	— CHERRY PICKER ARM	✓		✓		✓	✓	✓	✓	✓	
	— MANIPULATOR	✓		✓	✓	✓	✓	✓	✓	✓	
	— STABILIZER	✓		✓		✓	✓	✓	✓	✓	
	— GIMBAL YOKE — BEAM MACHINE		✓			✓					
	— TELESCOPING ARM		✓	✓	✓	✓	✓	✓			
MANIPULATOR REQMTS	● VERIFY THAT MANIPULATOR SLAVE/MASTER CAN PERFORM THE VARIOUS CONSTR TASKS	✓		✓	✓	✓	✓	✓	✓	✓	B, D, E, F, G, H
	● EVALUATE THE VARIOUS END EFFECTOR REQUIRED	✓		✓	✓	✓	✓	✓	✓	✓	"
STABILIZER REQMTS	● EVALUATE THE VARIOUS STABILIZER DESIGNS & VERIFY THAT ONE STABILIZER CAN STABILIZE THE MRWS	✓		✓		✓	✓	✓	✓	✓	C, D, E, F, G, H

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TABLE 8

CLOSED CABIN CHERRY PICKER — FAR-TERM (SHEET 3 OF 6)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION									SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		TRANSPORTER	BEAM MACHINE	JOINT MACHINE	SOLAR BLANKET DEPLOYER	BUS BAR INSTALLER	ANTENNA CONST.	SUBSYSTEM INSTAL.	GEO BERTHING	GEO MAINTENANCE	
	• DETERMINE ADEQUACY OF GRAPPLER FITTING ON VARIOUS STRUCTURES	√		√		√	√	√	√	√	C,D,E,F,G,H
	• VERIFY END EFFECTOR DESIGN	√		√		√	√	√	√	√	"
CCTV	• DETERMINE REQMTS FOR CCTV: NUMBER CAMERAS, LOCATION, ETC	√	√	√	√	√	√	√	√	√	A, C, D, E
	• EVALUATE USE OF COLOR TV	√	√	√	√	√	√	√	√	√	"
	• SIZE & NUMBER OF MONITORS	√	√	√	√	√	√	√	√	√	"
EQUIPMENT/TOOL STORAGE	• OPTIMIZE LOCATION & SIZE OF BINS FOR ASSEMBLY PARTS & TOOLS IN RELATION TO MANIPULATOR SLAVE ARMS & ASTROWORKER'S VIEW	√		√	√	√	√	√	√	√	C, D, E, F
CHERRY PICKER ARM REQMTS	• EVALUATE EFFECT OF ARM STIFFNESS, VELOCITY, TIP FORCE & POSITION ACCURACY ON CONSTR TASKS	√		√		√	√	√	√	√	A, B, D, E, F
TOOLS/CHECKOUT EQUIPMENT	• EVALUATE PERFORMANCE OF VARIOUS ASSEMBLY & CHECKOUT TOOLS & EQUIPMENT THAT ARE REQUIRED FOR VARIOUS CONSTR TASKS	√	√	√	√	√	√	√	√	√	B, D, E, F, G, H

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TABLE 8

CLOSED CABIN CHERRY PICKER — FAR-TERM
(SHEET 4 OF 6)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION: TRANSPORTER	BEAM MACHINE	JOINT MACHINE	SOLAR BLANKET DEPLOYER	BUS BAR INSTALLER	ANTENNA CONST.	SUBSYSTEM INSTAL.	GEO BERTHING	GEO MAINTENANCE	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CONSTRUCTION CRANE ARM STIFFNESS	● EVALUATE PERFORMANCE OF CRANE ARM WITH VARIOUS STRUCTURAL STIFFNESS	√					√	√	√		A, B, D, E
CATEGORY III: PROCEDURES DEVELOPMENT											
CONSTRUCTION EQUIPMENT SERVICING	● DEVELOP PROCEDURES FOR RESUPPLY OF BEAM FABRICATION MACHINES		√								C, D, E, F
MAINTENANCE	● DEVELOP PROCEDURES FOR REPLACEMENT OF KLYSTRON TUBE MODULES PLUS ITS THERMAL CONTROL SYSTEM									√	A, B, D, E, F
	● PROCESS FOR ANNEALING RADIATION DEGRADATION OF THE SOLAR CELLS									√	"
HANDLING	● DEVELOP PROCEDURES FOR TRANSPORT & HANDLING OF LARGE STRUCTURES & COMPONENTS	√		√	√	√	√	√	√	√	A, B, D, E, F
STRUCTURAL JOINING & ALIGNING	● EVALUATE PROCEDURES FOR:										A, B, D, E, F
	— JOINING OF PRIMARY MODULE STRUCTURE			√							
	— ALIGNMENT & JOINING OF ANTENNA PRIMARY & SECONDARY STRUCTURE						√				
	— POLAR ARRAY BLANKETS				√						
	— MODULE SECTIONS JOINING								√		

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TABLE 8

CLOSED CABIN CHERRY PICKER — FAR-TERM (SHEET 5 OF 6)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION: TRANSPORTER	BEAM MACHINE	JOINT MACHINE	SOLAR BLANKET DEPLOYER	BUS BAR INSTALLER	ANTENNA CONST.	SUBSYSTEM INSTAL.	GEO BERTHING	GEO MAINTENANCE	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
SUBSYSTEM INSTALLATION	• DEVELOP PROCEDURES FOR:										A, B, D, E, F
	– POWER BUS SUPPORT CABLES					√					
	– ANTENNA SUBARRAYS						√				
	– YOKE ELECTRICAL ROTARY JOINT						√				
	– ANTENNA SWITCH GEAR						√				
	– VARIOUS SUBSYSTEMS: ATTITUDE CONTROL, COMMUNICATIONS, DATA PROCESSING							√			
CATEGORY IV: MAN/MACHINE INTERFACE FACTORS											
WORKSITE/ WORKTASK ACCESSIBILITY	• DETERMINE CLEARANCES, MANIPULATOR SLAVE REACH, & GRAPPLE REACH FOR VARIOUS WORK-SITE CONFIGURATIONS	√		√	√	√	√	√	√	√	B, C, D, E, F
LIGHTING & VISIBILITY	• ACCESS REQMTS FOR WORK-SITE ILLUMINATION DURING LIGHT & DARK ORBIT CONDITIONS	√	√	√	√	√	√	√	√	√	A, B, C, D, E
FATIGUE/TASK DURATION	• ESTABLISH TIMELINES FOR VARIOUS MRWS ROLES & TASKS	√	√	√	√	√	√	√	√	√	A, B, D, E, F, G, H
	• EVALUATE WORK TASK PRODUCTIVITY VS FATIGUE	√	√	√	√	√	√	√	√	√	"

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TABLE 8

CLOSED CABIN CHERRY PICKER — FAR-TERM
(SHEET 6 OF 6)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION: TRANSPORTER	BEAM MACHINE	JOINT MACHINE	SOLAR BLANKET DEPLOYER	BUS BAR INSTALLER	ANTENNA CONST.	SUBSYSTEM INSTAL.	GEO BERTHING	GEO MAINTENANCE	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY V: CONSTRUCTION BASE INTERFACE FACTORS											
CREW TRANSFER	● VERIFY CREW TRANSFER PROCEDURES FROM CREW TRANSPORTER TO MRWS		√	√	√	√	√	√	√	√	A, C, D, E, F
RESCUE OPERATION	● DEVELOP RESCUE PROCEDURES FOR ASTROWORKER IN DISABLED MRWS	√	√	√	√	√	√	√	√	√	A, C, D, E, F
OBSTACLE AVOIDANCE	● ACCESS ABILITY OF MRWS OPERATOR TO AVOID OBSTACLES IN WORK-SITE AREA			√	√	√	√	√	√	√	A, B, D, E, F
	● ACCESS NEED FOR AUTOMATIC OBSTACLE AVOIDANCE SYSTEM			√	√	√	√	√	√	√	"
CARGO TRANSFER	● DETERMINE INTERFACES BETWEEN MRWS & CARGO TRANSFER POINTS IN WORK-SITE	√	√	√	√	√	√	√	√	√	A, B, C, E
BERTHING MODULES	● DETERMINE INTERFACES BETWEEN DOCKING CRANES WHEN BERTHING MODULES IN GEO									√	A

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TABLE 9

FREE FLYER — FAR-TERM
(SHEET 1 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		RESCUE	CRANE REPAIR	
CATEGORY I: CABIN DESIGN FACTORS				
METABOLIC WORK LOAD	● DETERMINE METABOLIC WORKLOAD FOR VARIOUS CRANE REPAIR TASKS		√	A, B, E, F
DISPLAYS	● VERIFY ADEQUACY OF DISPLAYS FOR TRANSLATION THROUGH WORK-SITE & RENDEZVOUS & DOCKING WITH DISABLED CRANE	√	√	A, B, C, E
	● EVALUATE VARIOUS DISPLAY DEVICES (HELMET, CRT, ETC)	√	√	"
VIEWING	● VERIFY THAT WINDOW VIEWING IS ADEQUATE FOR OBSTACLE AVOIDANCE WITH TRANSLATING THROUGH WORK-SITE	√	√	A, C, E
LIGHTING (INTERNAL)	● VERIFY INTERNAL LIGHTING FOR DISPLAYS IS ADEQUATE IN LIGHT & DARK ORBIT CONDITIONS	√	√	A, C, E
CREW/CONSOLES	● OPTIMIZE POSITIONS OF VARIOUS SWITCHES, LIGHTS & INSTRUMENTS IN DISPLAY PANEL	√	√	A, C, E
CATEGORY II: EQUIPMENT DESIGN FACTORS				
GUIDANCE/CONTROL SYSTEM	● OPTIMIZE CONTROL SYSTEM FOR — NUMBER OF JETS AND LOCATION — THRUST LEVEL (BILEVEL) — FREE FLYER RATES & ACCELERATION — PROPELLANT MANAGEMENT — GUIDANCE REQMTS — INTEGRATED TRANSLATION & ROTATIONAL CONTROL — DISPLAYS REQMTS	√	√	A, B, C, D, E

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TABLE 9

FREE FLYER – FAR-TERM (SHEET 2 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		RESCUE	CRANE REPAIR	
STABILIZER REQMTS	● OPTIMIZE THE NUMBER OF STABILIZERS REQUIRED FOR CRANE REPAIR TASK	√	√	B, D, E, F, G
	● VERIFY THAT PRESENT STABILIZER DESIGN SATISFIES REPAIR REQMTS	√	√	"
	● OPTIMIZE LOCATIONS OF STABILIZER FITTINGS ON DISABLED CRANE	√	√	
	● VERIFY END EFFECTOR DESIGN	√	√	
EQUIPMENT/TOOL STORAGE	● OPTIMIZE LOCATION & SIZE OF STORAGE BIN FOR ASSEMBLY TOOLS IN RELATIVE TO MANIPULATOR ARMS & ASTROWORKER'S VIEW		√	C, E
	● VERIFY SIZE OF CARGO STORAGE & TIE DOWN		√	"
TOOLS/CHECKOUT EQUIPMENT	● VERIFY PERFORMANCE OF TOOLS & HARDWARE FOR REMOVAL & INSTALLATION OF BOOM & MAST JOINT		√	B, C, D, E, F, G
	● DETERMINE ADEQUACY OF CHECKOUT EQUIPMENT		√	"
MANIPULATOR REQMTS	● VERIFY THAT PRESENT MANIPULATOR SLAVE/ MASTER CAN PERFORM THE CRANE REPAIR TASK EFFECTIVELY		√	B, E, F, G, H
	● VERIFY END EFFECTOR DESIGN		√	"
CONTROLLERS	● VERIFY THAT PROPOSED CONTROLLER CONFIGURATION IS ADEQUATE FOR CONTROLLING FREE FLYER PROPULSION SYSTEM	√	√	A, B, D, E
	● ASSESS THAT THE USER OF RCS HAND CONTROLLERS FOR STABILIZER CONTROL IS FEASIBLE	√	√	"

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TABLE 9

FREE FLYER – FAR-TERM
(SHEET 3 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		RESCUE	CRANE REPAIR	
CCTV	● OPTIMIZE THE LOCATION OF CCTV CAMERAS ON THE FREE FLYER	√	√	A, B, C, E
	● DETERMINE THE NEED FOR CAMERA BOOMS AND NUMBER OF CAMERAS	√	√	"
	● EVALUATE THE USE OF COLOR TV	√	√	"
	● DETERMINE REQMTS FOR TV MONITOR – NUMBER, SIZE SCREEN & SPLIT IMAGE	√	√	"
CATEGORY III: PROCEDURES DEVELOPMENT				
COMPONENT HANDLING	● DEVELOP PROCEDURES FOR HANDLING CRANE ARM BOOM DURING REPAIR TASK USING MANIPULATORS & GRAPPLERS		√	B, E, F
STRUCTURAL JOINING & ALIGNING	● DEVELOP PROCEDURES FOR REMOVAL & INSTALLATION OF CRANE ARM JOINT ASSEMBLY		√	B, E, F
WIRE INSTALLATION	● DETERMINE PROCEDURES FOR INSTALLATION OF WIRES FOR NEW DRIVE JOINT		√	B, E, F, G
TRANSLATION, RENDEZVOUS & DOCKING	● DETERMINE PROCEDURES FOR FREE FLIGHT THROUGH CONSTR SITE TO DISABLED CRANE	√	√	A, B, E
	● DETERMINE PROCEDURES FOR OBSTACLE AVOIDANCE	√	√	"
CHECKOUT	● DEVELOP PROCEDURES FOR CHECKING OUT NEW CRANE ARM DRIVE JOINT		√	C, E
RESCUE	● EVALUATE RESCUE PROCEDURES & ESCAPE ROUTES FROM DISABLED VEHICLE TO FREE FLYER	√		B, C, E, F
	● EVALUATE OPERATIONAL PROCEDURES FOR PERSONAL RESCUE SYSTEM OR EVA METHODS OF RESCUE	√		"

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TABLE 9

FREE FLYER — FAR-TERM
(SHEET 4 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION		SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
		RESCUE	CRANE REPAIR	
CATEGORY IV: MAN/MACHINE INTERFACE FACTORS				
WORK-SITE/ ACCESSIBILITY WORK TASK	● DETERMINE OPTIMUM ACCESSIBILITY ROUTE TO DISABLED CRANE		√	A, B, C, E
	● CHECK CLEARANCES OF FREE FLYER TO CONSTR BEAMS & CRANE		√	"
	● VERIFY FREE FLYER TO WORK-SITE DISTANCE FOR MANIPULATOR SLAVE REACH		√	"
LIGHTING & VISIBILITY	● DETERMINE ILLUMINATION REQMTS – NUMBER LIGHTS & LOCATIONS – INTENSITY – TYPE OF LAMP – NEED FOR BOOMS	√	√	B, C, E
	● VERIFY ILLUMINATION FOR ORBIT LIGHT/DARK CONDITIONS	√	√	"
FATIGUE/TASK DURATION	● DETERMINE TIMELINES FOR VARIOUS TASKS	√	√	A, B, E, F, G
	● EVALUATE FATIGUE VS WORK TASK PRODUCTIVITY	√	√	"
CATEGORY V: CONSTRUCTION BASE INTERFACE FACTORS				
TRANSFER VEHICLE	● VERIFY FREE FLYER TRACKED VEHICLE INTERFACES	√	√	A, C
	● DEVELOP PROCEDURES FOR LAUNCHING & CAPTURING FREE FLYER TO TRACK VEHICLE	√	√	"
CREW TRANSFER	● VERIFY CREW TRANSFER PROCEDURES FROM CONSTR BASE MODULE TO FREE FLYER ON TRACKED VEHICLE	√	√	C, F

0081-041(4)

TABLE 9

FREE FLYER – FAR-TERM
(SHEET 5 OF 5)

SIMULATION OBJECTIVES	DESCRIPTION	SPS MISSION RESCUE	SPS MISSION CRANE REPAIR	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
COMM/POWER/SIGNAL INTERFACES	● DETERMINE NECESSARY COMMUNICATION INTERFACES BETWEEN FREE FLYER, TRANSFER VEHICLE & CONSTR CREW MODULES	√	√	C
	● DETERMINE INTERFACES FOR RESUPPLY OF FREE FLYER PROPELLANT SUPPLY & EPS	√	√	C

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TABLE 10

POTV – FAR-TERM
(SHEET 1 OF 1)

SIMULATION OBJECTIVES	DESCRIPTION	MISSION GEO MMS SERVICING	SIMULATION CONCEPTS (SEE TABLE 3 FOR CONCEPTS)
CATEGORY III: PROCEDURES DEVELOPMENT			
RENDEZVOUS & DOCKING OF MRWS WITH SPACECRAFT	• DEVELOP PROCEDURES FOR MRWS TO MOVE IN CLOSE TO SPACECRAFT USING ROBUST ARMS, GRAPPLE SPACECRAFT & CAPTURE IT	√	A, B, C, E
REMOVAL & INSTALLATION OF SPACECRAFT SUBSYSTEMS	• EVALUATE NECESSARY TASKS REQUIRED TO REPLACE SPACECRAFT INSTRUMENTS, SOLAR ARRAYS & PROPULSION EQUIPMENT USING DEXTROUS MANIPULATORS	√	C, E, F, G
CHECKOUT OF SUBSYSTEMS	• DEFINE PROCEDURES & INSTRUMENTS NECESSARY TO CHECK OUT SUBSYSTEMS OF SPACECRAFT	√	C, E, F

0081-042

Section 3

SIMULATION CONCEPTS

3.1 INTRODUCTION

In developing the simulator objectives, particular attention was paid to zero-g fidelity and methods of producing the required simulator data. The degree of fidelity for each simulation is a function of the criticality and complexity of the tasks that need to be duplicated during the simulation. This section summarizes the various simulation concepts that were considered during the preliminary simulator requirements and planning phase of the DTA design.

3.2 SIMULATOR DESIGN CONSIDERATIONS

There are three main zero-g areas of interest that were considered in the design of the DTA for simulating orbital operations:

- Crew activities at the work-site had to be analyzed to define the best simulation approach that would produce the required answers to the problems uncovered during the MRWS flight article requirements and concepts phase
- The dexterous interaction between the MRWS manipulators and any free floating work-site or work object
- Manipulator mechanization.

Analysis of the MRWS flight article requirements indicates that its near-term applications are in support of STS operations as an open cherry picker mounted to the end of the SRMS. This MRWS configuration provides a platform for extra vehicular activity (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 work-sites 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 deleting the need to man-rate all hardware in the path of the astronaut during transport to the work-site and minimizes physical contact with the payload once the astronaut is at the work-site.

In the mid to late 1980's several planned programs can utilize the MRWS's. The initial construction base utilizes an MRWS as a Crane Turret (CT) and as a Closed Cabin Cherry Picker (CCP) for assembly of large antenna and solar power development articles. The longer duration and mul -shift missions will benefit from a CCP in terms of reduced radiation exposure and longer crew work periods.

The ultimate application of the MRWS is in construction of the Solar Power Satellite (SPS). The varied roles of the MRWS apply to both Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO) operations. The MRWS crane turret and cherry picker is joined in SPS construction operations by Free Flyers, Control Center Cabins, and Railed Work Stations.

Figure 6 summarizes a possible 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 spring 1983 to phase with planned construction R&D activity. The three CCP concept development starts in 1981 and runs for three years. This is followed by a $2\frac{1}{2}$ year manufacturing and test phase that meets an early 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 Personnel Orbital Transfer Vehicle (POTV) airlock in the later half of the 1980's and the need for the MRWS Free Flyer when the SPS construction effort is initiated beyond 1990.

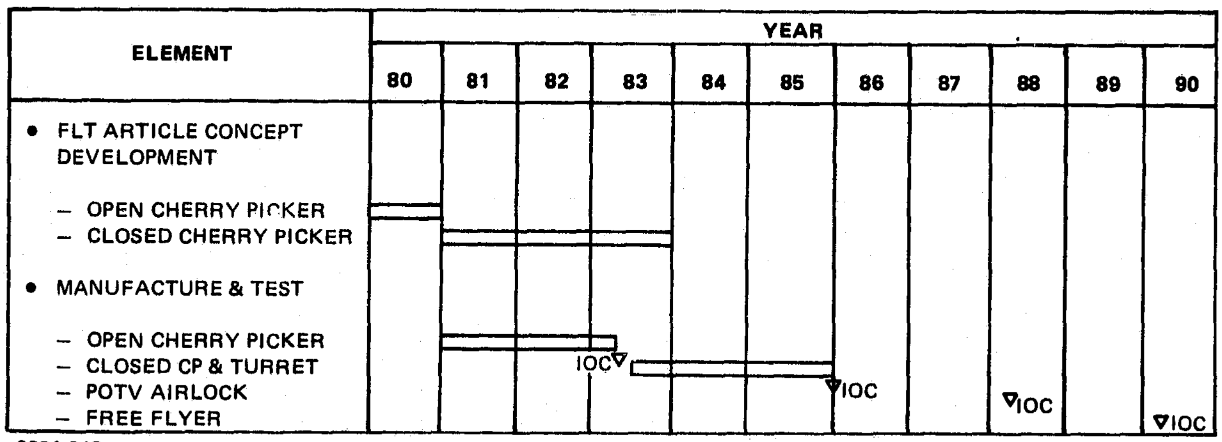

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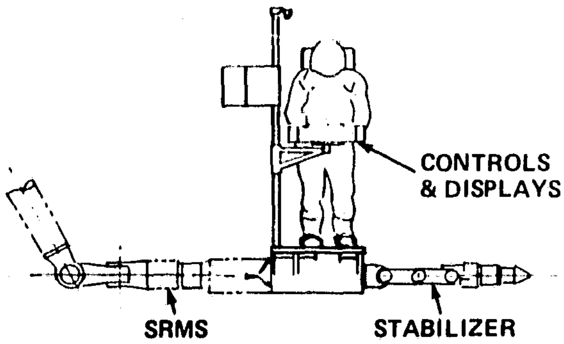
Figure 6. MRWS Flight Article Development



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
  - SPACE TELESCOPE SERVICING
- CONSTRUCTION R&D
  - DEPLOY FIXTURES
  - RESUPPLY FAB MACHINES
  - JOINING & ALIGN OPERATIONS
  - DISASSEMBLE STRUCTURE
- SHUTTLE INSPECTION/REPAIR
  - FORWARD RCS
  - RADIATORS
  - EXPERIMENT TIE DOWNS

0081-044

Figure 7. Open Cherry Picker Missions

Figure 7 lists potential OCP applications in support of Shuttle operations. A platform mounted at the end of the 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 improve productivity during 6-hr EVA periods.

The OCP will support Spacelab Sortie 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.

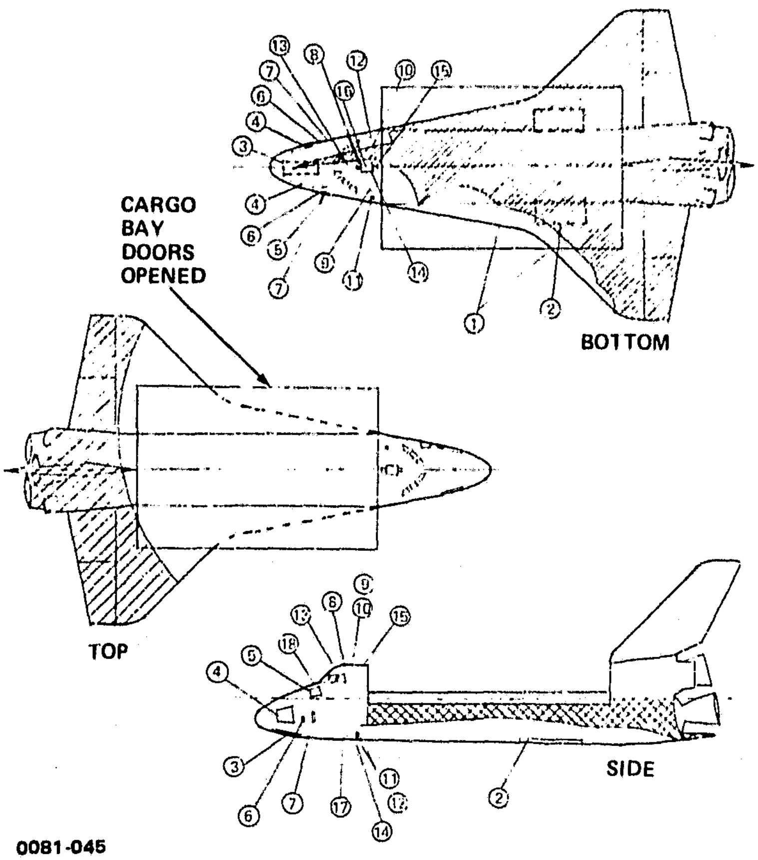
The concept of in-orbit servicing of automated payloads can be enhanced with use of the OCP. The multi-mission spacecraft with its replacement subsystem modules is particularly suited to service using an astronaut in an OCP. The replacement module and the torque tools needed to withdraw the spent module 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 High Energy Astronomy Observatory (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 Reaction Control Subsystem and Guidance, Navigation and Control equipments, could be serviced with an OCP.

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 perform inspection, maintenance, and possible repair of the Orbiter itself. Using the allowable limits for the shoulder, elbow, and wrist of the RMS as defined in NASA document JSC-07700 Vol. XIV, the areas accessible to an RMS/OCP mounted on the port side of the Orbiter were developed (Figure 8). Discreet items accessible for possible on-orbit inspection or repair are identified in the chart.

Figure 9 is a rendering of the 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 degrees rotation by the astronaut. A 6 DOF stabilizer is mounted to the platform and is used to grapple a work-site to minimize OCP motions during crew work periods. A control console which includes Manned Maneuvering Unit (MMU) hand controllers and essential RMS controls and displays is mounted on a swivel.



	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

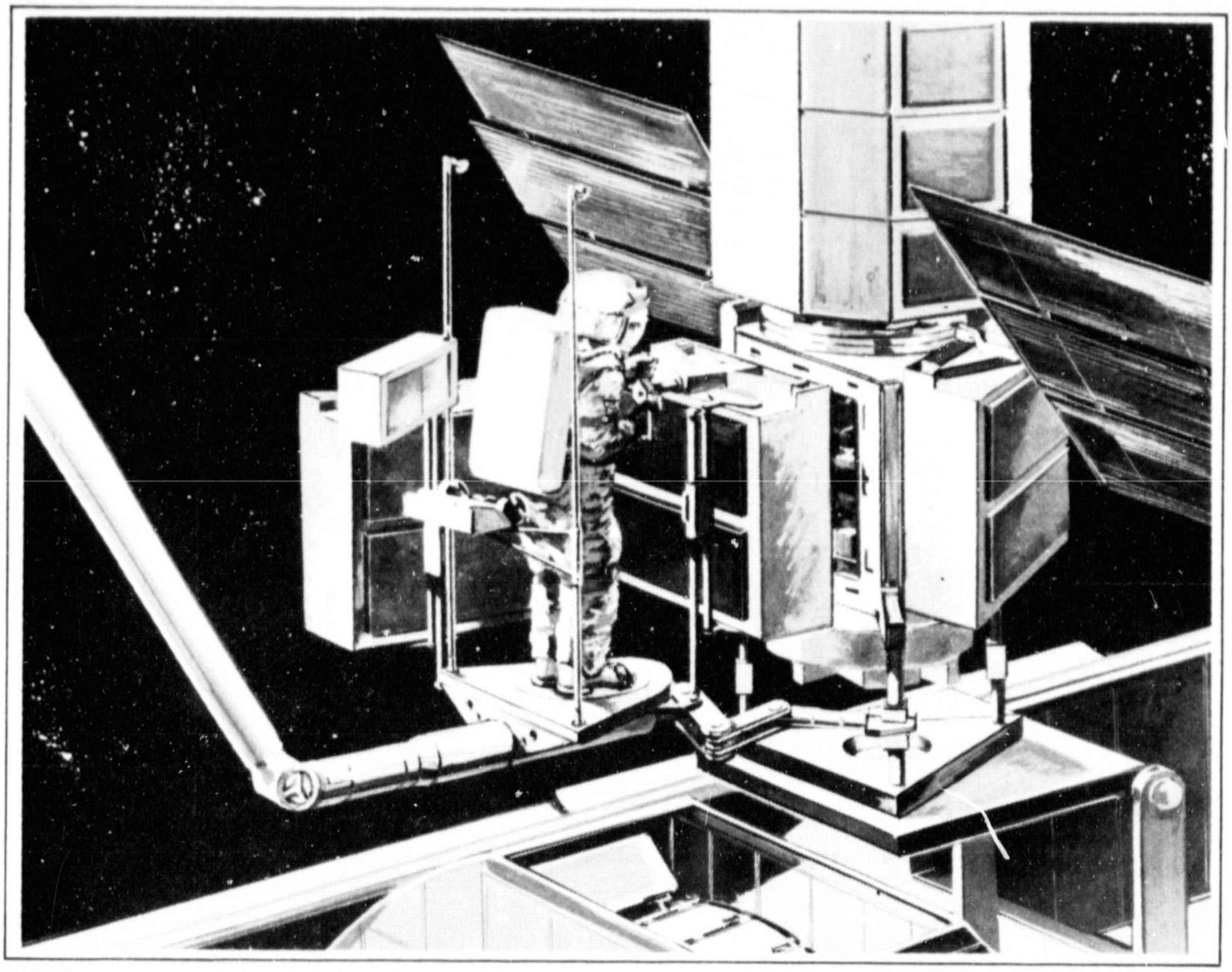
NOT ACCESSIBLE ORBITER BOTTOM SURFACE

NOT ACCESSIBLE ORBITER TOP SURFACE

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

0081-045

Figure 8. OCP On-Orbit Access to Orbiter for Inspection, Maintenance, and Repair



0081-046

Figure 9. Open Cherry Picker Servicing MMS (Rendering)

This feature allows the astronaut to rotate the control console to the rear while working out the front of the open 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 50 ft-c of illumination at the work-site.

The concept shown is designed with deployment mechanisms so that it can be folded 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 MMR. The overall mass of the OCP is 197 kg including 25% contingency.

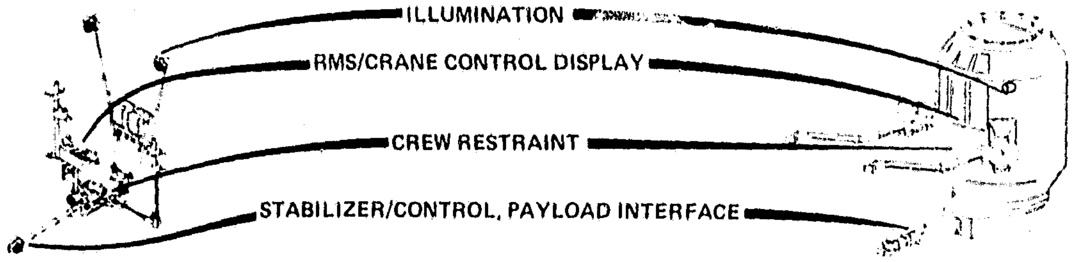
Mechanical and electrical interfaces with the SRMS is through the standard snare-type end effector. The 250 W of power provided as a payload service at the end effector is adequate for OCP operations. A data bus system currently available in the SRMS up to the end effector can be utilized for signal 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 equipment and capabilities already available at the JSC Mock-Up and Integration Laboratory would be sufficient to flight-qualify the system as well as provide a training facility for the operational system.

The MRWS development will be supported by a DTA which initially emphasizes the OCP configuration. By performing OCP simulation tests through 1980, the high fidelity makeup of the DTA and JSC/MDF will provide timely technology data to meet a 1982 IOC. Manipulator design and fabrication should be performed in 1979 and utilized in a bench test mode in 1980 while design and fabrication of the CCP 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. Figure 10 diagrammatically depicts the technology follow-through from the open cherry picker to the closed cherry picker.

3.3 OCP SIMULATOR CONCEPTS

Various full-scale simulator concepts were considered for the MRWS OCP, running the gamut from a ground based mockup to an experimental evaluation on the STS. The advantages, limitations, applications and other data for the various simu-



FUNCTIONAL TRANSFER

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

0081-047

Figure 10. Technology Follow-Through from Open Cherry Picker to Closed Cherry Picker

lation modes are presented in Table 11. The most viable solution satisfying simultaneously the constraints of simulator fidelity, time, and expense is to utilize the various MDF systems, subsystems and equipment to produce a high fidelity zero-g MRWS simulation capability on the air bearing floor. A stabilizer fixture mounted on top of an air bearing platform containing the DTA can be used in conjunction with the existing manipulator to maneuver the platform over the air bearing floor for simulation of the MRWS movement in a 3-DOF weightless environment in the plane of the floor.

The block diagram for the basic OCP-DTA simulator configuration utilizing the JSC MDF air bearing table is shown in Figure 11. The OCP zero-g simulation concept for evaluation involving the three coupled degrees of freedom of planer translations and rotation using the MDF is shown in Figure 3. With modification to the RMS controller and utilization of an astronaut harness (Peter Pan type rig) to suspend the subject in a side position with the equivalent 90 degree rotation of the base of the OCP it is possible to increase the DTA's capabilities. This approach will allow for two additional degrees-of-freedom, one translation and one rotation, with one redundant translation for correlation purposes.

TABLE 11

MRWS OCP FULL-SCALE SIMULATOR CONCEPTS COMPARISON

MRWS SIMULATOR	DOF	SIMULATOR CONSTRUCTION	SIMULATOR FIDELITY	ADVANTAGES/ DISADVANTAGES	APPLICATION
MOCK-UP	ONE-G, NON-DYNAMIC, FIXED BASE	FOAMCORE, PLYWOOD, OR CARDBOARD	POOR-FAIR	INEXPENSIVE	ENGRG EVALUATION OF MAN/MACHINE WORK SPACE
TERRESTRIAL OCP	ONE-G, 4 DOF, MOVING BASE	MODIFIED OFF-THE-SHELF CONSTRUCTION-TYPE HARDWARE, HYDRAULIC DRIVE, (RUGGED)	FAIR	AVAILABLE, CAN READILY BE MODIFIED; 4 DOF (x, y, z, ψ), INEXPENSIVE	ENGRG & EVALUATION DURING INITIAL PHASES OF OCP DESIGN CONCEPTS
AIR BEARING 3 DOF	ZERO-G, 3 DOF, MOVING BASE	EXPERIMENTAL LAB-TYPE HARDWARE ON AIR BEARING PAD	GOOD-CONSTRAINED, 3 DOF, ZERO-G MOTION	3 DOF; AVAILABLE READILY; MODIFIED LAB SETUP; INEXPENSIVE SIMULATION OF INERTIA REQD	ENGRG EVALUATION OF DTA CONCEPTS MAN/MACHINE EVALUATION TRAINING
AIR BEARING 6 DOF	ZERO-G, 4 DOF RELATIVE 2 DOF, MOVING BASE	EXPERIMENTAL LAB-TYPE HARDWARE IN GIMBLE ON AIR BEARING PAD	GOOD-CONSTRAINED, 6 DOF, ZERO-G MOTION	6 DOF THRU COMPUTER MATH MODEL; MODERATELY EXPENSIVE SIMULATION OF INERTIA REQD	ENGRG EVALUATION OF DTA CONCEPTS MAN/MACHINE EVALUATIONS
WATER TANK	ZERO-G, 6 DOF	EXPERIMENTAL, SPECIAL DESIGN & CONSTRUCTION TO WITHSTAND WATER ENVIRONMENT; MUST BE INERT TO WATER	GOOD	6 DOF WATER DRAG VISUAL DISTORTION; HARDWARE MUST BE CONFIGURED FOR WATER MODERATELY EXPENSIVE	ENGRG EVALUATIONS OF DTA DATA USED TO CORRELATE WITH AIRBEARING EXPS
FLIGHT TEST KC-135	ZERO-G, 6 DOF	EXPERIMENTAL LAB/FLIGHT-TYPE HARDWARE; SELF-CONTAINED HARDWARE ON PALLET	EXCELLENT MOTION CONSTRAINED BY CABIN DIMENSIONS & SHORT PERIODS OF ZERO-G	6 DOF-RESTRICTED MOTION; ZERO-G CONDITION FOR SHORT PERIODS, EXPENSIVE	ENGRG EVALUATIONS OF DTA
FLIGHT TEST SPACE LAB	ZERO-G, 6 DOF	EXPERIMENTAL LAB/FLIGHT-TYPE HARDWARE; SELF-CONTAINED HARDWARE ON PALLET	EXCELLENT MOTION CONSTRAINED BY LAB DIMENSIONS	6 DOF SHIRTSLEEVE ATMOSPHERE; RESTRICTED MOTION; EXPENSIVE; TRUE ZERO-G	ENGRG EVALUATIONS OF DTA-OCP, i.e., RESTRAINT SYSTEM STABILIZER SATELLITE HANDLING
FLIGHT TEST SHUTTLE	ZERO-G, 6 DOF	SPACE QUALIFIED EXPERIMENTAL-TYPE HARDWARE; HARDWARE MUST INTERFACE WITH SST SYSTEMS	SUPERB – IT'S THE REAL THING	6 DOF; NO RESTRICTION; DUPLICATES ACTUAL ZERO-G CONDITION; VERY EXPENSIVE; USEFULLNESS OF MRWS READILY ACCESSED	FULL OCP HARDWARE CHECKOUT & TEST BEFORE PRODUCTION

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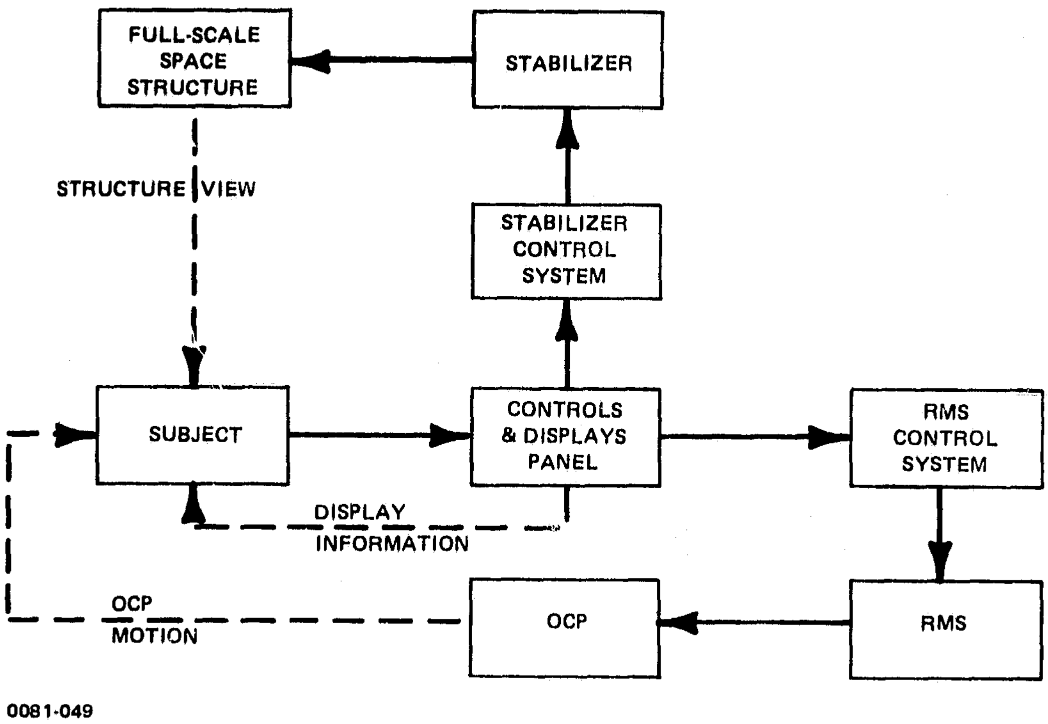

Figure 11. Basic OCP-DTA Simulator Block Diagram Utilizing MDF Air Bearing Table

3.4 CCP SIMULATOR CONCEPTS

3.4.1 Basic CCP Simulation Configuration Utilizing MDF A/B Table

The block diagram for a typical high fidelity full-scale MRWS-DTA simulation configuration utilizing the JSC MDF air bearing table is shown in Figure 12. 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.

After the OCP phase of the MRWS simulations, the next phase will require a DTA configured for closed cabin zero-g studies involving dexterous manipulator development. Figure 13 conceptually shows a full-scale CCP operating in the JSC MDF.

Many construction tasks, in particular SPS construction, involve large and massive elements. Using balloons as shown in Figure 14 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

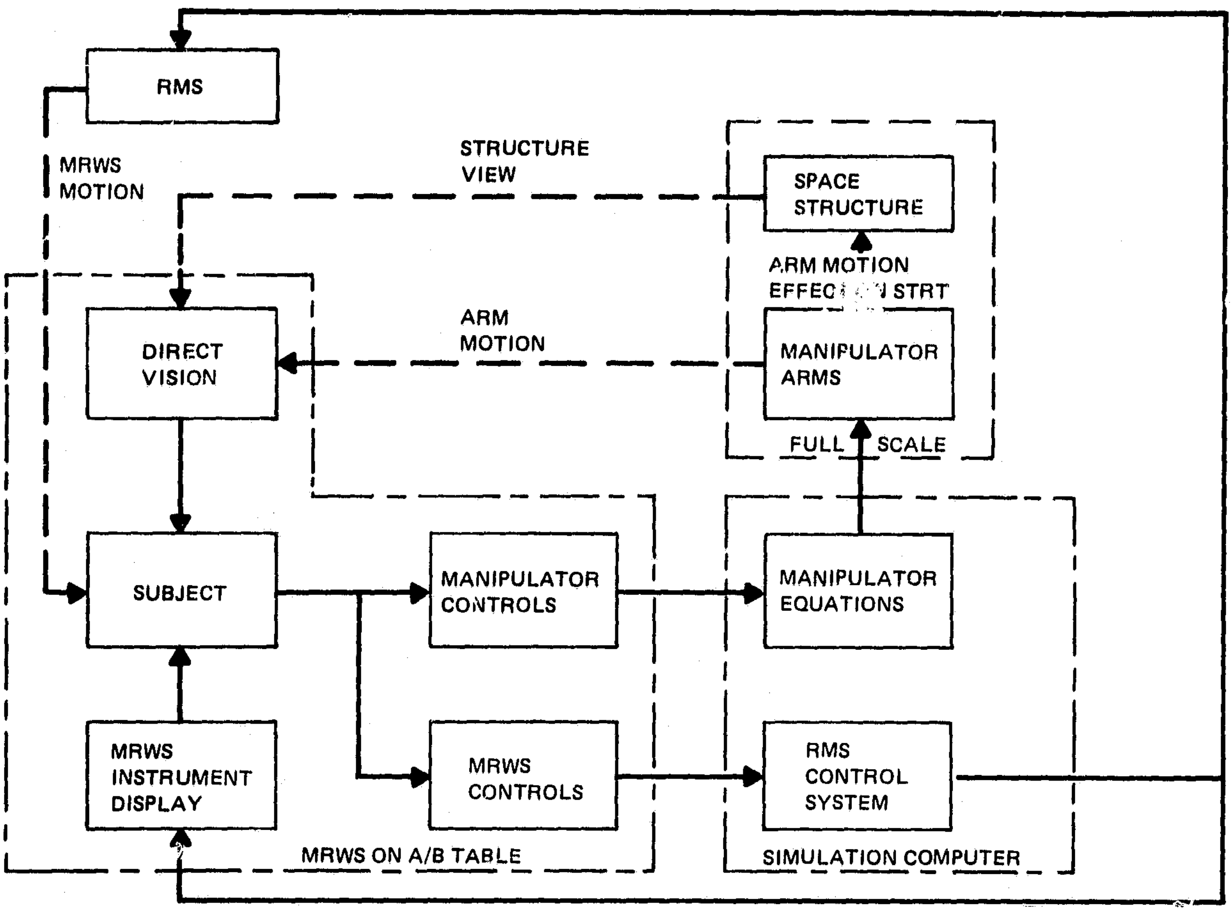

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Figure 12. Typical High Fidelity Full-Scale MRWS Simulations Utilizing MDF Air Bearing Table

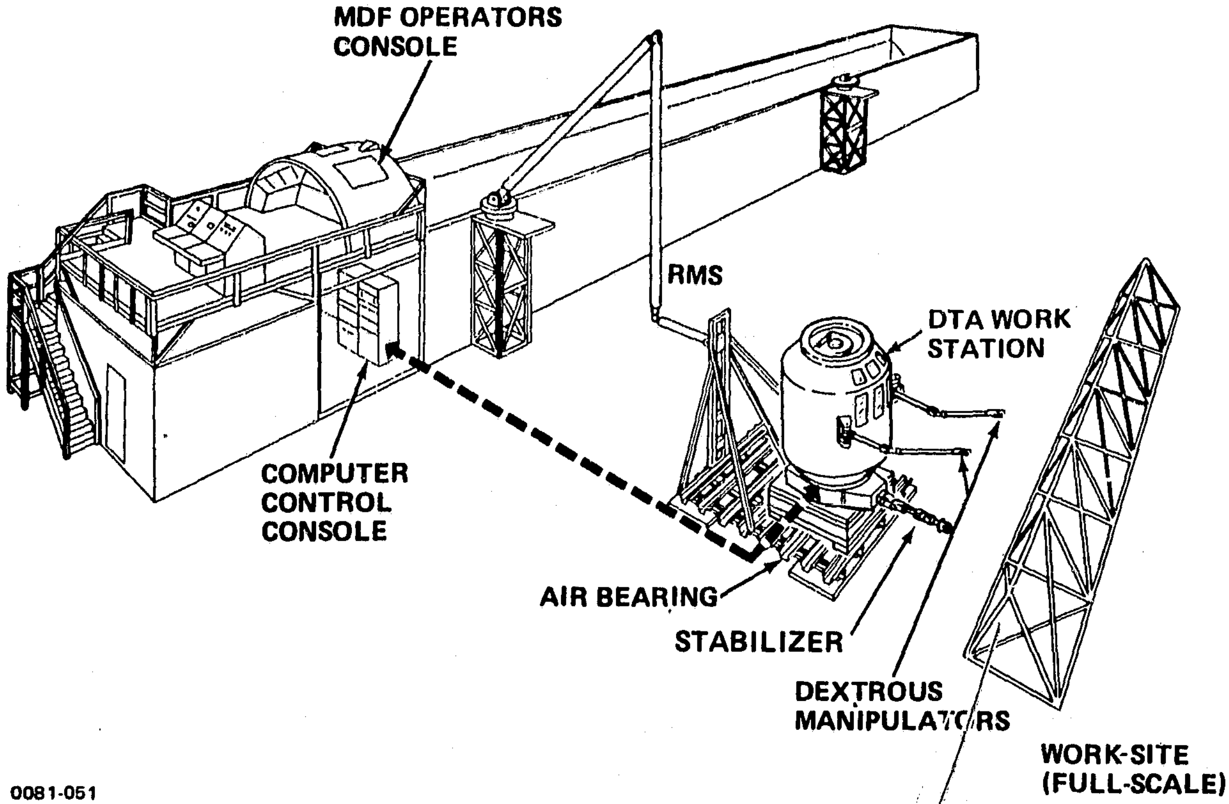

Figure 13. Full-Scale Closed Cherry Picker Simulation Concept for Operating in the JSC MDF

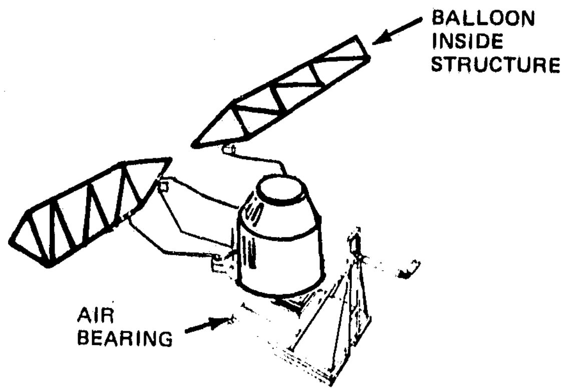

Figure 14. Work-Site 6 DOF Neutral Buoyancy (Balloon) Concept

- Flexibility - poor; each structural configuration has its own balloon shape and correct inertia
- Total DOF - 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.

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 in Figure 15, the weight per meter of three typical construction beams are plotted. The Large Space Structures (LSS) and Space Construction Automated Fabrication Equipment (SCAFE) beams are 1-m and the SPS is a 7.5-m beam. The lifting capacity is plotted for each beam if it is assumed that the entire internal volume of the beam is filled with helium. As can be seen from the plot, the internal volume of a 1-m beam would have to be supported with external helium-filled balloons, or use structural material lighter than the 15 mil aluminum used in the calculations for the Figure 15 relationship. The external helium balloons would result in an intetia mismatch of 200% for 10.5-m long LSS beam. The large beams can accommodate an internal balloon and the resulting mismatch in inertia would only be 30%.

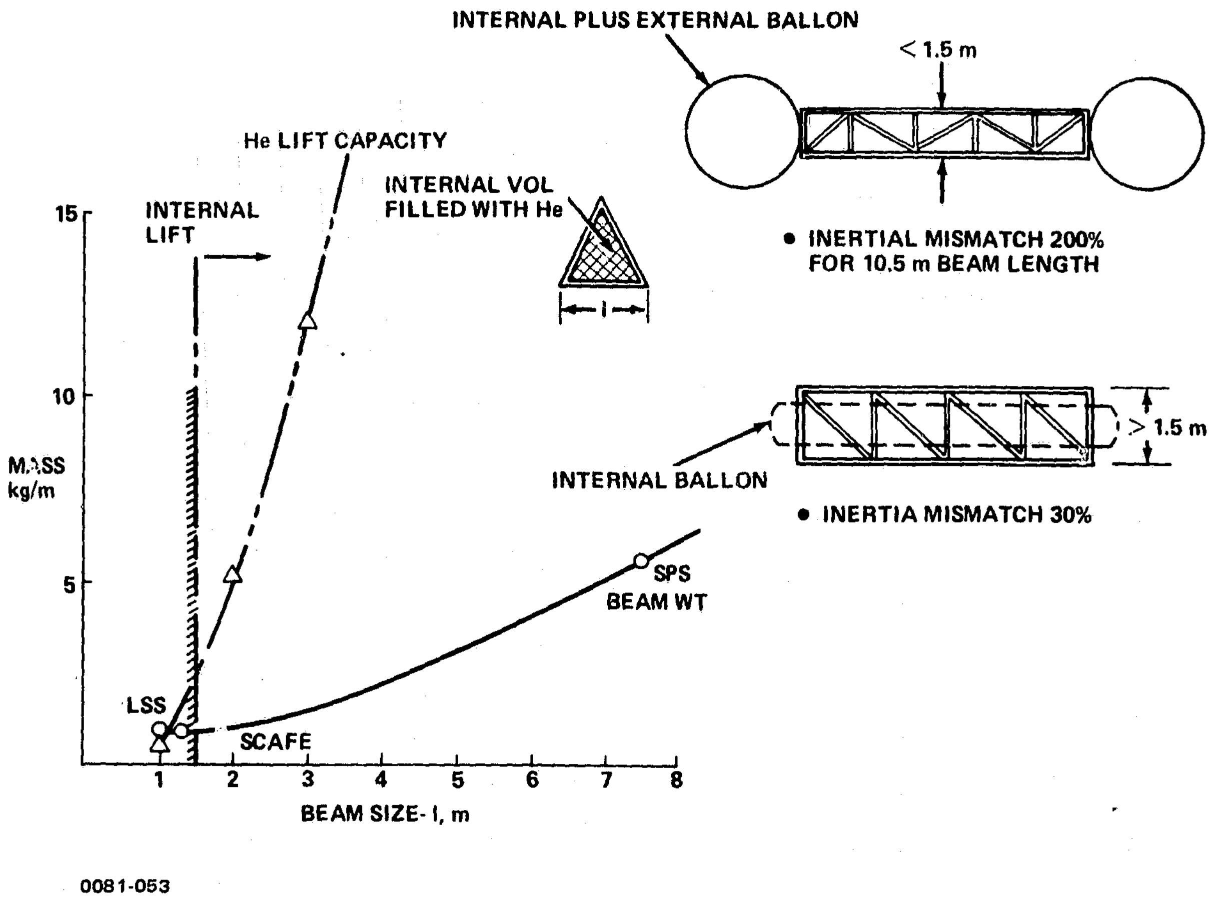

Figure 15. Helium-Filled Beam Concept

Another concept (Figure 16) uses 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 configuration can be mounted to the air bearing support frame
- Total DOF - 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.

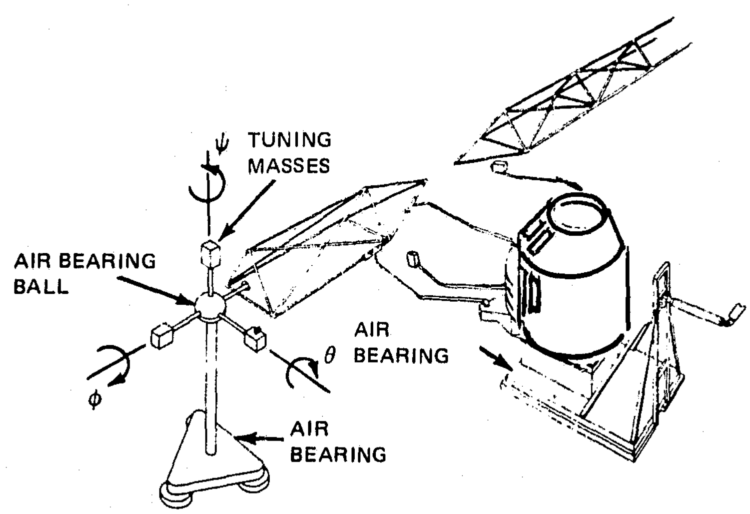

Figure 16. Work-Site 5-DOF Natural Reaction Simulator (Zero-g)

One of the basic methods proposed for simulating zero-g is the use of air bearings (Figure 17). 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-in. diameter steel ball will have an inertia of 0.053 $N\text{-}m/s^2$ where as a one meter LSS beam, 10.5 m long will have a rotational inertia of 122 $N\text{-}m/s^2$ 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 $N\text{-}m/s^2$ and is independent of supported beam length. The graph also shows planer inertia of a 1-m and 7.5-m beam versus length. The inertia of the air bearing support has a large effect on the inertia fidelity of the 1-m beam, but its impact on the inertia of the 7.5-m beam is diminished as the length of the beam is increased.

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 in Figure 18 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.

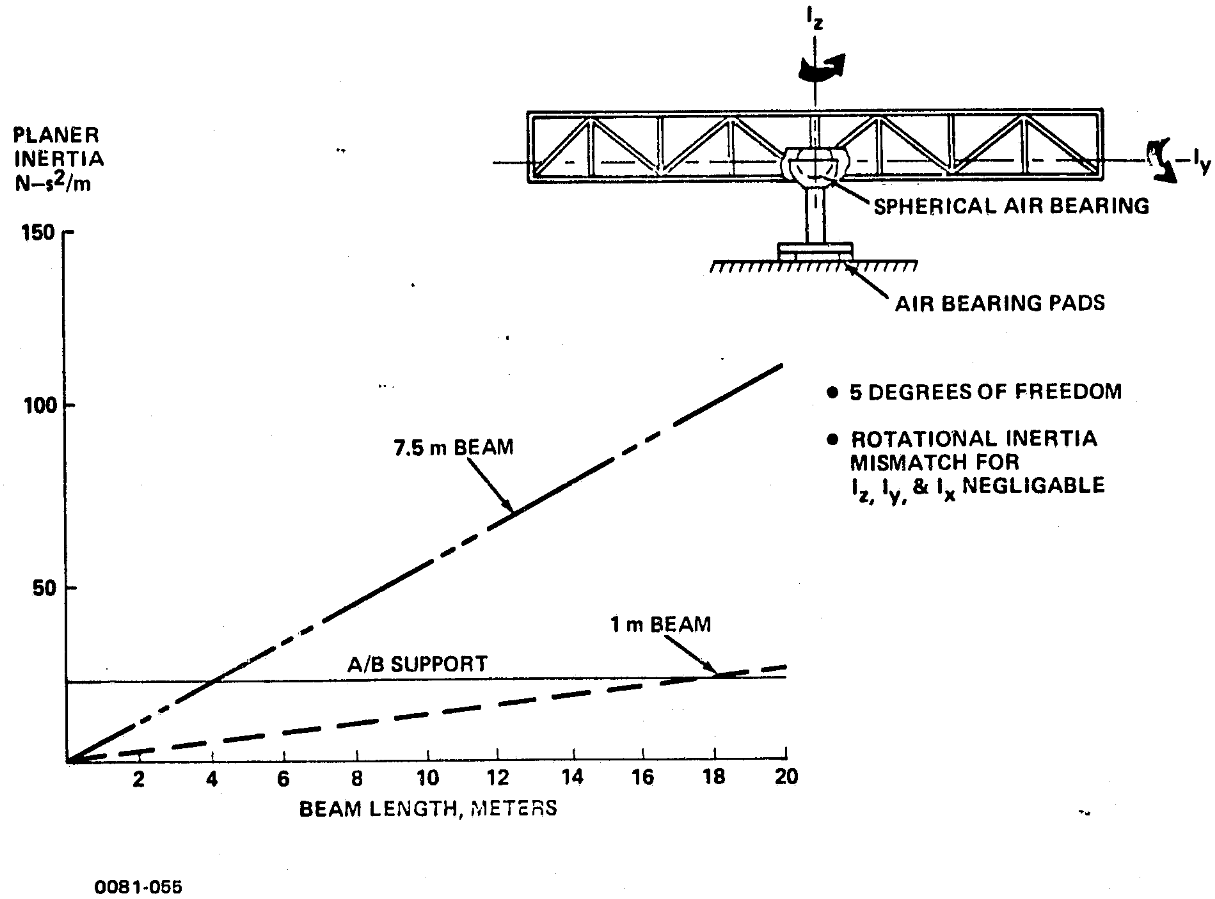

Figure 17. Air Bearing Support Beam Inertia Fidelity (Zero-g)

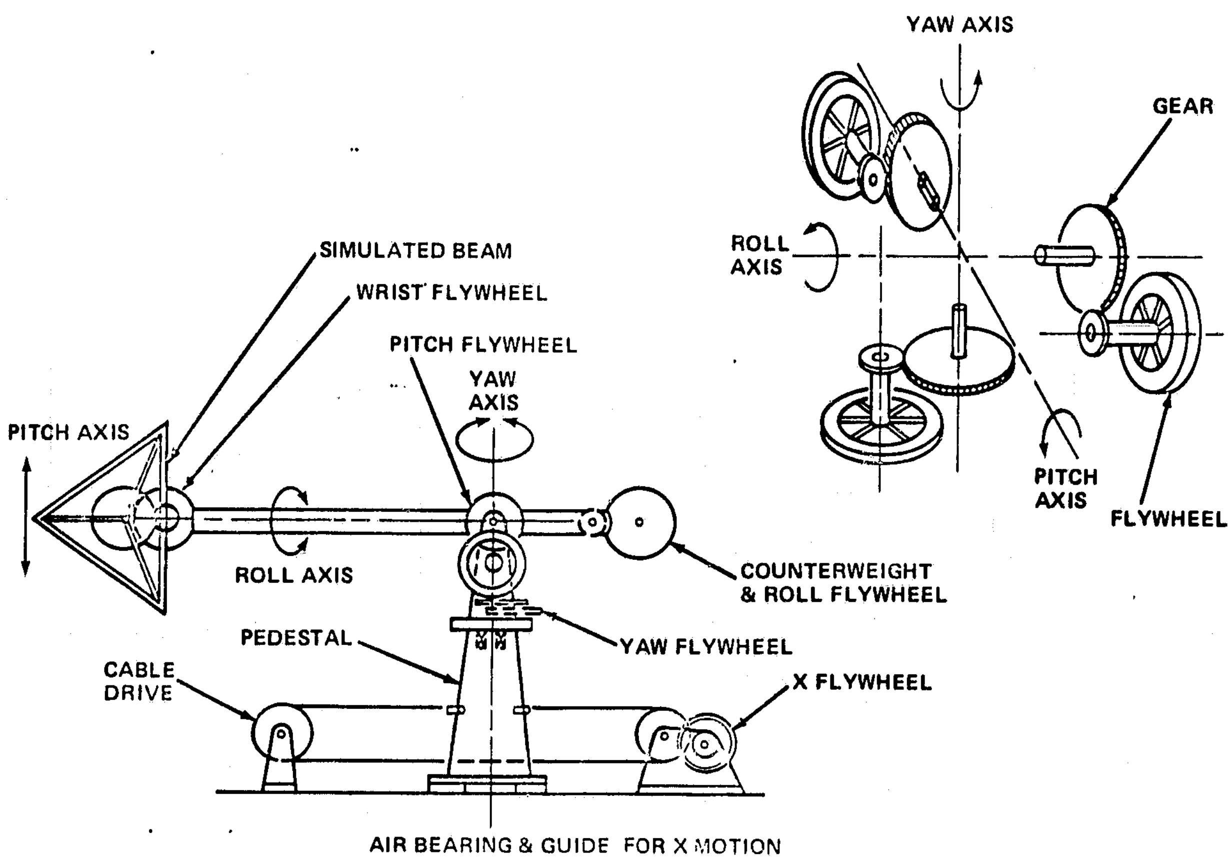

Figure 18. 5-DOF Zero-g Mass Inertial Simulator

3.4.2 Typical High Fidelity CCP Simulation Configurations

The majority of work-sites and structural elements will be anchored into a construction fixture; 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 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 in Figure 19. It represents the near term open cherry picker information flow.

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 the approach shown in Figure 20 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 configuration 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 difference simulation configurations
- Complexity - high; requires servo and computer interfaces
- Availability - fair; once servo-driven support structure is available, it can be fairly easily modified for new configurations.

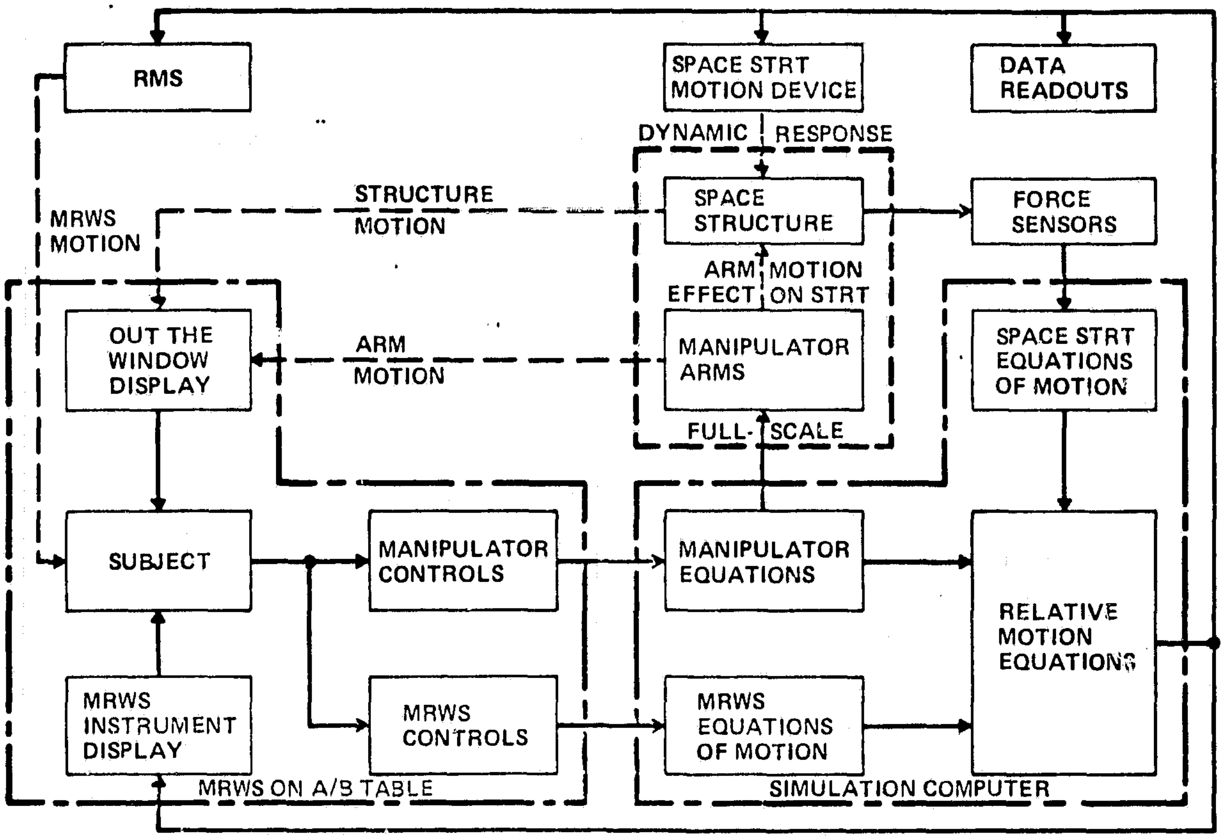

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Figure 19. Typical High Fidelity MRWS Simulation Configuration Utilizing MDF Air Bearing Table

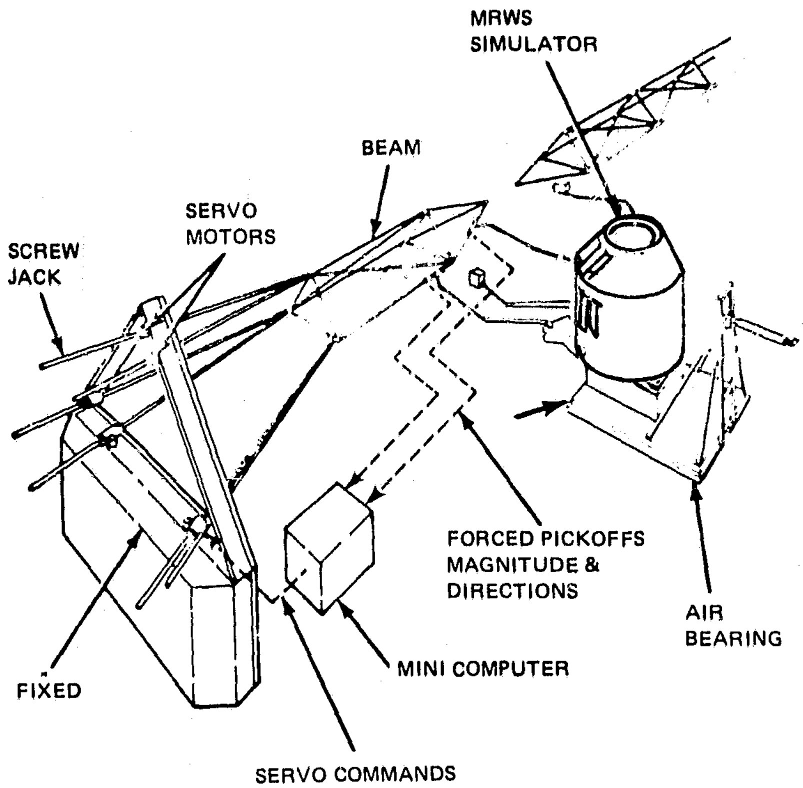

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Figure 20. Work-Site 6-DOF Servo-Driver Simulator (Zero-g)

3.4.3 Typical CCP Sub-Scale Construction Simulation

The block diagram for a typical MRWS DTA simulation of large space structure work-site utilizing the JSC MDF air bearing table is shown in Figure 21. It represents the ultimate evolutionary step that will provide laboratory capabilities for zero-g simulations of the full gamut 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 Closed Circuit Television (CCTV) system. The camera of the CCTV, mounted on a JSC MDF air bearing platform, represents the subject's eye point. 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.

It is presently envisioned that because of the enormity of the space structure worksites the ultimate MRWS DTA zero-g simulation will also involve sub-scale modeling techniques. Figure 22 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 modeled worksite structures.

3.4.4 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 (Figure 23), two viable approaches are possible, involving hardware or software techniques. The software

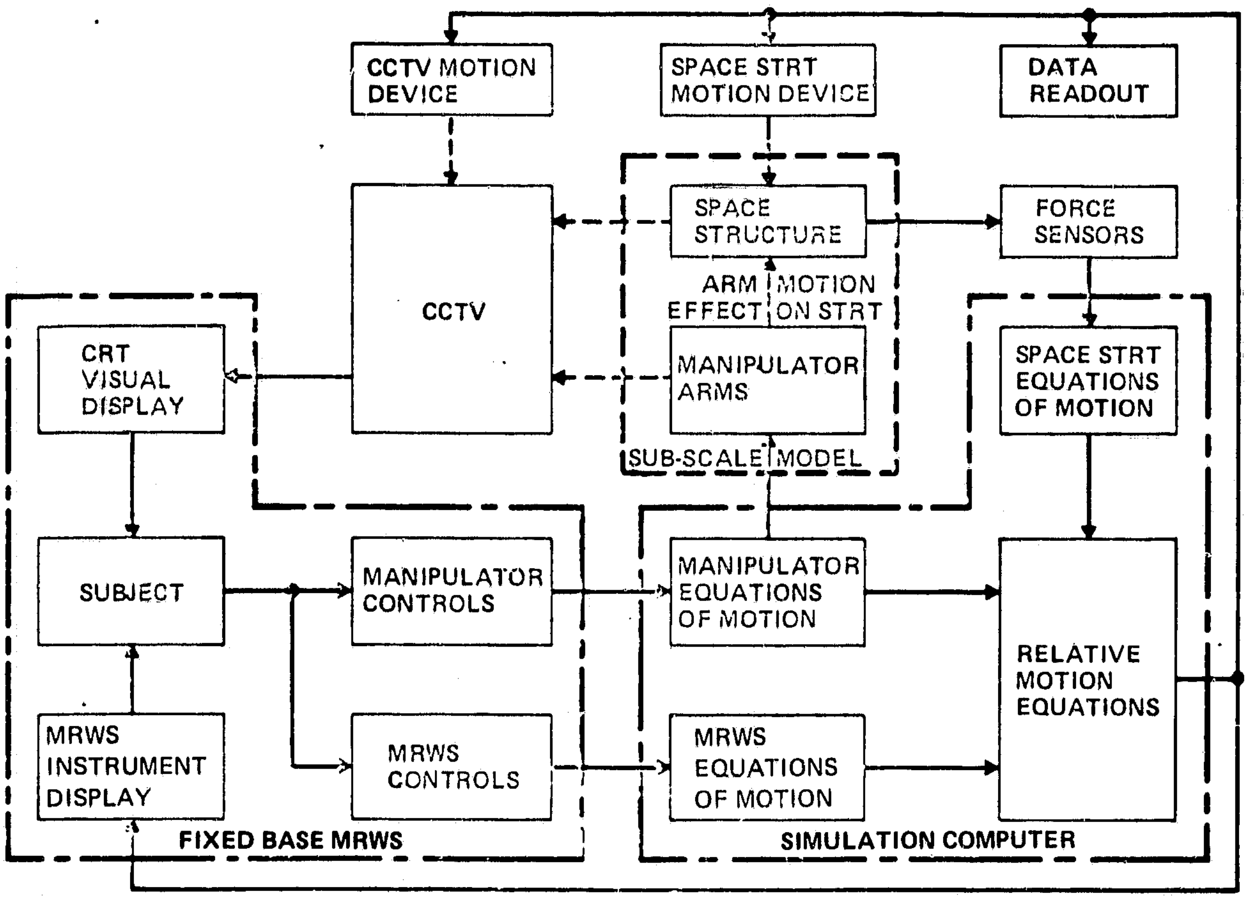

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Figure 21. Typical MRWS Sub-Scale Model Construction Simulating Configuration

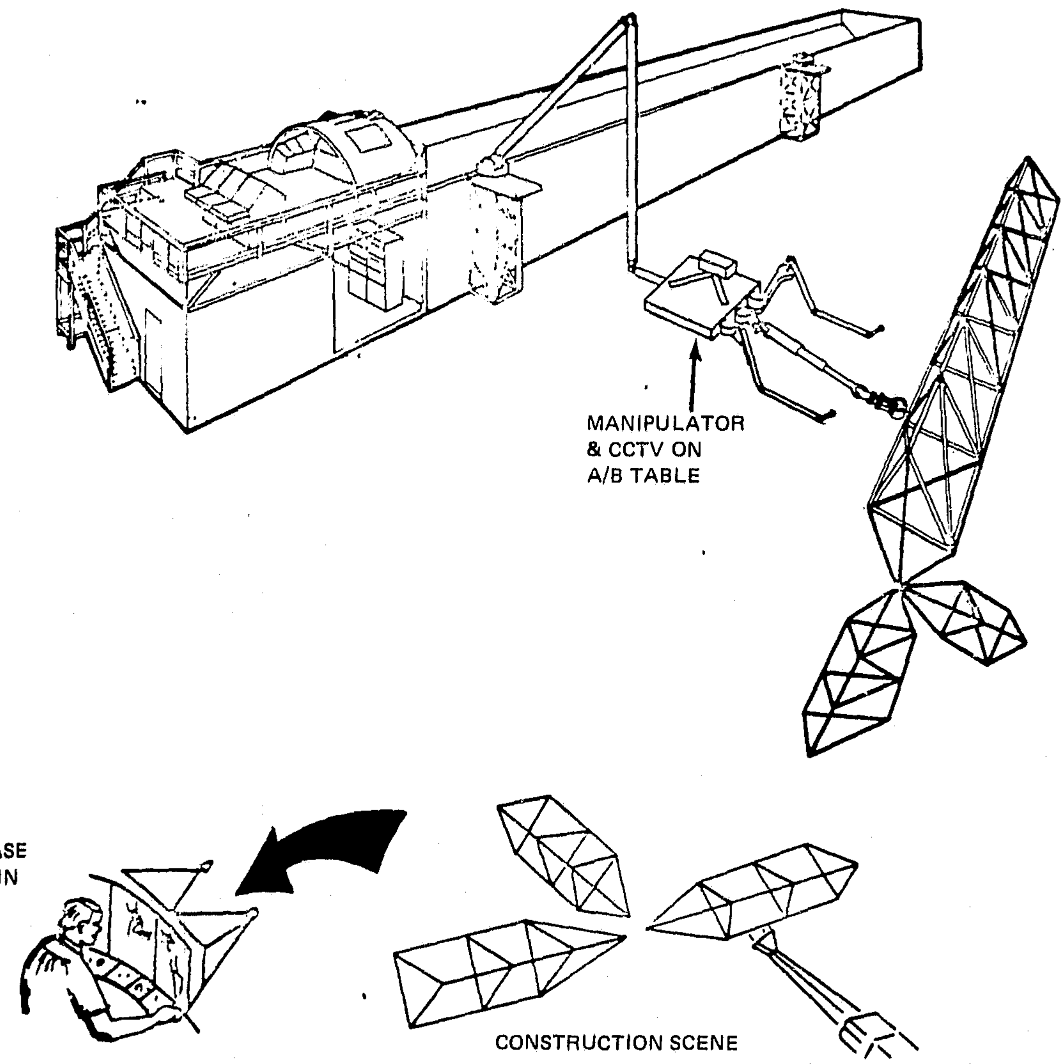

Figure 22. Closed Cherry Picker MRWS Sub-Scale Model Simulation

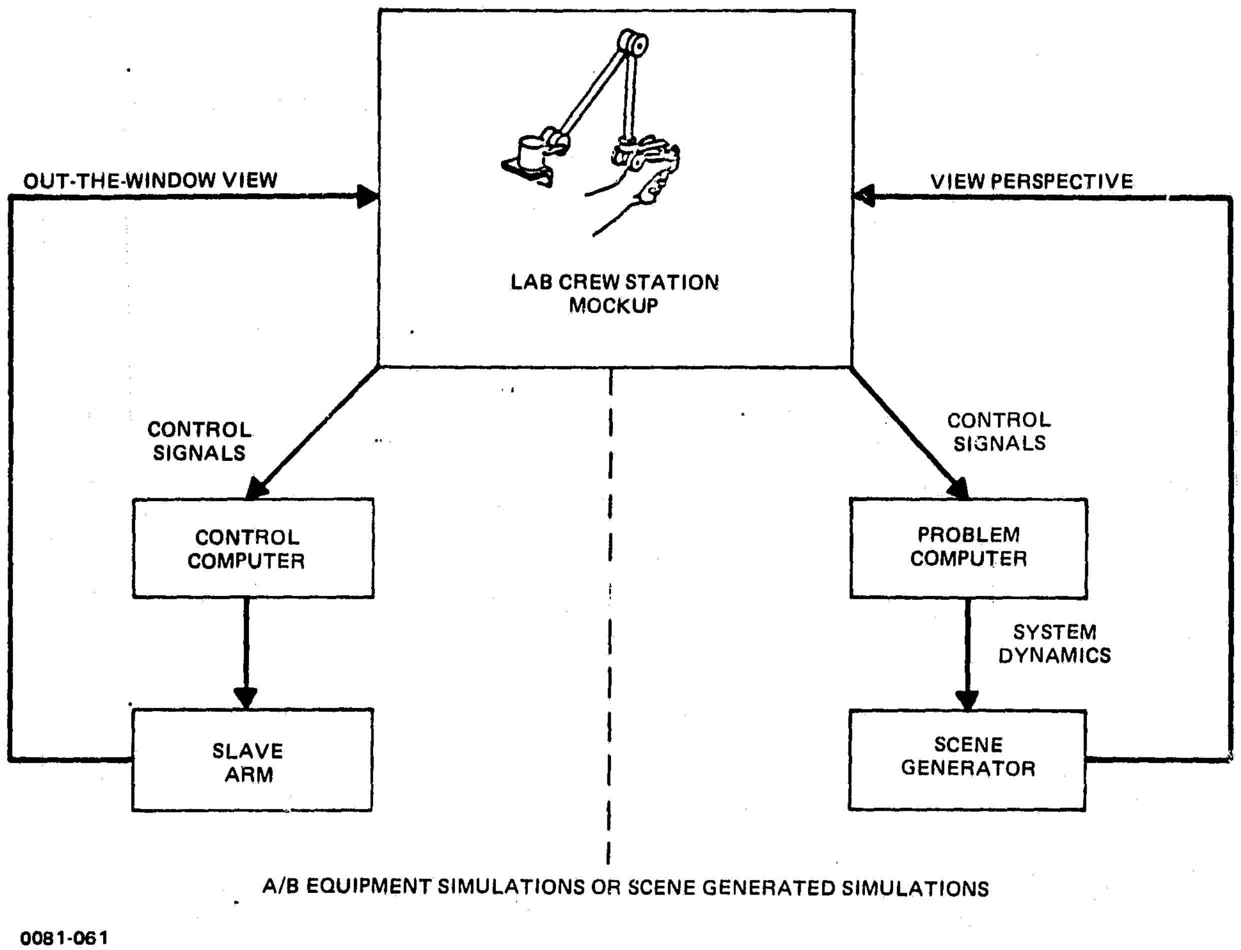

Figure 23. Laboratory Simulation Concepts

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.

3.4.5 Neutral Buoyancy Water Tank

A neutral buoyancy facility could be used for the three-dimensional work site simulation. The basic system shown in Figure 24 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.

3.4.6 Zero-g Manipulator Mechanization Concepts

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

- 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 including:

- 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.

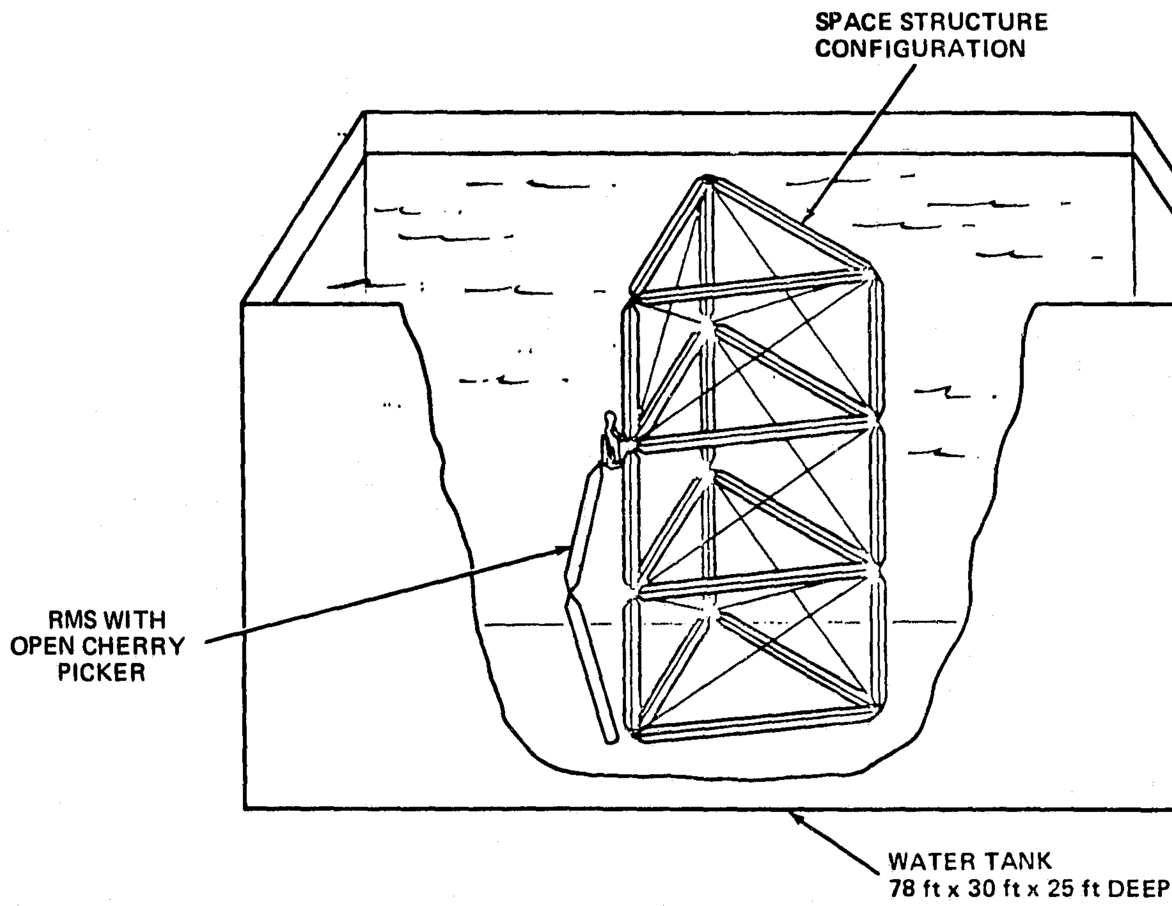

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Figure 24. Neutral Buoyancy 3-D Part Task Work-Site Simulator (Water Immersion Facility)

Three possible mechanizations for zero-g manipulator simulations are presented in Table 12 with appropriate comments regarding each concept.

3.4.7 Flight Test

Although the dexterous manipulator for zero-g usage will follow an orderly earthbound 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 (Figure 25) 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.

3.4.8 Free Flyer Simulation

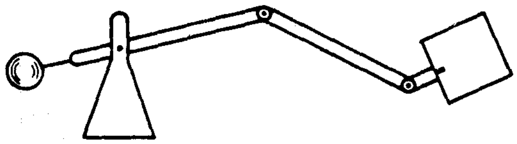
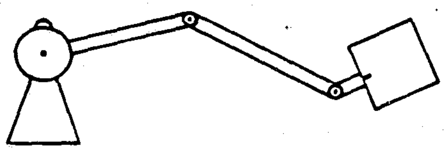
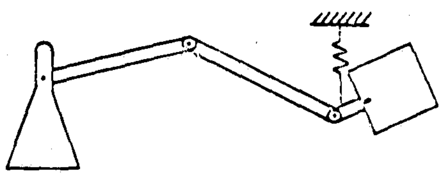
Rescue and crane repair roles were identified for the Free Flyer during the mission and trade study analyses. The various issues that must be resolved by simulation are:

- Evaluate cabin configuration for:
  - Controls/displays
  - Visibility
  - Metabolic workload
  - Men/consoles
- Determine requirements for guidance and control subsystem
  - Vehicle translation and rotational acceleration and rates
  - Guidance techniques
- Determine lighting and visibility requirements
- Evaluate stabilizer design
- Establish rescue operational procedures
- Develop repair operational procedures.

The cabin design factors such as controls/displays, visibility, metabolic workload, and men/consoles must be evaluated during the simulation program. The

TABLE 12

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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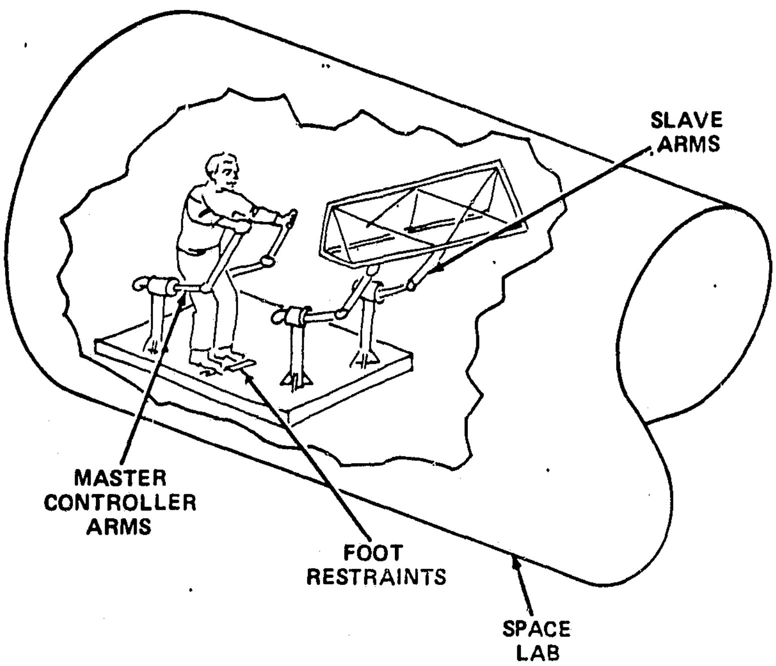


- OPEN CHERRY PICKER VERIFIES:
  - STABILIZER CONCEPTS & UTILIZATION
  - RMS CONTROL MODES
  - ASTROWORKER RESTRAINTS SYSTEM
- SPACE LABORATORY LIFE SCIENCES MODULE
  - ZERO G VERIFICATION OF MANIPULATOR H/W
  - FATIGUE/TASK DURATION
  - COMPONENT JOINING

0081-064

Figure 25. DTA Flight Test Concept Using the Space Laboratory Life Science Module

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 all 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 Personnel Rescue System (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.

The simulation concept proposed for the Free Flyer is shown in Figure 26. Because the initial part of the Free Flyer rescue and repair missions involves translating large distances through 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 cabin with an out-the-window CRT display. Air for the thrust nozzles, air pads, and electrical wires are hard wired to the platform.

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 subsystem; 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 (Table 13). 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.

3.4.9 Space Crane Simulation

The various issues that resulted from the mission and trade studies analysis and that will have to be resolved by simulation are:

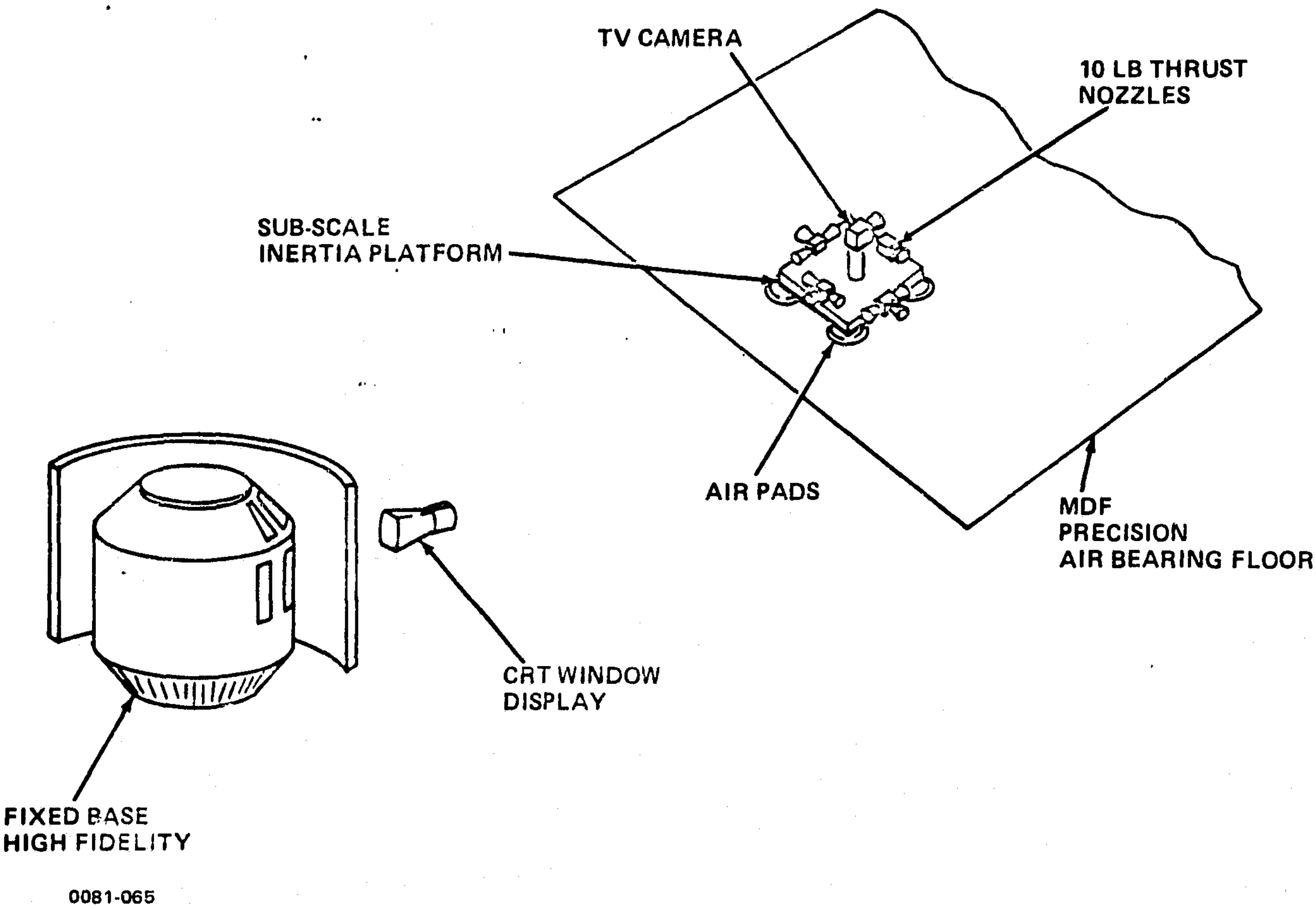
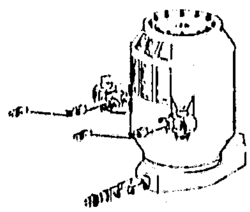
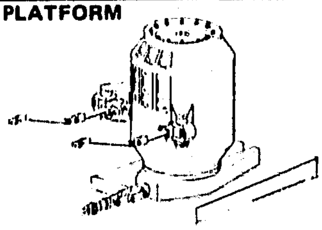


Figure 26. Free Flyer Sub-Scale Simulation Concept

TABLE 13

DTA CONTROL AUTHORITY REQUIREMENTS

	REQUIRED THRUST LEVEL *(LBF)		
	LINEAR ACCEL. 0.3 ft/sec^2	ANGULAR ACCEL. 5 deg/sec^2	ANGULAR ACCEL. 10 deg/sec^2
DTA ALONE 1512 kg (3334 lb) I_Z = 1755 kgm^2 (1294 SLUG ft^2) 	31	23	46
DTA & AIR PAD PLATFORM 3326 kg (7334 lb) I_Z = 5428 kgm^2 (4403 SLUGft^2) 	62	71	142
*1.5 m MOMENT ARM			

0081-066

- 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
- Evaluate lighting and visibility requirements
- Determine ability of OCP astroworker to control Turret Crane Arm and OCP Arm simultaneously.

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.

A proposed simulator concept is shown in Figure 27 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 the 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 cathode ray tub (CRT) display.

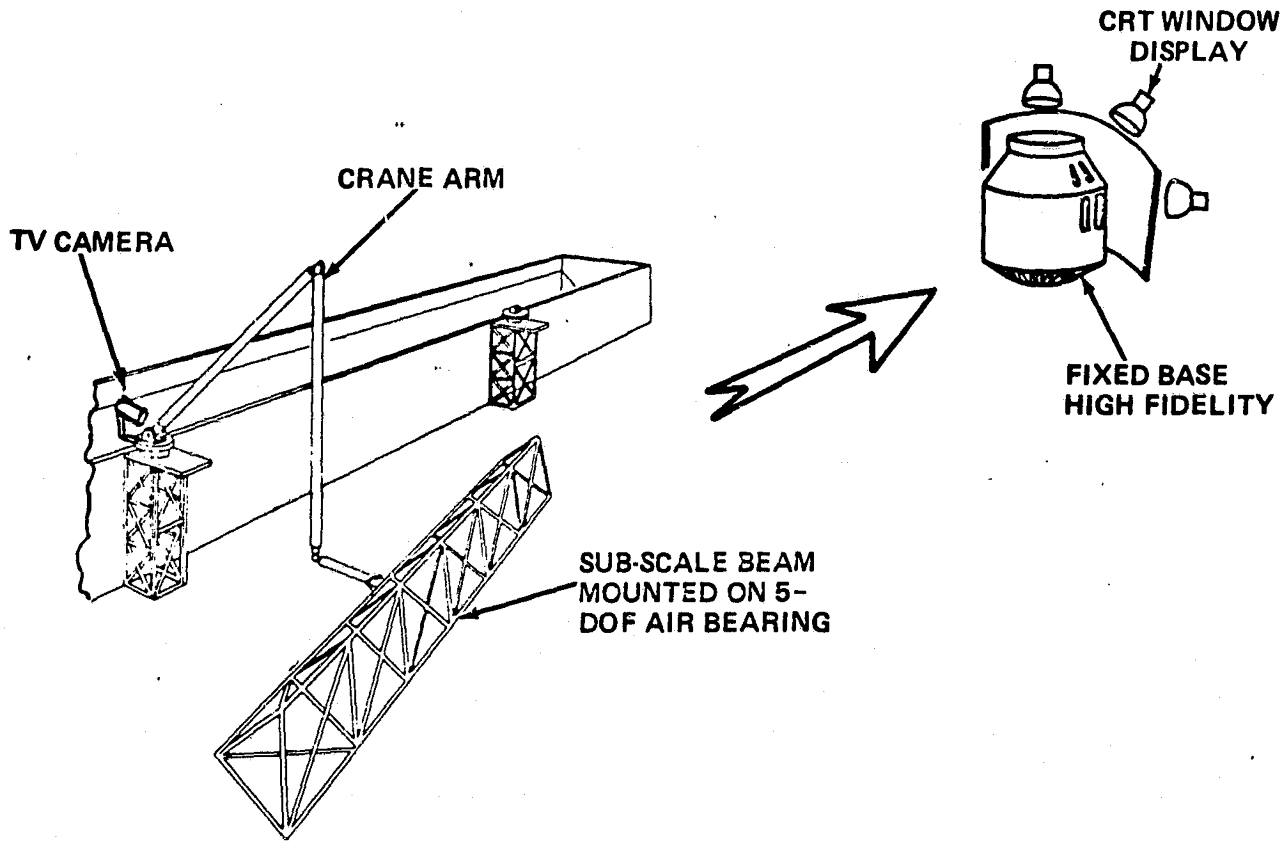


Figure 27. Space Crane Simulation Concept

3.5 DTA SIMULATOR PROGRAM PLAN

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

Figure 28 summarizes the four steps in the simulation program and how they phase 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.

The DTA program begins with the deployment of a dedicated high fidelity OCP which includes a stabilizer and payload handling fixtures. They key piece of equipment to be purchased for the simulator startup is the stabilizer. Devices are available with 6 DOF that could meet initial testing requirements. Various tests to be performed are numerated in Figure 29. The emphasis during the OCP test phase is to determine approaches to the OCP/SRMS control interface and the stabilizer operations. Other key design parameters that impact flight article arrangements are the design loads and lighting requirements. The high fidelity makeup of the OCP DTA in this program should provide timely technology data to meet a MRWS 1982 IOC.

In step two of this program, a dedicated CCP including two dexterous manipulators are added to the simulation program. The one-year period prior to the introduction of the CCP shall be used to design and fabricate the dexterous manipulators. A survey of available Bilateral Force Reflecting (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 stabilizer used in the OCP tests can be interchanged with the CCP.

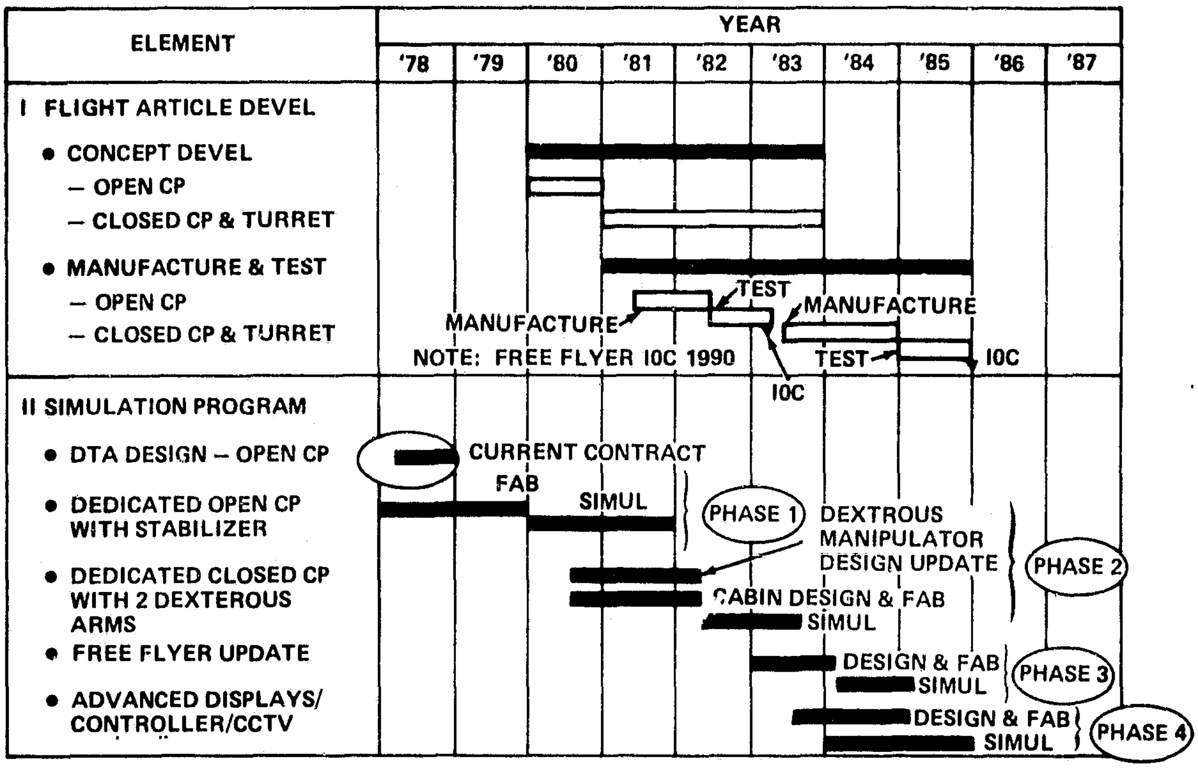


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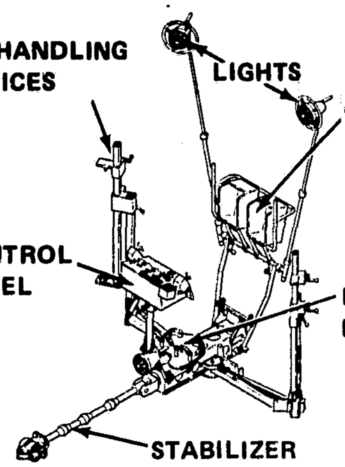
Figure 28. DTA Simulation Schedule

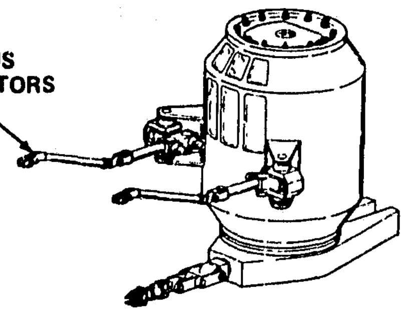
PHASE 1
DEDICATED OPEN CHERRY PICKER



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

PHASE 2
DEDICATED CLOSED CABIN CHERRY PICKER



TEST TO DETERMINE:

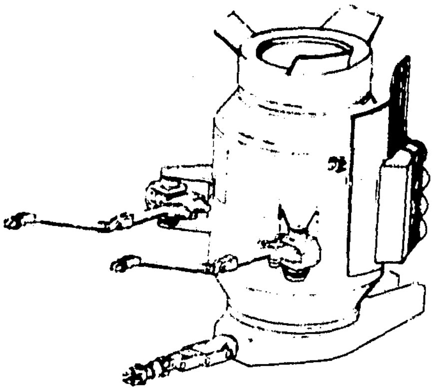
- DESTEROUS MANIPULATOR PERFORMANCE USING MASTER VARY
  - MASTER FORCE
  - MASTER INDEXING SCHEMES
- HUMAN FACTORS
  - METABOLIC WORK LOAD
  - WORK DURATION
- WORKSITE FACTORS
  - ACCESSIBILITY
  - MANIPULATOR LENGTH
- STABILIZER OPERATIONS/DESIGN LOADS
- LIGHTING REQUIRED
- STRUCTURAL ASSEMBLY PROCEDURES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

0081-069

Figure 29. DTA Development Program Phases 1 and 2

Hardware and testing requirements for Steps 3 and 4 are summarized in Figure 30. In Step 3, jets, control electronics and a gas system are added to the CCP to meet requirements for the Free Flyer DTA simulation. Advanced controls and displays are added to the CCP in Step 4.

PHASE 3
ADD FREE FLYER CAPABILITY



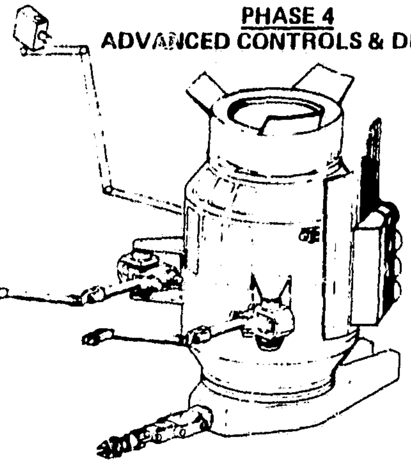
DTA MODIFICATIONS

- ADD
  - THRUSTERS
  - CONTROL ELECTRONICS

TEST TO DETERMINE:

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

PHASE 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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Figure 30. DTA Development Program Phases 3 and 4

Section 4

DTA DESIGN

4.1 INTRODUCTION

Mission analysis indicates the need for the near-term application (Open Cherry Picker mounted to the end of the Orbiter RMS) of the MRWS to support mission operations. The DTA, utilizing the JSC MDF air bearing table, therefore, is the first step in the evolutionary process from the OCP configuration to the full-scale closed MRWS DTA that will provide laboratory capabilities for simulating the MRWS in a zero-g environment.

This section presents the MRWS and DTA subsystems, and the simulator design guidelines derived from the original statement of work (SOW). The design specification for the OCP DTA is contained in Appendix A.

4.2 MRWS-DTA SUBSYSTEMS

Table 14 presents, the subsystems required for the various MRWS and DTA configurations. These subsystems are the primary ones that must be analyzed for the DTA hardware and software integration requirements.

4.3 DTA DESIGN GUIDELINES

The Manned Remote Work Station (MRWS) Development Test Article (DTA) shall be designed to operate in a sequence of tests and simulations at the NASA Manipulator Development Facility (MDF). These tests and simulations with DTA shall develop the flight article system requirements and performance specifications.

The following paragraphs are from this study statement of work:

- System requirements and tests shall be tailored for operation in simulated zero-g on an air-bearing floor
- A cursory effort shall be made to assess the impact of modifying/reconfiguring the MRWS simulator for operation and testing on an air-bearing floor in other modes such as a free flyer

TABLE 14

MRWS AND DTA SUBSYSTEMS

SUBSYSTEMS \ CONFIGURATIONS	OPEN CHERRY PICKER		CLOSED CABIN CHERRY PICKER		RAILED CHERRY PICKER		RAILED CRANE AND CABIN		FIXED CRANE AND CABIN		FREE FLYER		ORBIT TRANSFER VEHICLE CABIN		IMPACT ON SIMULATOR	
	MRWS	DTA	MRWS	DTA	MRWS	DTA	MRWS	DTA	MRWS	DTA	MRWS	DTA	MRWS	DTA	YES	NO
ENVIRONMENTAL CONTROL/LIFE SUPPORT			●		●		●		●		●		●			●
EVA	●														●	
PROPULSION											●		●			
GUIDANCE											●		●			
STABILIZER & CONTROL											●		●			
COMMUNICATIONS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
ELECTRICAL POWER	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
MANIPULATOR			●	●	●	●	●	●	●	●	●	●	●	●	●	
DISPLAYS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
ALERT ALARM			●		●		●		●		●		●			●
ASTRONAUT RESTRAINT	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
TELEMETRY											●		●			●
DOCKING			●		●		●		●		●		●			●
LIGHTING	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
STRUCTURE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
CCTV			●	●	●	●	●	●	●	●	●	●	●	●	●	
STABILIZER (GRAPPLER)	●	●	●	●	●	●					●	●	●	●	●	
ON-BOARD COMPUTER											●	●	●	●	●	
CONTROLS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
AIR CONDITIONING	●		●		●		●		●		●		●		●	
RMS INTERFACE	●	●	●	●	●	●	●	●	●	●					●	
JSC-MDF INTERFACE		●		●		●		●		●		●		●	●	
AIR BEARING PLATFORM INTERFACE		●		●		●		●		●		●		●	●	
SOFTWARE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	

0081-071

- Human Performance/Human Engineering - The design shall consider the capabilities and limitations of the human operator wherever a man-machine interface exists, including torques, forces, and other functional design characteristics of controls, displays, and work stations. The principal design guide for the man-machine interface shall be MIL-STD-1472B; however, in the area of crew station design, MSC-07387 document shall take precedence

- Factors of Safety - The following factors of safety are considered to be minimum and shall be used in addition to vibration amplification factors and all other corrective factors.

  - Yield factor of safety - The yield factor of safety shall be 1.2 times the limit load

  - Ultimate factor of safety - The ultimate factor of safety shall be 2.0 times the limit load

- Equipment, Tools, and Installation

  - The equipment shall be designed such that transient out-of-tolerance conditions or component failures will not cause other component/subsystem failures

  - Unless absolutely necessary, use of special tools and equipment shall be avoided for site maintenance and repair. Any special tool deemed necessary and approved for use shall be designed for use throughout the life of the system

  - Equipment design shall physically prevent the incorrect installation of modules and submodules. Clearly visible color coding and labeling in close proximity to maintenance disconnect points shall be used to facilitate removal and replacement of any subassembly level of equipment

  - Mechanical retention devices for equipment components shall not require safety wiring.

- Selection of Specifications and Standards - Specifications and standards for use in design and construction of the equipment other than those specified herein, shall be selected in the order of precedence in accordance with MIL-STD-143, except NASA documents shall take precedence where pertinent

- The MRWS simulator shall be designed for operation by one operator and shall be configured for enclosed (pressurized) and open (EVA suited) modes of operation
- Manipulator arms shall be operated independently
- Unobstructed direct vision shall be provided for the MRWS operator with the manipulator arm(s) fully extended at any attitude. Vision in "reach around" maneuvers may be supplemented by CCTV
- TV cameras and lights, if required, shall be located to provide adequate field-of-view coverage and depth perception function to the operator
- Translation, positioning, and indexing of parts/materials shall be provided by the MRWS
- The MRWS shall be designed to interface with the JSC manipulator and operated in simulated zero-g on an air-bearing floor
- Anthropometric data shall be obtained from the Anthropometric Source Book generated under NASA Contract NAS9-14720.
- Cooling capability shall be provided for the MRWS for enclosed operation, if required
- Communications and caution and warning capability shall be provided
- The MRWS displays and controls (D&C) shall provide information to and accept commands from the operator. The D&C shall consist of an operator's control panel console located in the MRWS. A rotational and translational hand controller shall be provided. A number of control modes shall be provided, including manual and automatic, to simulate control for the degrees-of-freedom required
- The MRWS software shall accommodate the capability to handle the required degrees-of-freedom for the manipulator arms
- The control system shall provide manual and override capability. Control shall be provided within the MRWS and from the JSC RMS station for positioning of the MRWS on the air bearing floor

- Electrical power system shall be provided by facility power
- An interface shall be provided on the simulator MRWS manipulator arms for installation/exchange of various end effectors required for parts/material handling operations
- The MRWS simulator cabin appearance shall be representative of the flight article where practical, and when functional operation is not compromised.

APPENDIX A

OPEN CHERRY PICKER DEVELOPMENT TEST ARTICLE SPECIFICATION

The Manned Remote Work Station (MRWS) Open Cherry Picker (OCP) Development Test Article (DTA) shall operate in a sequence of tests and simulations at the NASA/JSC Manipulator Development Facility (MDF). These tests and simulations with the DTA shall develop the flight article system requirements and performance specifications. This appendix is a specification for the OCP-DTA that will be manufactured for use at the JSC MDF.

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DRL T-1422
Line Item 6
DRD SE 812T

CONTENTS

CONTENTS (contd)

CONTENTS (contd)

ILLUSTRATIONS

TABLES

Section 1

SCOPE

This specification addresses the interface between the open cherry picker DTA and the MDF. It includes the system specification for the DTA and specifies subsystems and lists components.

Section 2

APPLICABLE DOCUMENTS

Specifications and standards for use in design and construction of the equipment, other than those specified herein, shall be selected in the order of precedence in accordance with MIL-STD-143, except NASA documents shall take precedence where pertinent.

The following documents are applicable to the design:

- JSCM 8080 - Manned Spacecraft Criteria and Standards (NASA)
- JSC 10615 - Shuttle EVA Description and Design Criteria
- MSC 07387 - Crew Station Specifications
- JSC 10874 - Facilities for Orbiter/Payload Engineering Development Support (NASA)
- JSC 11029 - Manipulator Development Facility - Bldg. 9A - General Description (NASA)
- MIL-STD 1472B - Human Engineering Design Criteria for Military Systems, Equipment, and Facilities
- JSC 09962 - Zero G Work Station Design (NASA)
- NASA RP 1024 - Anthropometric Source Book

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Section 3

REQUIREMENTS

3.1 MANIPULATOR DEVELOPMENT FACILITY INTERFACES

The DTA design shall interface with the JSC MDF and operate in a simulated zero-g environment on the air bearing floor (Figure A-1). The specific interfaces are the air bearing platform, manipulator, communications, facility computer, and power.

3.1.1 Manipulator Structural Interface

The DTA shall interface with the grapple fitting (Figure A-2). The manipulator attaches to the grapple fixture using an end effector. The manipulator can apply a force at the tip of 50 lb (depending on arm geometry and force direction) and has a maximum tip speed of 2 fps.

3.1.2 Manipulator Control

The DTA design shall provide for the electrical signal interface between the DTA hand controllers or control switches and the MDF computer for control of the MDF manipulation (Figure A-3).

The command signals from the hand controllers or control switches and display console switches will be hardwired from the DTA interface located at the bottom of the base module support rails to the MDF facility. The hand controllers, which are modified MMU type controllers, shall be supplied GFE.

Control switches and display caution/warning lights shall also be hardwired from the DTA interface to the MDF facility.

3.1.3 Electrical Power and Signals

NASA shall supply the following power and signal interfaces at the DTA support rails; connectors TBD:

- Power
  - Lighting: 115 V, 60 Hz, 360 watts
  - Controls and displays panel: 28 VDC, 4.0 amps
- Real Time Peripheral Signals

No.	Type	Signal Characteristics
3	Digital/analog converters	± 10 VDC, 10 ma
6	Analog/digital converters	± 10 VDC (proportional rate controller)
43	Discrete inputs	DTA will provide RTP ground through switch contacts
32	Discrete output	28 VDC, 25 ma

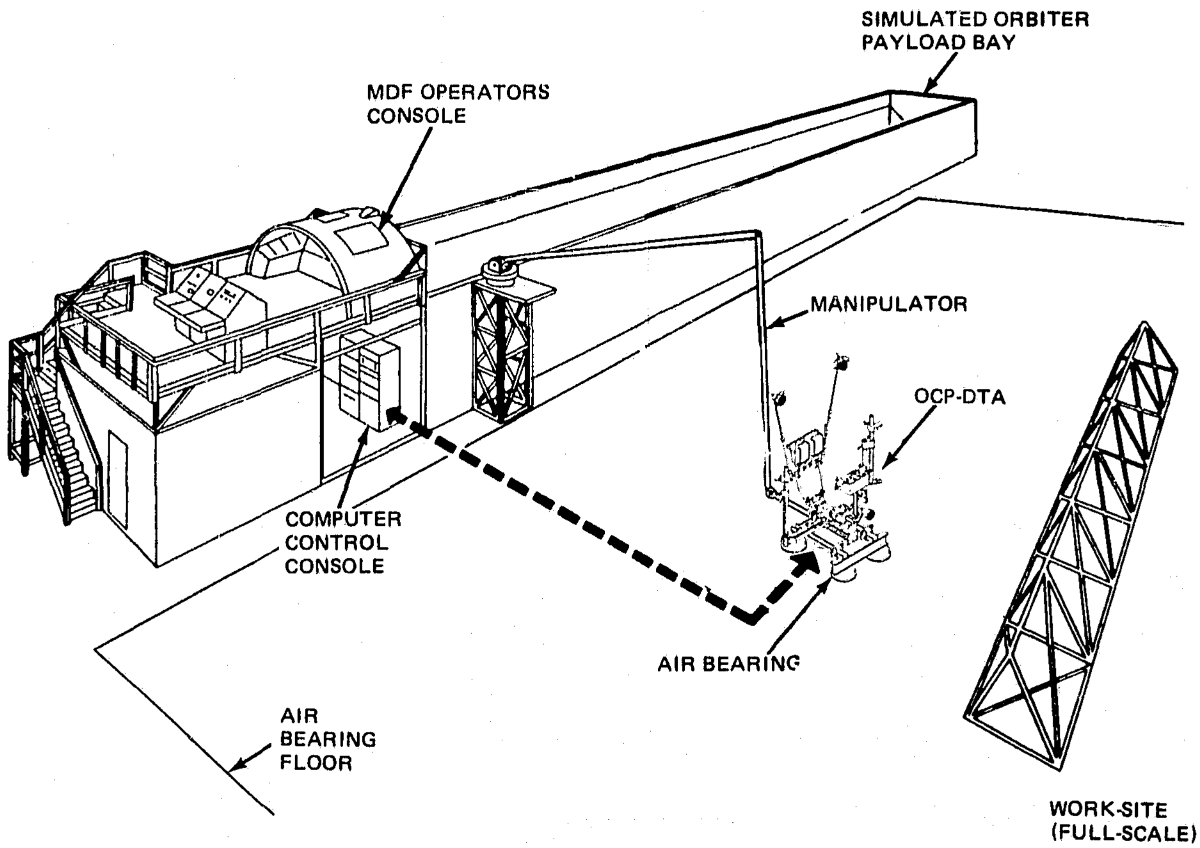

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Figure A-1. Open Cherry Picker Development Test Article Operating on the MDF Air Bearing Floor

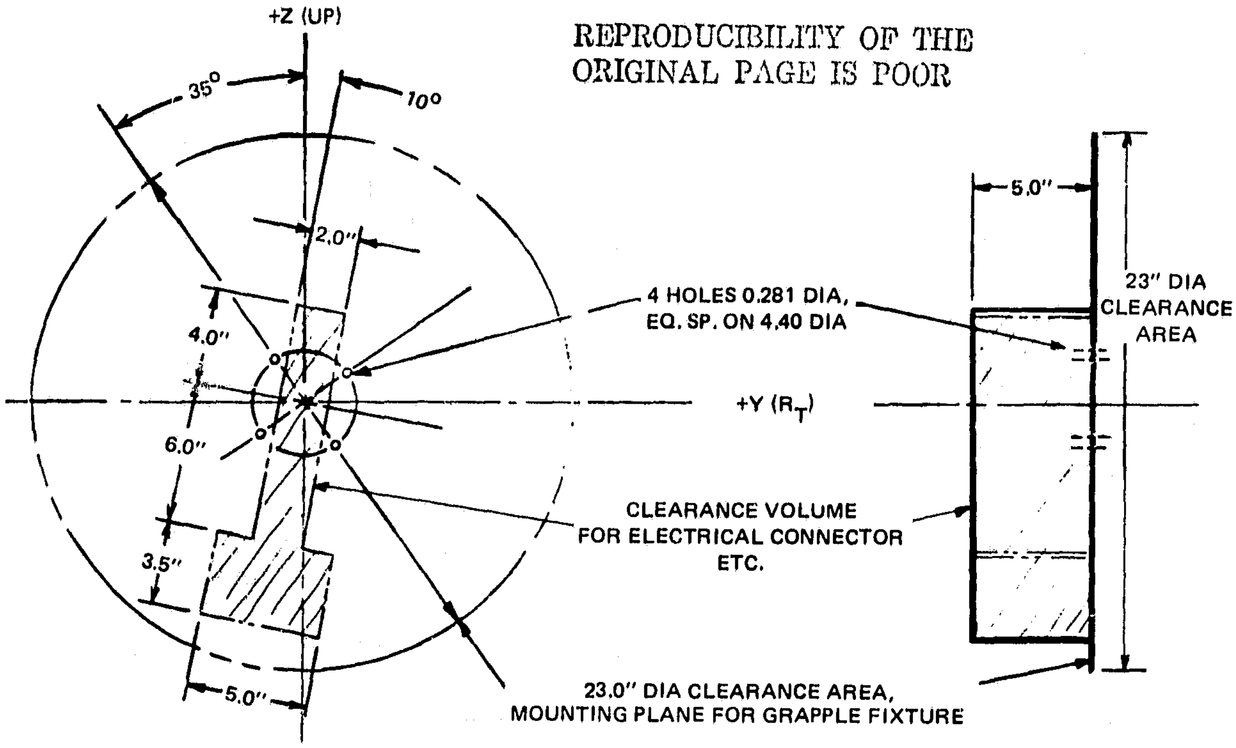

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Figure A-2. Area and Volume Required to Mount Grapple Fixture

3.1.4 Communications/Computer Control

The DTA shall utilize the present MDF intercom system. A GFE intercom/computer control box (Figure A-4) shall be mounted to the DTA C&D console, and a headset plugged into the panel. The facility signals shall be routed via GFE supplied hardwire to the DTA GFE intercom panel.

3.1.5 Air Bearing Platform

The NASA small air bearing platform approximately 14 x 32 x 48 in. (Figure A-5) shall be utilized for the DTA test program. Interface fittings shall be provided on the DTA base module for mounting the DTA to the platform. The air bearing platform shall be designed to support the DTA and EMU suited operator.

3.1.6 Safety/Rest Restraint

A safety/rest restraint shall be provided that mounts on the air bearing platform and attaches to the EMU (Figure A-6).

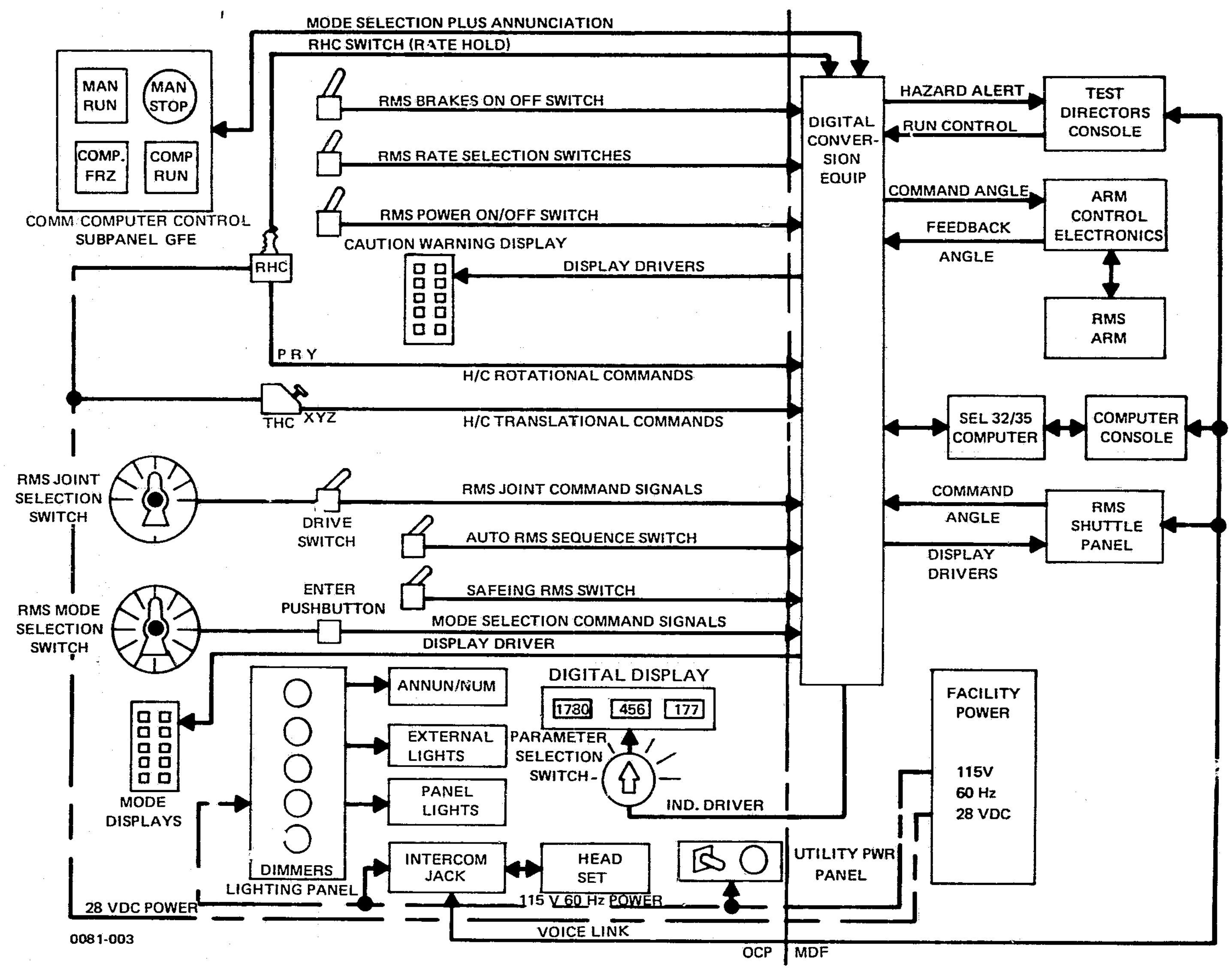


Figure A-3. OCP-DTA/MDF Electrical Interface Schematic

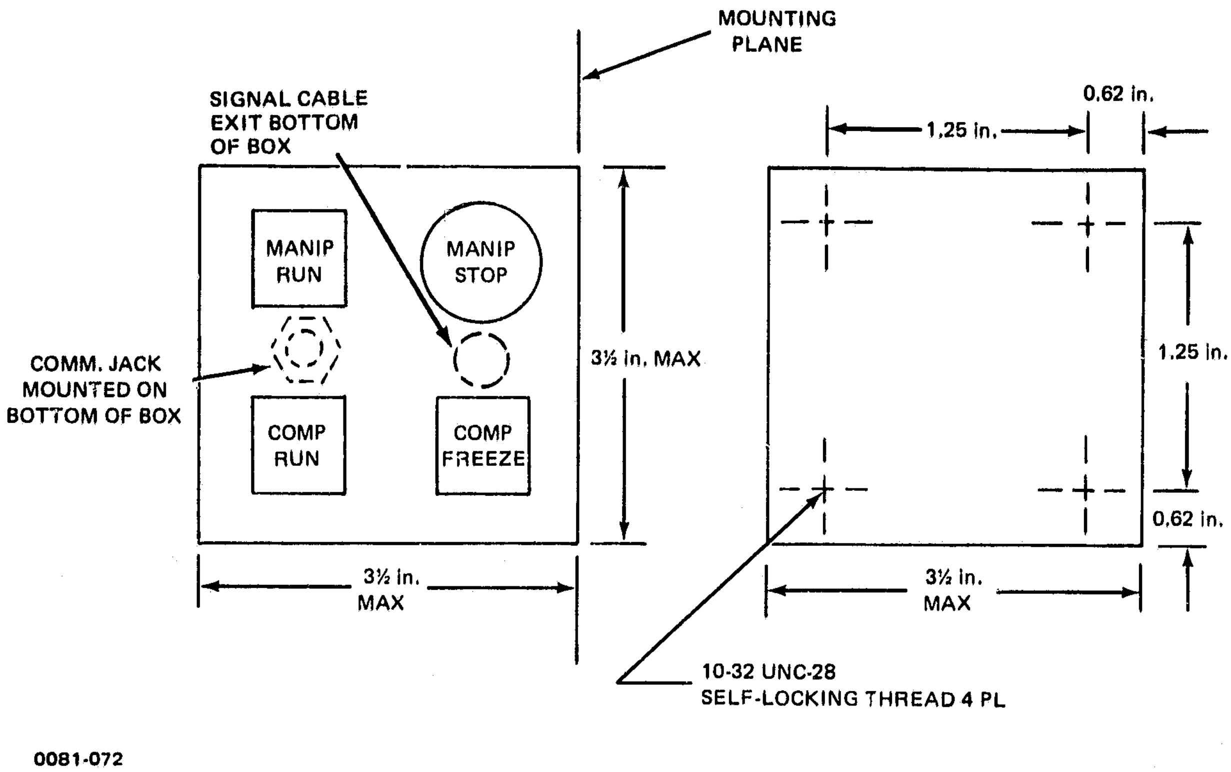
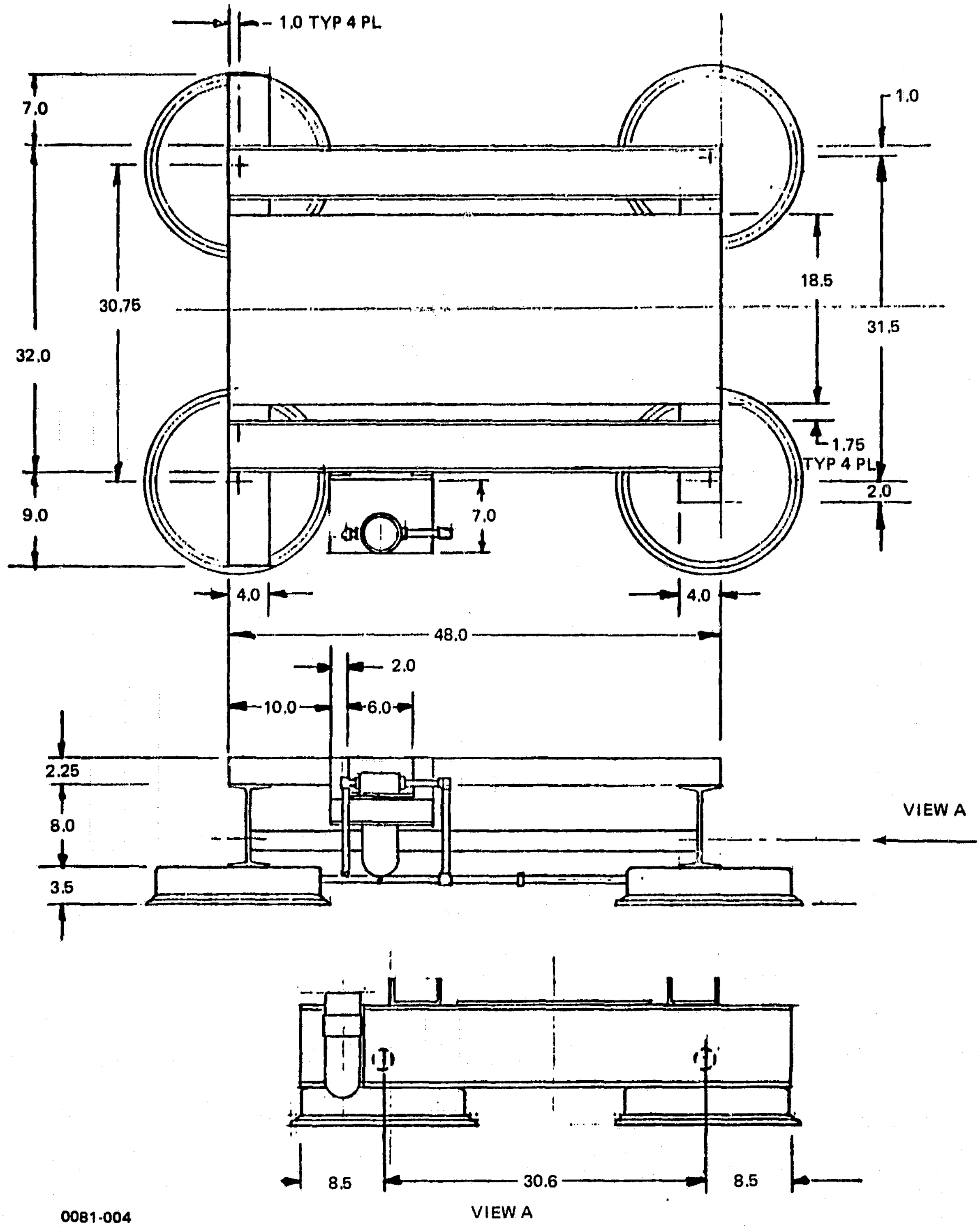


Figure A-4. Intercom/Computer Control Box

3.1.7 Software

The MDF computer system master control console and peripheral equipment are located in the MDF. The present computer is the SEL 32/35 with 256K bytes of core. Programming will use Assembly Language. Manual inputs and control signals from the Shuttle operator's console are processed by the computer system that contains the manipulator control system algorithms and has pre-programmed software boundaries to limit travel and speed of the manipulator arm and its joints. Display signals are fed back to the operator and test director's consoles for status indication through panel displays.

The coordinate references system (Figure A-7) for the manipulator control system shall be used when the hand controllers/display console is located in its most forward operational position. Computer software will prohibit all motions except that in the plane of the air bearing floor.



ALL MEASUREMENTS GIVEN IN INCHES

Figure A-5. MDF – Air Bearing Platform

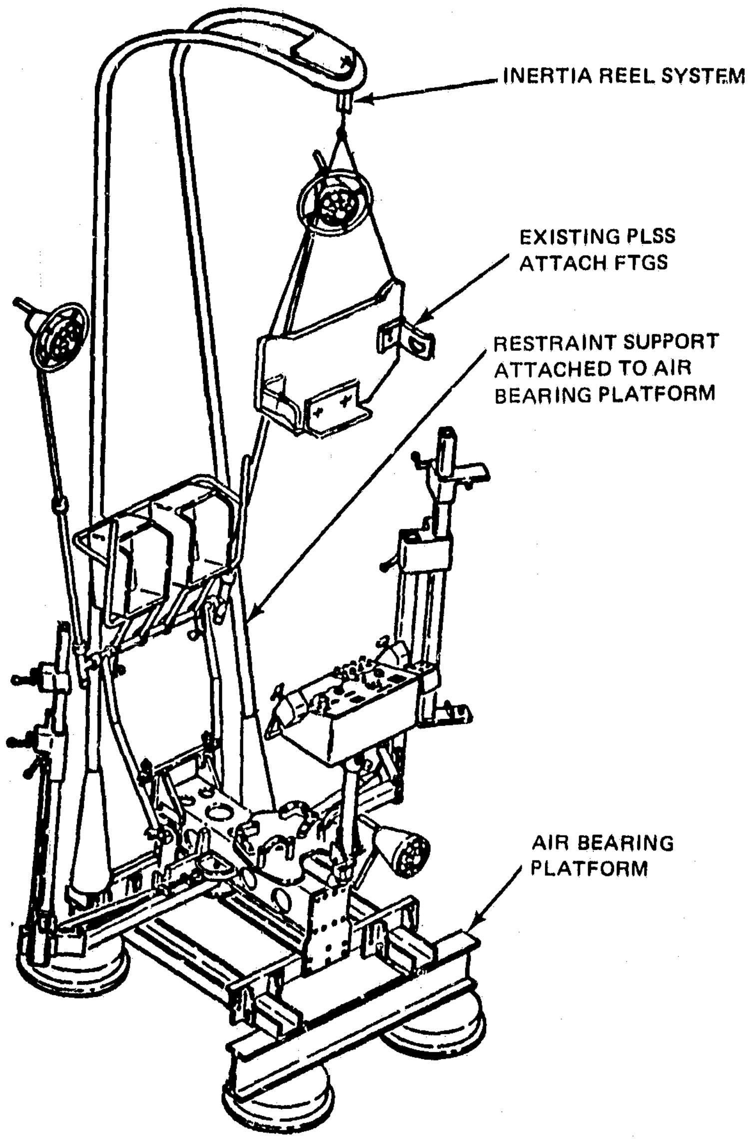
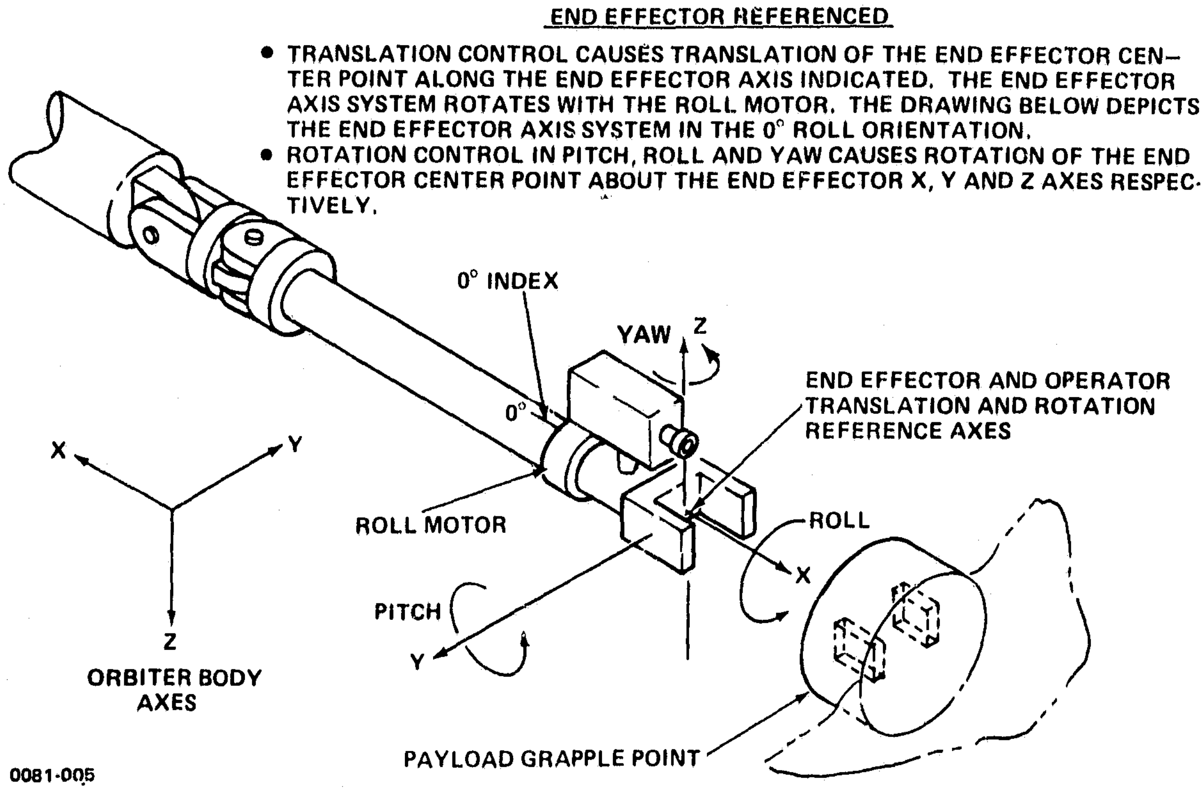


Figure A-6. DTA – Operator Safety/Rest Restraint



NOTE: 1. Operator translation reference axis is parallel, but opposite in sense to the Orbiter body axes.

2. Motion in Z, roll, and pitch locked out by the computer when DTA is used on the air bearing floor.

Figure A-7. MDF Manipulator Coordinate Reference System

A preliminary analysis indicates the SEL 32/35 and Test Conductors Console data acquisition requirements are adequate to support phase I testing.

It is planned to use the existing MDF software to minimize software changes. Software changes for the DTA C&D shall be implemented by NASA in the following areas:

- Rate selection input
- Rate selection annunciation feedback
- Variable rate control law
- Mode selection annunciation feedback
- MRWS power selection
- Digital data monitor eq's
- "SYSGEN" if new devices are added at the I/F.

The major area of change will be in "MCIU" and "COP" subroutines. The specific changes are TBD at this time. The contractor will provide math model requirements and the software changes are GFE.

3.1.8 Test Articles

Representative space structure, assembly components, and service test articles shall be provided by NASA.

3.2 SYSTEM

3.2.1 Configuration

The DTA configuration (Figure A-8) shall be designed for operation by one extravehicular activity EMU suited operator. The OCP-DTA simulator appearance shall be representative of the flight article where practical and when functional operation is not compromised.

3.2.2 OCP-DTA Design

The DTA shall consist of the following components:

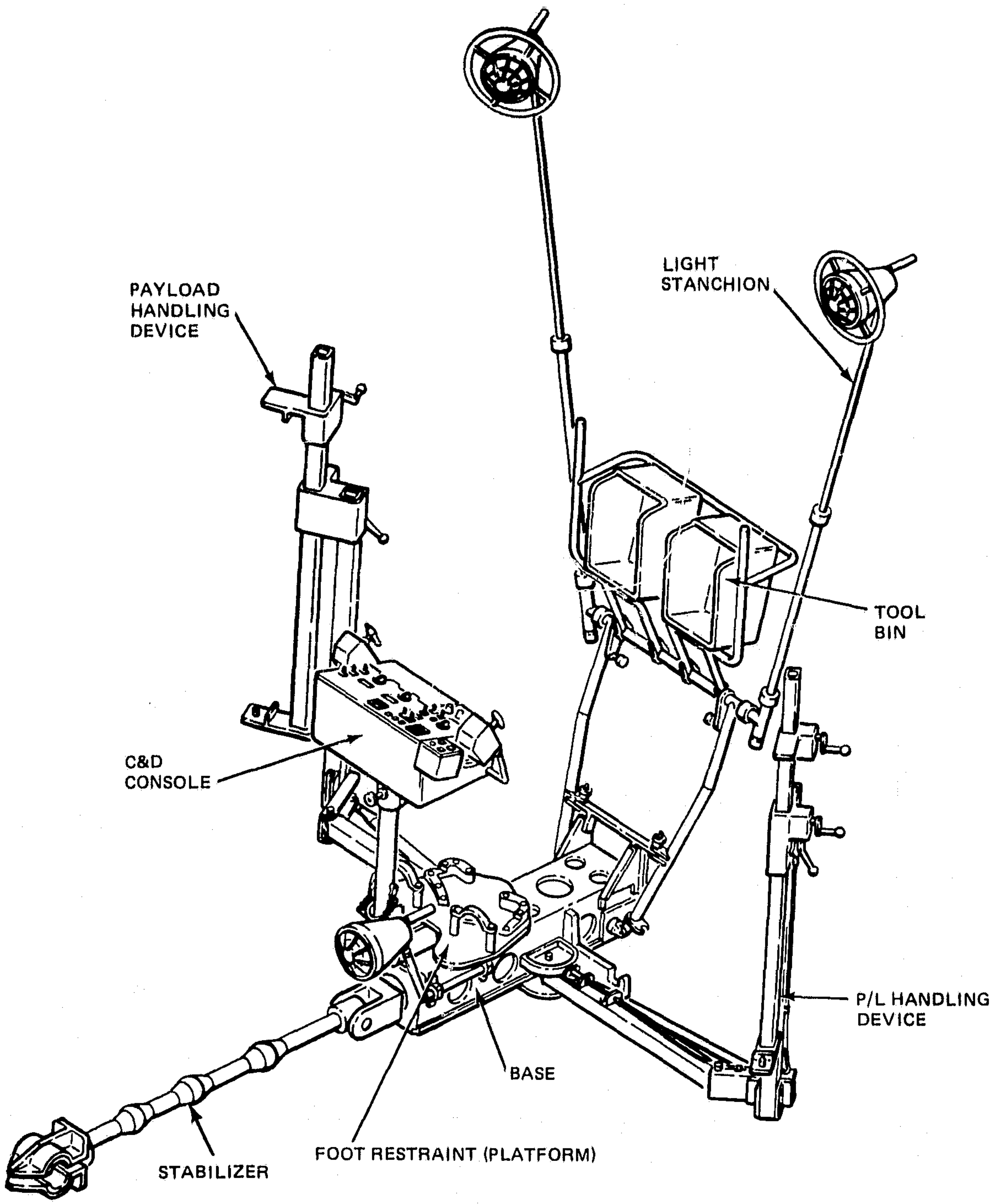


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Figure A-8. Open Cherry Picker Development Test Article

- Base Structure - The primary element of the DTA, which is attached to the MDF air bearing platform, serves as the mounting structure for the stabilizer and is the base that supports all other components
- Work Platform - The operator stands on this platform with feet attached to toe and heel restraints. The platform is mounted to the base structure and rotates for operator repositioning
- Stabilizer - An articulating arm mounted to the base is used for stabilizing the DTA at the work-site
- Controls and Displays (C&D) Console - This console supports hand controllers that are used for controlling the MDF manipulator and provides the display information required by the operator to control the DTA in the MDF
- Light Stanchion - This provides mounting for lights to illuminate the work area
- Payload Handling Device - This device assists the operator in handling various types of space equipment
- Equipment Storage - This container stores tools and assembly components
- Safety/Rest Restraint - Supports the DTA operator during test operations and restrains the operator in the event of sudden stops.

3.2.3 Man/Machine Interface

The design shall consider the capabilities and limitations of the human operator in the Extravehicular Mobility Unit (EMU) wherever a man-machine interface exists, including torques, forces, and other functional design characteristics of controls, displays, and work stations. The principal design guide for the man-machine interface shall be MIL-STD-1472B; however, in the area of crew station design MSC-07387 document shall take precedence. The design shall accommodate the range of personnel from 5 percentile female to 95 percentile male based on anthropometric data extrapolated to 1985.

3.2.4 Operator Vision

Components shall be located to minimize obstruction to direct vision of the DTA operator.

3.2.5 Illumination

Lights shall be located to provide adequate field-of-view coverage and depth perception function to the operator. Work-site illumination shall be variable from 20 to 100 ft-c.

3.2.6 Anthropometric Data

Anthropometric data shall be obtained from the Anthropometric Source Book, NASA RP 1024, Vol I - III. All operations shall be capable of being performed while the operator is in an EMU and feet restrained in the work platform. Operator reach area design goal is defined in Figure A-9.

3.2.7 Foldability

The DTA design shall permit manual folding for storage.

3.2.8 Reliability

The equipment shall be designed such that transient out-of-tolerance conditions or component failures will not cause other component/subsystem failures.

3.2.9 Weight

The maximum DTA weight shall be 227 kg (500 lb).

3.2.10 Design Loads

The DTA shall be designed to the loads contained in Table A-1.

3.2.11 Structural Factors of Safety

The following factors of safety are considered to be minimum and shall be used in addition to vibration amplification factors and all other corrective factors:

- Yield Factor of Safety - The yield factor of safety shall be 1.2 times the limit load
- Ultimate Factor of Safety - The ultimate factor of safety shall be 2.0 times the limit load.

3.2.12 Operator Safety

3.2.12.1 Equipment Location - Equipment shall not be located in the work zone that could cause hazard to the operator because of impact. All protrusions and sharp edges shall be eliminated.

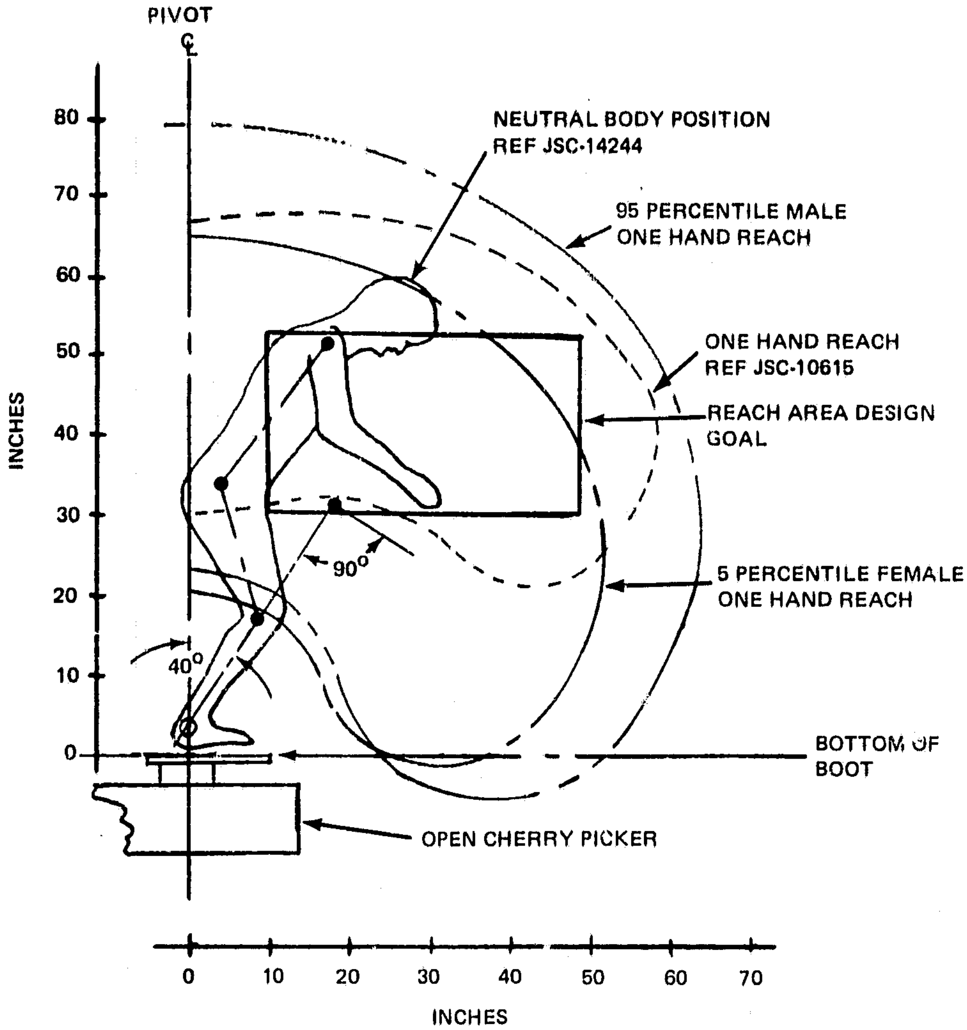


Figure A-9. Astronaut Reach Relative to Pivot Axis

3.2.12.2 Safety/Rest Restraint - A safety/rest restraint shall be installed for operator support to eliminate the possibility of the operator falling because of loss of balance and to minimize operator fatigue.

3.2.12.3 Switches and Controls - Switches and controls shall be designed to minimize inadvertent operation.

3.2.13 Maintainability

The DTA shall be designed to provide access to equipment interfaces, installations, and service cables requiring inspection or verification.

TABLE A-1

DTA – DESIGN LOADS AND CRITERIA

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

0081-008

The DTA shall be capable of having planned maintenance. Components and modules shall be located and access provided for removal and replacement.

Use of special tools and equipment shall be avoided for site maintenance and repair. Any special tool deemed necessary and approved for use shall be designed for use through the life of the system.

Equipment design shall physically prevent the incorrect installation of modules and submodules. Clearly visible color coding and labeling in close proximity to maintenance disconnect points shall be used to facilitate removal and replacement of any subassembly level of equipment.

Mechanical retention devices for equipment components shall not require safety wiring.

3.3 SUBSYSTEM REQUIREMENTS

3.3.1 Base Module

3.3.1.1 Structure Assembly - The general arrangement for the DTA (Figure A-10) shall be the design for manufacture. Assembly tolerances for the DTA structure shall be the standard manufacturing tolerances in use at the contractor, with the exception of those interfaces identifying close tolerance requirements.

3.3.1.2 Base Structure - Figure A-11 shows the base structure, the primary element of the DTA, upon which all other components are mounted.

3.3.1.3 Stabilizer Supports - The DTA base shall interface with and provide support for a stabilizer. The stabilizer shall be mounted to the forward end of the base.

3.3.1.4 Manipulator Attachment - The DTA base module design shall provide for attachment to the MFD manipulator. The DTA attachment fitting located at the aft end of base shall interface with the manipulator grappler (GFE) and be capable of supporting a 100-lb load applied in any direction at this interface.

3.3.1.5 Control Console Pedestal - The DTA base shall provide for the attachment and support of a rotatable control console pedestal.

3.3.1.6 Air Bearing Table Fittings - The DTA base module design shall provide support fittings to interface with the MDF air bearing platform (Figure A-12).

3.3.1.7 Light Support - The base structure design shall provide support for one adjustable 120 W flood light fixture.

3.3.1.8 Light Stanchion Support - The DTA base module design shall provide support for a light stanchion assembly.

3.3.1.9 Payload Handling Device Attachment - Support fittings for the payload handling device interface attachment shall be fastened to the DTA base.

3.3.1.10 Work Platform - The DTA Platform Design shall be mounted on the base structure and shall provide accommodations for one EMU-suited operator. The platform shall be manually continuously rotatable and be capable of being indexed and locked at discrete locations in 45° increments through 360° by the operator, and shall be operated in the nominal zero-g and one-g standing position.

3.3.1.11 Foot Restraint Assembly - The DTA work platform shall contain Shuttle-type heel and toe foot restraint fittings (GFE) (Figure A-13). The restraints shall be assembled to the work platform. The foot restraint hardware described shall be supplied by NASA (GFE) and installed by the contractor.

3.3.2 Stabilizer

3.3.2.1 Configuration - The stabilizer shall be designed as a manually operated mechanical device with at least 6 DOF.

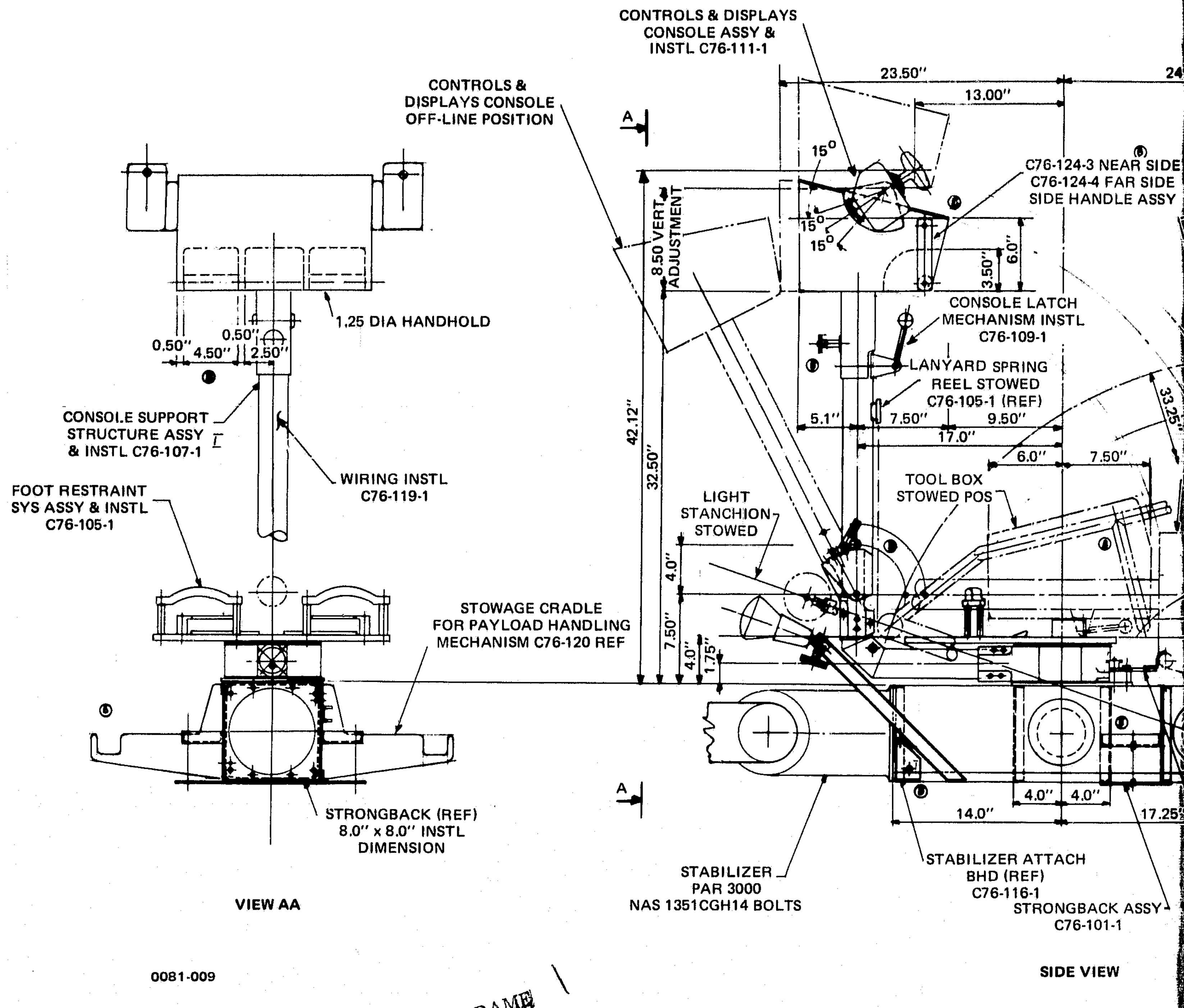
The stabilizer configuration shall permit reach around capability. With the shoulder located 0.5 m from a 90° outside corner, reach around 90° corner 0.5 m to grapple fixture, for a total reach of 1.0 m (Figure A-14).

3.3.2.2 Interfaces - The stabilizer shall interface with the forward end of the base module (Figure A-15).

An end effector that is used to grapple structure shall be fitted to the end of the stabilizer. The stabilizer design shall permit replacement of the end effector.

3.3.2.3 Characteristics - The stabilizer shall have the following characteristics: (Figure A-14).

Parameter	Value
Reach	0 to 1.5 m (5 ft)
Pitch	-110°, + 90°
Yaw	±110°
Tip Load	22.4 N (50 lb) straight arm, any direction
Stiffness (straight arm)	175 N/cm (100 lb/in)
Operating Temperature	10° to $32^{\circ}C$ (50° - $90^{\circ}F$)
Wrist Pitch	± 45°
Wrist Yaw	± 45°
Wrist Roll	± continuous



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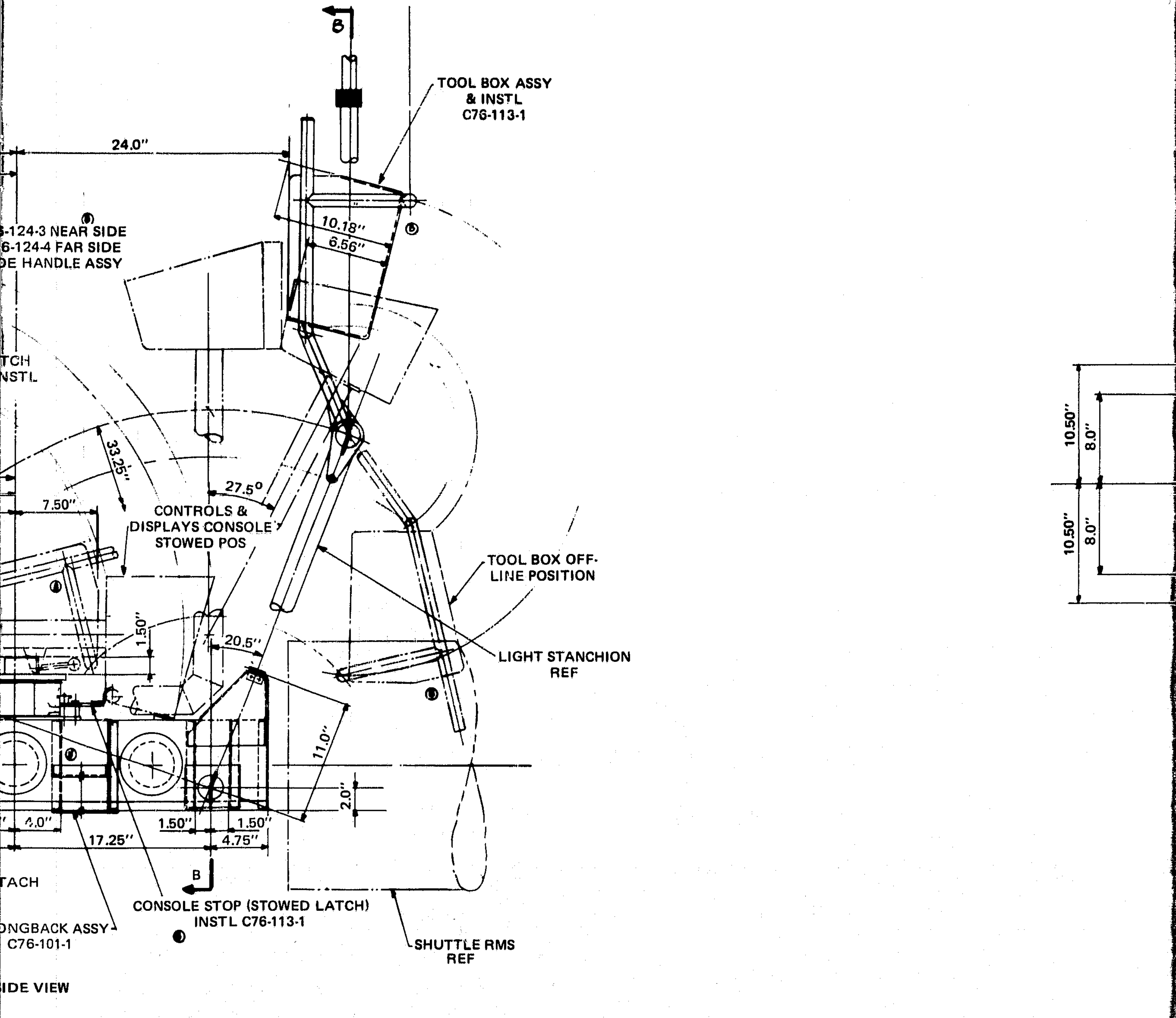
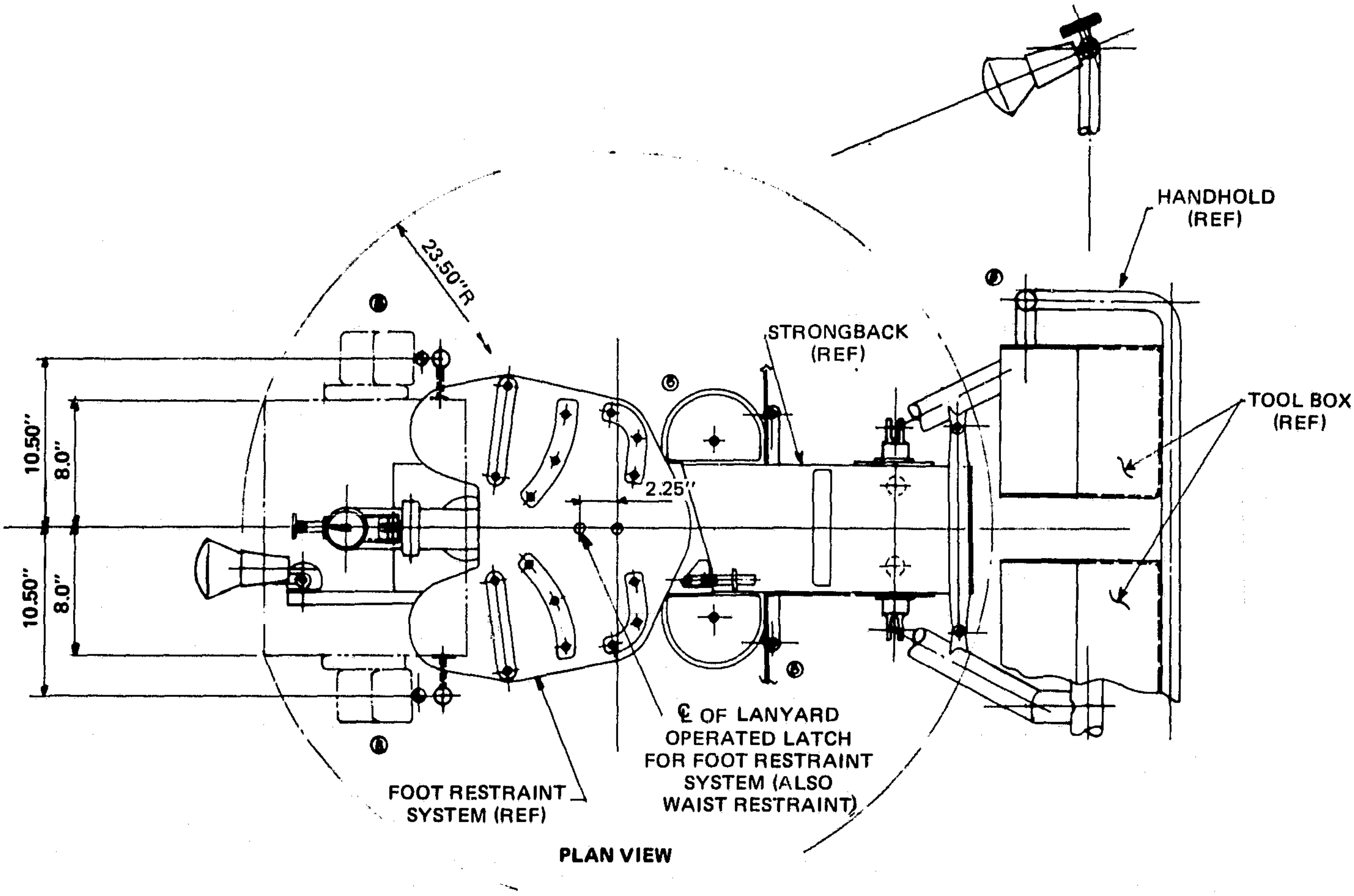
FOLDOUT FRAME

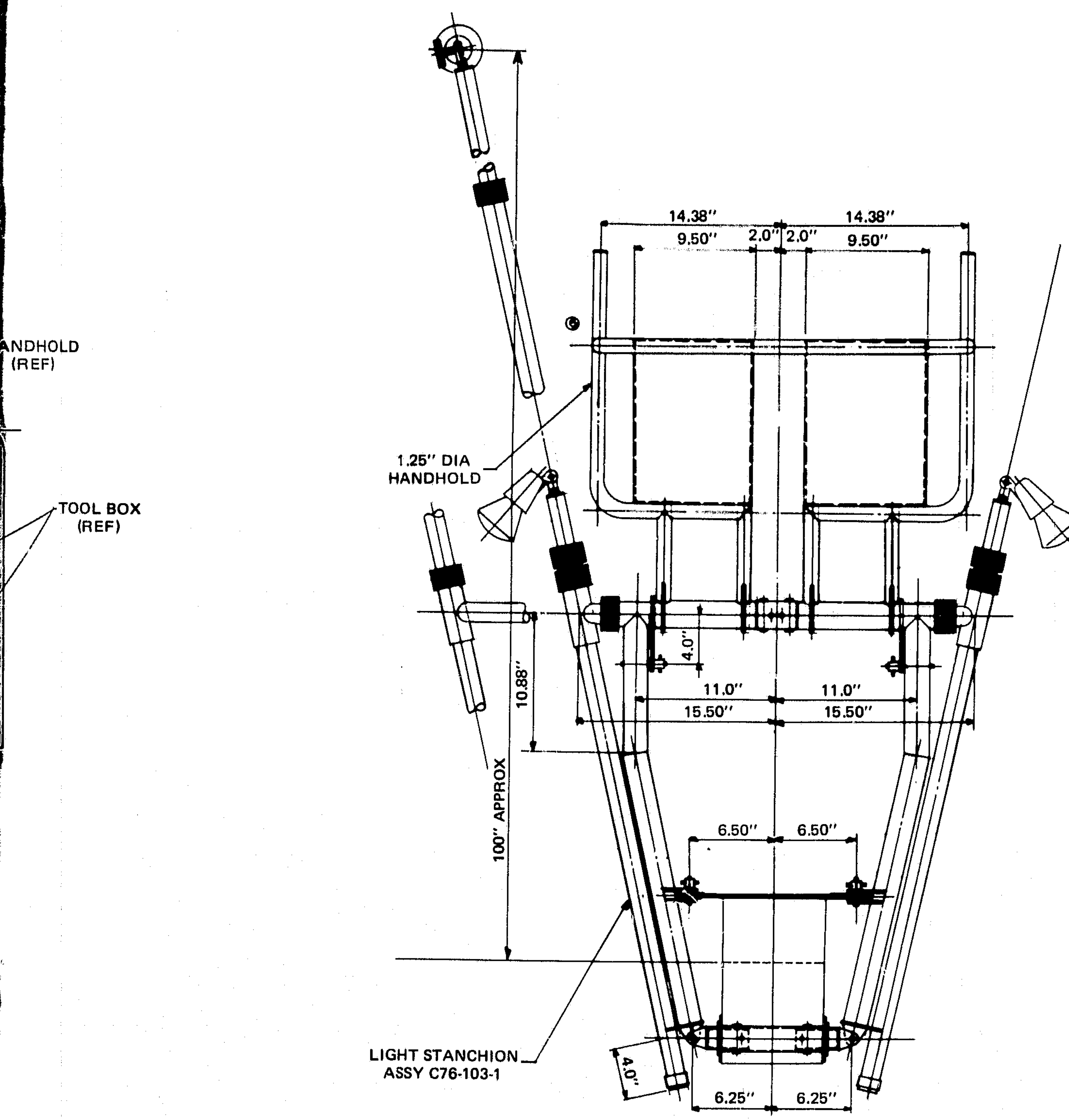


FOLDOUT FRAME 2



PLAN VIEW

FOLDOUT FRAME 3



SECTION BB

Figure A-10. General Arrangement of OCP-DTA

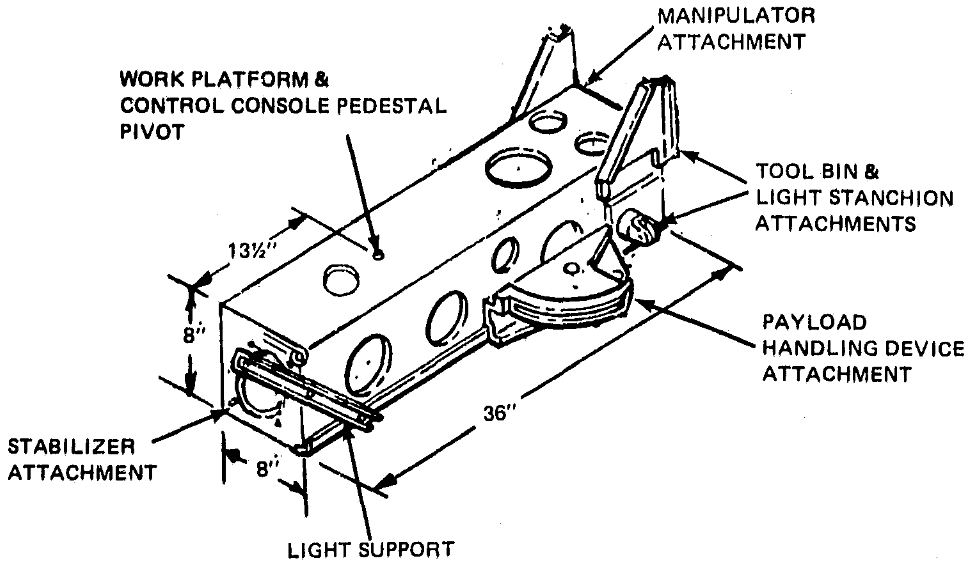


Figure A-11. DTA Base Structure

3.3.2.4 <u>Control</u> - The location/positioning of the stabilizer shall be manually controlled by the OCP-DTA operator.

3.3.2.5 <u>Back Drive Capability</u> - All motions of the stabilizer and end effector shall be provided with back drive capability beyond load values specified herein.

3.3.2.6 <u>Storage</u> - Stowage of the stabilizer and end effector will be provided with stowage volume 20 x 20 x 137 cm located on the underside of the OCP (Figure A-16).

3.3.2.7 <u>Mass</u> - Mass of stabilizer including end effector shall be less than 50 lb.

3.3.3 <u>End Effectors</u>

3.3.3.1 <u>Configuration</u> - The end effector shall be designed as a mechanical device.

The end effector jaw configuration shall permit grappling the Orbiter EVA hand rails (Figure A-17) and flat surfaces.

Other configurations shall permit handling large lightweight structure.

3.3.3.2 <u>Interfaces</u> - The end effector shall mechanically interface with the stabilizer. Means shall be provided for the OCP-DTA operator to remove and replace the end effector.

3.3.3.3 Characteristics - The end effector shall have the following characteristics: (Figure A-15).

Parameter	Value
Jaw Travel	0-12 cm (5 in.)
Jaw Force	variable, 0 to 890 N (200 lb)

3.3.3.4 Control - The operator shall manually control the pitch, yaw, and rotation, and the opening and closing of the end effector jaws. A manual remote capability shall be provided for opening the end effector jaws.

3.3.4 Controls and Displays Console

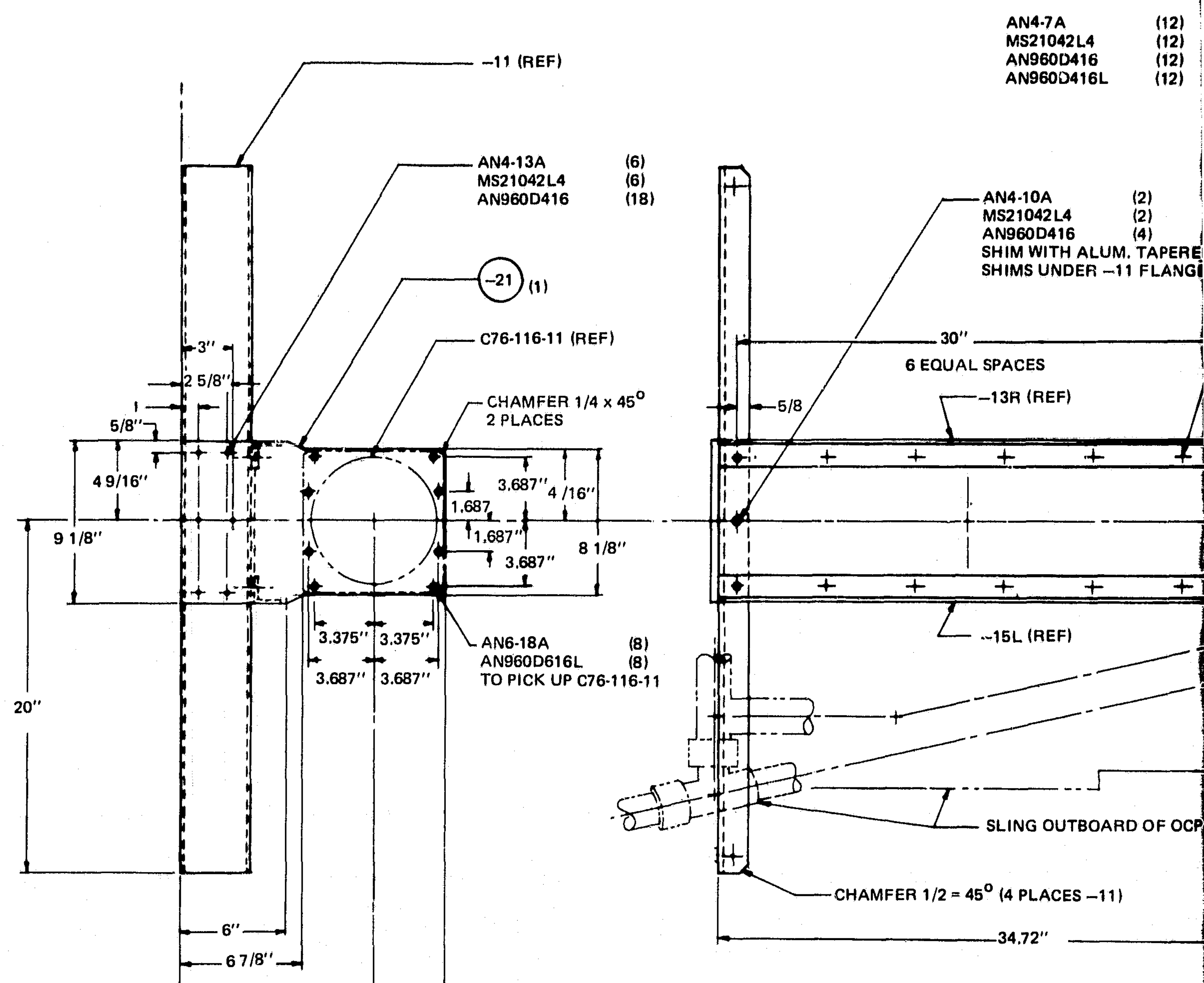
The DTA console design shall provide support for modified Manned Maneuvering Unit (MMU) type rotational and translation hand controllers or a box containing individual joint control switches and a display panel used to operate the MDF manipulator. The console shall rotate to different positions to facilitate operator control of the OCP-DTA during maneuver and for clearance during operator work tasks. The console pedestal height shall be adjustable from the top surface of the foot restraint platform to the lower edge of the top surface of the console from 88 cm (34-1/2 in.) to 122 cm (48 in.). The console shall fold for storage.

3.3.4.1 Controller - The DTA design shall provide for the interface and support of MMU rotation and translation and controllers to be provided GFE. The controllers shall be located on the DTA C&D Console (Figure A-18). The mechanical and electrical interfaces shall be per NASA drawings: TBD rotation control and TBD translation control. The controller position shall be adjustable in pitch attitude.

3.3.4.2 Controls and Displays Panel - The DTA panel design shall provide for mounting the components listed in Table A-2. See Figure A-18 for panel layout.

- Digital Display - Digital Display indicator will be a Weston Instruments Model No. 2470. Three displays each consisting of four digits, ± sign, and a fixed decimal point will be provided. Each display will be driven by a ±10 VDC D/A converter located in the RTP. The scale factors will be as follows:

  X, Y, Z 999.9 = 10.0 volts
  p, q, r 999.9 = 10.0 volts
  Joint Angle 99.99 = 10.0 volts

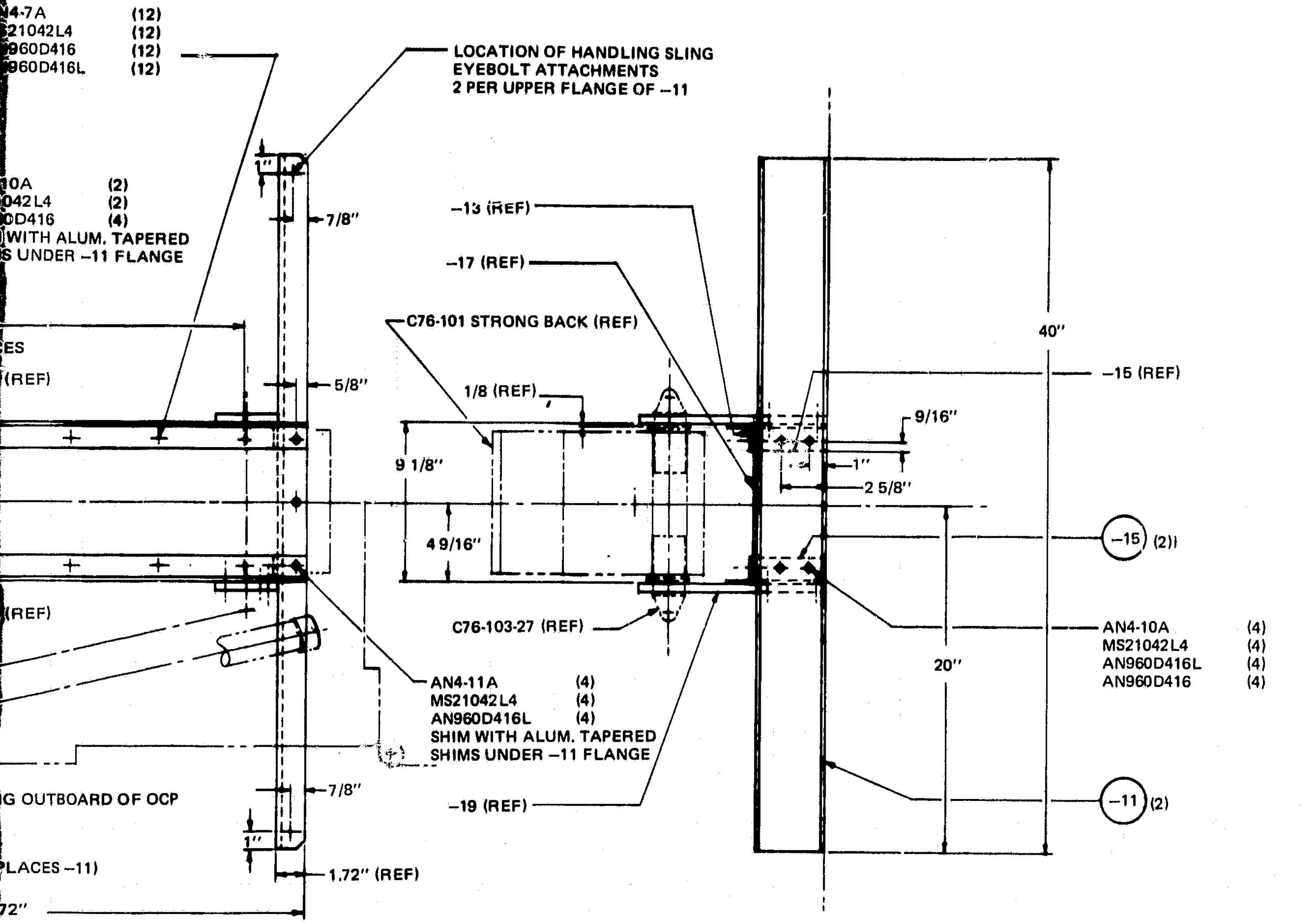


NOTE:

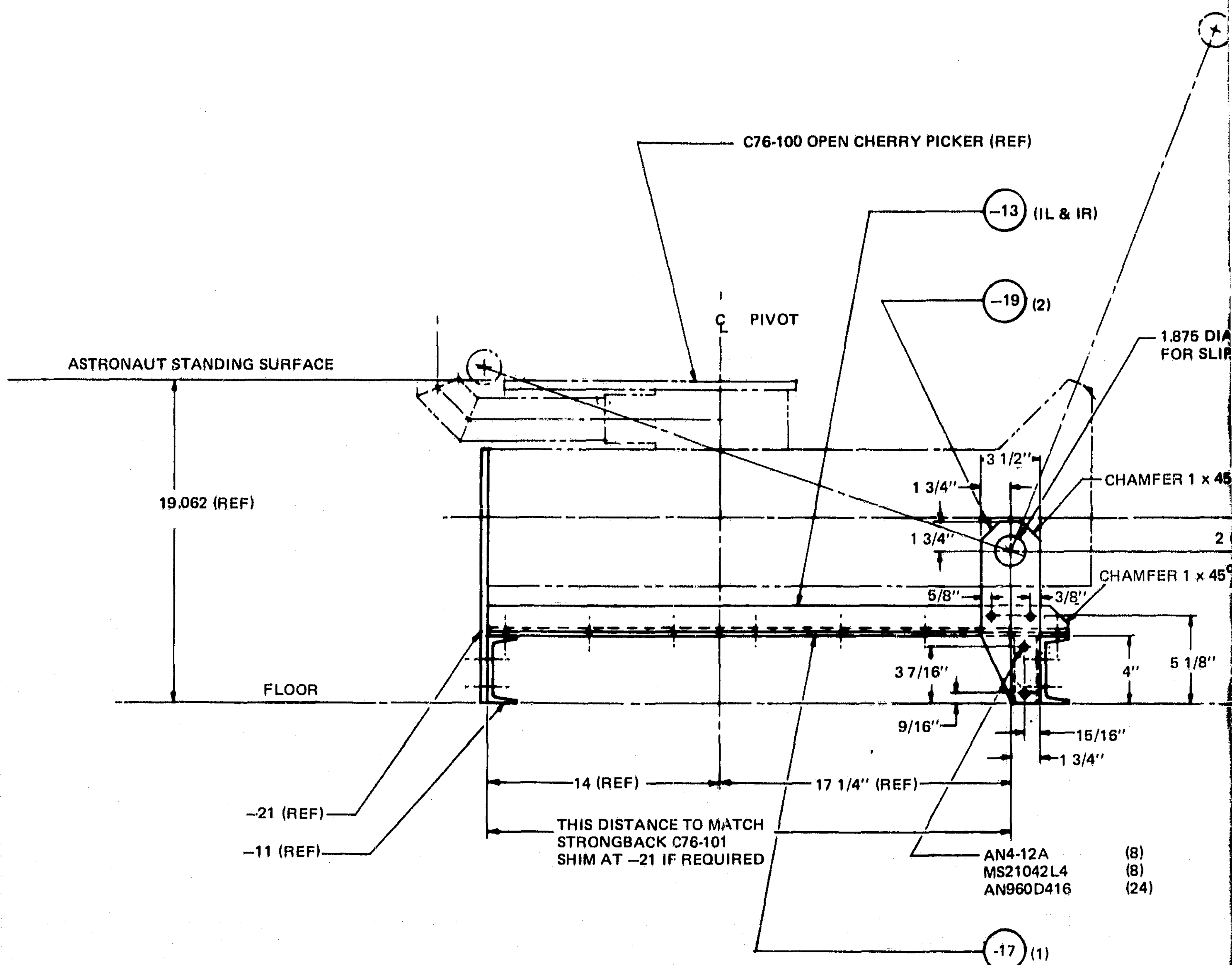
BREAK ALL EDGES 1/16

0081-011

FOLDOUT FRAME



FOLDOUT FRAME 2



C76-125 CRADLE INSTALLATION (1) REQD

C76-125 CRADLE ASSEMBLY (1) REQD

Figure A-12. DTA/A

FOLDOUT FRAME 3

A

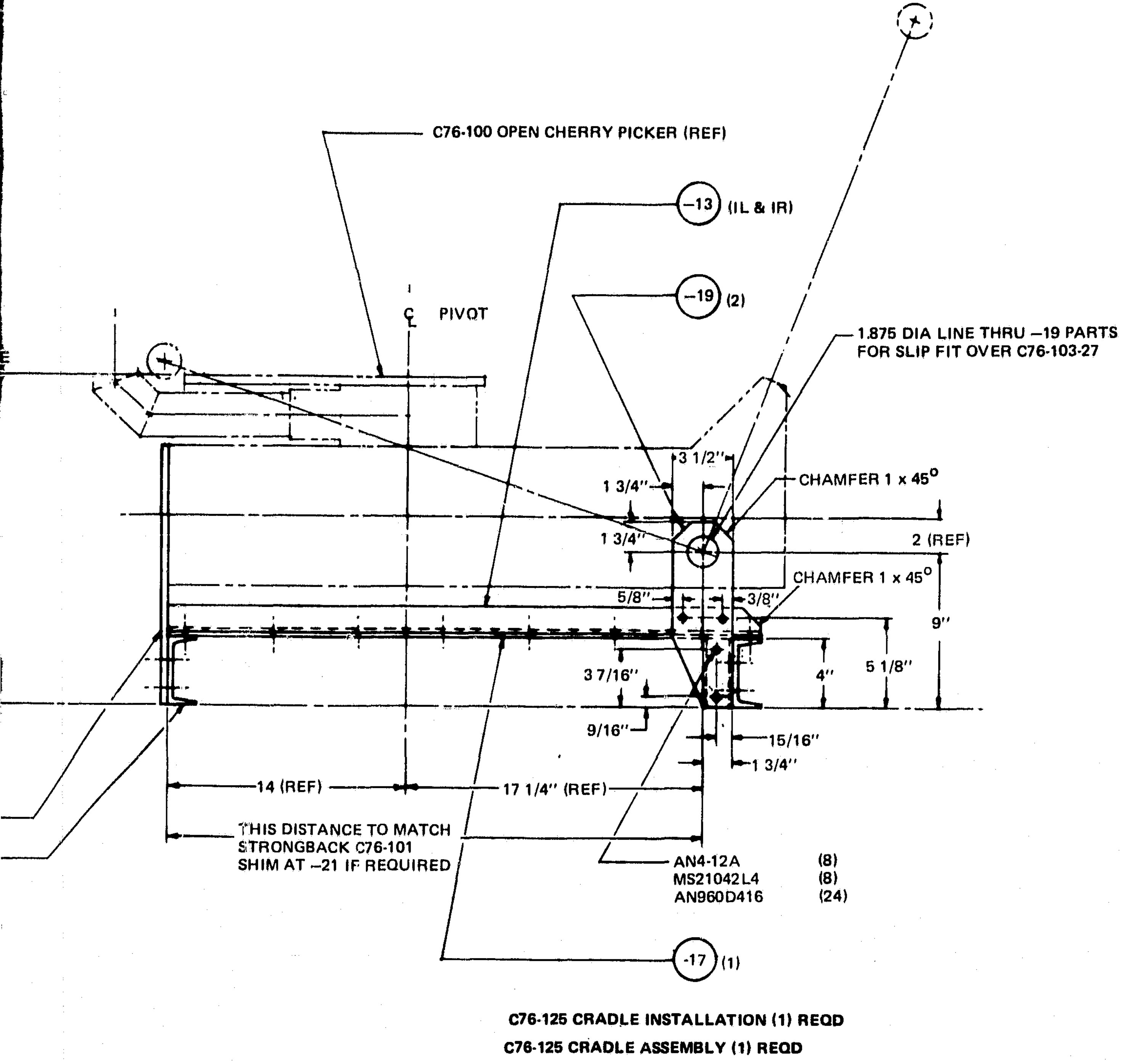


Figure A-12. DTA/Air Bearing Platform Interface

T FRAME 3

FOLDOUT FRAME 4

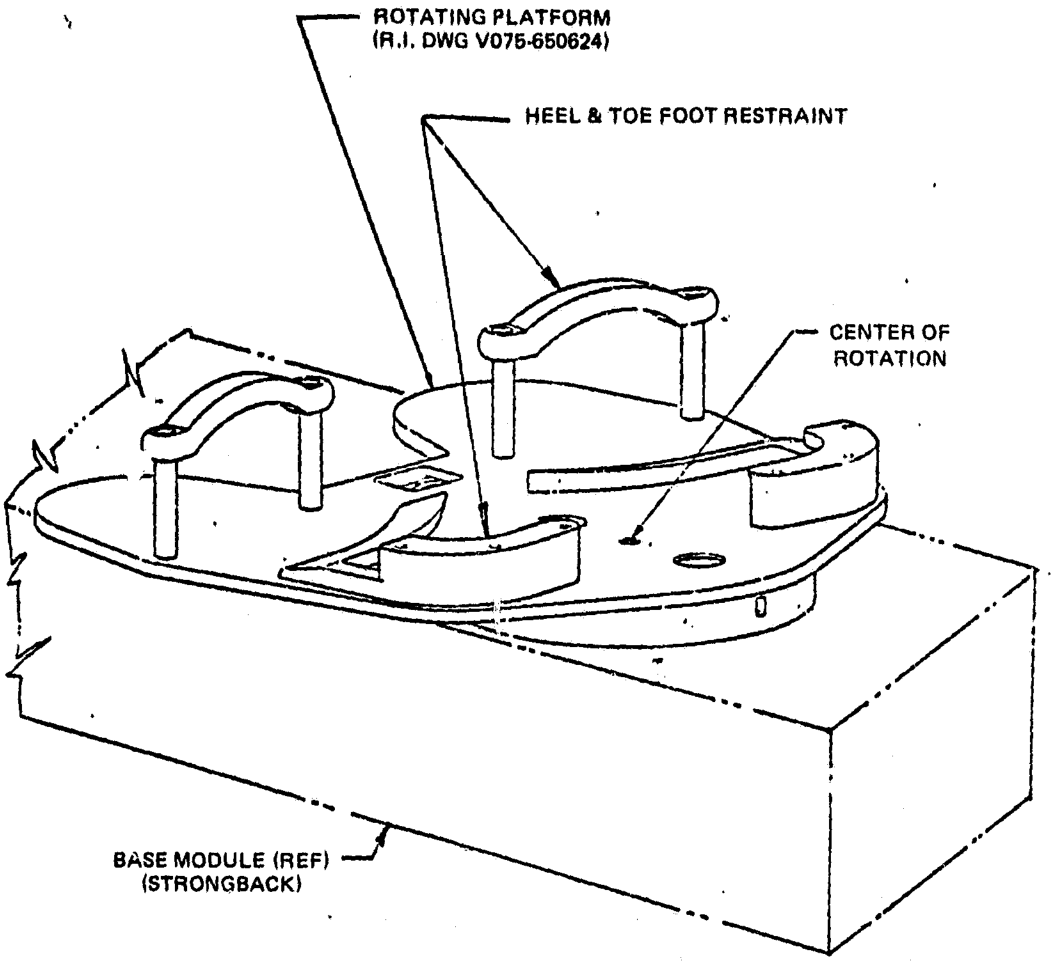


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Figure A-13. Rotatable Foot Restraint Platform

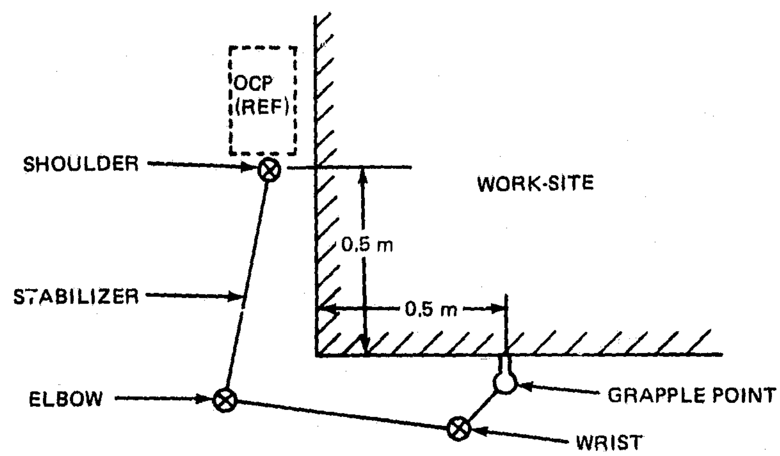

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Figure A-14. Stabilizer Reach Around Capability

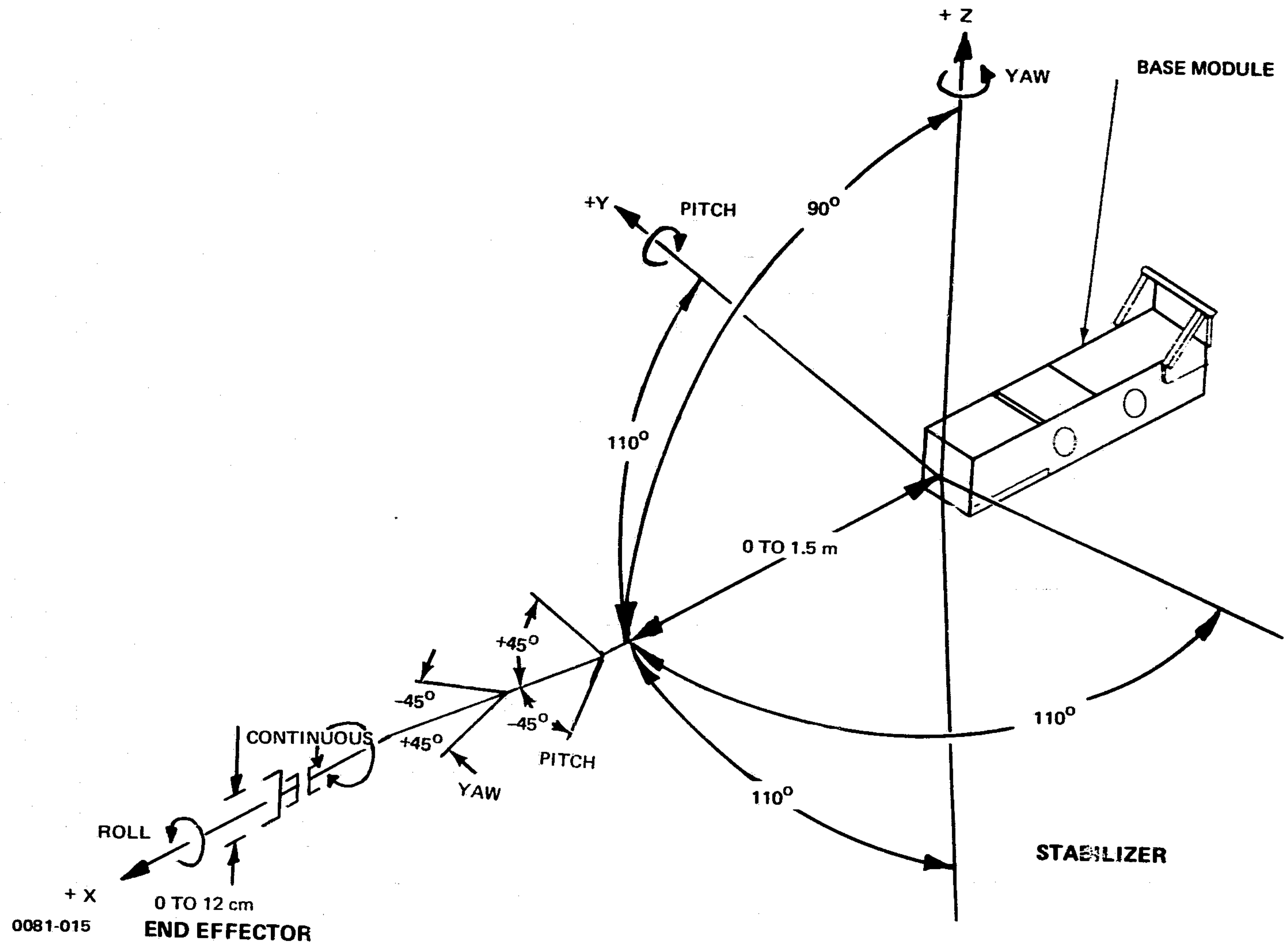

Figure A-15. Stabilizer and End Effector Travel

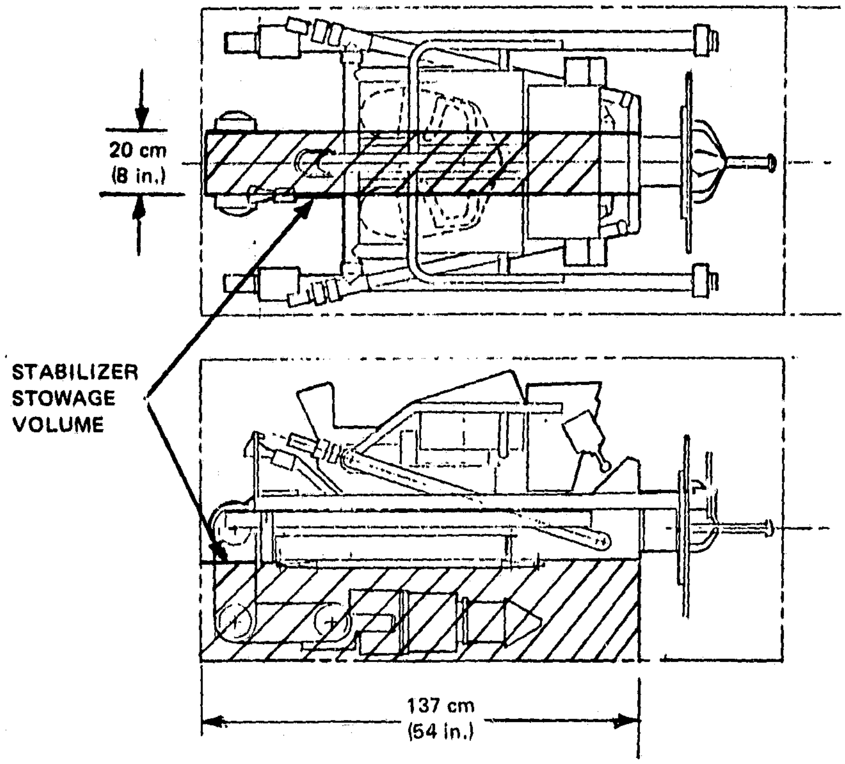

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Figure A-16. Stabilizer Stowage Location and Volume

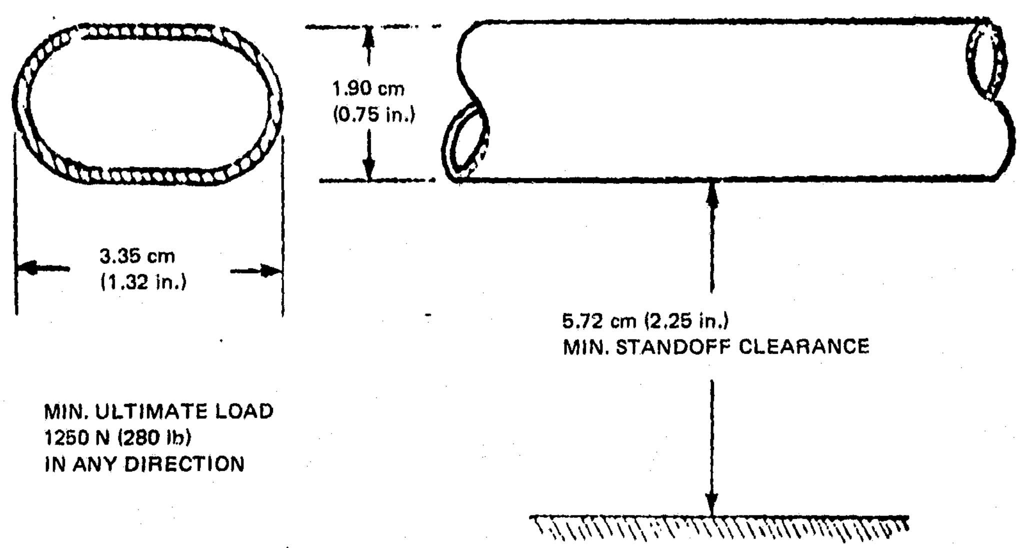

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Figure A-17. EVA Handrail Grip

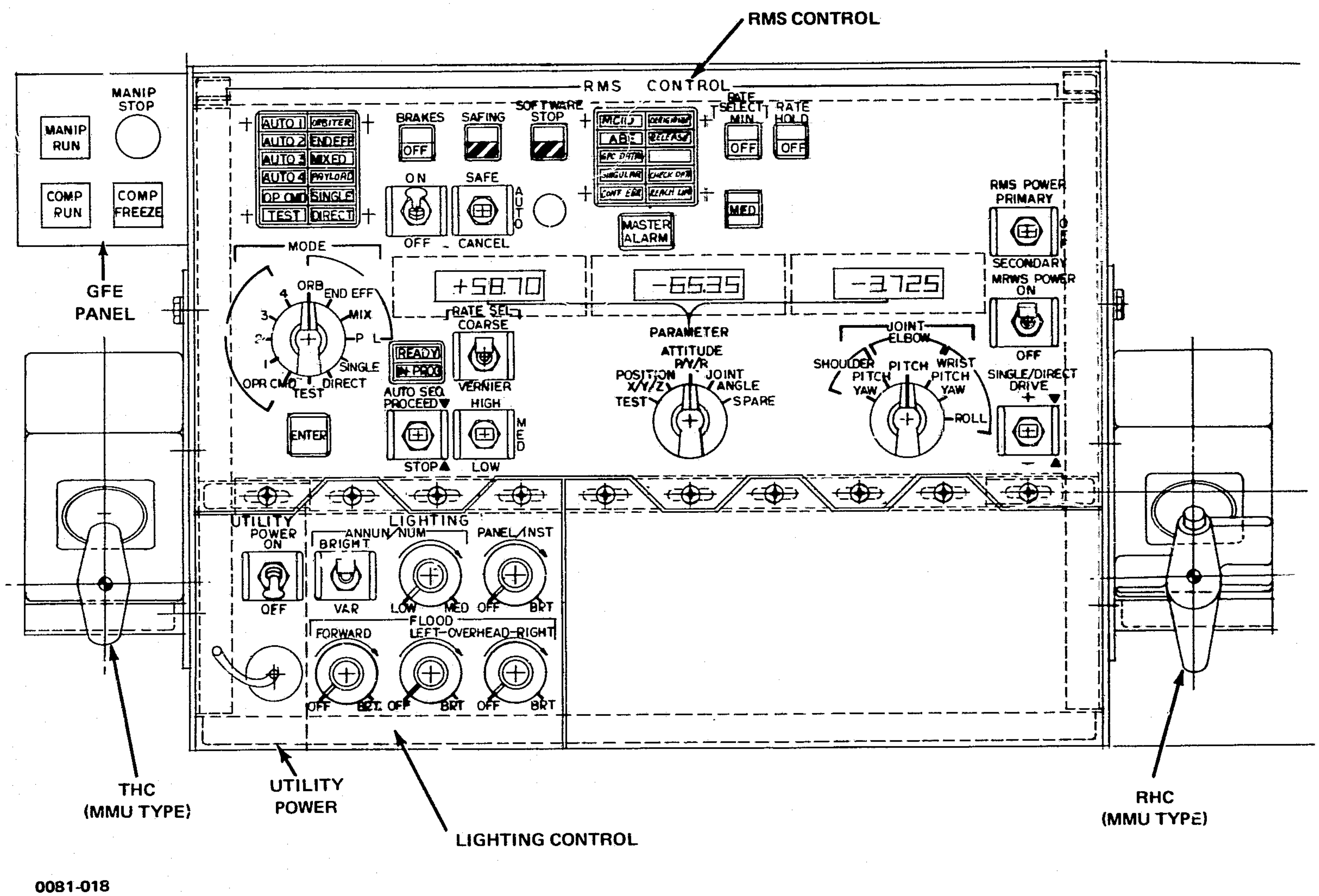


Figure A-18. Controls and Displays Console

TABLE A-2

CONTROLS AND DISPLAYS COMPONENTS
(Sheet 1 of 2)

PANEL FUNCTION	PANEL FUNCTION
• MODE SELECTION SWITCH TEST OPR CMD AUTO 1 AUTO 2 AUTO 3 AUTO 4 ORB END EFF MIX PL SINGLE DIRECT • MODE ENTRY SWITCH • AUTO SEQUENCE PROCEED/STOP • RATE HOLD SWITCH ON RHC • SAFETY START/AUTO/CANCEL • BRAKES ON/OFF SWITCH • RMS RATE SEL VER/COARSE SWITCH • RMS RATE SEL LOW/MED/HIGH SWITCH	• SAFEING STATUS FLAG • MASTER ALARM ANNUN. • CAUTION/WARNING ANNUN. SINGULAR CONTR ERR CHECK CRT REACH LIM MCIU ABE GPC DATA DERIGIDIZE RELEASE • PARAMETER SELECT SWITCH TEST POSITION X/Y/Z ATTITUDE P/Y/R JOINT ANGLE SPARE • THREE DIGITAL INDICATORS • THREE FLOOD LIGHT INTENSITY CONTROL SWITCHES • UTILITY POWER SWITCH/PLUG • ANNUN. BRIGHTNESS SELECT SWITCH BRIGHT/VAR

0081-019(1)

TABLE A-2

CONTROLS AND DISPLAYS COMPONENTS
(Sheet 2 of 2)

PANEL FUNCTION	PANEL FUNCTION
• RMS JOINT SELECTION SWITCH SHLD PITCH SHLD YAW ELBOW PITCH WRIST PITCH WRIST YAW WRIST ROLL • RMS SINGLE/DIRECT DRIVE SWITCH • MODE STATUS INDICATOR ANNUN. TEST OPR CMD AUTO 1 AUTO 2 AUTO 3 AUTO 4 ORBITER END EFF MIXED PAYLOAD SINGLE DIRECT • AUTO SEQUENCE STATUS ANNUN. READY IN PROG • BRAKE STATUS FLAG • SOFTWARE STOP FLAG	• ANNUN./NUM INTENSITY CONTROL SWITCH • PANEL LIGHT INTENSITY SWITCH • RATE HOLD ANNUN. • RATE SELECT COARSE/VER ANNUN. • RATE SELECT MED ANNUN. • RMS POWER ON/OFF SWITCH PRIMARY • RMS POWER ON/OFF SWITCH SECONDARY • ROTATIONAL HAND CONTROLLER • TRANSLATION HAND CONTROLLER • COMPUTER CONTROL PANEL (GFE) MANIP RUN MANIP STOP COMP RUN COMP FREEZE INTERCOM PLUG

0081-019(2)

3.3.4.3 Swing Arm Assembly - The DTA swing arm design shall provide support for the console pedestal. The swing arm shall be capable of rotating 180° and be indexed and locked at five flight station locations (Figure A-19) 0°, 45°, 90°, 120°, and 180°.

3.3.4.4 Pedestal Console Latch - A manually operated latch release shall be provided for the EMU suited operator. The manual release shall be a one-handed operation compatible with a gloved hand. The location of the latch release shall be readily accessible to the operator. The pedestal shall be rotatable from operate position (90°) to three off-line positions, 99°, 108°, and 117°, to provide clearance for the operator EMU PLSS movement (Figure A-19).

3.3.4.5 Console Hand-Hold - An EMU gloved hand compatible hand-hold shall be provided on the console to be used by the operator when the console is to be moved and for support when the operator attaches or releases his foot restraint.

3.3.4.6 Audio Communications - The DTA shall provide for on-board facility audio communications. The intercom panel shall be mounted on the C&D Console and shall be provided GFE.

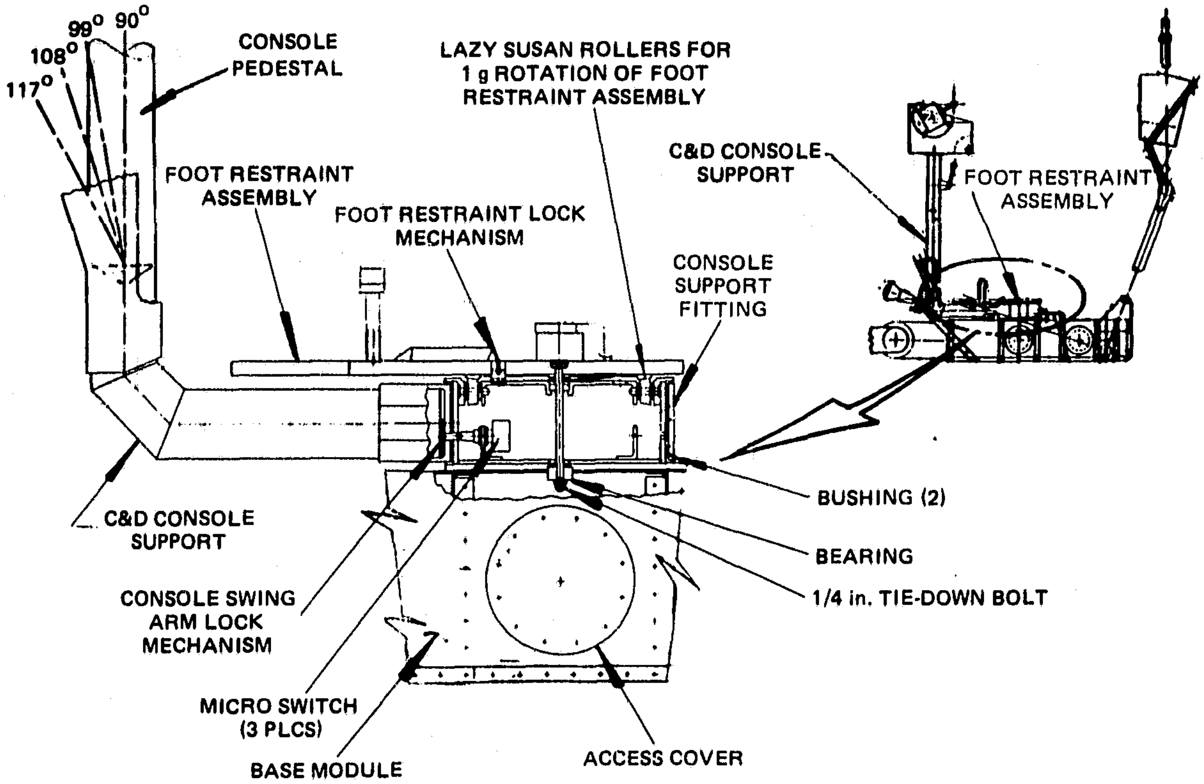
3.3.5 Light Stanchion

3.3.5.1 Stanchion Assembly - The DTA stanchion (Figure A-20) shall be designed to provide support for:

- (2) 120 W light fixtures
- (2) EVA hand-holds
- (2) Tool storage bins.

The location of the stanchion on the DTA shall not inhibit the EVA crewman from rotating himself 360° with the EVA foot restraint assembly. The stanchion shall be capable of being folded/telescoped manually for compact stowage of the DTA. The stanchion shall be manually deployed by the operator from its stowed position to the stanchion operating position.

3.3.5.2 Hand-Holds - The DTA stanchion shall be designed to support (two) hand-holds. The hand-holds are to be compatible with the EMU gloved hand and shall be located to assist the operator in egress/ingress the EVA foot restraints. The stanchion shall be designed for the loads defined in Table A-1.



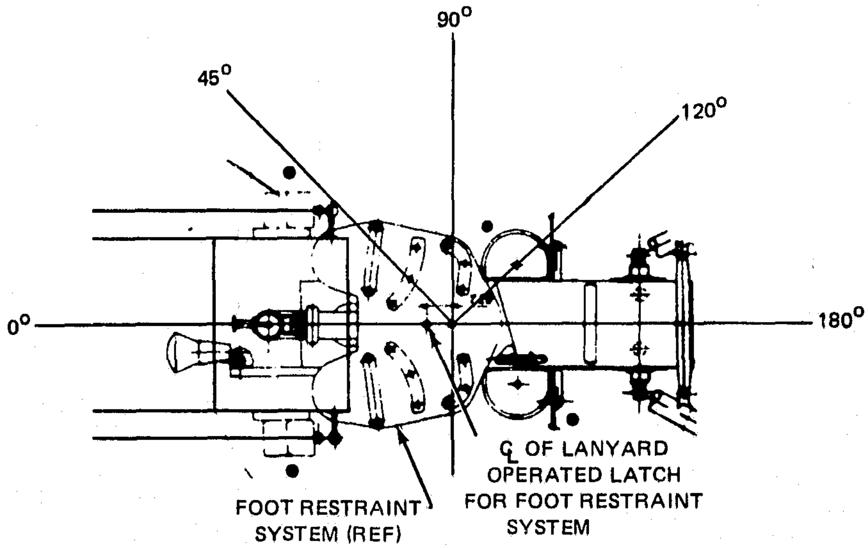


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Figure A-19. DTA Foot Restraint and Console Attachment to Base Module

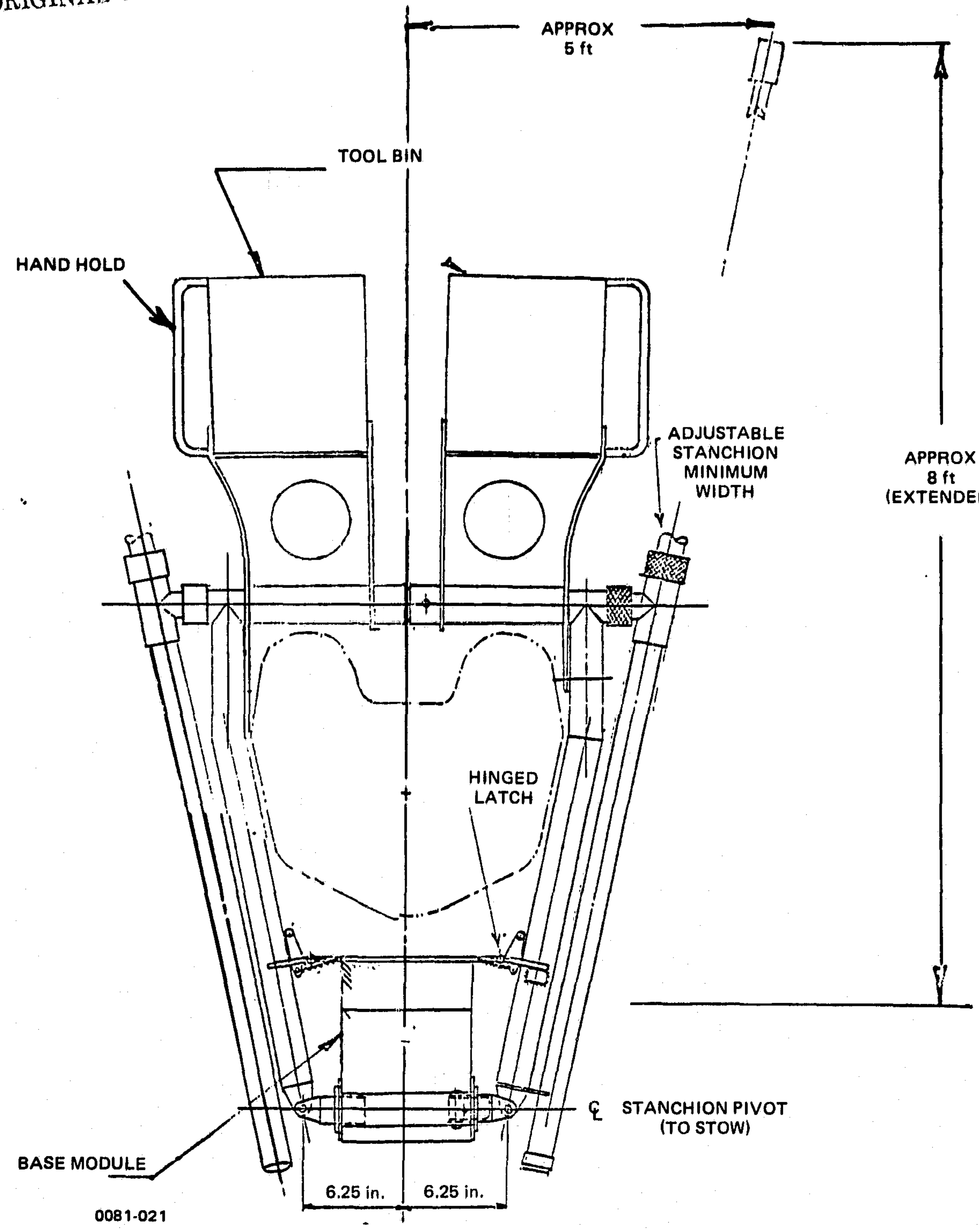

Figure A-20. Flood Light Stanchion

3.3.5.3 Light Fixtures - The DTA design shall provide two light fixtures for over the shoulder flood lighting and one light mounted on the base. The fixtures shall be capable of utilizing 120 W tungsten-type flood lights. The fixtures shall be attached to the stanchion, and each fixture shall be capable of one-hand pan and tilt adjustment by the operator in EMU. The over-the-shoulder light fixture shall provide a vertical adjustment of 1.7 m (5.5 ft) to 2.4 m (8 ft) above the foot restraint platform and a horizontal separation of 0.8 m (2.5 ft) minimum to 1.5 m (5 ft) maximum (Figure A-20). The flood light controls shall be located on the C&D control console. Hot surfaces shall be guarded by insulation/protective devices to prevent the possibility of operator being burned.

3.3.5.4 Tool Bin - The DTA design (Figure A-21) shall provide approximately 0.036 m^3 (1.25 cu ft) of tool storage volume to carry 23 kg (50 lb) of mission-peculiar tools. The tool bin will be attached to and supported by the stanchion. The attachment mechanism (hinge) shall provide for two positions (operating, off-line/stow) of the tool bin. The operating position shall be adjustable to provide adequate access to the hand tools for both the 95th percentile man and the 5th percentile woman operator. The off-line/stow position shall locate the bin so as not to interfere with the operator when rotating (360°) with the foot restraint assembly. The tool bin shall be capable of manually being moved to and locked at each of the two positions.

3.3.5.5 Latching Assembly - The DTA shall provide a latching assembly to position the light stanchion in the erected (operate) and folded (stowed) position. The assembly shall be capable of being locked in either position by a laboratory technician.

3.3.6 Payload Handling Device

3.3.6.1 Mechanical Assembly - A Payload Handling Device (concept Figure A-22) shall be provided. This device shall be capable of assisting the operator in handling the subsystem modules of the Multi-Mission Modular Spacecraft (MMS) and the experiment trays of the Long Duration Experiment Facility Spacecraft (LDEF), as well as being adaptable to handle the sizes and shapes identified in Figure A-22. The device shall be used to assist in the removal, replacement of these equipments from the spacecraft and provide for their stowage and retention aboard the DTA.

3.3.6.2 Pedestal and Clamp - The DTA design shall provide a pedestal and clamp to interface with the equipments shown in Figure A-22. The pedestal and clamp assembly shall be capable of a vertical translation of the payload equipment from 0 to

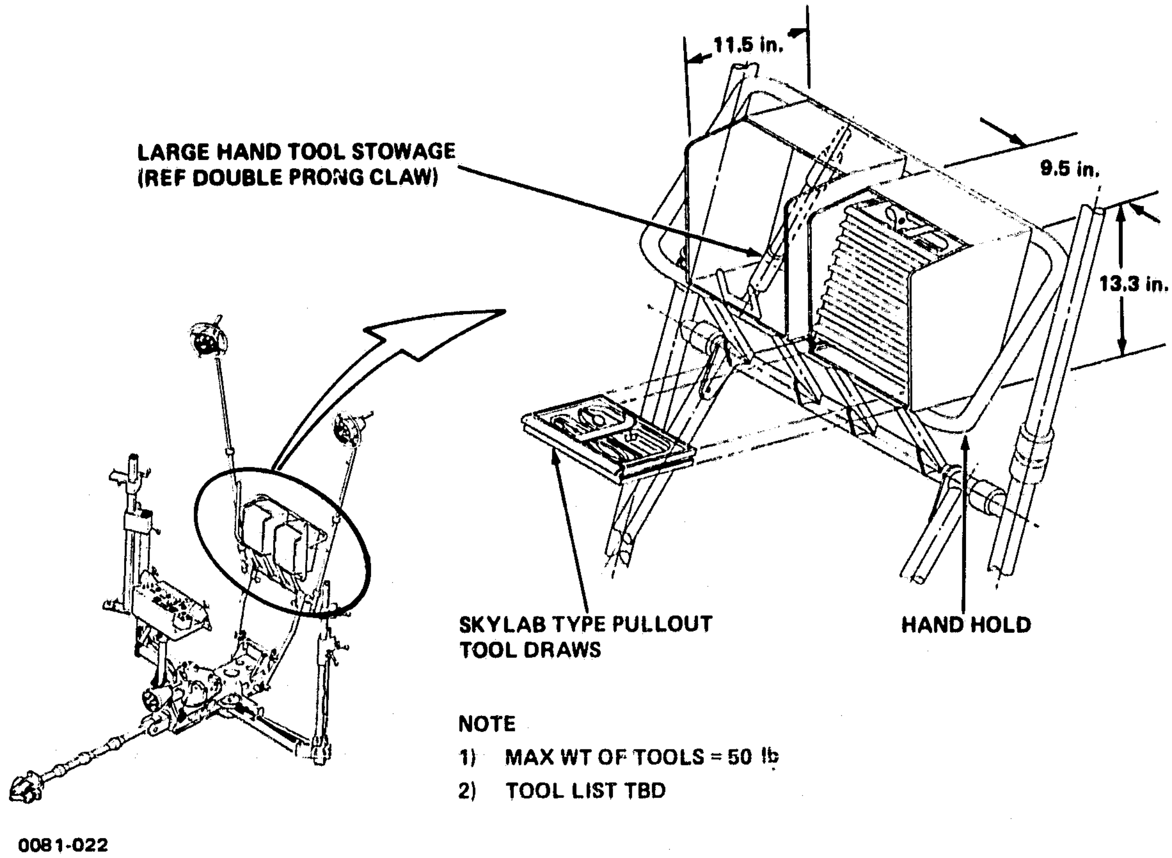

Figure A-21. DTA Tool Bin Stowage Arrangement

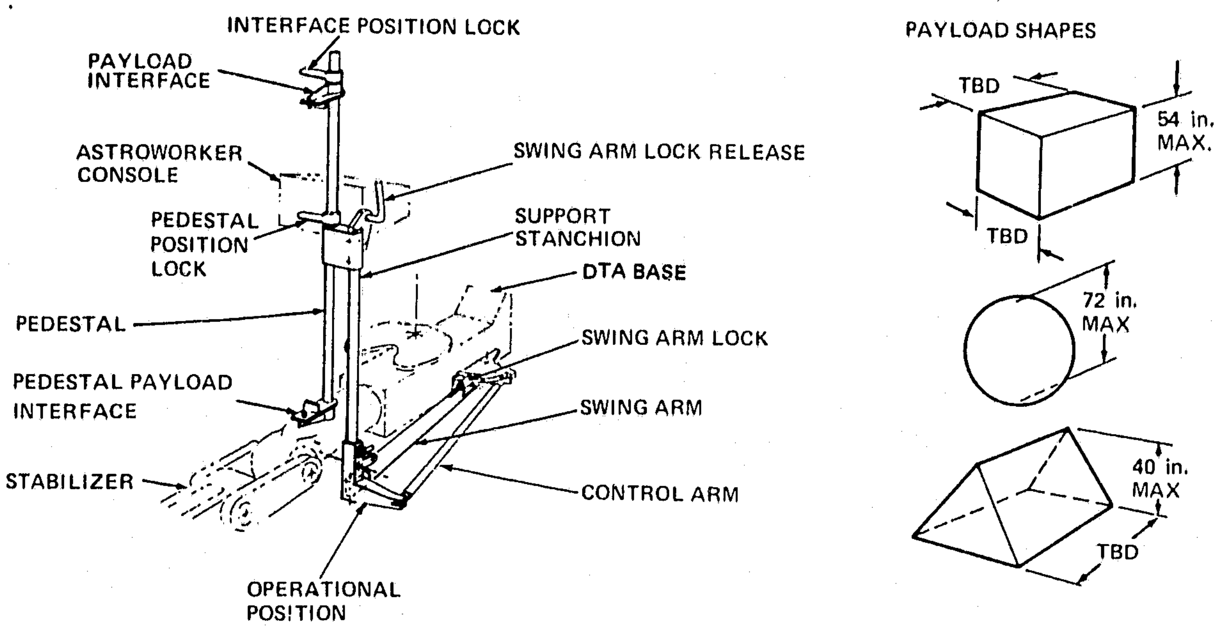

Figure A-22. Payload Handling Device

43 in. depending on the size of the payload. The pedestal and clamp assembly shall be attached to and supported by a swing arm assembly.

3.3.6.3 Swing Arm - The DTA Payload Handling Device Swing Arm shall be designed to provide support for payload pedestal and clamp assembly and payload. The swing arm shall be capable of rotating 87° and be indexed and latched at preselected locations.

3.3.7 Electrical Assembly

3.3.7.1 Electrical Schematics - Electrical schematics are Figures A-23, "Manipulator Electrical Schematic," and A-24, "Lighting and Intercom Schematic."

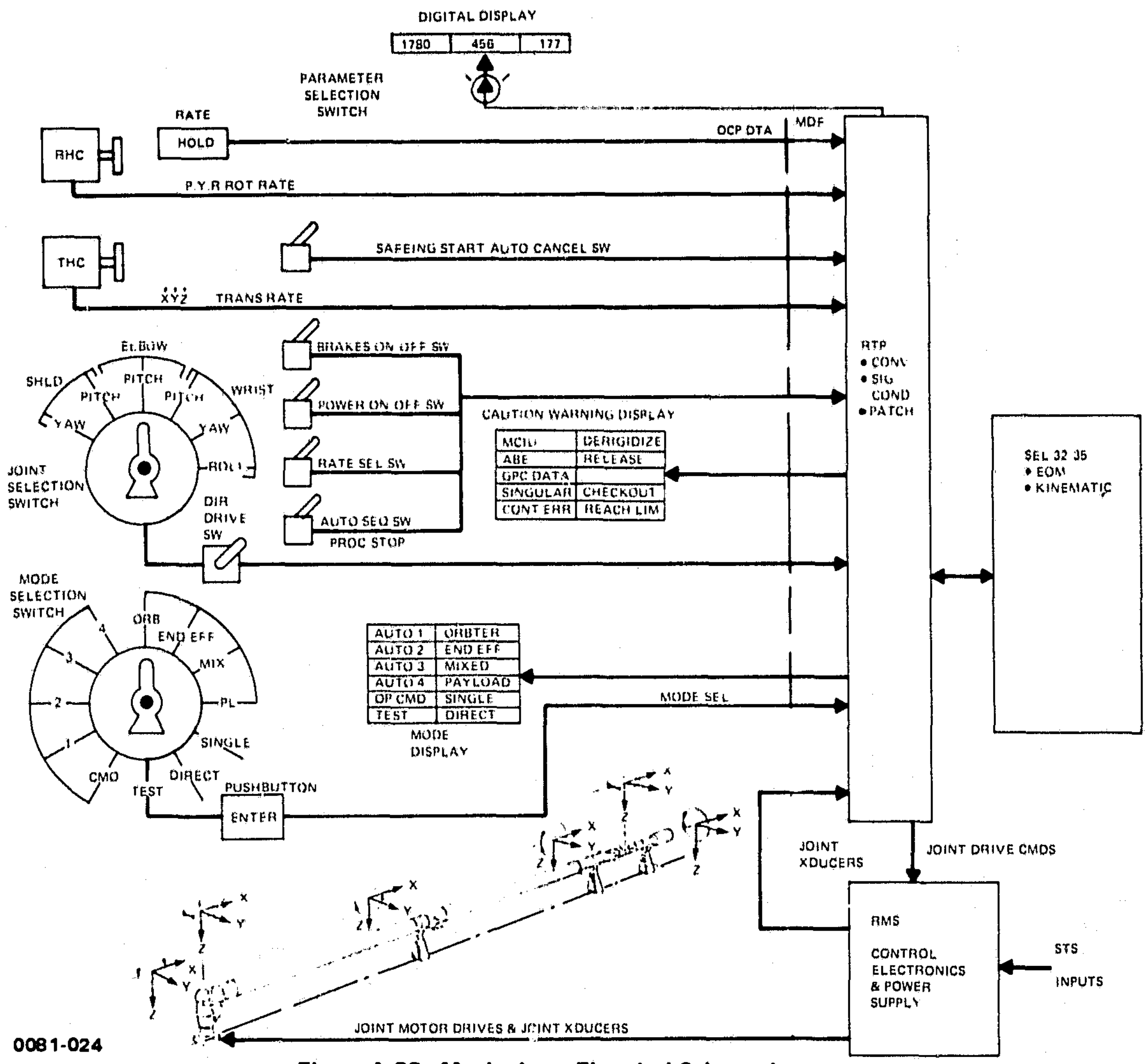

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Figure A-23. Manipulator Electrical Schematic

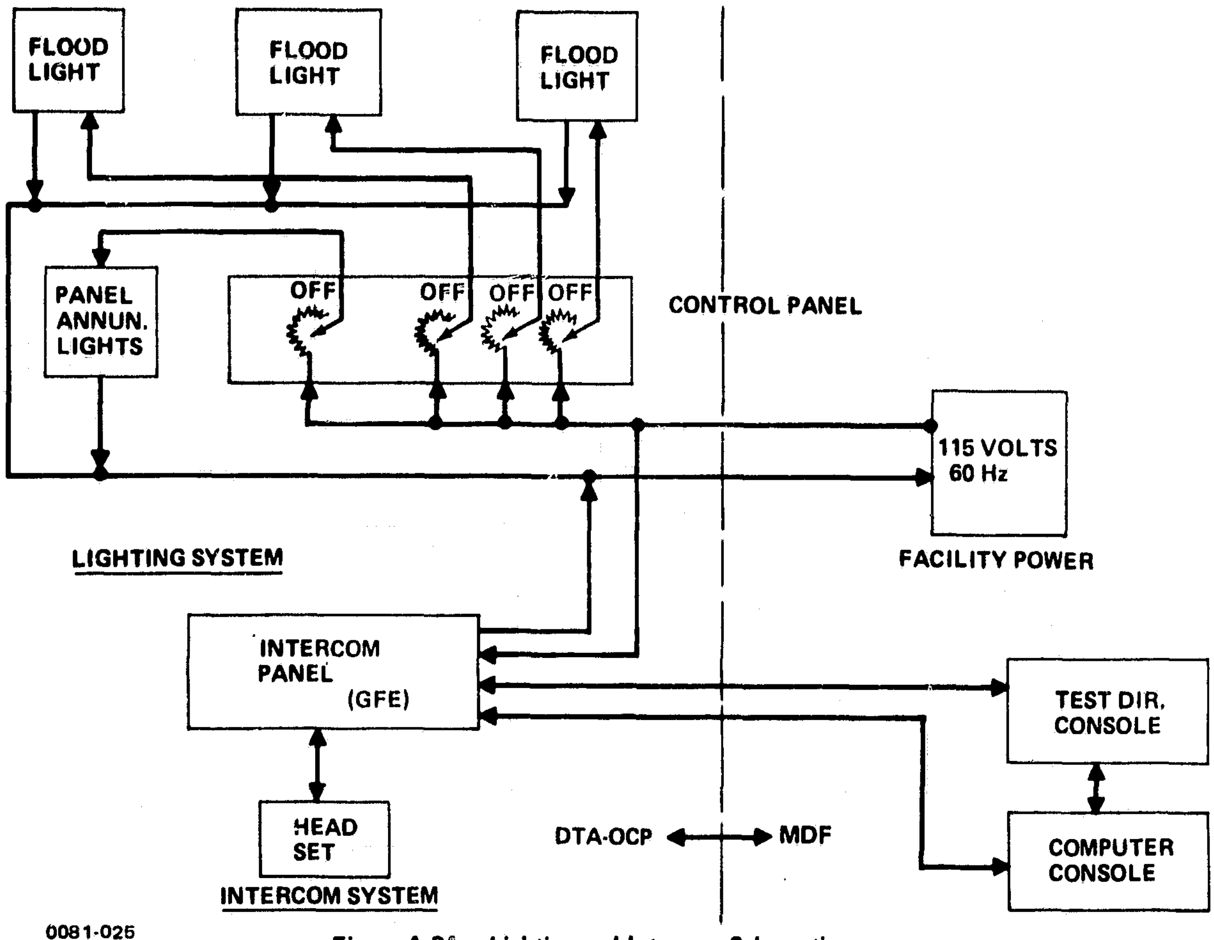


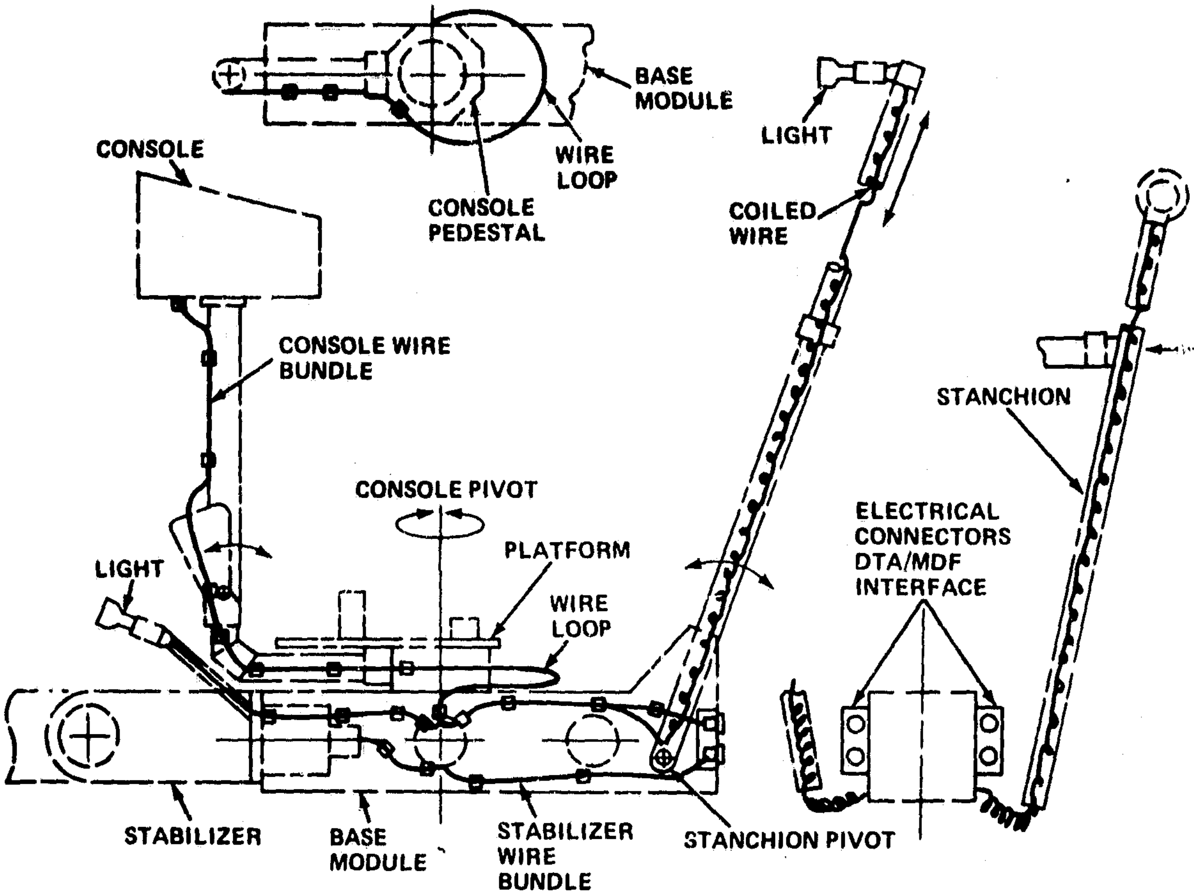
Figure A-24. Lighting and Intercom Schematic

The manipulator schematic shows two modes of control, the RHC and THC hand controllers, and switches for individual joint operation. Each light in Figure A-24 has individual dimmer controls for illumination assessment.

3.3.7.2 Wiring Harness - The wiring harness shall meet the requirements of the final electrical schematics and shall be routed from the MDF manipulator interface at the DTA base to the console panel and lights (Figure A-25).

3.3.8 Safety/Rest Restraint

The DTA design shall provide a safety/rest restraint for the DTA operator that shall be hand adjustable by a laboratory technician to fit the operator.



0081-026

Figure A-25. Open Cherry Picker Electric Wire Routing

3.4 COMPONENTS

3.4.1 GFE Components

Component	Qty
Translation Hand Controller (MMU Type)	1
Rotational Hand Controller (MMU Type)	1
Foot Restraint Assembly (Shuttle Type)	1
Comm/Computer Control Panel	1
Power/Signal Electrical Harness	1
Air Bearing Platform	1
Spar Grapple Fitting	1

3.4.2 Contractor Components and Parts

3.4.2.1 Components

	Qty
Base Module	
Base Structure	1
Stabilizer Supports	1
Manipulator Attachments	1
Control Console Bearing	1
Air Bearing Table Fittings	4
Light Support	1
Light Stanchion Attachments	2
Payload Handling Device Attachments	2
Work Platform Bearing	1
Safety/Rest Restraint Attachments	2
Stabilizer	1
End Effectors	TBD
Controls & Displays Console	
Controls & Displays Panel	1
Swing Arm Assembly	1
Latch Assembly	1
Light Stanchion	
Stanchion Assembly	1
Hand Holds	
Light Fixtures	2
Tool Bins	2
Latch Assembly	1
Payload Handling Device	
Pedestal and Clamp	2
Swing Arm	2
Safety/Rest Restraint	1

3.4.2.2 Parts

Controls & Displays Console

Part	Qty
Connector	3
Pwr Controller	3
Potentiometer	2
Digital Display Monitor (Weston Instruments, Model 2470)	3
Flag Indicator	6
Annunciator Indicator	3
Toggle Switch	10
Rotary Switch	3
Pushbutton Switch	2

Section 4

QUALITY ASSURANCE PROVISIONS

The OCP integration and checkout shall be accomplished in three phases (Figure A-26).

4.1 COMPONENT TESTS

Components will be bench tested prior to subsystem/module assembly.

4.2 DTA CHECKOUT

During the DTA checkout phase, after all subsystem assemblies have been installed on the DTA, all mechanical deployment and adjusting mechanisms will be checked out for proper operation. Each mechanical subsystem shall be powered and exercised to verify operation and shall be checked for various interfaces with other subsystems. External DTA interfaces with the MDF facility shall be verified before shipment to JSC to assure compatibility with documented interface requirements.

4.3 DTA/MDF INTEGRATION

The integrated OCP-DTA shall be delivered to JSC-MDF and installed on the air bearing platform and attached to the manipulator. The operation of all mechanical/structural deployment and adjustment mechanism will be demonstrated. All facility wire harnesses shall be attached to the DTA interface (electric power, intercom, computer) and each subsystem powered and exercised to ensure proper operation in the DTA and various monitoring consoles in the MDF (test director, computer). The DTA/manipulator/SEL 32/35 drive loop shall be verified by applying command signals from the DTA hand controllers and joint drive switches on the DTA console to demonstrate that the DTA's travel and velocity on the MDF air bearing floor are within specified limits. All movements are software limited to wrist and shoulder yaw on the air bearing floor. Operation of DTA console control switches and status displays which are exercised from the MDF computer system shall be verified.

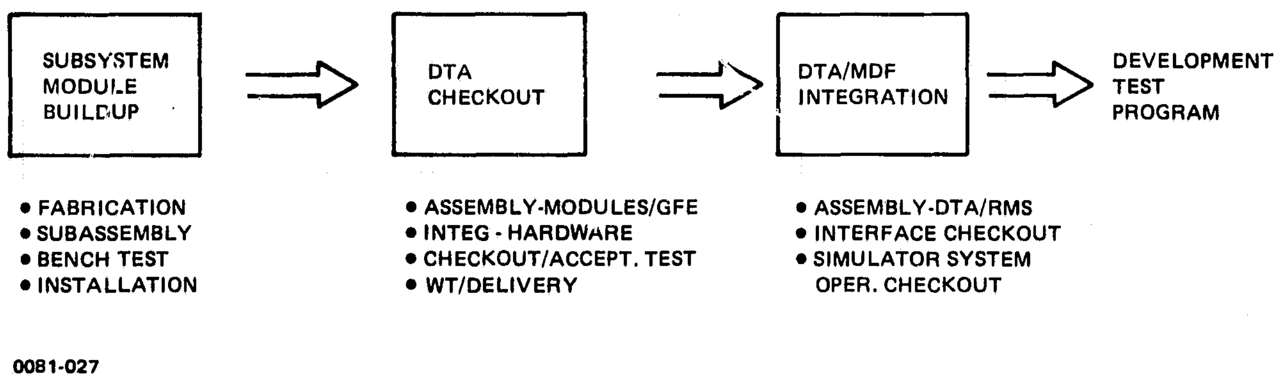


Figure A-26. OCP-DTA Integration and Checkout