



SSSWG MEETING #22

PRESENTATION MATERIALS

NOVEMBER 29, 1989

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WEDNESDAY NOVEMBER 29, 1989

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BUILDING 30 AUDITORIUM
Houston, Texas

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SPACE STATION EXTERNAL MAINTENANCE REQUIREMENTS STATUS

NOVEMBER 29, 1989

CAREY COBB/ BARRIOS for PAUL MARSHALL/ NASA-Space Station Program Office



- **Current EVA demand far exceeds EVA availability in new baseline**
 - As much as 1700 m-hrs/year vs. 132 m-hours/year available

- **External robots viewed as “underutilized” by program**
 - Robot providers require much better intuition of tasks to successfully complete their development effort

 - Investment in robots is very large: visibility into their utility must be improved



- **Develop optimum “pathway” for meeting baseline EVA constraints**
- **Develop recommendations for increasing reliance on external robots**
- **Develop task-level partitioning between robots and EVA**



- **Baseline EVA time allocation recommendation**
 - Reconciled supply vs. demand
 - EVA task menu data base (U&O)
 - Summary EVA maintenance time data (SE&A: input to ASRA)
 - Programmatic impacts (e.g. cost, schedule, weight, design standards, etc.)
 - AMIDD changes
- **Strawman robot time allocation**
 - Additional robot design requirements (capabilities, tools, etc.)
 - Robot task menu data base (U&O)
 - Summary robot maintenance time data (SE&A)
 - AMIDD changes
- **Recommendations for EVA and robotics demonstrations**
- **Refined maintenance concept definition**
- **Documented external task analysis process**

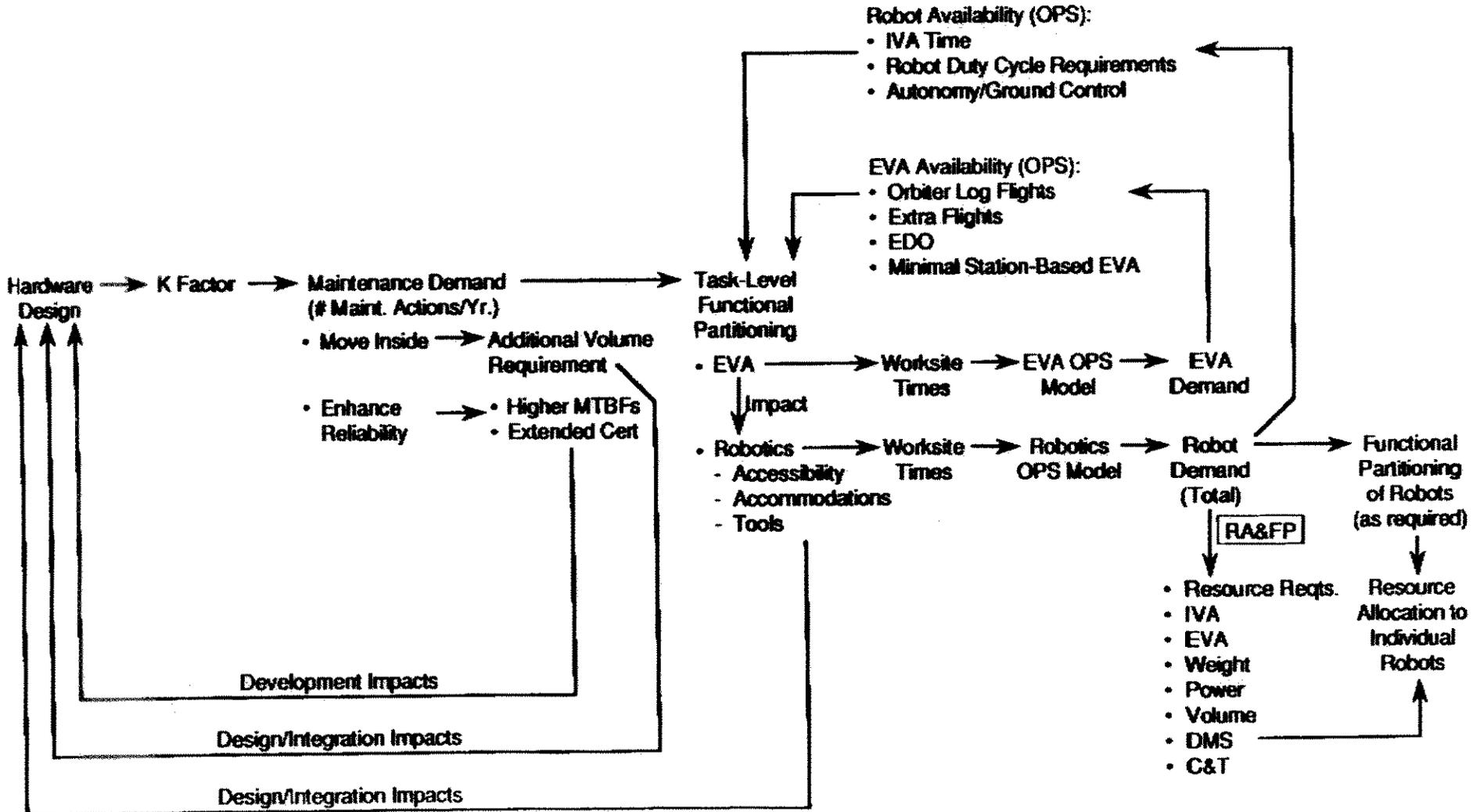


- **Move hardware inside**
- **Improve reliability**
 - Increase MTBF
 - Expanded certification/verification program
 - Preventive maintenance strategy
- **Perform more maintenance tasks with external robots**
 - Integrate robot accommodations into hardware (tools, interfaces, restraints, expand design standards, etc)
 - Improve accessibility
 - Expand robot capabilities
 - Improve performance
 - Increase availability
 - Autonomy options
 - Increase resource allocation (weight, power)

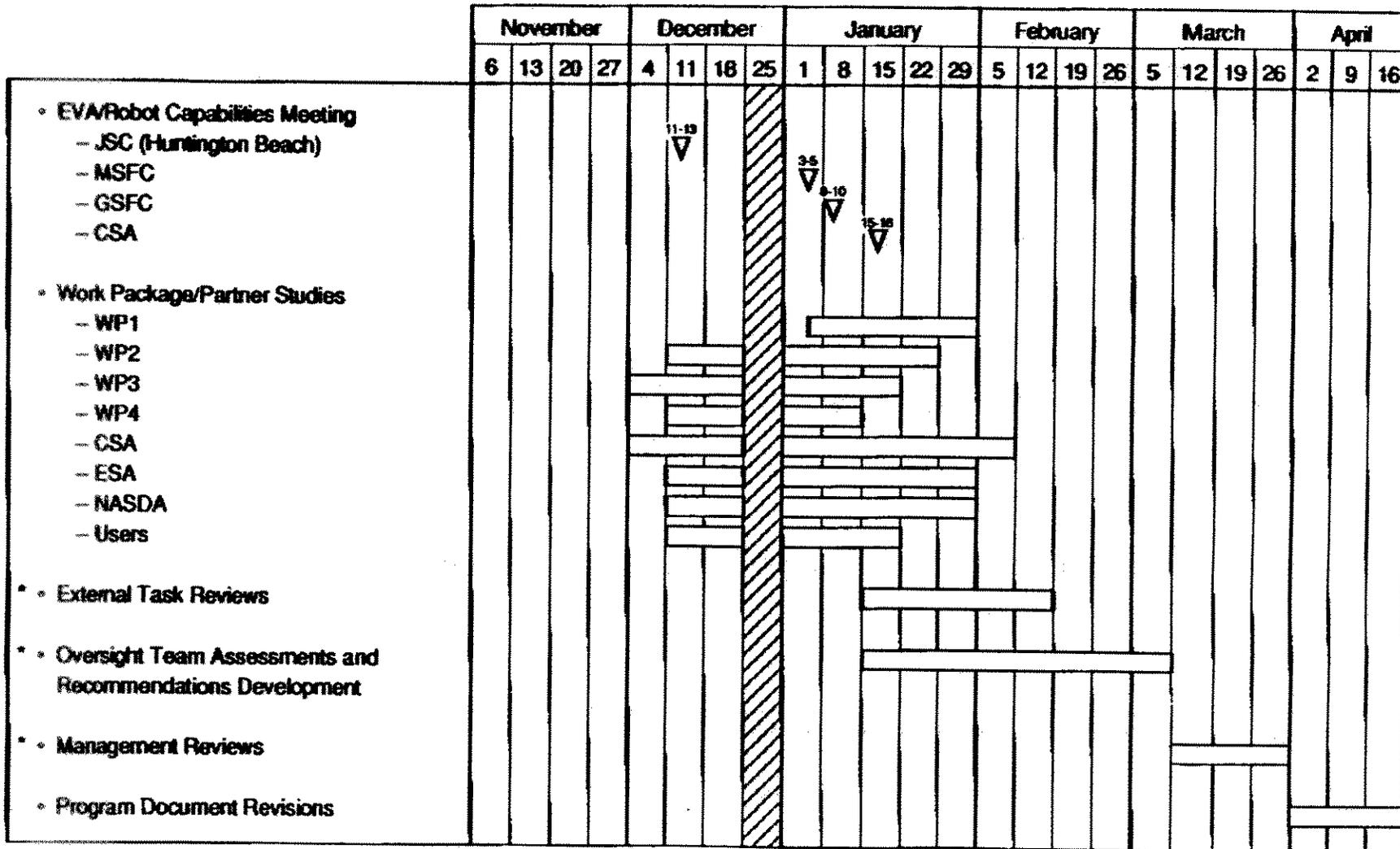


- **Projects/partners verify maintenance demand and develop options**
 - Verify failure characteristics and time projections
 - Study four scenarios (with target EVA time allocations):
 - Revised baseline (no program impacts)
 - 300 m-hour/year total worksite time constraint
 - 150 m-hour/year total worksite time constraint
 - 75 m-hour/year total worksite time constraint
 - Develop ROM impacts for meeting targets
- **Oversight team conduct External Task Review meeting**
 - Consists mostly of EVA/robot providers and operations representatives
 - Review project/partner results
 - Consolidate results
 - Prepare recommendations to program

Detailed Assessment Process



External Maintenance Study Schedule

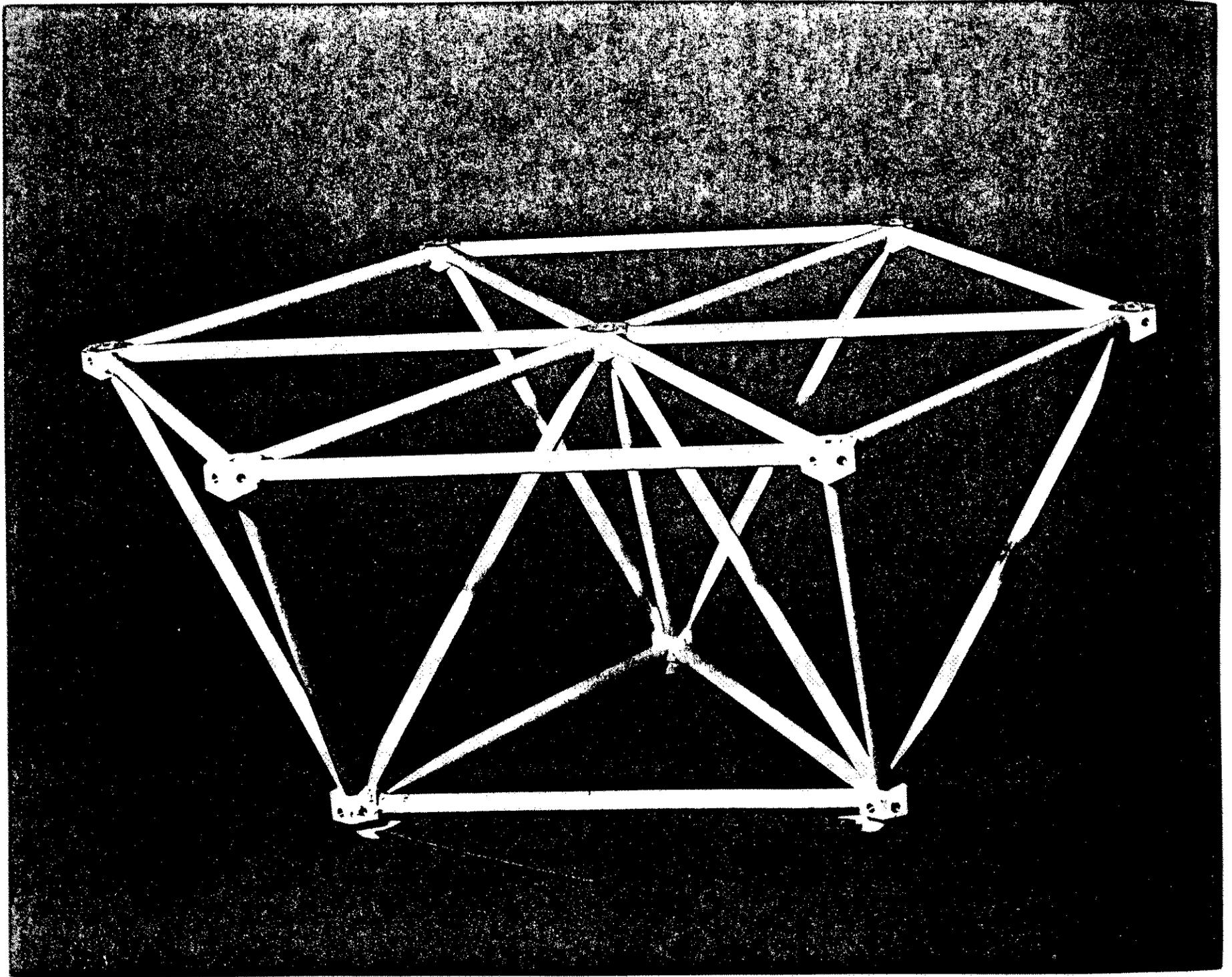


* Details on expanded schedule

ADVANCED ASSEMBLY CONCEPTS
PRECISION ASSEMBLY ON THE SPACE STATION

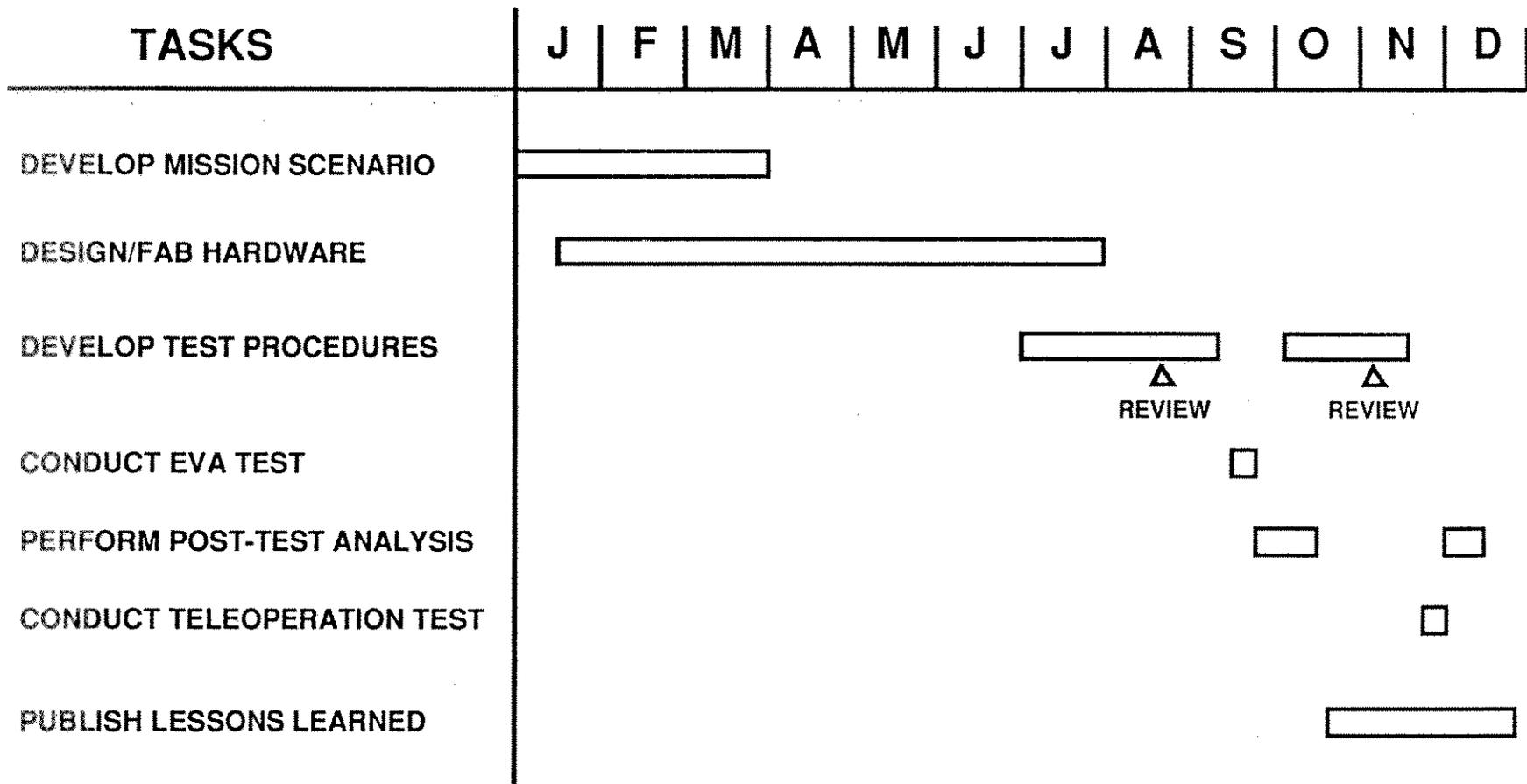
**PRESENTED TO: SATELLITE SERVICES SYSTEM
WORKING GROUP
NOVEMBER 29, 1989**

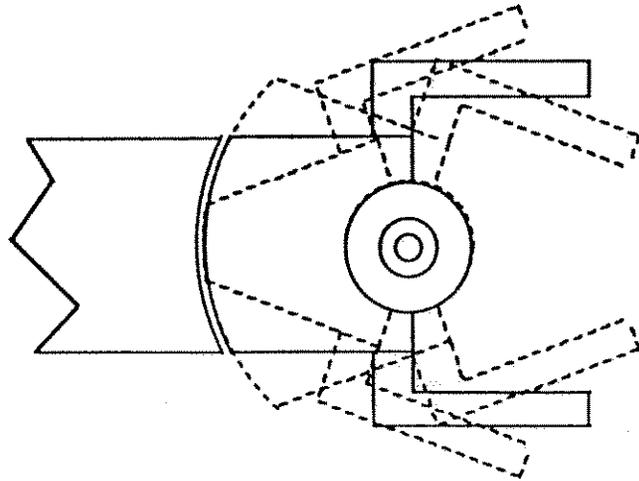
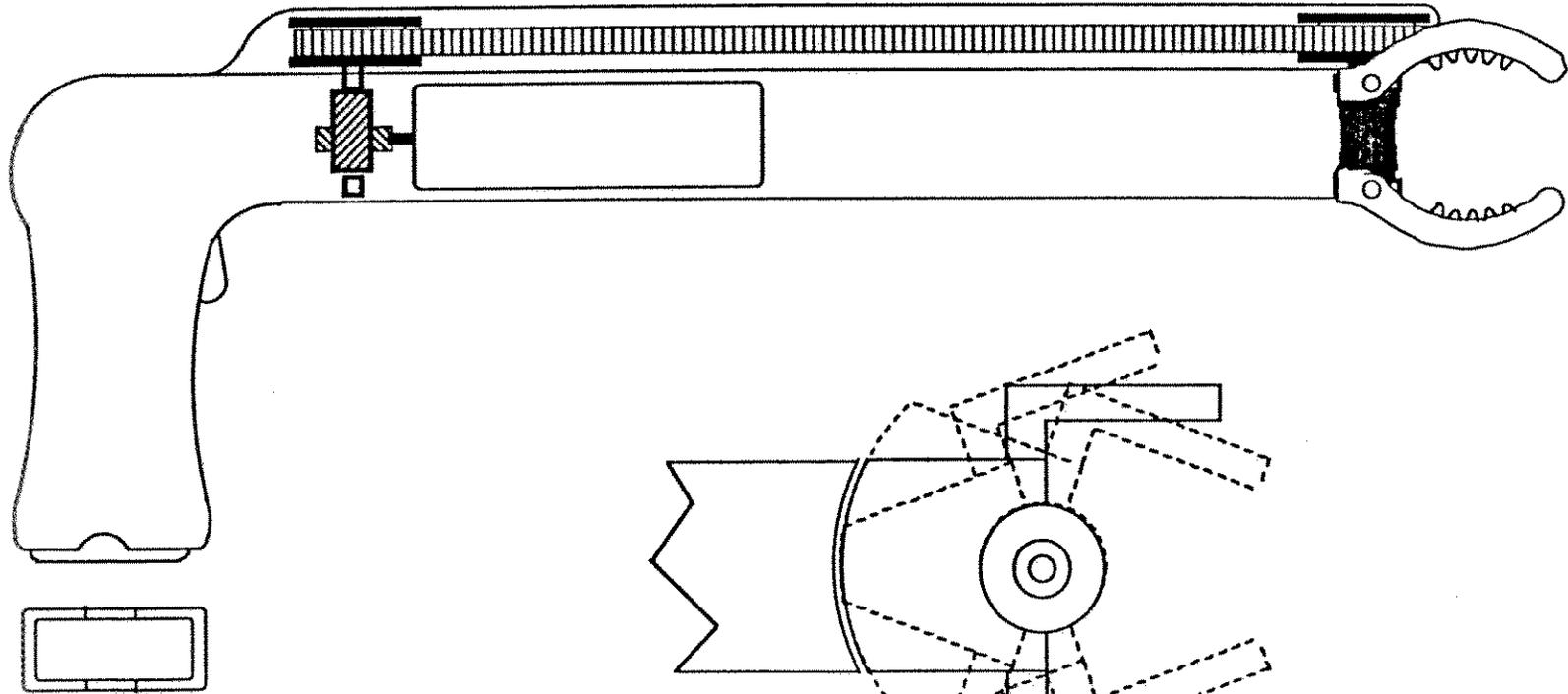
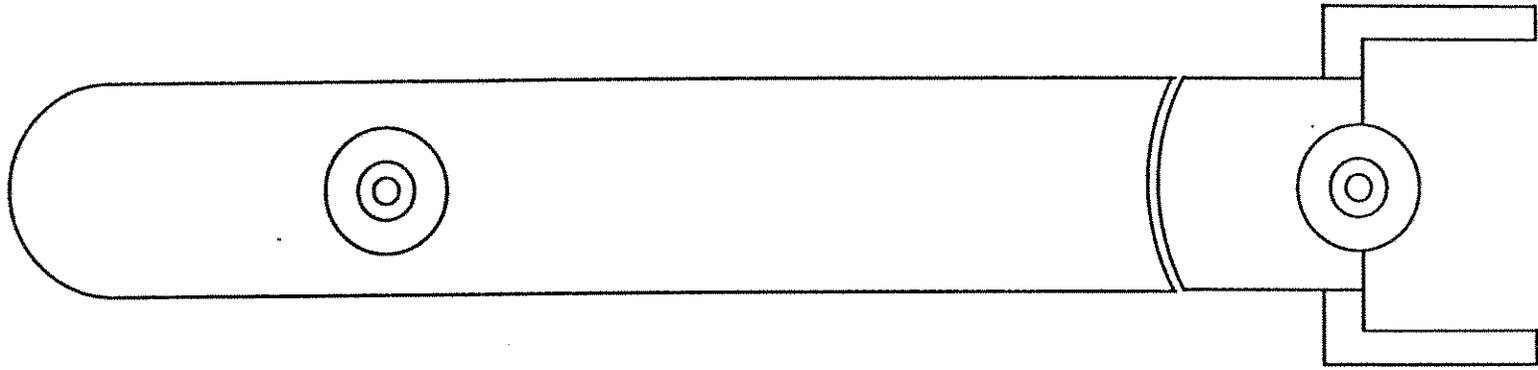
**PRESENTED BY: STEVE CHUCKER
MCDONNELL DOUGLAS
HUNTINGTON BEACH, CA**

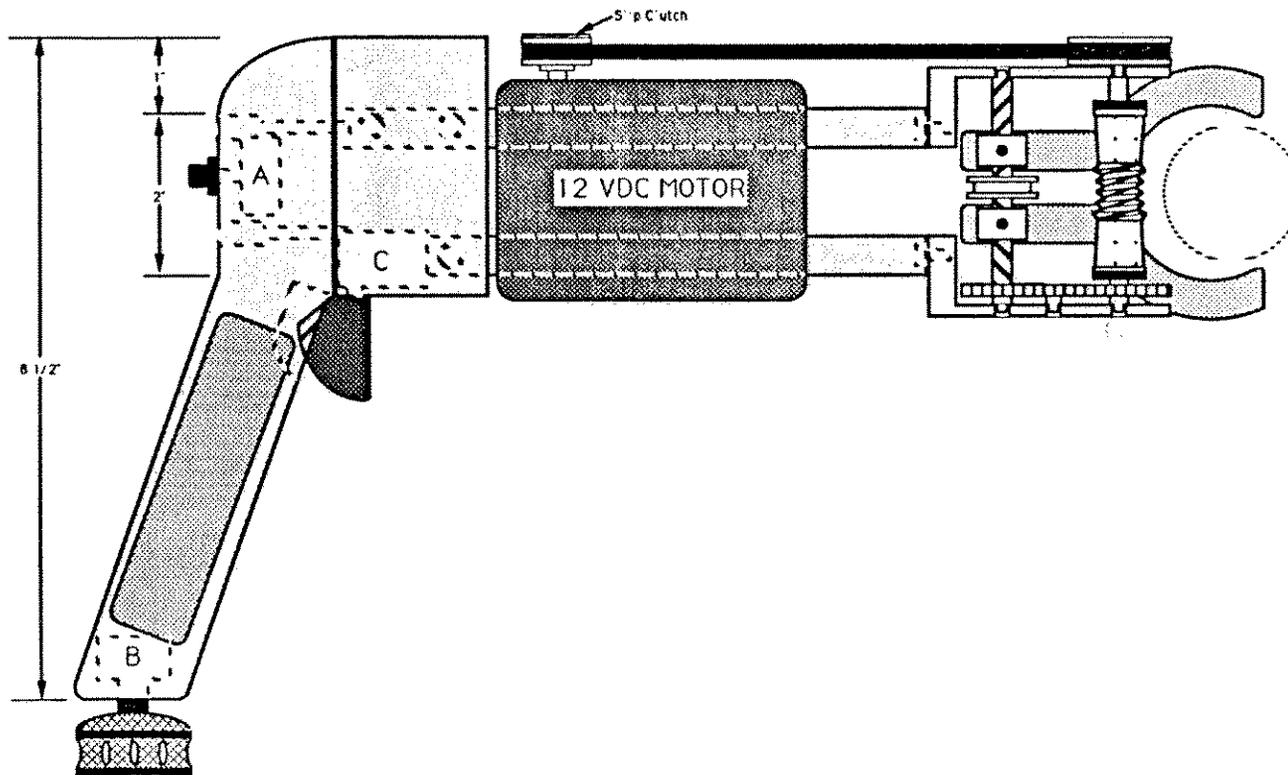
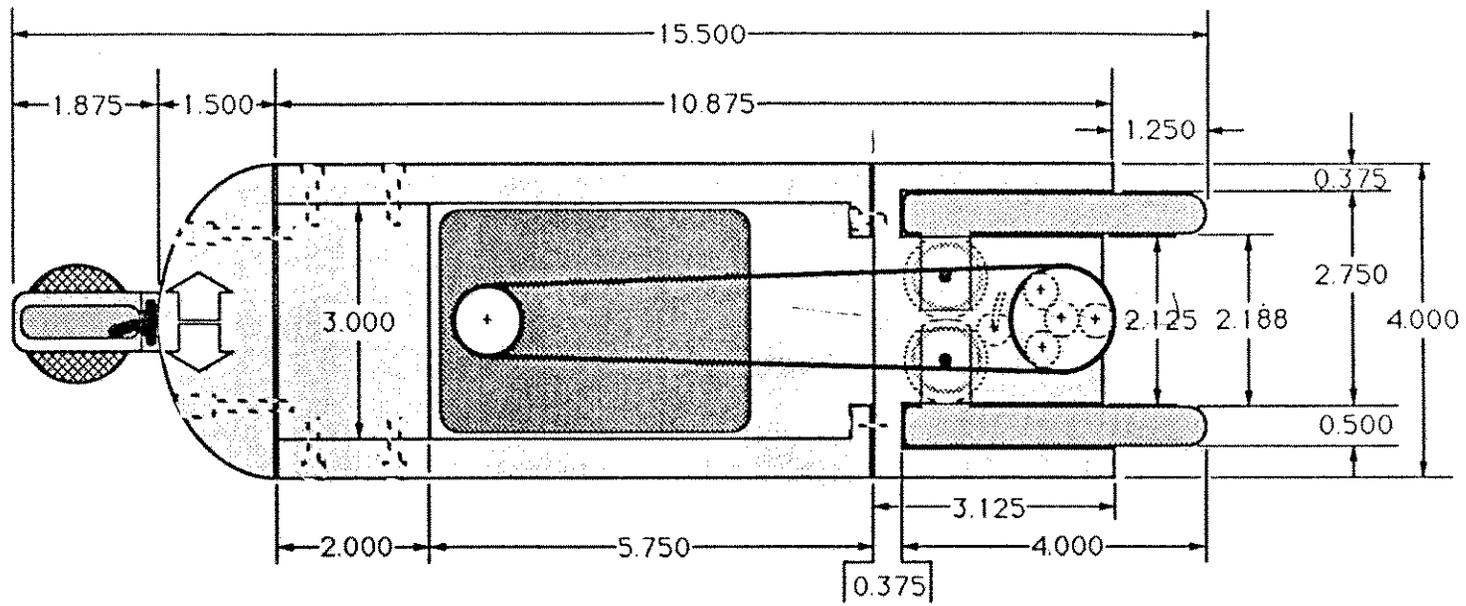


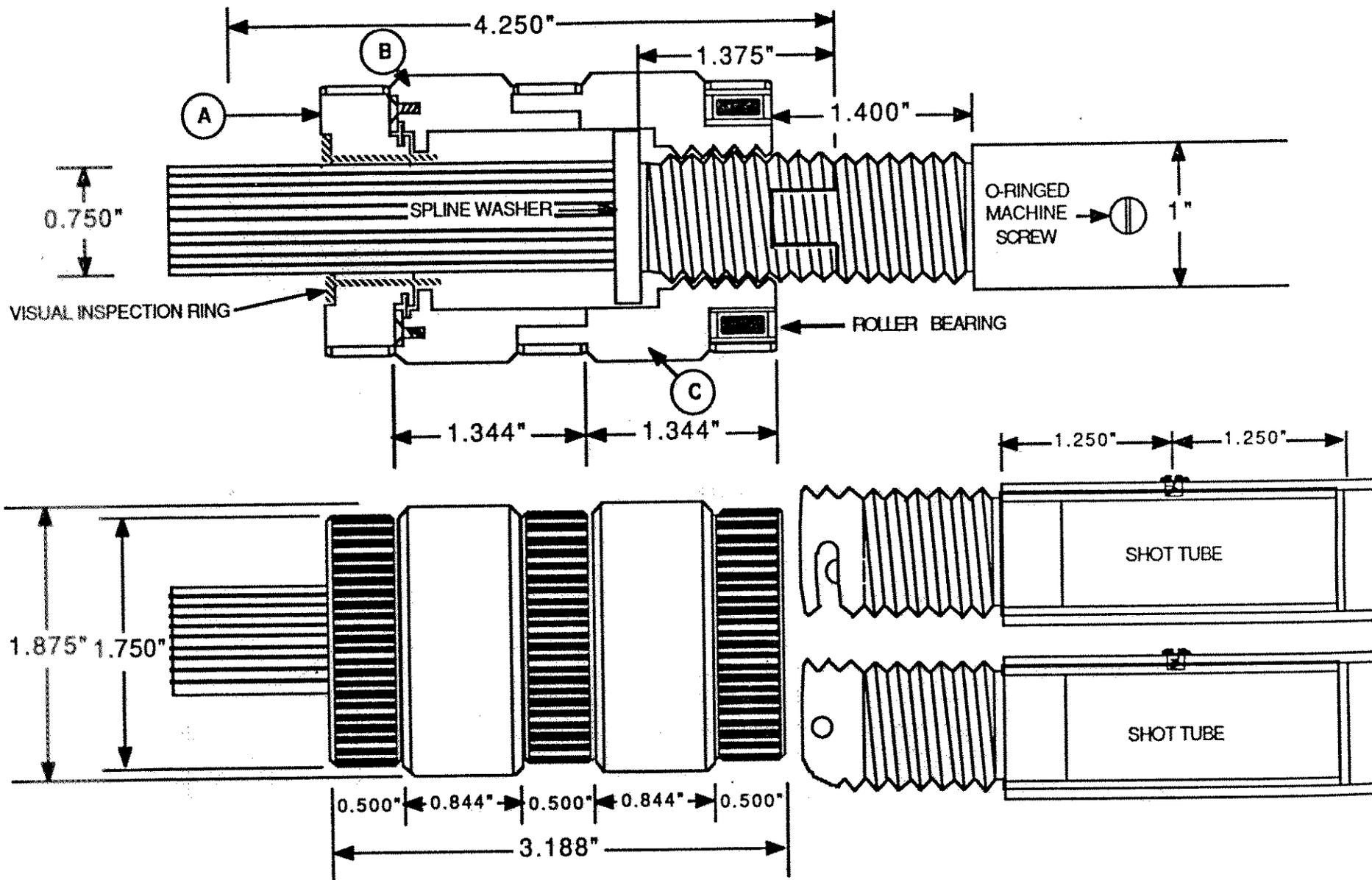
SCHEDULE OF EVENTS FOR ADVANCED ASSEMBLY CONCEPTS TASK

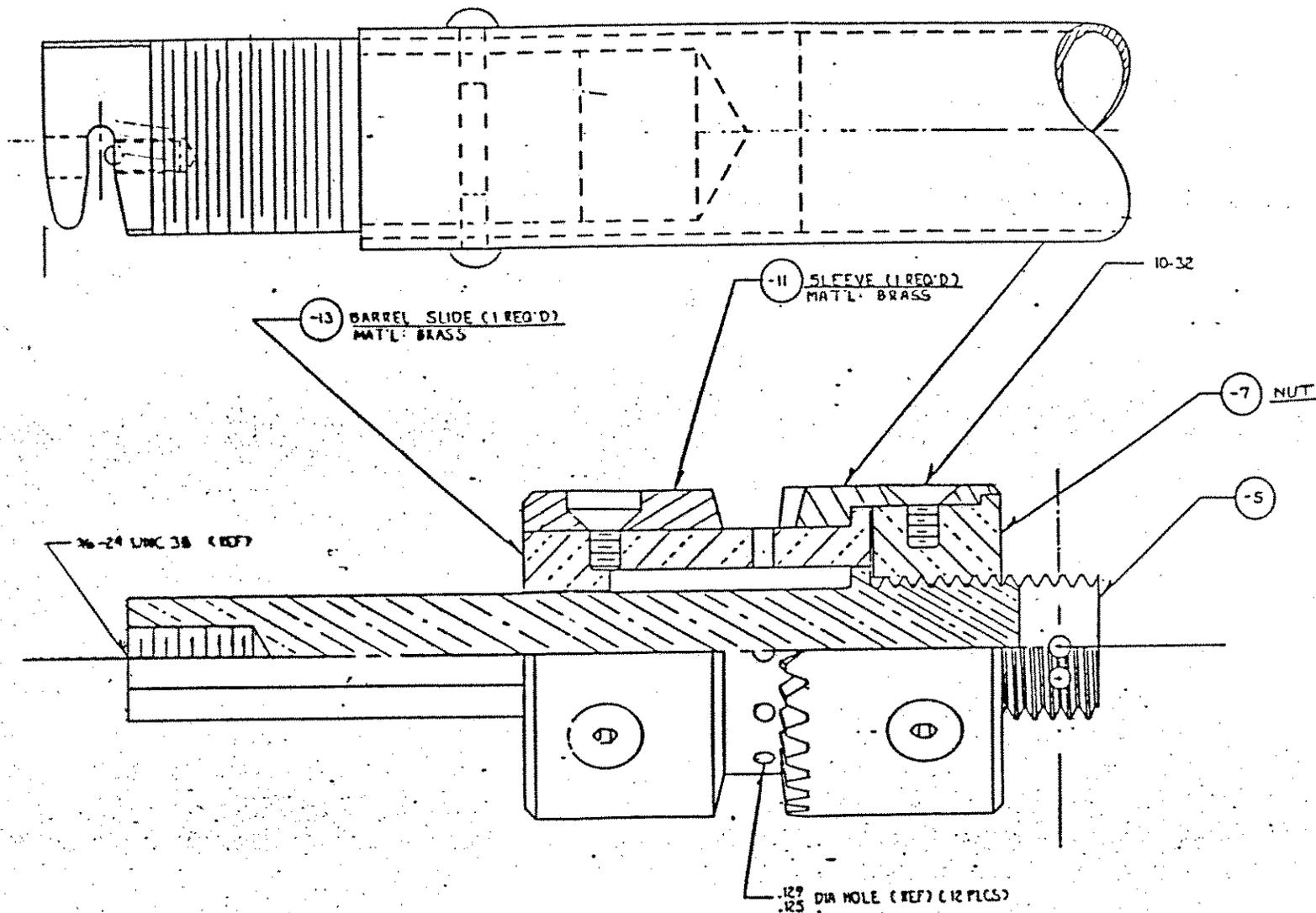
CY '89







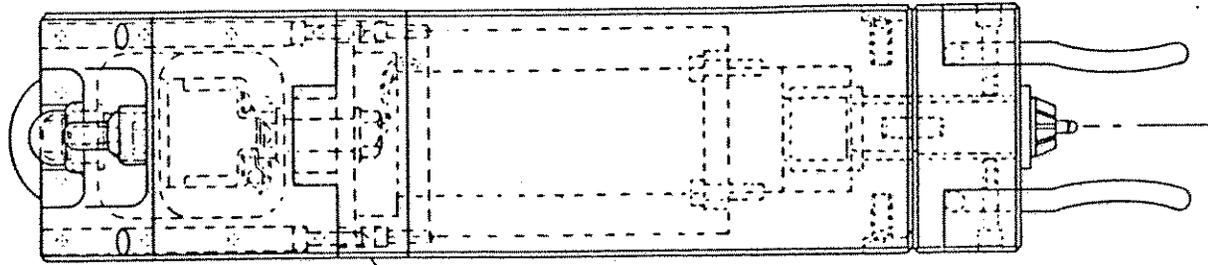




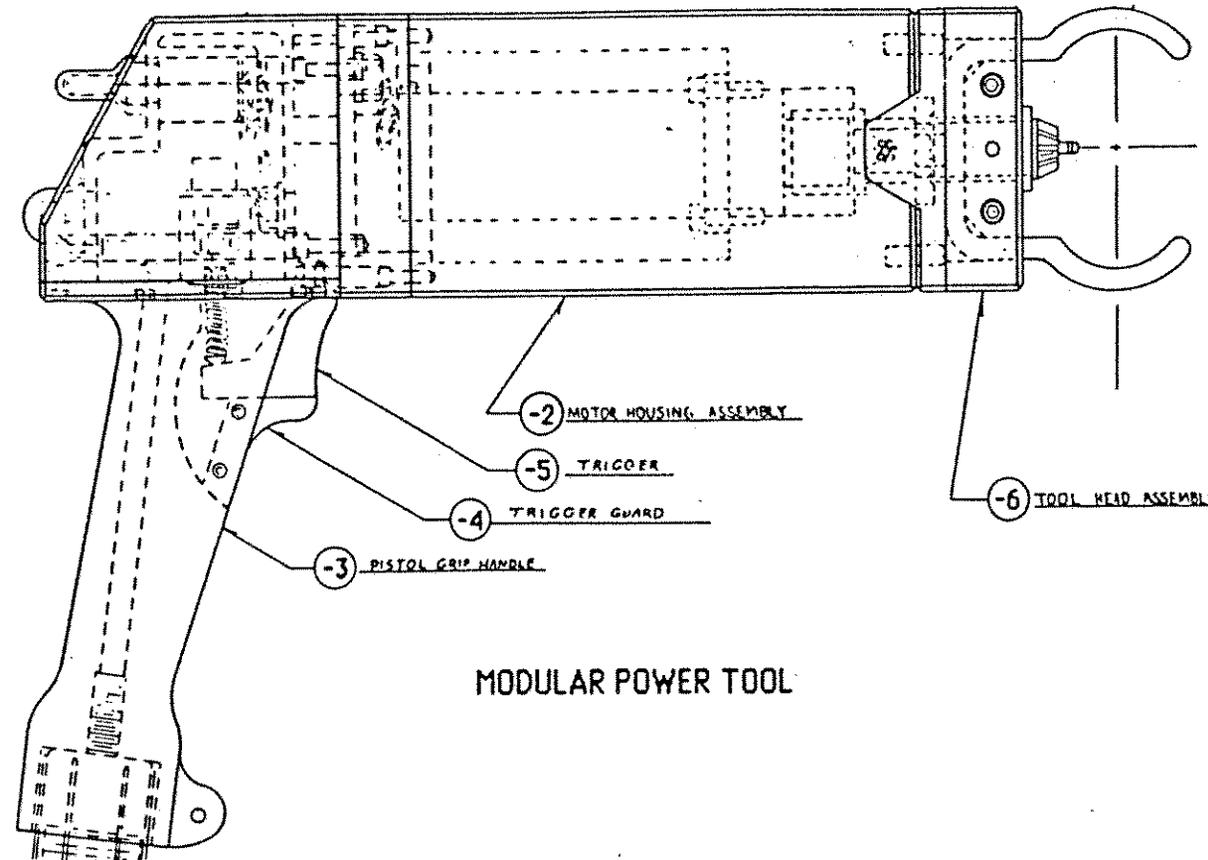
-3 COUPLER ASSEMBLY (48 REQ'D)

SIZE: 2 * FULL

MATL: NOTED



-1 HOUSING COVER/SEAL



-2 MOTOR HOUSING ASSEMBLY

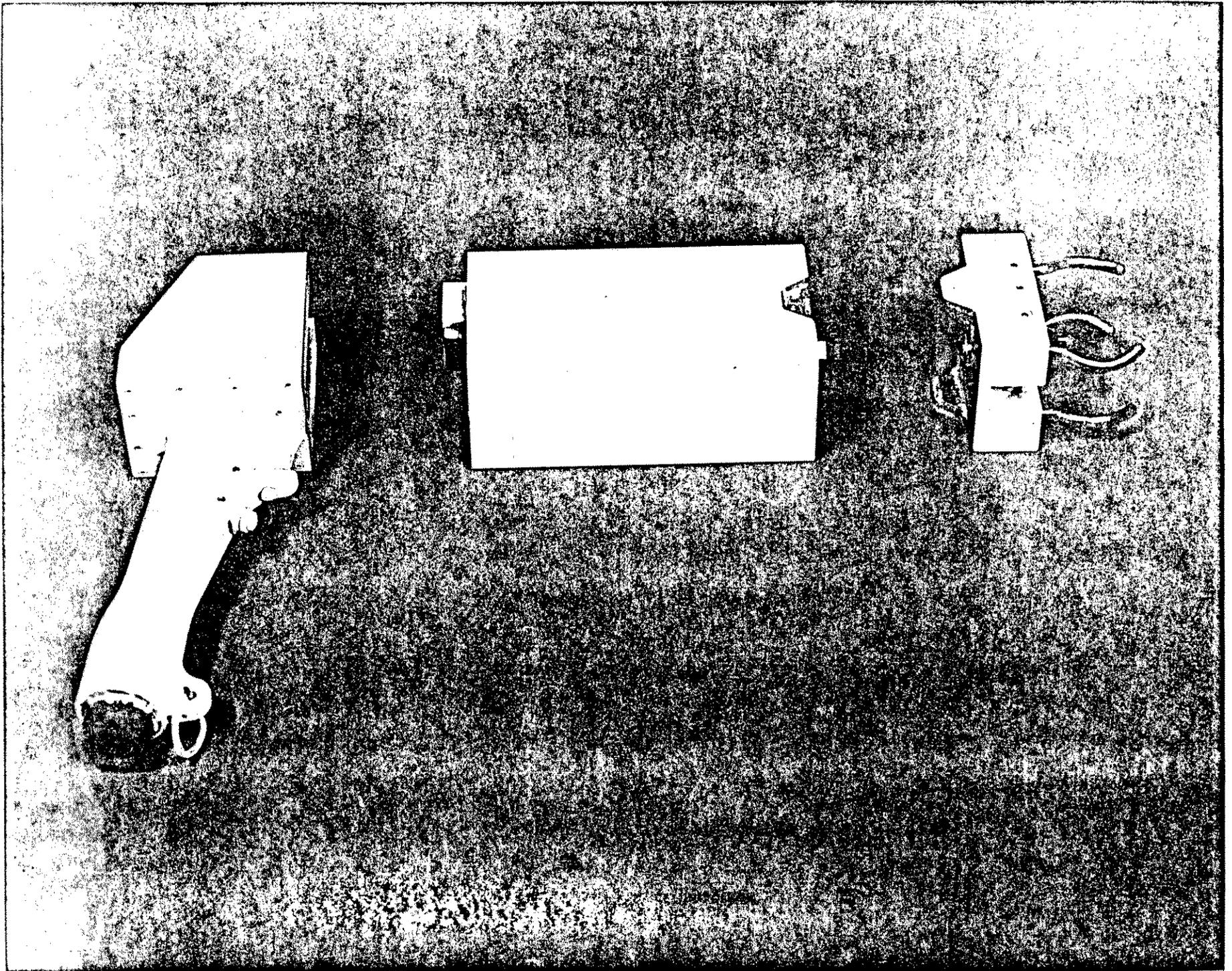
-5 TRIGGER

-4 TRIGGER GUARD

-3 PISTOL GRIP HANDLE

-6 TOOL HEAD ASSEMBLY

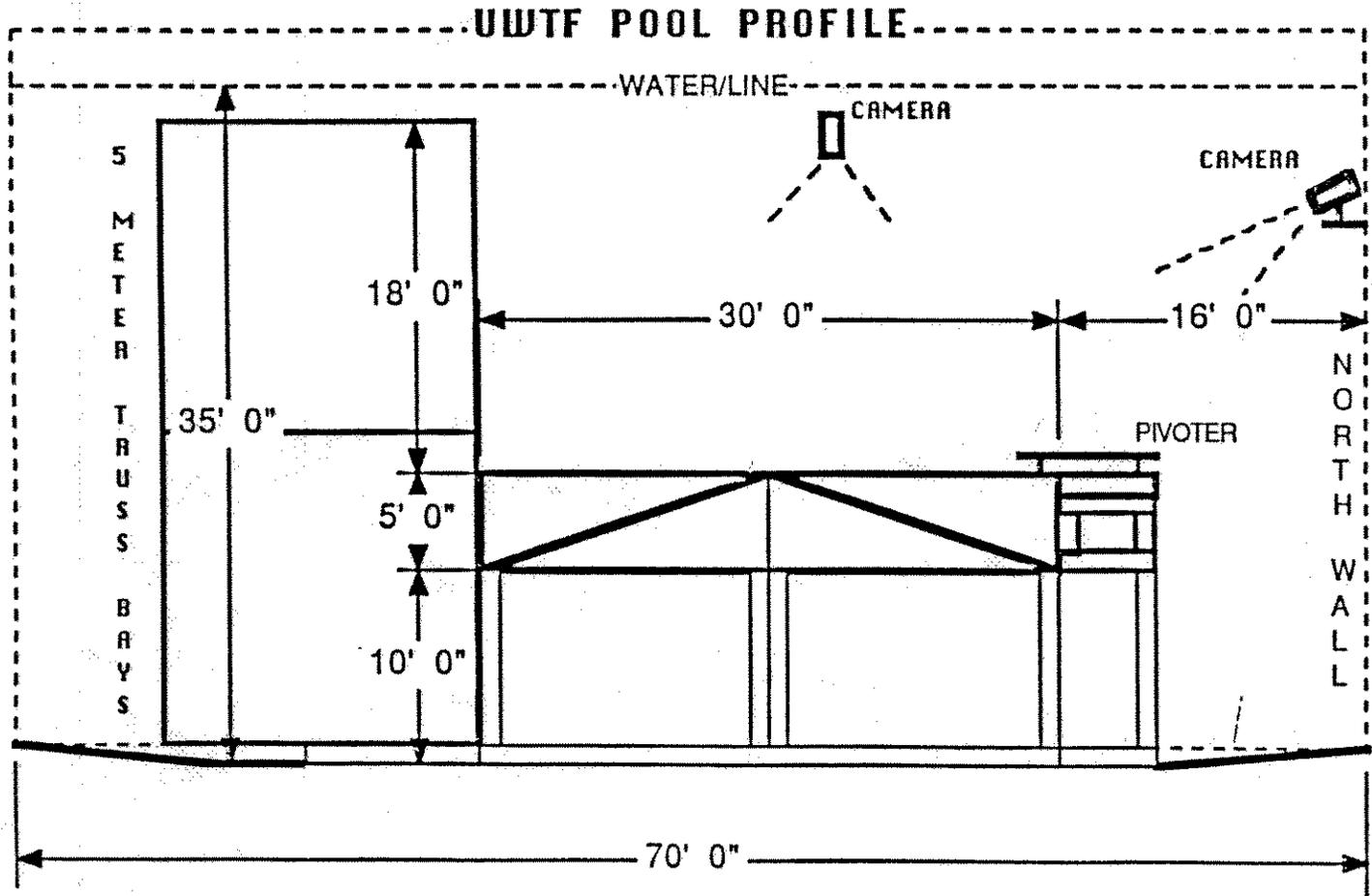
MODULAR POWER TOOL

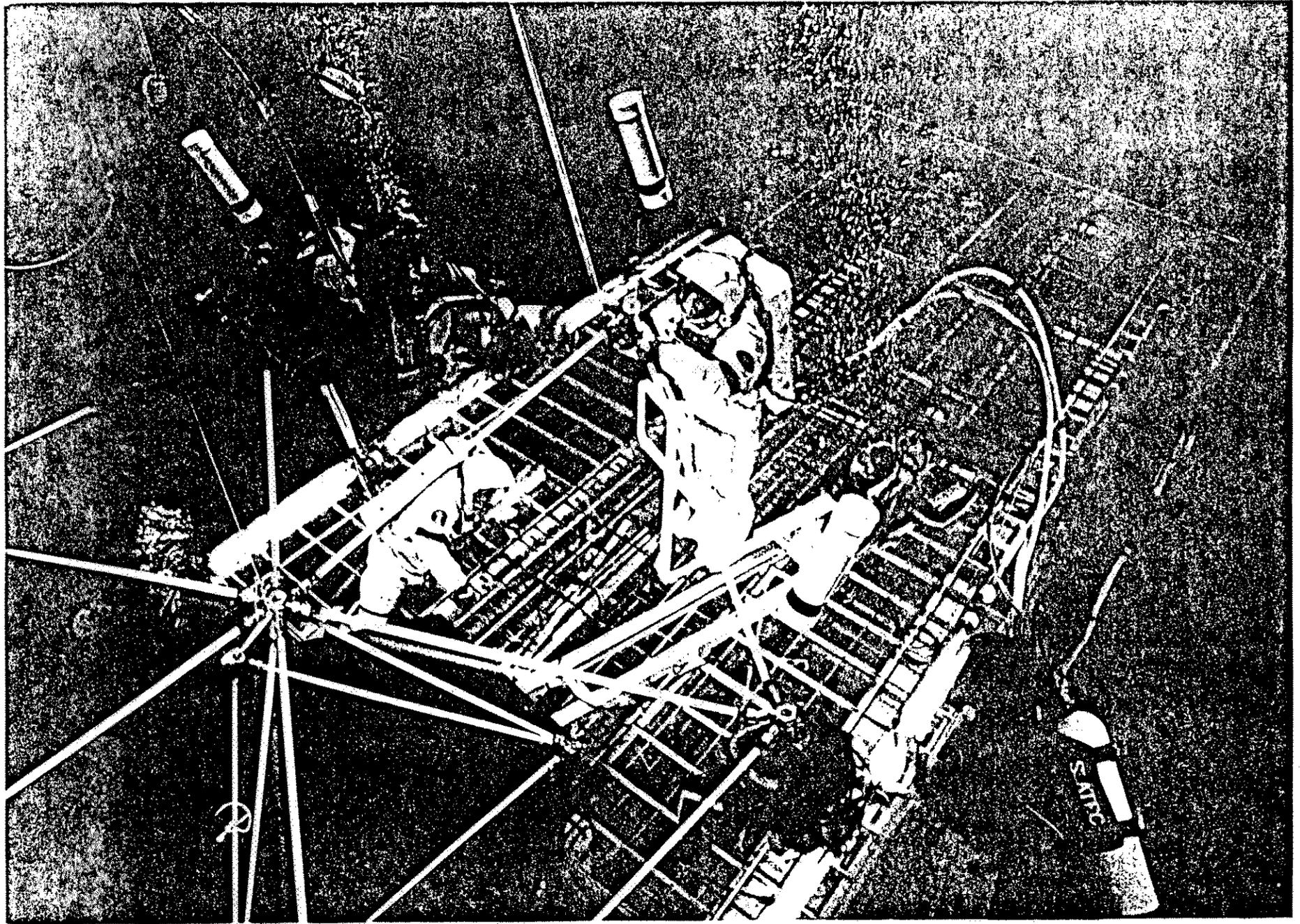


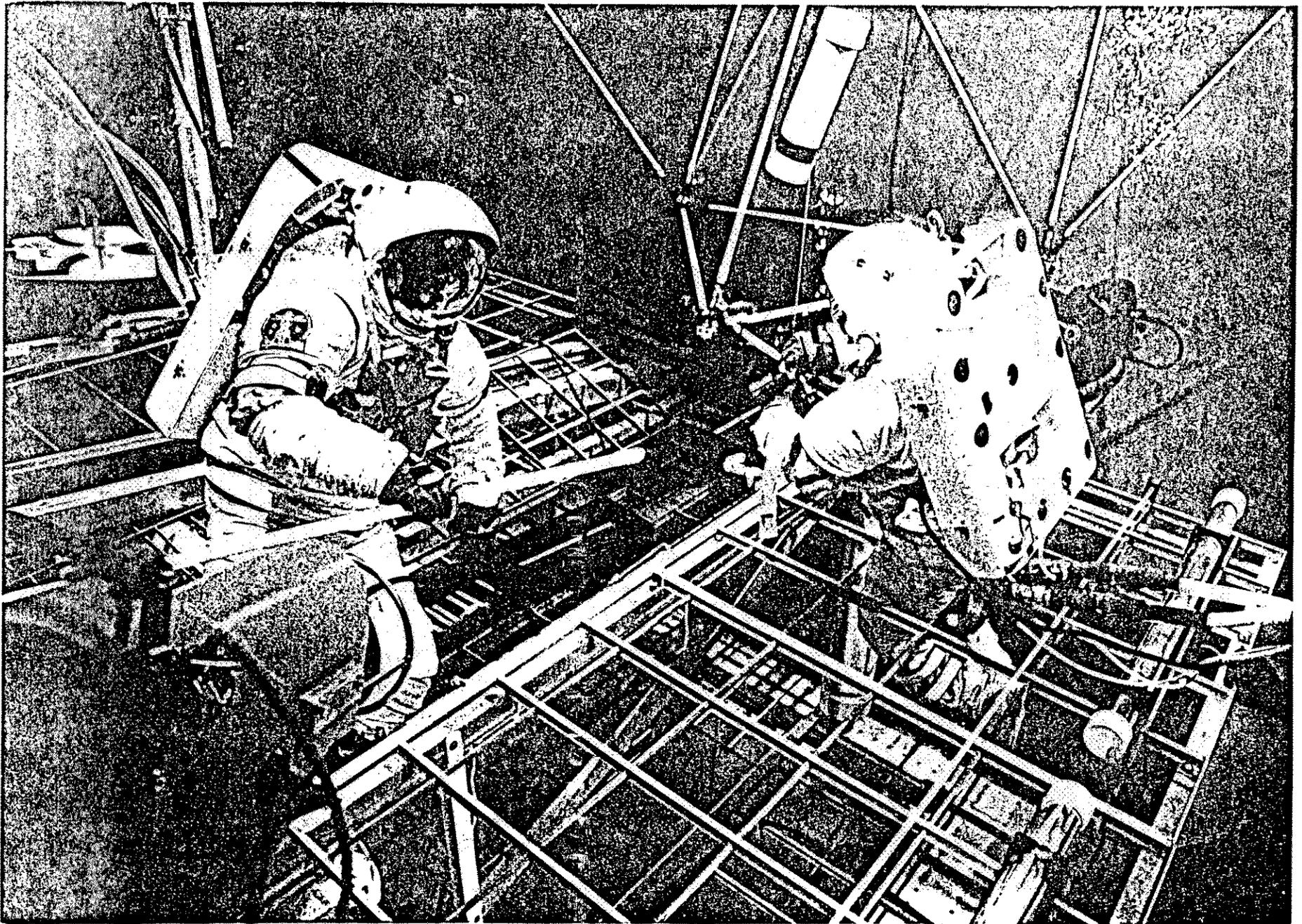
NB TEST OBJECTIVES

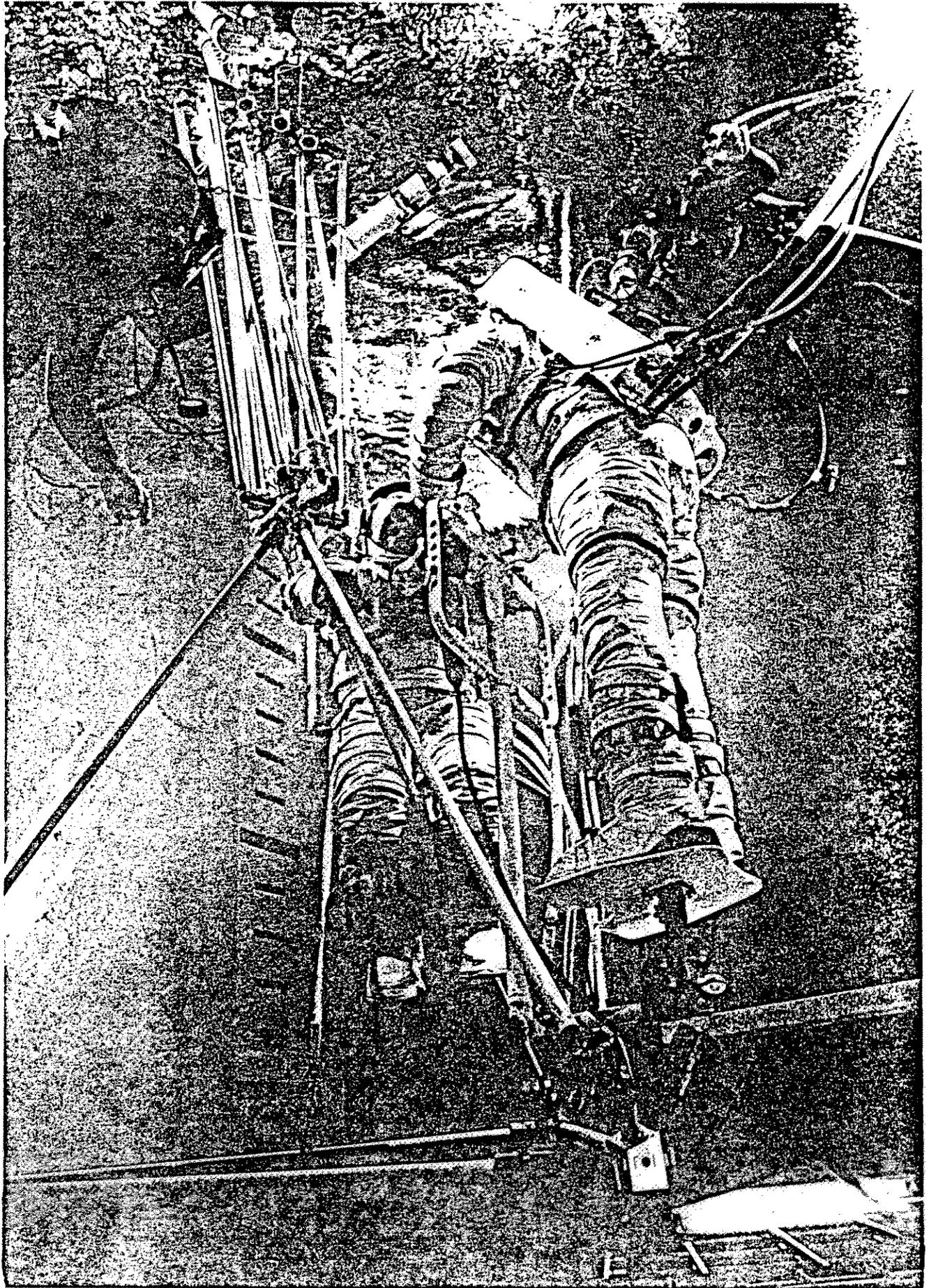
- **EVALUATE EV CREWMEN ABILITY/EFFECTIVENESS TO ASSEMBLE VARIOUS CONFIGURATIONS OF LSS TETRAHEDRAL ELEMENTS**
 - **TRANSPORT/MANIPULATE/ASSEMBLE HARDWARE ELEMENTS**
 - **MANNED INTERFACE WITH POWERED ASSEMBLY TOOL**
 - **FUNCTIONALITY OF MWP**
- **EVALUATE MAINTENANCE OPERATIONS FOR LSS SYSTEMS**
- **ADDRESS CONTINGENCY ASSEMBLY OPERATIONS**
 - **MANUAL BACKUP FOR FAILED POWER TOOL**
- **OBTAIN PRELIMINARY VALIDATION OF OPERATIONAL TIMELINES FOR VARIOUS ASSEMBLY ACTIVITIES**

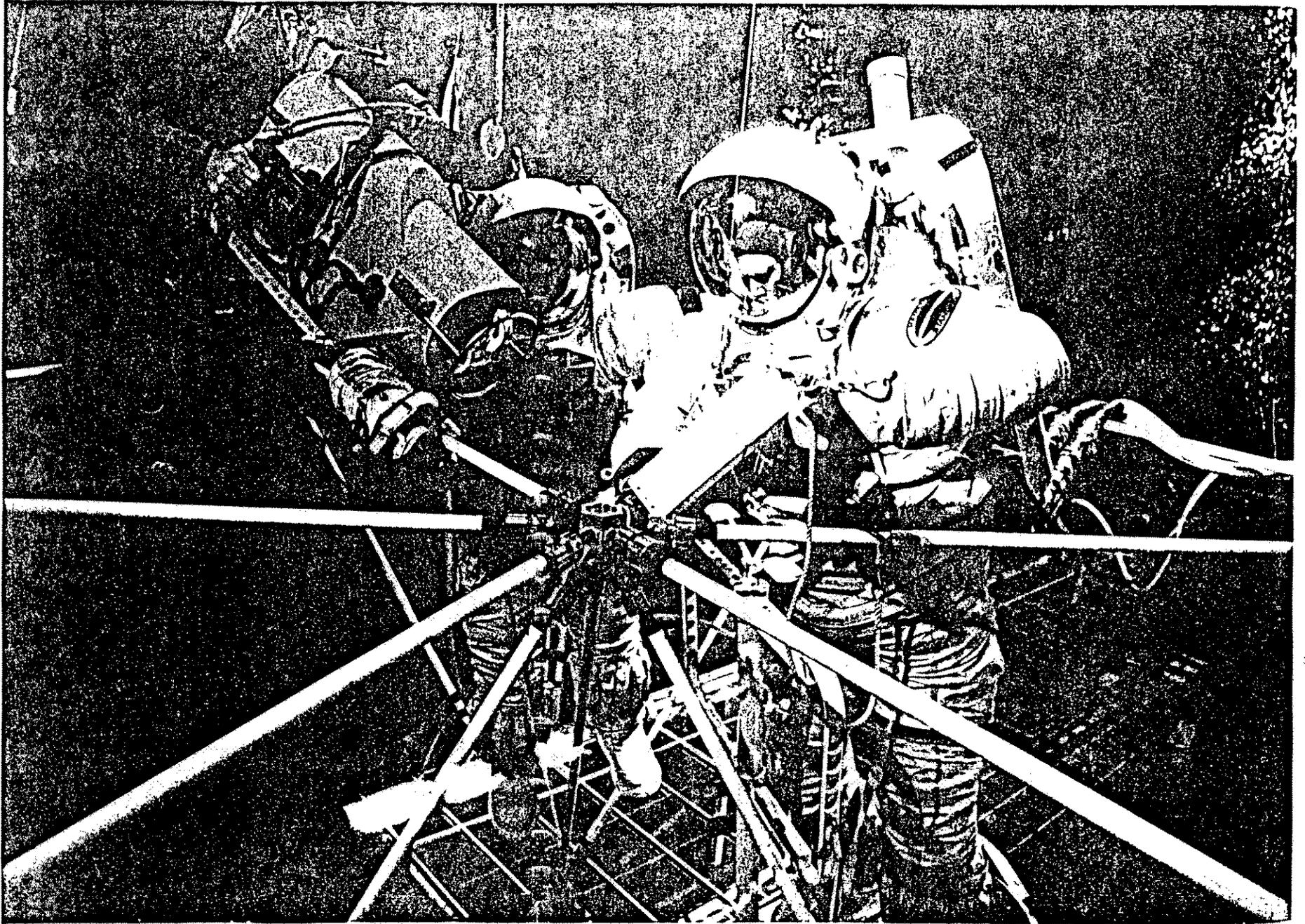
NEUTRAL BUOYANCY TEST CONFIGURATION







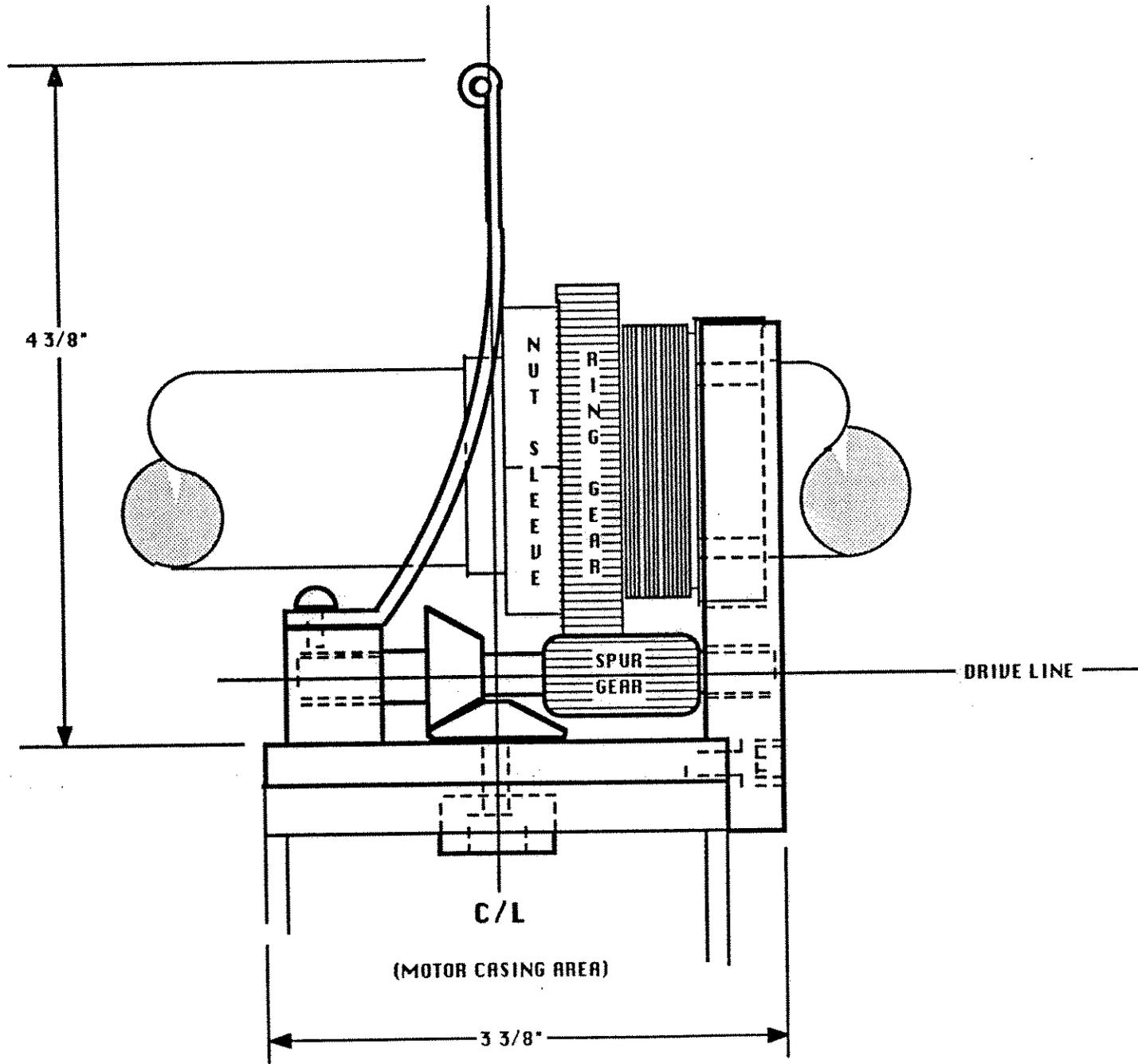


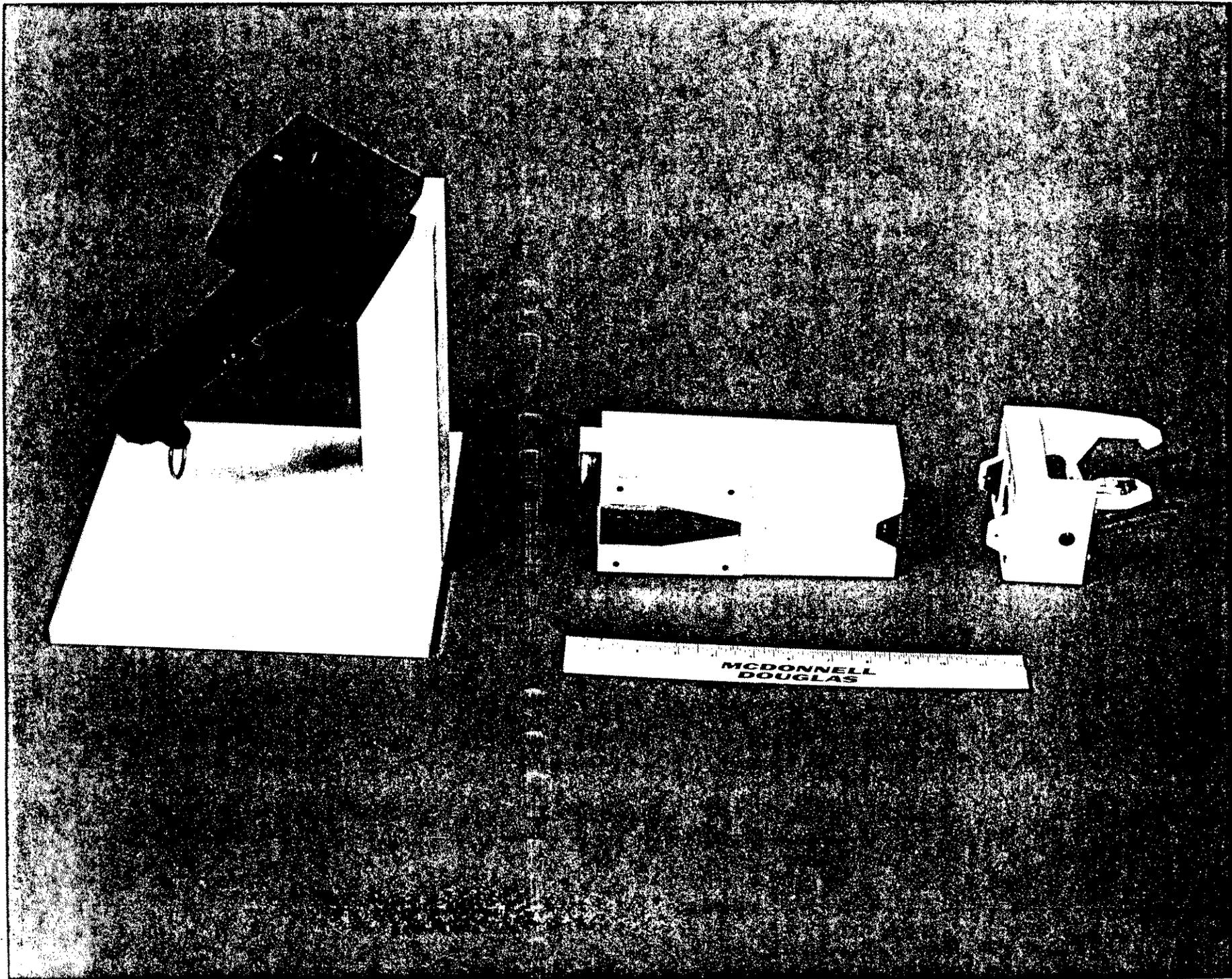


TELEOPERATIONAL TEST OBJECTIVES

- **EVALUATE ABILITY/EFFECTIVENESS TO TELEROBOTICALLY ASSEMBLE LARGE SPACE STRUCTURAL ELEMENTS**
- **ASSESS ABILITY TO OBTAIN, TRANSPORT, AND MANIPULATE TRUSS ELEMENTS WITH THE KRAFT TELEROBOTIC ARM**
- **ASSESS INTERFACE CONSIDERATIONS BETWEEN THE MPT AND THE KRAFT TELEROBOTIC ARM**
- **ASSESS OPERATIONAL REQUIREMENTS ADDRESSING OPERATOR ACCOMMODATIONS (VISION REQUIREMENTS, CAMERA LOCATIONS, FORCE REFLECTION, ETC.)**

OTHER APPLICATIONS OF THE MODULAR POWER TOOL





SUMMARY

- **ASSESS FEASIBILITY OF HAVING VARIOUS MODES OF OPERATION TO PERFORM ASSEMBLY TASK WITH COMMON SET OF HARDWARE**
- **EVALUATE INCORPORATION OF OPERATIONAL FLEXIBILITY INTO THE HARDWARE DESIGN TO MAXIMIZE TASK ACCOMPLISHMENT**
- **DETERMINE OPTIMIZATION BETWEEN VARYING CONFIGURATION ELEMENTS AND CREWMAN PRODUCTIVITY**
- **CONTINUE ASSESSMENT OF OPERATIONAL APPLICATIONS FOR MPT**

SPACE ENVIRONMENT EFFECTS ON MATERIALS

NOVEMBER 29, 1989

DR. STEVE KOONTZ/ NASA-JSC



SPACE ENVIRONMENT EFFECTS ON MATERIALS
JSC RESEARCH AND TECHNOLOGY ACTIVITIES

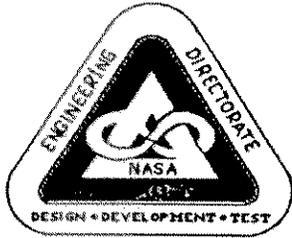
Structures and Mechanics Division

Dr. Steve Koontz

October 10, 1989

SPACE ENVIRONMENT EFFECTS ON MATERIALS

**STATUS OF JOHNSON SPACE CENTER
RESEARCH AND TECHNOLOGY EFFORT**



SPACE ENVIRONMENT EFFECTS ON MATERIALS
JSC RESEARCH AND TECHNOLOGY ACTIVITIES

Structures and Mechanics Division

Dr. Steve Koontz

October 10, 1989

SPACE ENVIRONMENT EFFECTS ON MATERIALS AT JOHNSON SPACE CENTER

- **EMPHASIS ON LONG LIFE OF STRUCTURAL, THERMAL CONTROL, AND ELECTRICAL MATERIALS IN LOW EARTH ORBIT**
- **SPACE ENVIRONMENT FACTORS UNDER INVESTIGATION**
 - **ATOMIC OXYGEN**
 - **DEBRIS AND METEOROIDS**
 - **ULTRAVIOLET AND VACUUM ULTRAVIOLET RADIATION**
 - **SYNERGISTIC INTERACTIONS OF SPACE ENVIRONMENT FACTORS**
- **LONG LIFE MATERIALS DEVELOPMENT**
 - **ANODIZED FILM COATINGS**
 - **LONG LIFE FLUOROCARBONS**

**IMPACT OF ENVIRONMENTAL FACTORS
ON PROGRAM LIFE****STRUCTURES AND MECHANICS DIVISION****AUGUST 30, 1988**

N802809B

- **THE SPACE ENVIRONMENT CAN EFFECT THE LIFE OF PROGRAM ELEMENTS AND THE EFFECTIVENESS OF PROGRAM SYSTEMS**
 - **MATERIALS DEGRADATION LEADING TO IMPAIRED PERFORMANCE OF PROGRAM ELEMENTS**
 - **IMPAIRMENT OF PROGRAM ELEMENT EFFECTIVENESS BY SPACE ENVIRONMENT FACTORS**
 - **FACTORS LEADING TO MATERIALS DEGRADATION**
 - **ULTRAVIOLET AND VACUUM ULTRAVIOLET RADIATION**
 - **ATOMIC OXYGEN**
 - **IONIZING RADIATION**
 - **DEBRIS AND METEOROIDS**
 - **FACTORS DEGRADING EFFECTIVENESS**
 - **SPACECRAFT GLOW**
 - **CONTAMINATION**
 - **PROGRAM LIFE CHART**
 - **CHART SHOWS PROGRAM ELEMENT LIFE AT VARIOUS ALTITUDES DUE TO SPACE ENVIRONMENT FACTORS**
 - **SYNERGESTIC INTERACTIONS ARE NOT CONSIDERED**
 - **THE LIFE LIMITING DOSE OF ULTRAVIOLET AND VACUUM ULTRAVIOLET RADIATION IS ESTIMATED AS TWICE THE ON ORBIT LIFE OF TEFLON AND SILVER TEFLON IN LEO**
-



IMPACT OF ENVIRONMENTAL FACTORS ON PROGRAM LIFE	STRUCTURES AND MECHANICS DIVISION	
	AUGUST 23, 1988	

N802799B

- **BACKGROUND FOR PROGRAM LIFE SUMMARY CHART**
 - **ATOMIC OXYGEN**
 - **THE LIFE LIMITING DOSE OF ATOMIC OXYGEN IS THE AMOUNT NEEDED TO PRODUCE A 2 MIL RECESSON IN KAPTON**
 - **IONIZING RADIATION**
 - **THE LIFE LIMITING DOSE OF IONIZING RADIATION IS 1 X 10E10 RADS OF HIGH ENERGY ELECTRONS**
 - **MICROMETEOROIDS AND DEBRIS**
 - **MICROMETEOROIDS AND MICRO-DEBRIS DO NOT LIMIT LIFE IN A 30 YEAR TIME FRAME (CURRENT BEST INFORMATION)**
 - **LIFE LIMIT FOR DEBRIS IS THE TIME NEEDED FOR THE PROBABILITY OF IMPACT BY A PARTICLE TO INCREASE TO 0.01; PROBABILITY OF NO IMPACT = 0.99; SPACECRAFT AREA = 100 SQUARE METERS**
-

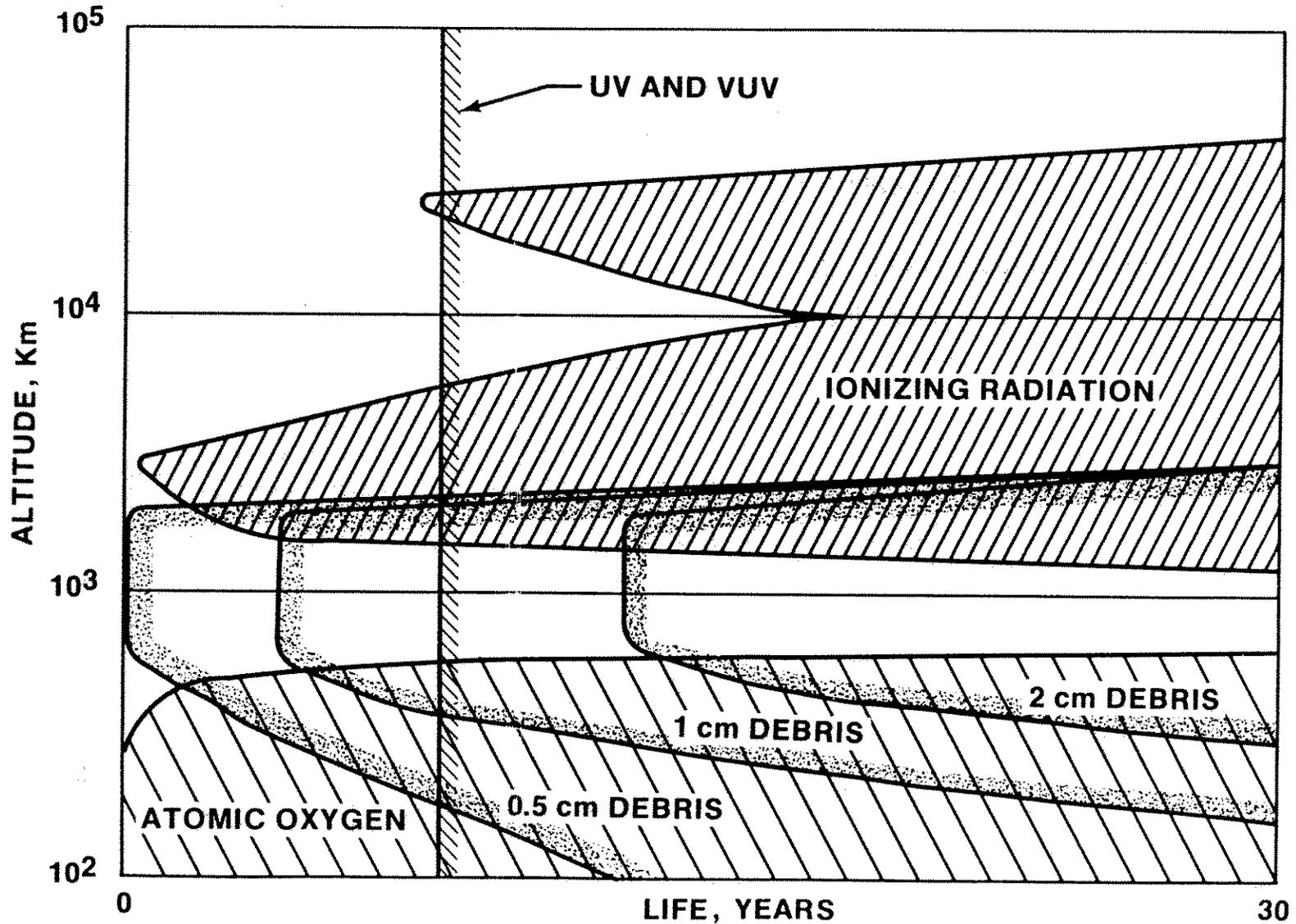


IMPACT OF ENVIRONMENTAL FACTORS ON PROGRAM LIFE

STRUCTURES AND MECHANICS DIVISION

AUGUST 23, 1988

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SPACE ENVIRONMENT EFFECTS ON MATERIALS
JSC RESEARCH AND TECHNOLOGY ACTIVITIES

Structures and Mechanics Division

Dr. Steve Koontz

October 10, 1989

PROJECT STATUS

- **ATOMIC OXYGEN**
 - EOIM-III ATOMIC OXYGEN EFFECTS FLIGHT EXPERIMENT MANIFESTED ON STS-46, 5/16/91; FLIGHT HARDWARE CERTIFICATION TESTING IN PROGRESS
 - LOW EARTH ORBIT ENVIRONMENT LABORATORY SIMULATION OPERATIONAL AT LOS ALAMOS NATIONAL LABORATORIES;
 - ATOMS NEAR ORBITAL VELOCITY (0.8, 1.5, 2.5, 4.0 eV)
 - SIMULTANEOUS VACUUM ULTRAVIOLET/ATOMIC OXYGEN
 - EOIM-III MASS SPECTROMETER CALIBRATION COMPLETE
 - ATOMIC OXYGEN/VACUUM ULTRAVIOLET SYNERGISM SHOWN IN FLUOROCARBON REACTIVITY
 - ATOMIC OXYGEN REACTIVITY OF MoS₂ (DRY LUBE) MEASURED
 - NO REACTION OF ANODIZED FILMS OBSERVED TO DATE
 - SUPPORTING DEVELOPMENT OF ALTERNATIVE LABORATORY SIMULATION OF THE LOW EARTH ORBIT ENVIRONMENT AT PHYSICAL SCIENCES INC.
 - THERMAL ENERGY (0.04 eV) ATOMIC OXYGEN RESEARCH SYSTEM AT JSC
 - ATOMIC OXYGEN/VACUUM ULTRAVIOLET SYNERGISM IN FLUOROCARBON REACTIVITY
 - ATOM ENERGY DEPENDENCE OF MATERIALS REACTIVITY (WITH LOS ALAMOS)
 - KNOWN ATOM FLUXES IN WELL CHARACTERIZED ENVIRONMENT



Johnson Space Center - Houston, Texas

SPACE ENVIRONMENT EFFECTS ON MATERIALS
JSC RESEARCH AND TECHNOLOGY ACTIVITIES

Structures and Mechanics Division

Dr. Steve Koontz

October 10, 1989

- **DEBRIS AND METEOROIDS**
 - **JSC HYPERVELOCITY GUN FACILITY**
 - **DEVELOPMENT/EVALUATION OF HYPERVELOCITY IMPACT ARMOR**
 - **EVALUATION OF BUMPER SYSTEMS FOR SPACE STATION**
 - **DEVELOPMENT OF NEW ARMOR CONCEPTS**
 - **DETERMINATION OF HYPERVELOCITY IMPACT EFFECTS ON NEW MATERIALS AND MATERIAL CONFIGURATIONS**
 - **HYPERVELOCITY IMPACT/ATOMIC OXYGEN SYNERGISM**
 - **MICROMETEOROID/DEBRIS IMPACT EFFECTS ON PROTECTIVE FILMS AND COATINGS**
 - **ESTIMATE THICKNESS OF ALUMINUM FOIL SURFACE FOR COMPOSITE TRUSS TUBES**
 - **EVALUATION OF HYPERVELOCITY IMPACT EFFECTS ON PRESSURE VESSELS AND PROPELLANT TANKS**
 - **VACUUM ULTRAVIOLET EFFECTS ON MATERIALS**
 - **EXISTING DATA BASE VERY LIMITED**
 - **JSC EFFORT TO STRESS CHANGES IN MECHANICAL AND THERMAL CONTROL PROPERTIES OF MATERIALS**
 - **LABORATORY SYSTEM 80% COMPLETE**
 - **DYNAMIC MECHANICAL ANALYZER OPERATIONAL**
 - **ULTRA HIGH VACUUM SYSTEM OPERATIONAL**
 - **CALIBRATED VACUUM ULTRAVIOLET SOLAR SIMULATOR LAMP IN PROCUREMENT**

ATOMIC OXYGEN EFFECTS ON SPACECRAFT MATERIALS

**Dr. Steven L. Koontz
NASA Johnson Space Center
Houston, Texas**

SPACE EXPOSURE DATA BASE - ATOMIC OXYGEN EFFECTS ON SPACECRAFT MATERIALS

THREE SPACE SHUTTLE FLIGHT EXPERIMENTS ONE RECOVERED SATELLITE

FLIGHT	ALTITUDE (INCLIN.)	EXPOSURE TIME	FLUENCE* (ATTITUDE)
STS - 5	222 km (28.5°)	44 hours	1×10^{20} (VAR)
STS - 8	222 km (28.5°)	41.75 hours	3.5×10^{20} (RAM)
STS - 41G	225 km (57°)	38 hours	3×10^{20} (RAM)
SMRM	574 - 491 km	50 MONTHS	2×10^{21} (VAR)

* FLUENCE IS IN ATOMS/CM²

- DETAILED DESCRIPTIONS OF THE FLIGHT EXPERIMENTS CAN BE FOUND IN REFERENCES 1 - 21

REACTION EFFICIENCIES OF SELECTED MATERIALS WITH ATOMIC OXYGEN IN LOW EARTH ORBIT

<u>MATERIAL</u>	<u>REACTION EFFICIENCY, cm³/ATOM</u>	<u>MATERIAL</u>	<u>REACTION EFFICIENCY, cm³/ATOM</u>
KAPTON	3×10^{-24}	SILICONES	
MYLAR	3.4	RTV-560	0.2*
TEDLAR	3.2	DC6-1104	0.2*
POLYETHYLENE	3.7	T-650	0.2*
POLYSULFONE	2.4	DC1-2577	0.2*
GRAPHITE/EPOXY		BLACK PAINT Z306	0.3-0.4*
1034C	2.1	WHITE PAINT A276	0.3-0.4*
5208/T300	2.6	BLACK PAINT Z302	2.03*
EPOXY	1.7	PERFLUORINATED POLYMERS	
POLYSTYRENE	1.7	TEFLON, TFE	<0.05
POLYBENZIMIDAZOLE	1.5	TEFLON, FEP	<0.05
25% POLYSILOXANE/45% POLYIMIDE	0.3	CARBON (VARIOUS FORMS)	0.9-1.7
POLYESTER 7%		SILVER (VARIOUS FORMS)	HEAVILY ATTACKED
POLYSILANE/93% POLYIMIDE	0.6	OSMIUM	0.026*
POLYESTER	HEAVILY ATTACKED		
POLYESTER WITH ANTIOXIDANT	HEAVILY ATTACKED		

*UNITS OF mg/cm² FOR STS-8 MISSION. LOSS IS ASSUMED TO OCCUR IN EARLY PART OF EXPOSURE; THEREFORE, NO ASSESSMENT OF EFFICIENCY CAN BE MADE.

SHUTTLE FLIGHT EXPERIMENT ATOMIC OXYGEN EFFECTS DATA BASE

- ABOUT 300 DIFFERENT MATERIALS HAVE BEEN EVALUATED AND SEVERAL MECHANISM STUDIES HAVE BEEN CONDUCTED DURING STS - 5, STS - 8 AND STS - 41G
- ATOMIC OXYGEN EFFECTS WERE DETERMINED BY POST FLIGHT MEASUREMENTS ON RETURNED SAMPLES; NO REAL TIME RATE DATA WAS OBTAINED; ONLY LIMITED VARIABLE EXPOSURE TIME DATA AVAILABLE
- REACTION EFFICIENCY OBTAINED FROM FLIGHT EXPERIMENT DATA PROVIDES A MEASURE OF MATERIAL SUSCEPTIBILITY TO ATOMIC OXYGEN ATTACK
 - REACTIVITY IS EXPRESSED AS THE VOLUME OR MASS OF MATERIAL LOST PER INCIDENT OXYGEN ATOM
 - IF THE ATOM FLUENCE IS KNOWN FOR A FUTURE MISSION, THEN SURFACE RECESSION OR MASS LOSS CAN BE ESTIMATED

$$\text{RECESSION} = \text{FLUENCE} * \text{REACTIVITY}$$

SHUTTLE FLIGHT EXPERIMENT ATOMIC OXYGEN EFFECTS DATA BASE (Continued)

- ATOMIC OXYGEN EFFECTS DATA OBTAINED FROM SPACE SHUTTLE FLIGHT EXPERIMENTS CAN BE FOUND IN REFERENCES 1 - 20. OXIDATION REACTIONS, NOT SPUTTERING, ARE RESPONSIBLE FOR REACTIVITY
 - POLYMERIC MATERIALS CONTAINING C-H BONDS, DIAMOND AND GRAPHITE HAVE REACTIVITIES ON THE ORDER OF 10^{-24} cm³/ATOM
 - OF THE METALS, ONLY SILVER AND OSMIUM ARE RAPIDLY ATTACKED BY FORMATION OF VOLATILE REACTION PRODUCTS OR SURFACE OXIDES LAYERS WHICH SPALL (PEEL OFF) READILY
 - SILICONES AND TEFLON APPEAR INERT
 - SILICONES REACT TO FORM A PROTECTIVE SURFACE OXIDE LAYER (SiO₂)
 - TEFLONS (PURE FLUOROCARBONS) SHOW VERY LOW REACTIVITIES; THE C-F AND C-C BONDS IN THESE MATERIALS APPEAR INERT
 - SURFACE TEMPERATURE CAN INFLUENCE REACTIVITY
 - ORGANIC MATERIALS SHOW A CHARACTERISTIC SURFACE DAMAGE MORPHOLOGY

LIMITATIONS OF CURRENT SPACE SHUTTLE FLIGHT EXPERIMENT DATA BASE

- ATOM FLUENCES WERE NOT MEASURED DURING FLIGHT BUT CALCULATED USING THE MSIS MODEL OF THE THERMOSPHERE (19); IT FOLLOWS THAT MODEL ERRORS ARE INCLUDED IN THE FLIGHT EXPERIMENT DATA BASE
- DATA BASE PROVIDES ONLY LIMITED BASIS FOR UNDERSTANDING THE KINETICS AND MECHANISM OF HYPERHERMAL ATOM - SURFACE REACTIONS
- REACTION EFFECIENCIES HAVE BEEN OBTAINED AT LOW FLUENCE
 - STS FLIGHTS: 10^{19} TO 10^{20} ATOMS/cm² IN ABOUT 40 HRS AT 222 TO 225 km ALTITUDE
 - SPACE STATION: 10^{22} TO 10^{23} ATOMS/cm² IN 30 YEARS (2.6×10^5 HOURS) AT 340 TO 475 km ALTITUDE

LIMITATIONS OF CURRENT SPACE SHUTTLE FLIGHT EXPERIMENT DATA BASE (Continued)

- **DATA BASE PROVIDES ONLY A LIMITED BASIS FOR EVALUATING EFFECTS OF OTHER SPACE ENVIRONMENT FACTORS ON OXYGEN REACTIVITY**
 - **SOLAR UV RADIATION (ESPECIALLY LYMAN ALPHA AT 121.6 nm) AND HIGH ENERGY CHARGED PARTICLES SHOULD INFLUENCE THE MAGNITUDE OF ATOMIC OXYGEN EFFECTS IN SOME MATERIALS THROUGH PHOTOCHEMICAL AND RADIOCHEMICAL MECHANISMS**
 - **AT 222 km ALTITUDE THE HIGH ATOMIC OXYGEN FLUX MAY WASH OUT SYNERGISTIC EFFECTS**
 - **SYNERGISTIC EFFECTS CANNOT BE EVALUATED WITH THE AVAILABLE DATA BASE**
 - **NO DATA IN POLAR ORBIT ENVIRONMENT**

LIMITATIONS OF CURRENT SPACE SHUTTLE FLIGHT EXPERIMENT DATA BASE (Continued)

- **THE VALIDITY OF EXTRAPOLATION TO HIGH FLUENCE CONDITIONS OR RADICALLY DIFFERENT ORBITAL ENVIRONMENTS IS UNKNOWN AT THIS TIME**
- **COMPONENTS OF THE SOLAR MAXIMUM SATELLITE (ALTITUDE 574 TO 491 km, INCLIN. 28.5°) RECOVERED IN APRIL 1984 SHOWED SURFACE RECESSION IN CRUDE AGREEMENT WITH PREDICTIONS MADE USING THE DATA BASE; TEFLON APPEARED TO BE MORE REACTIVE THAN ANTICIPATED; KAPTON REACTIVITY IN AGREEMENT WITH DATA BASE (20)**

LABORATORY SIMULATION AND MODELING OF ATOMIC OXYGEN EFFECTS ON SPACECRAFT MATERIALS

- GROUND BASED SIMULATION AND TEST SYSTEMS ARE NEEDED TO SUPPORT: 1) INTERPRETATION AND UNDERSTANDING OF ENVIRONMENTAL EFFECTS AND 2) DEVELOPMENT AND FLIGHT QUALIFICATION OF LONG LIFE SPACECRAFT MATERIALS AND COMPONENTS
- A COMPLETE UNDERSTANDING OF THE KINETICS AND MECHANISM OF HYPERHERMAL ATOM SURFACE REACTIONS DOES NOT EXIST; WITHOUT THE UNDERSTANDING PRODUCED BY LABORATORY SIMULATION AND MODELING STUDIES, WE CANNOT DEVELOP ACCELERATED TEST METHODS WITH HIGH CONFIDENCE AND WE CANNOT UNDERSTAND SYNERGISTIC EFFECTS

LABORATORY SIMULATION AND MODELING OF ATOMIC OXYGEN EFFECTS ON SPACECRAFT MATERIALS (Continued)

- AN IDEAL LABORATORY TEST AND SIMULATION SYSTEM WOULD PROVIDE A PURE, WELL COLLIMATED BEAM OF NEUTRAL OXYGEN ATOMS WITH A KINETIC ENERGY OF 5 eV (8km/sec) AND AN ATOM FLUX GREATER THAN 10^{14} ATOMS/cm²*sec. NO SUCH SYSTEM EXISTS AT THIS TIME
- NEARLY ALL THE NEUTRAL ATOM TEST METHODS UNDER DEVELOPMENT FALL INTO ONE OF 4 CATAGORIES
 - THERMAL ATOM SOURCES: OXYGEN ATOMS ARE PRODUCED IN RF OR MICROWAVE DISCHARGES TO PRODUCE HIGH OXYGEN CONCENTRATIONS AT THERMAL OR NEAR THERMAL ENERGIES
 - PLASMA TORCH, ATOMIC BEAM SOURCES: OXYGEN ATOMS ARE GENERATED IN A HIGH TEMPERATURE PLASMA, THEN FREE JET OR SUPERSONIC EXPANSION CONVERTS SENSIBLE HEAT TO VELOCITY: ATOM ENERGIES OF 1 TO 2 eV (POSSIBLY 4 eV) HAVE BEEN ACHIEVED
 - ION BEAM METHODS: POSITIVE OR NEGATIVE ATOMIC ION BEAMS ARE PRODUCED, ACCELERATED AND FOCUSED TO PROPER VELOCITY, THEN NEUTRALIZED TO GIVE A NOMINAL 5 eV OXYGEN ATOM BEAM
 - LASER SUSTAINED PLASMA, ATOMIC BEAM SOURCES: LASERS ARE USED TO PRODUCE HIGH TEMPERATURE/HIGH PRESSURE PLASMAS WHICH EXPAND AS FREE JETS OR SUPERSONIC BEAMS: ATOM KINETIC ENERGIES OF 1 TO 12 eV HAVE BEEN REPORTED WITH ATOM FLUXES OF 10^{15} TO 10^{18} ATOMS/cm²*sec

LABORATORY SIMULATION AND TEST SYSTEM EVALUATION

- DATA NECESSARY FOR COMPLETE EVALUATION OF TEST SYSTEM
 - DIRECT MEASUREMENT OF ATOM FLUX AND VELOCITY
 - DIRECT MEASUREMENT OF BEAM PURITY
 - REACTION EFFECIENCY MEASUREMENTS ON MATERIALS IN THE FLIGHT EXPERIMENT DATA BASE
 - REACTION EFFICIENCY MEASUREMENTS ON THE LeRC "ROUND ROBIN" MATERIALS SET

LABORATORY SIMULATION AND TEST SYSTEM EVALUATION (Continued)

- NO IDEAL, COMPLETELY CHARACTERIZED SYSTEM EXISTS; HOWEVER, THE LASER SUSTAINED PLASMA, ATOMIC BEAM SYSTEMS OFFER THE BEST APPROXIMATIONS
 - LOS ALAMOS NATIONAL LABORATORY (21)
 - CONTINUOUS BEAM (CW LASER SUSTAINED DISCHARGE)
 - 1.5 TO 5 eV O ATOMS; 10^{15} TO 10^{17} ATOMS/cm²*sec
 - BEAM PURITY VARIES; IN SITU DIAGNOSTICS MEASURE O₂, INERT GAS AND UV RADIATION CONTENT; IONS AND ELECTRONS AND O ATOM EXCITED STATES NEGLIGIBLE
 - KAPTON REACTIVITY AND SURFACE DAMAGE MORPHOLOGY IN REASONABLE AGREEMENT WITH FLIGHT DATA BASE
 - TEFLON APPEARS MORE REACTIVE THAN IN FLIGHT

LABORATORY SIMULATION AND TEST SYSTEM EVALUATION (Continued)

- **PHYSICAL SCIENCES INCORPORATED (23)**
 - **PULSED BEAM (PULSED LASER SUSTAINED DISCHARGE)**
 - **2 TO 14 eV ATOMS; 10^{15} TO 10^{17} ATOMS/cm²*sec
(INSTANTANEOUS FLUXES MUCH HIGHER, ABOUT 10^{21})**
 - **BEAM PURITY MEASURED WITH IN SITU DIAGNOSTICS; 98% O ATOMS,
NEGLIGIBLE UV, IONS, ELECTRONS AND O₂; O ATOM EXCITED STATES
NEGLIGIBLE**
 - **KAPTON AND TEFLON REACTIVITIES AND SURFACE DAMAGE
MORPHOLOGY IN REASONABLE AGREEMENT WITH FLIGHT DATA BASE**

SUMMARY

- IN FLIGHT MATERIALS EXPOSURE DATA BASE
 - EXTENSIVE QUANTITATIVE DATA AVAILABLE FROM LIMITED EXPOSURES IN A NARROW RANGE OF ORBITAL ENVIRONMENTS
 - MORE DATA IS NEEDED IN A WIDER RANGE OF ENVIRONMENTS AS WELL AS LONGER EXPOSURE TIMES
 - SYNERGESTIC EFFECTS WITH OTHER ENVIRONMENTAL FACTORS
 - POLAR ORBIT AND HIGHER ALTITUDE ENVIRONMENTS
 - REAL TIME MATERIALS DEGREDDATION DATA IS NEEDED TO UNDERSTAND DEGREDDATION KINETICS AND MECHANISM

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**OVERVIEW
OF
MOBILE SERVICING SYSTEM (MSS)
CONFIGURATION
AND
SERVICING CAPABILITY**

SATELLITE SERVICES SYSTEM WORKING GROUP MEETING #22

J S C

NOV. 28-29, 1989

MOSES WONG

SPAR AEROSPACE

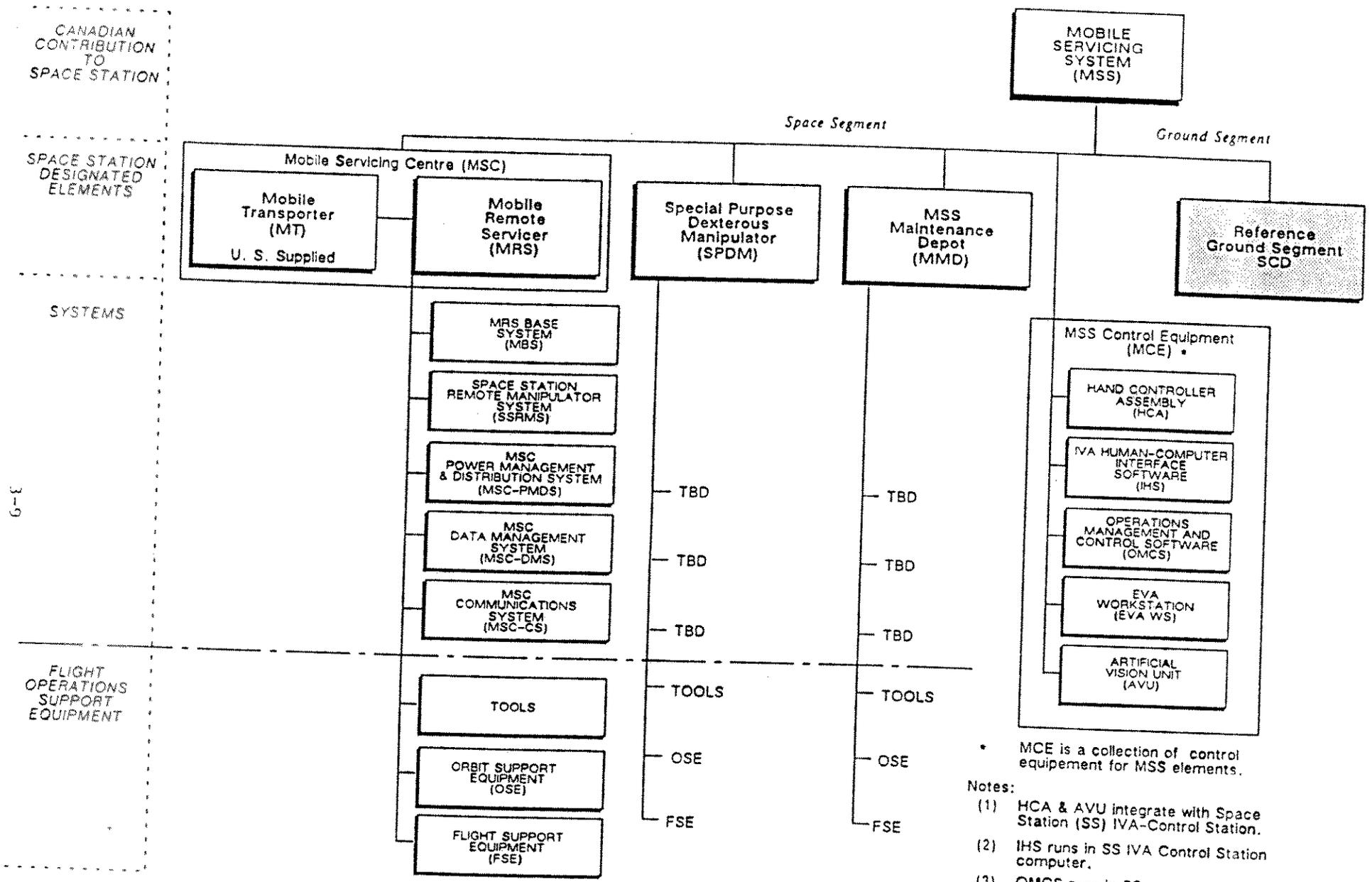
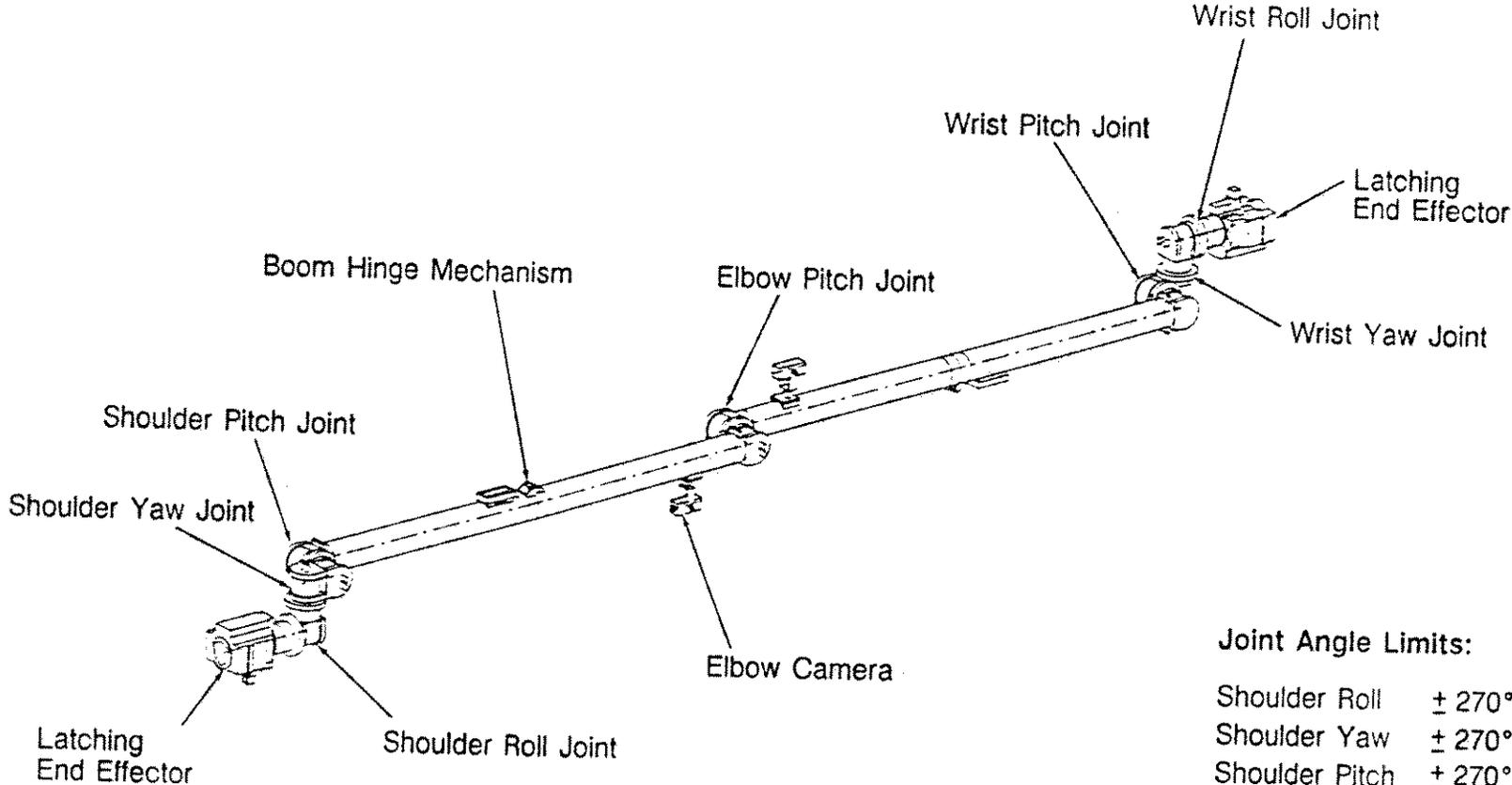


Figure 3-3 Mobile Servicing System (Space Segment) Hierarchy

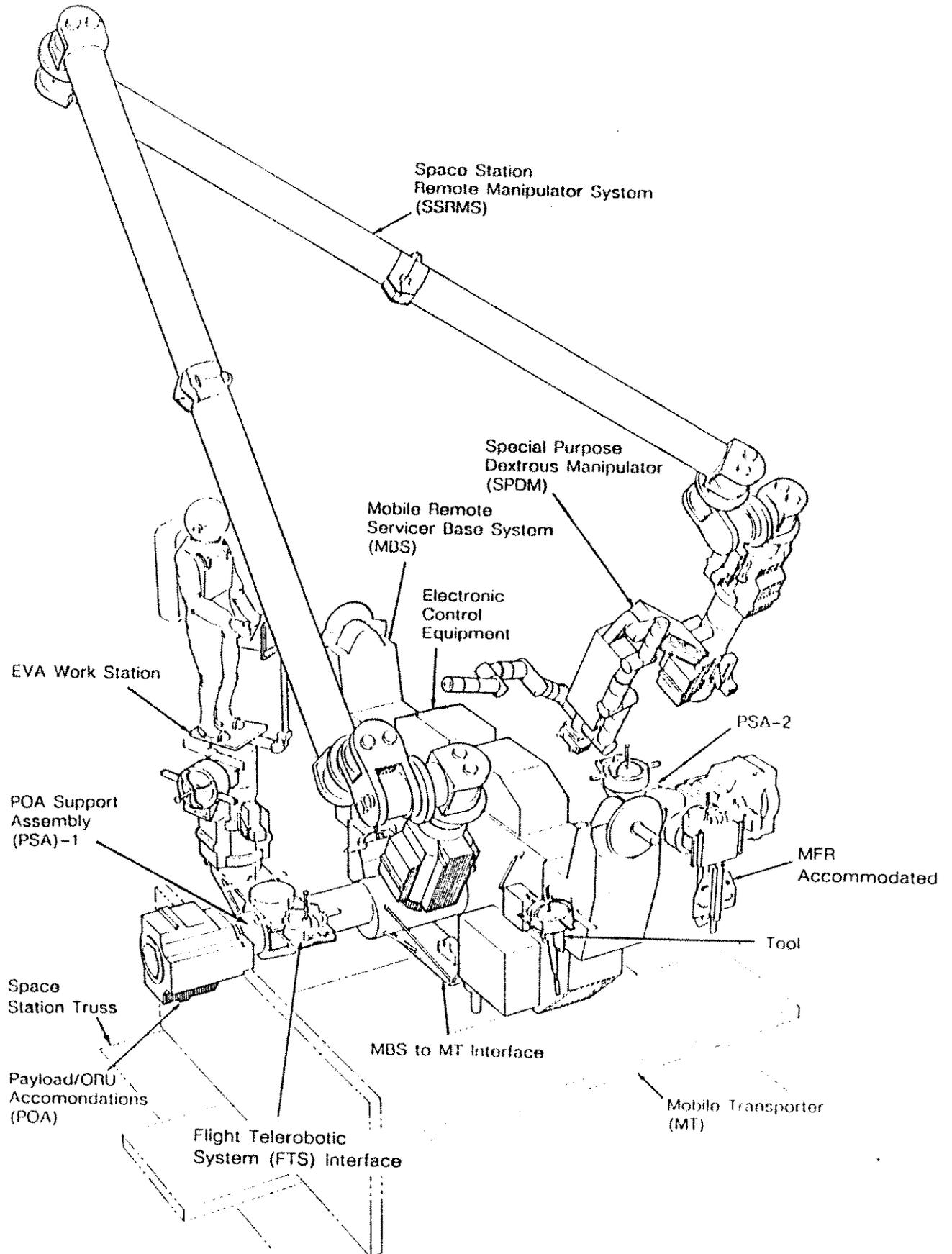
SSRMS Physical Configuration Perspective



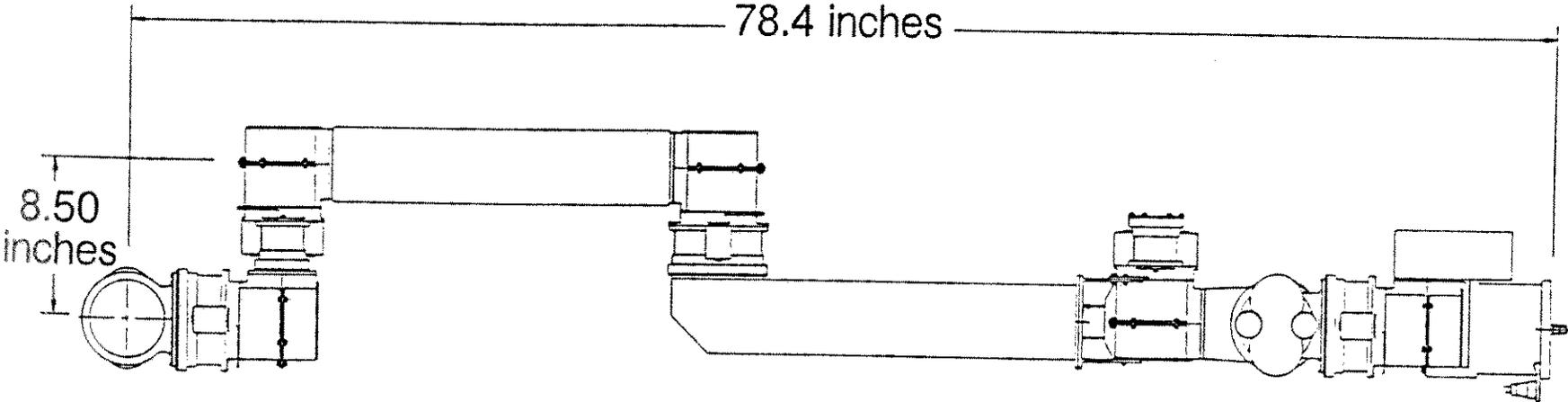
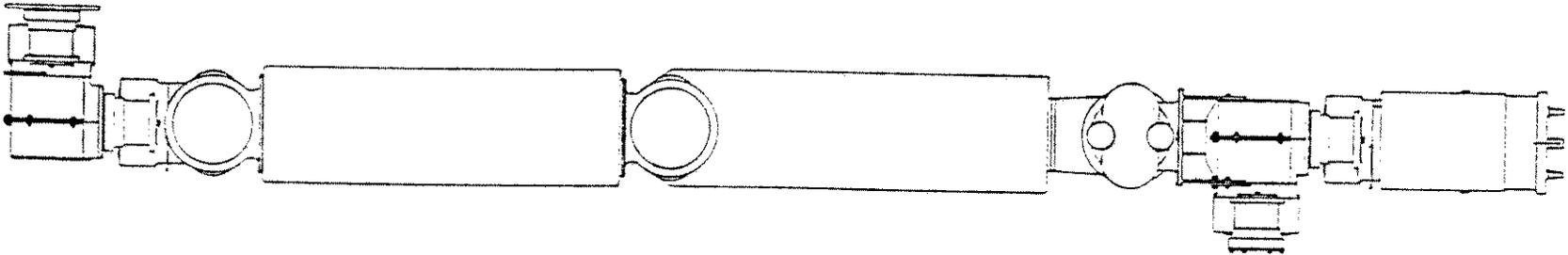
Joint Angle Limits:

- Shoulder Roll $\pm 270^\circ$
- Shoulder Yaw $\pm 270^\circ$
- Shoulder Pitch $\pm 270^\circ$
- Elbow Pitch $\pm 270^\circ$
- Wrist Roll $\pm 270^\circ$
- Wrist Yaw $\pm 270^\circ$
- Wrist Pitch $\pm 270^\circ$

Mobile Servicing Centre (MSC)



SPDM Arm Configuration



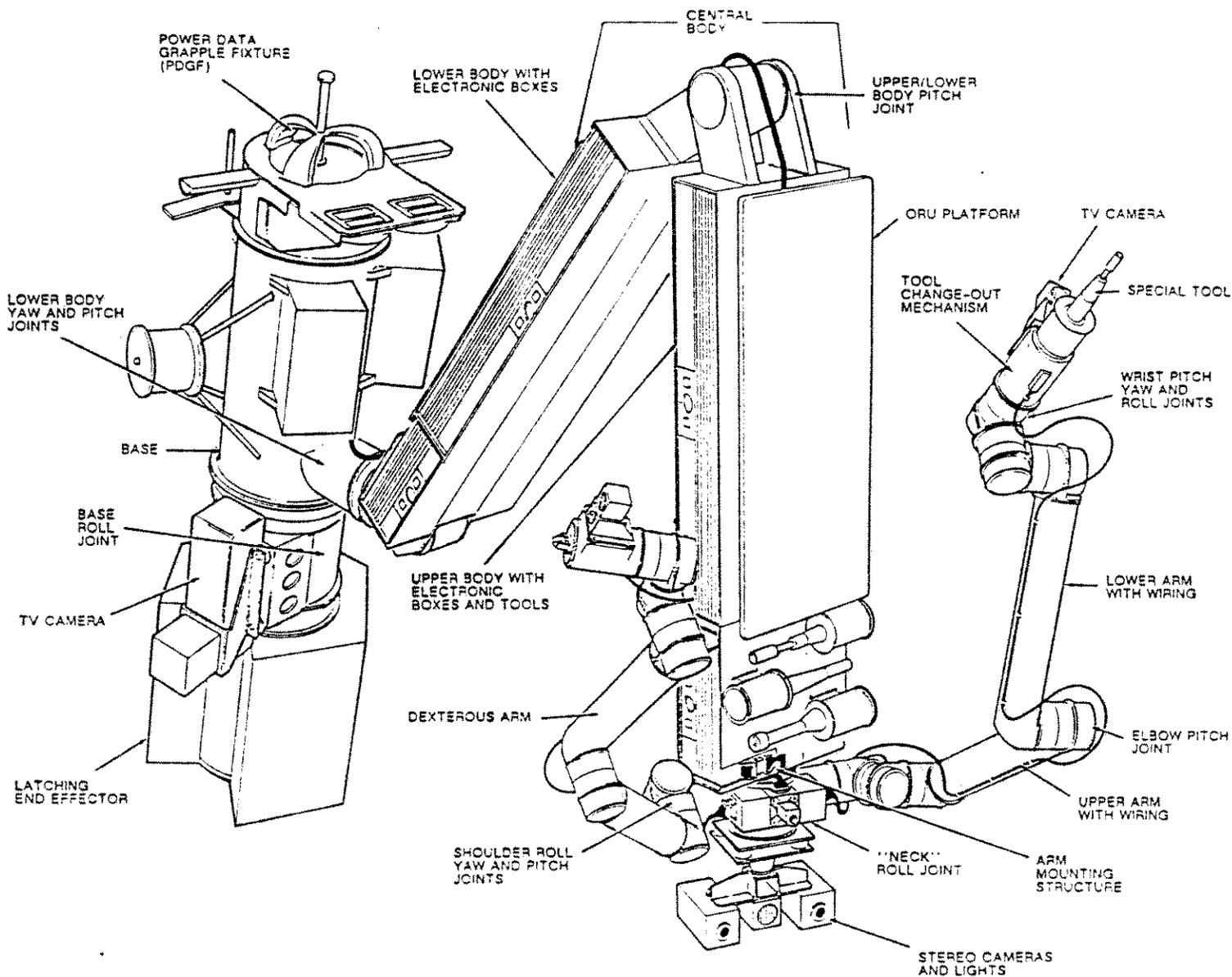


Figure 3-6 Special Purpose Dexterous Manipulator (SPDM) Concept - (TBD)

Dextrous Tasks for Assembly and Maintenance include

- Exchange ORU'S
- Attach / Detach ORU Interfaces
- Connect / Disconnect Utilities
- Mate / Demate Connectors
- Remove / Install Thermal Covers & Blankets
- Clean Surfaces
- Inspect and Monitor with Vision System
- Provide Lighting to Support EVA
- Position Tools & Materials to Support EVA
- Provide TV Views to Monitor EVA Activities

Perform Dextrous Tasks for Assembly & Maintenance of:

- Mobile Servicing Centre, including Mobile Transporter
- External Space Station Systems
 - Power System
 - Alpha & Beta Gimbals
 - C&T System
 - GN&C System
 - DMS System
 - RCS
 - SIA and PIA (for attached payloads)

Perform Dextrous Tasks for

- Handling Small Payloads (external)
- EVA-Support
- Safe Haven Support

- Vision System
 - Object recognition
 - Stereo vision
- Collision Avoidance
 - Safeing
 - Real-time path planning
- Hierarchical Control
 - Manual (telerobotic) mode
 - Supervisory mode
 - Autonomous mode
- Robot Programming Language
 - Hierarchical command structure
- Knowledge-Based Expert Systems
 - Fault detection and diagnosis
 - Anomaly/exception handling
 - Task planning

- Force/moment accommodation/limiting
 - Limit tip forces/moments
 - Apply controlled force/moments
 - Feedback of forces/moments to operator
- Closed-loop control with vision inputs
 - Auto tracking and capture of a target
- Co-ordinated control of two manipulators
 - Two manipulators holding and manoeuvring an object
- SSRMS/SPDM co-ordinated control
 - Co-ordinated motion of all joints in SSRMS and SPDM in performing tasks in constrained environment

Performance Requirements / Capabilities



- Max. size ORU to be handled = TBD (600kg)
- Tip force capability : 25 lbs (111N)
- Tip torque / moment capability : 40 lb–ft (54N–M)
- Tip positioning accuracy = 0.050 in (0.125 cm)
(with vision system)
- Max. stopping distance = 2 in. (5.0 cm)
- Weight = 1800 lbs. (815 kg)
- Standard interface for handling ORU's and tools
- A standard set of tools to be provided with SPDM

Operational Locations

- At the end of SSRMS
- Attached to MSC
- Attached to station locations (PDGF's)

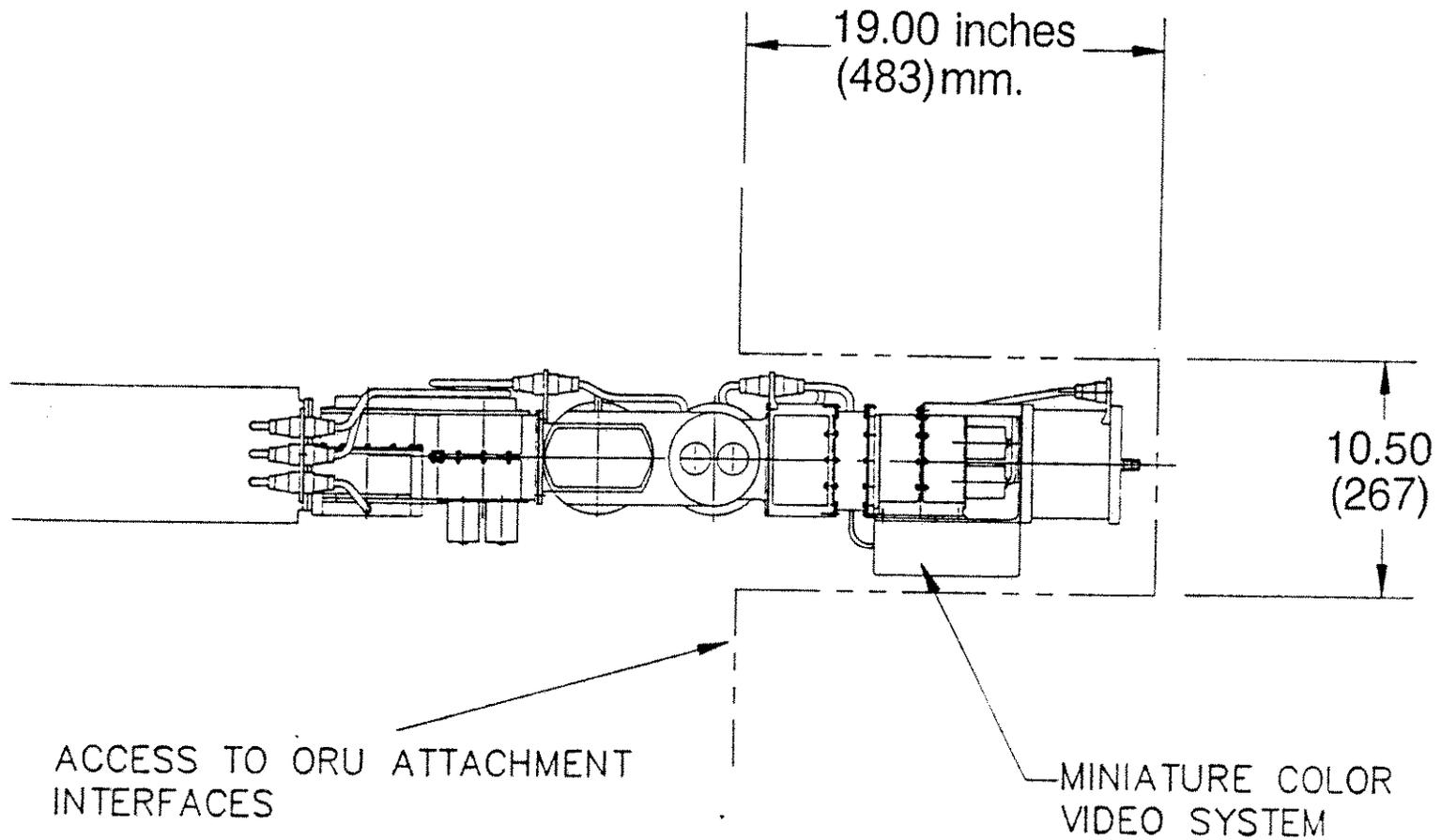
Operation from MSS IVA–Control Station

Human–machine interface integrated with MSS displays and controls

Insertion Of SPDM Arm Tip In Small Opening



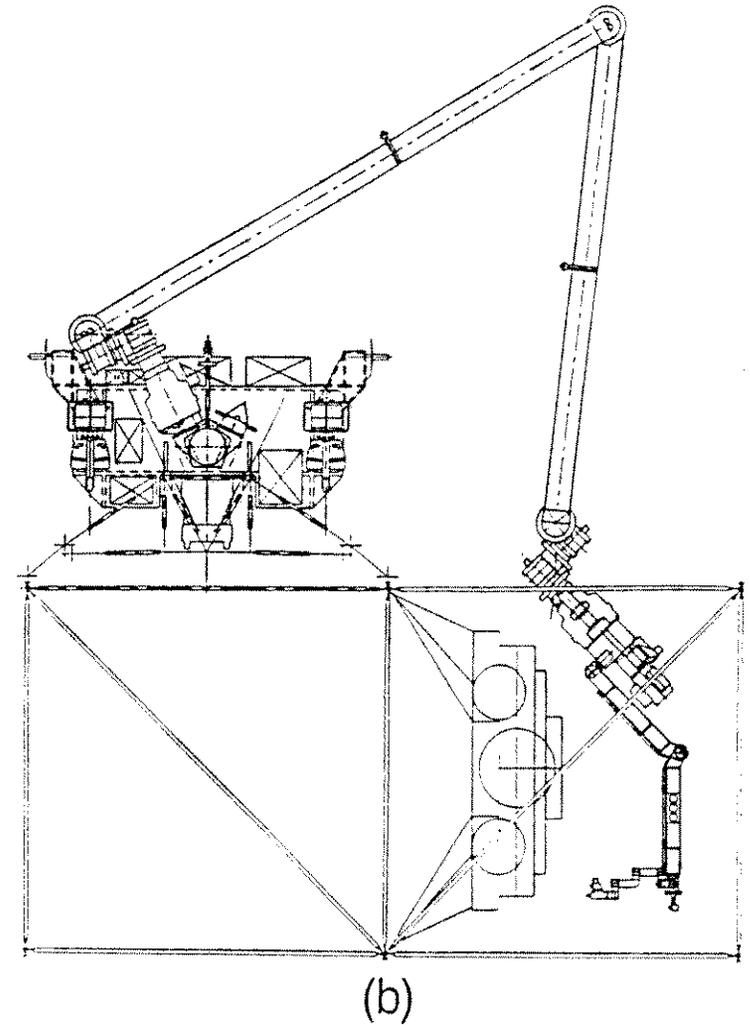
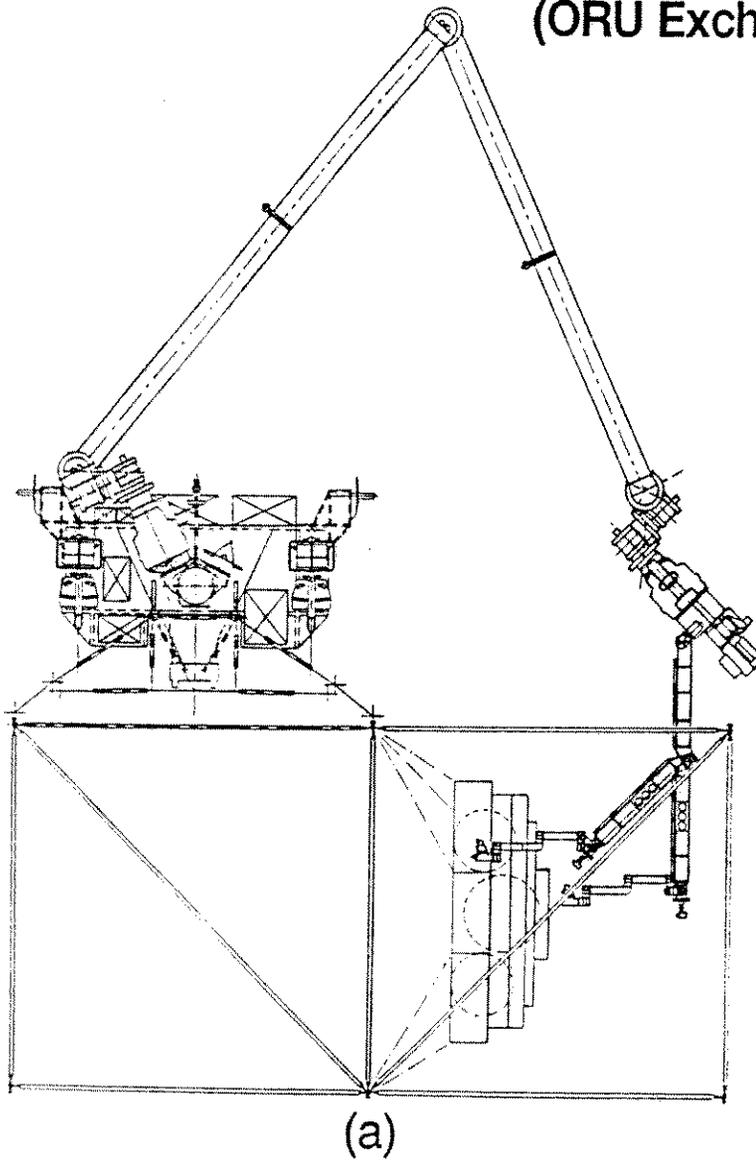
inches mm. 19.00 (483) 10.50 (267)



SPDM Operating At The End Of SSRMS



(ORU Exchange on Equipment Tray Inside Truss)



SPDM Tools Development

Robotic Tool Candidates – Task vs. Tool

Tasks

- Space Station Truss Assembly & Maintenance Support
- Carry, Install & Remove ORUs
- Mate & Demate Connectors
- Cleaning
- Gripping Handrails
- Thermal Blankets Change-Out
- Cable Cassette / Harness Replacement

Tool Candidate

- Gripper / Harpoon
- UST Type
- TBD (UST Type)
- Special Tool "A"
- Gripper
- Special Tool "B"
- UST Type / Special Tool "C"

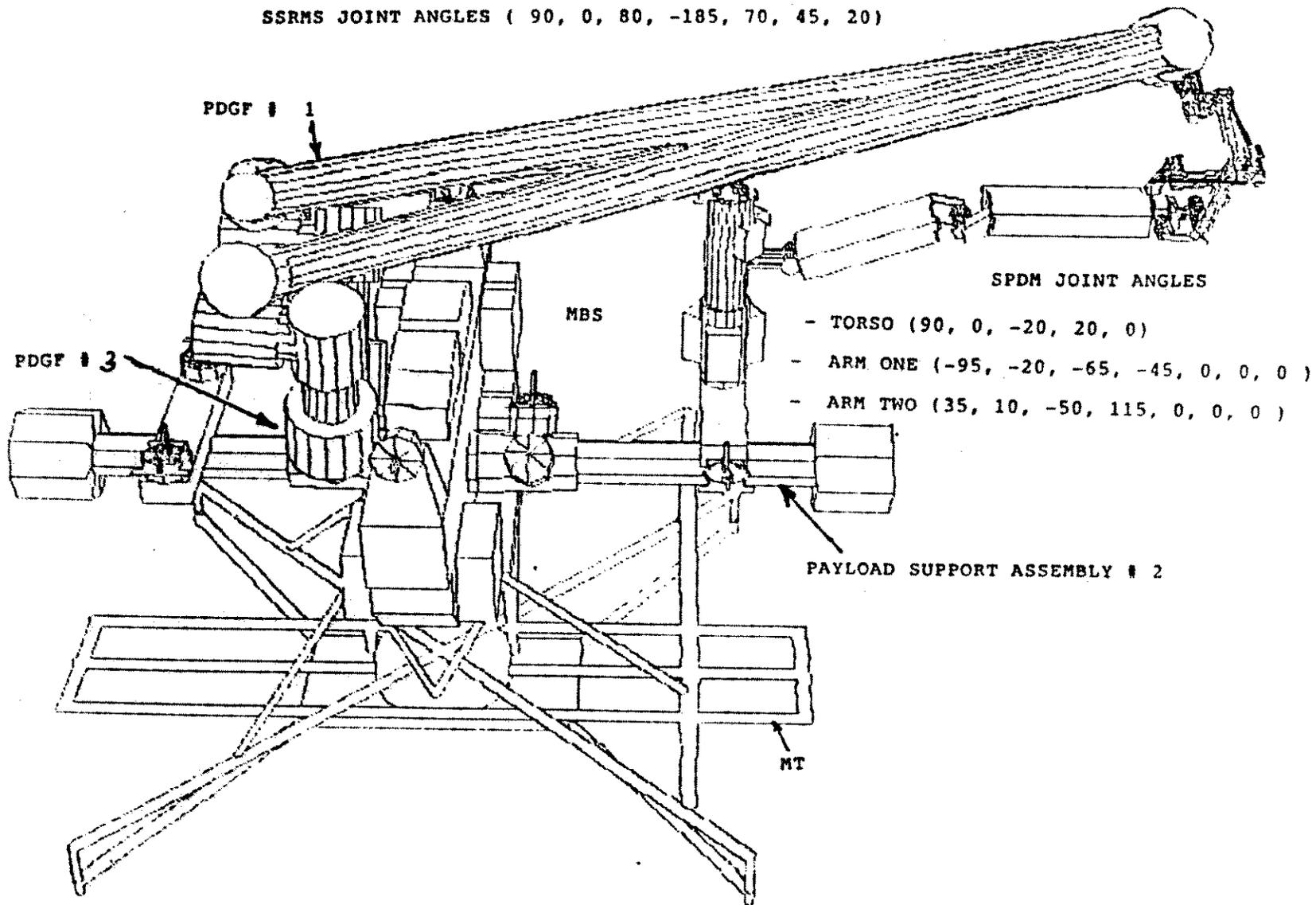


Fig. 5-2 GRAPPLE DEFECTIVE JDM AT CENTRAL INTERFACE LOCATION WITH
SPDM ARM ONE

TCM Functional Requirements

- **Standard Attachment** : The TCM shall have standard attachment to tools and other dedicated I/F's
- **Umbilical Connectors** : Electrical Power & Data Connectors shall be automatically mated when the TCM engages with a dedicated I/F
- **Tool Stowage** : The TCM shall pick up tools from their tool rack
- **Tool Capture** : The TCM shall latch on to a power or passive tool;
Other Capture : Locator fittings or handrail and, optionally TBD (ORU)
- **Sensing Capabilities** : The TCM shall have force/moment sensing capability
- **Tool Automation Mechanism** : The TCM shall provide a torque output shaft
- **Structural** : Resist forces and moments at all dedicated I/F

TCM – Tool Change – Out Mechanism

- Def : The Tool Change–Out Mechanism (TCM) is a device attached to the SPDM roll joint through which the SPDM interfaces with tools, tool–adapters, locator fitting, handrails, and optionally, TBD (ORU's).

MISSION OPERATIONS DIRECTORATE SYSTEMS DIVISION



STS-37 EVA DEVELOPMENT FLIGHT EXPERIMENT

SATELLITE SERVICES SYSTEM

WORKING GROUP MEETING #22

NOVEMBER 28-29, 1989

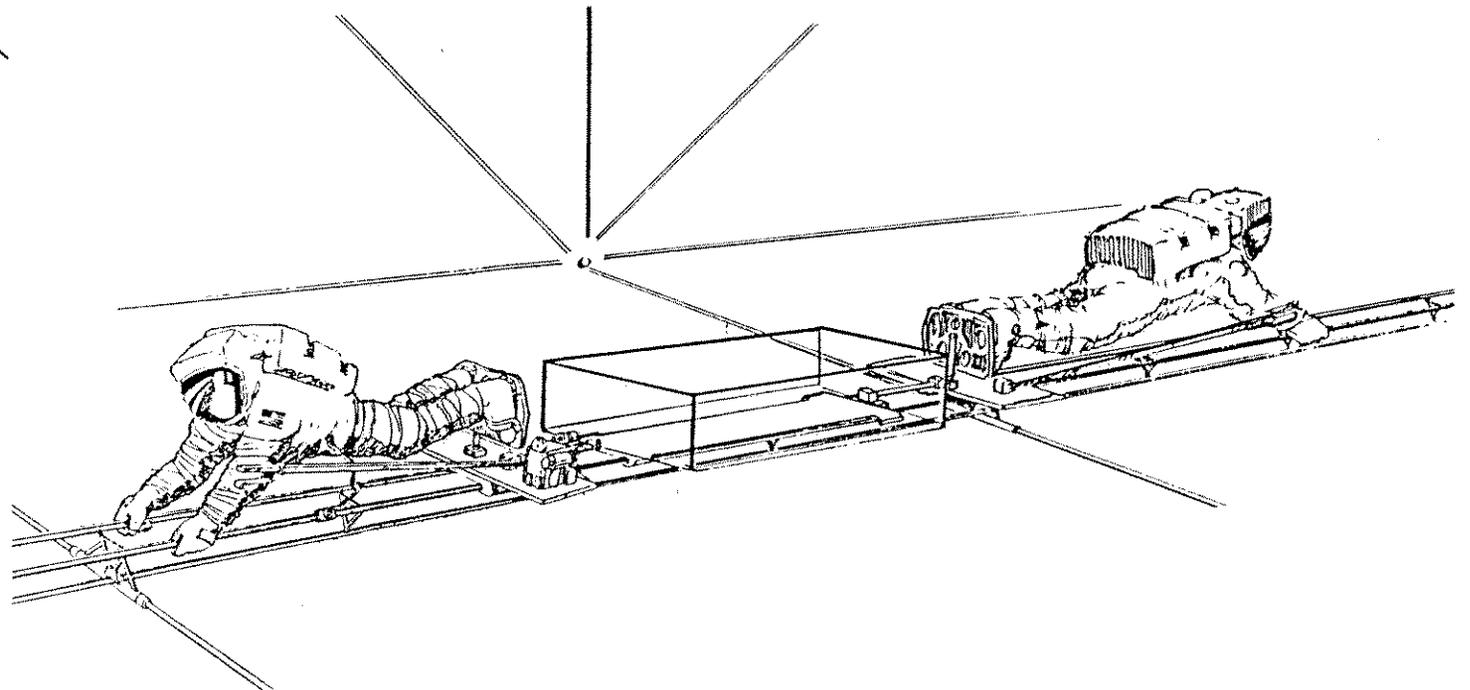
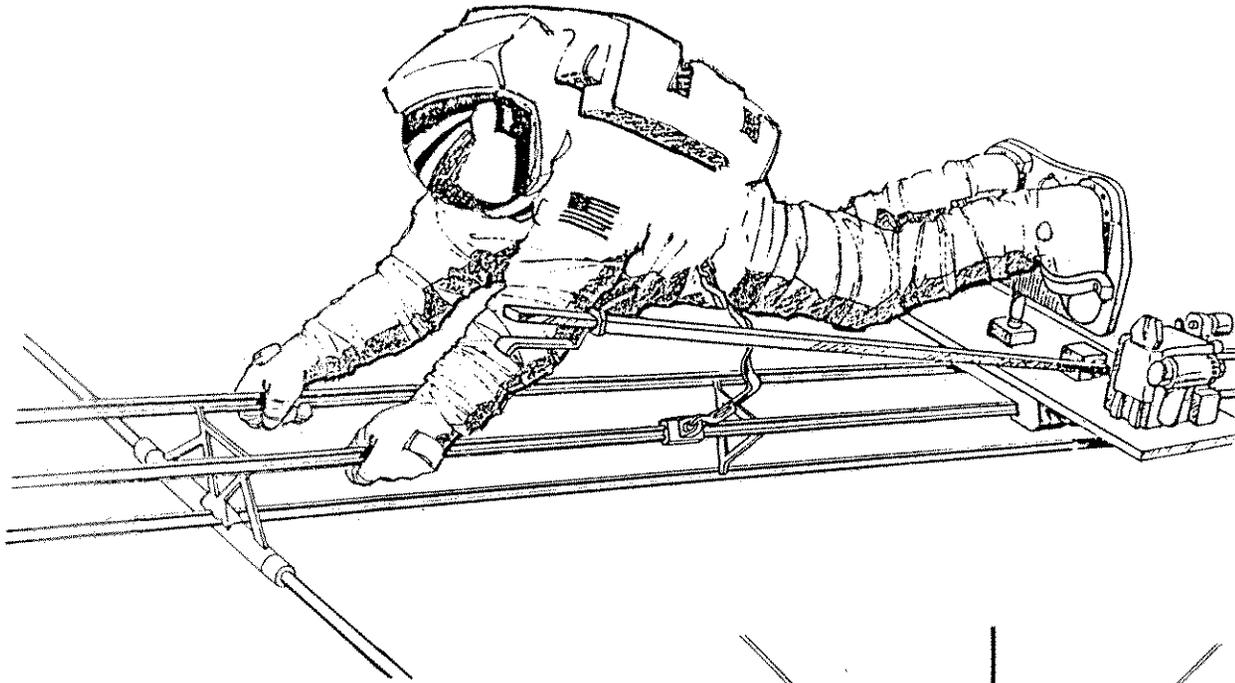
DF42/KAREN R. ARCHARD AND PATRICK E. CORNELIUS

QUESTIONS FACING SPACE STATION DESIGNERS AND OTHER USERS OF EVA

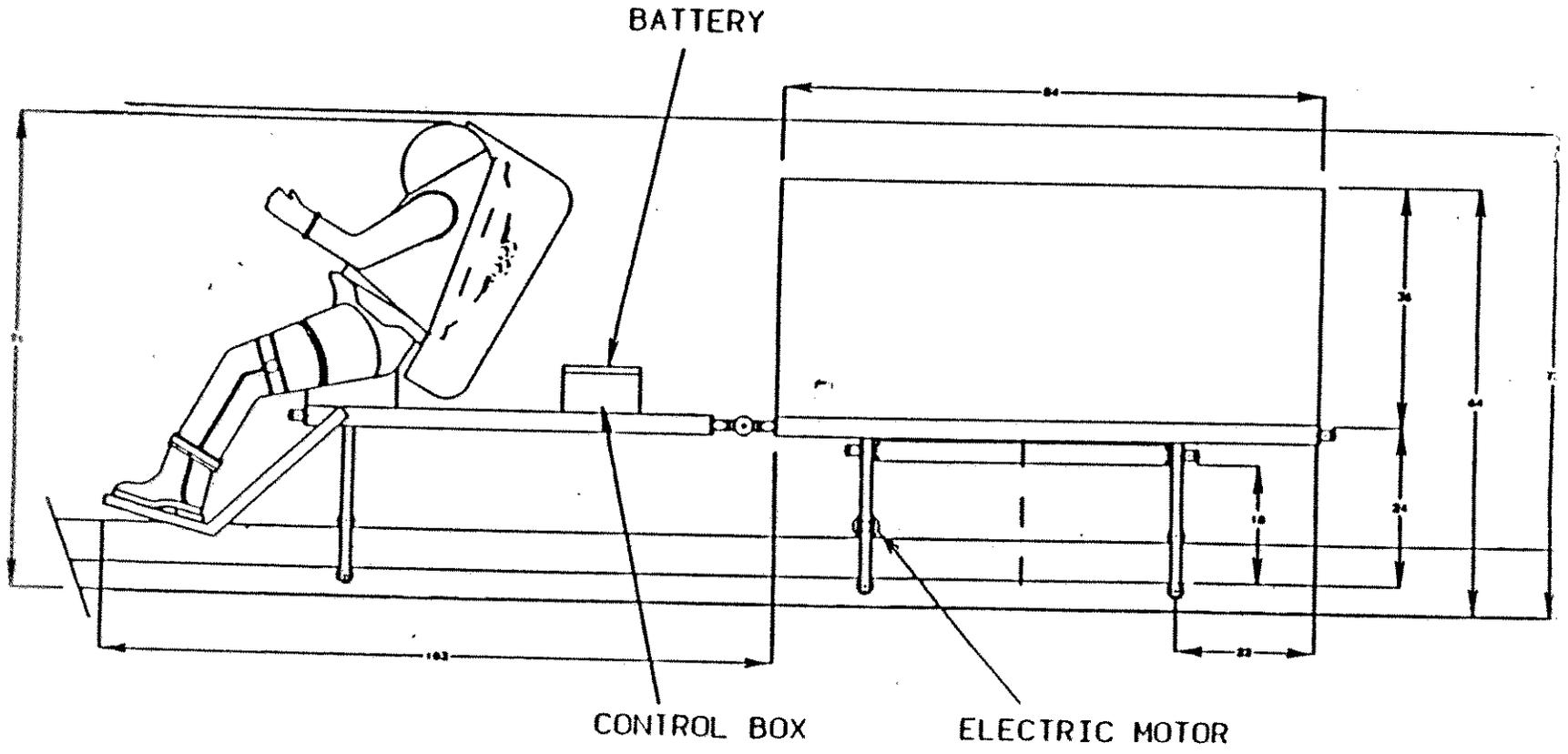
- **TECHNIQUES FOR TRANSLATING ABOUT THE STATION - CREW AND EQUIPMENT TRANSLATION AIDS (CETA)**
 - **RAPID CREW TRANSPORT**
 - **ONE OR TWO CREWMEMBERS**
 - **SMALL ORU AND TOOL TRANSPORT**
 - **CREW RESTRAINT DURING TRANSLATION**
 - **MANUAL VERSUS POWERED**

- **RATES AND LOADS ASSOCIATED WITH EVA - BASIC DESIGN DATA**
 - **MANUAL TRANSLATION RATES AND LOADS**
 - **TRANSLATION AID RATES AND LOADS**
 - **MANIPULATOR RATES AND STIFFNESS**
 - **CREW APPLIED LOADS CAPABILITIES**
 - **CREW INDUCED LOADS INTO STRUCTURE**

SPACE STATION CETA CONCEPT



SPACE STATION CETA CONCEPT

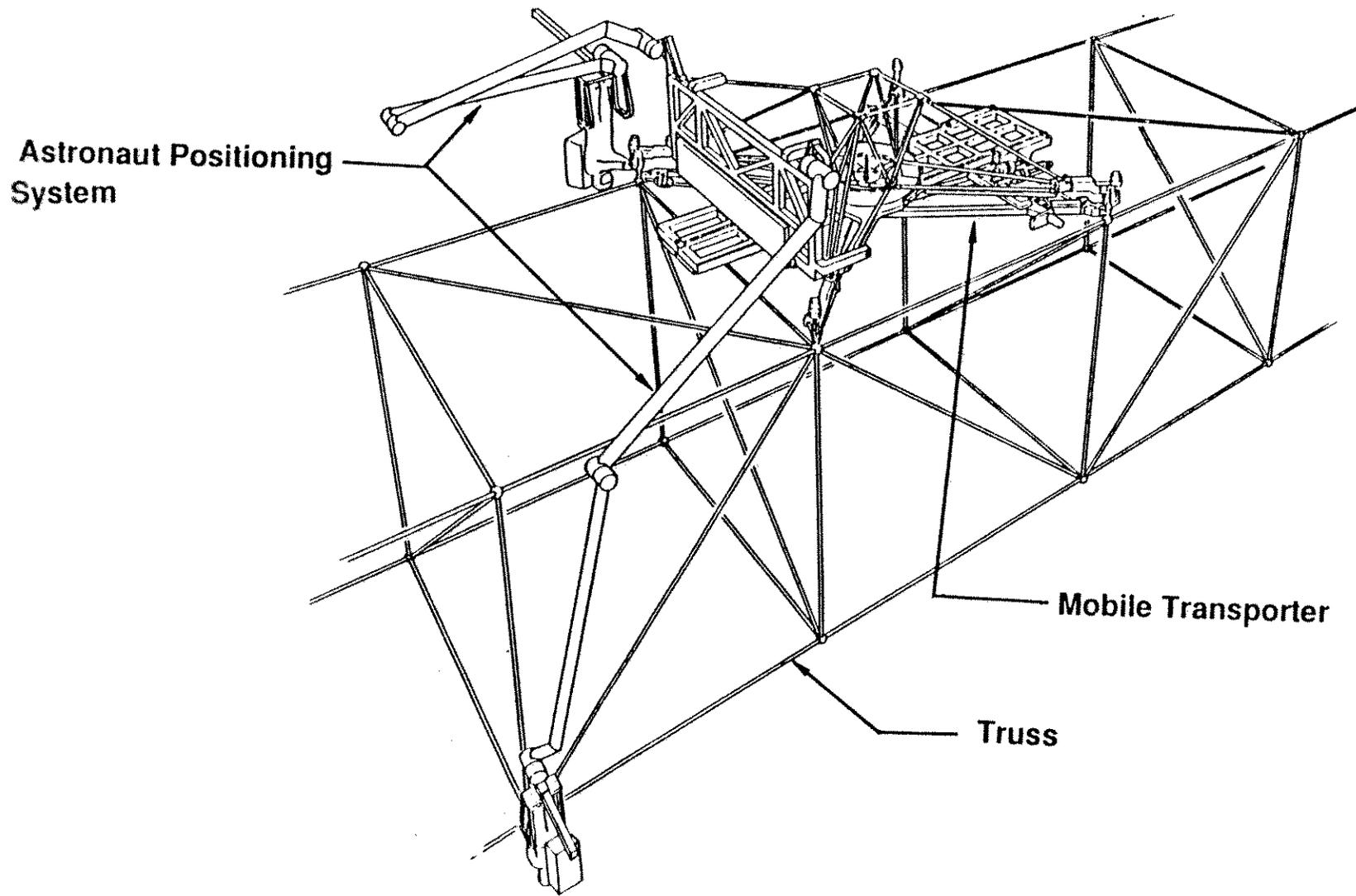


EDFE OBJECTIVES

- **EVALUATE CANDIDATE PROPULSION TECHNIQUES FOR THE CREW AND EQUIPMENT TRANSLATION AID (CETA)**
 - **MANUAL (HANDRAILS)**
 - **CENTERLINE HANDRAIL**
 - **OFFSET HANDRAIL**
 - **TWO HANDRAILS**
 - **MECHANICAL (PUMP LEVER)**
 - **ELECTRICAL (MANUAL GENERATOR)**

- **EVALUATE CANDIDATE CREW RESTRAINTS FOR THE CETA**
 - **FOOT RESTRAINT**
 - **LEG RESTRAINT**
 - **SAFETY TETHER ONLY**

ASTRONAUT POSITIONING SYSTEM (APS)



**STS-37 EVA DEVELOPMENT
FLIGHT EXPERIMENTS (EDFE)**

**CREW AND EQUIPMENT
TRANSLATION AIDS (CETA)
A. K. A. DTO 1201**

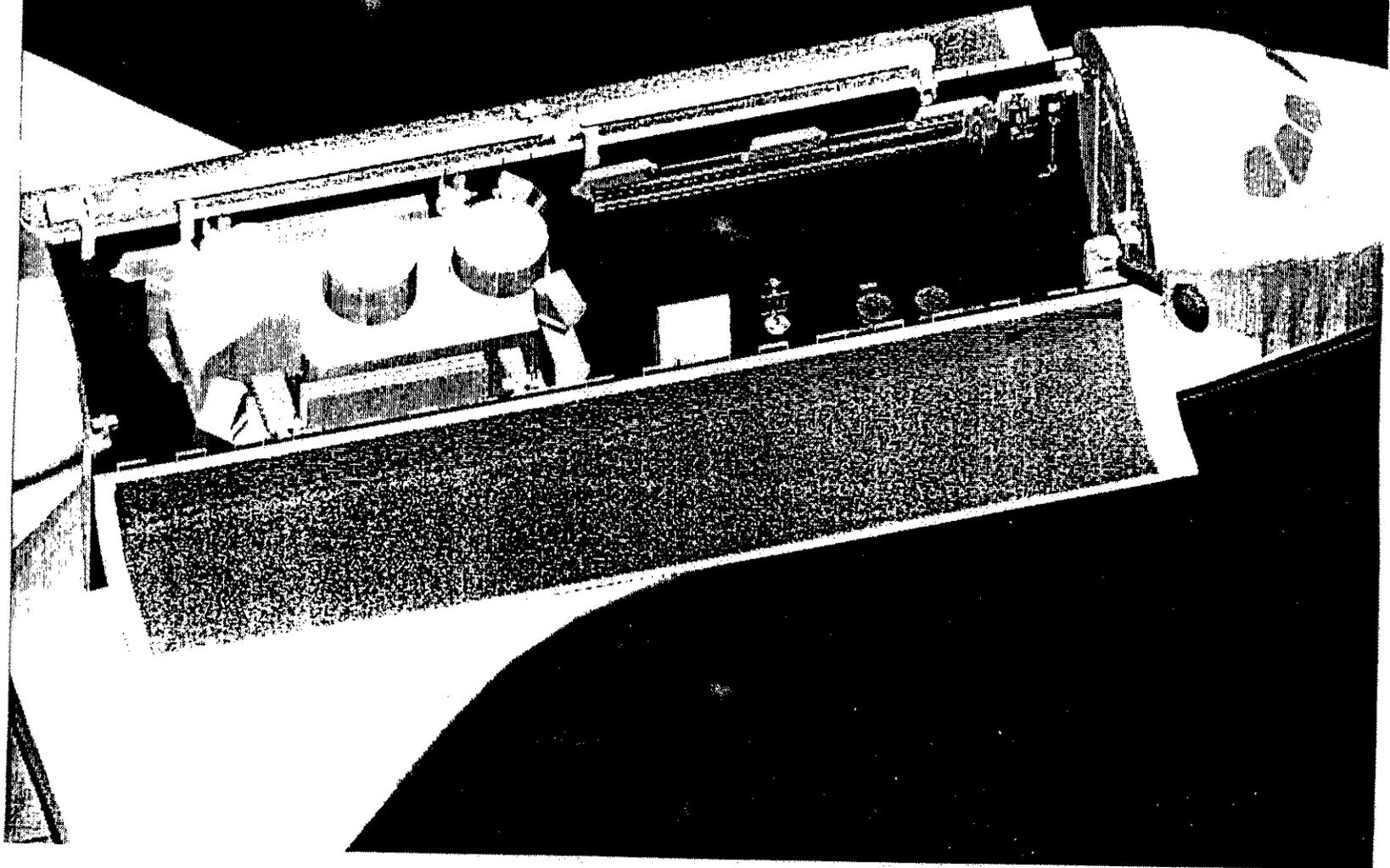
**EVA CREW TRANSLATION
EVALUATION (ETE)
DTO 1202**

**CREW LOADS INSTRU-
MENTED PALLET (CLIP)
DTO 1202**

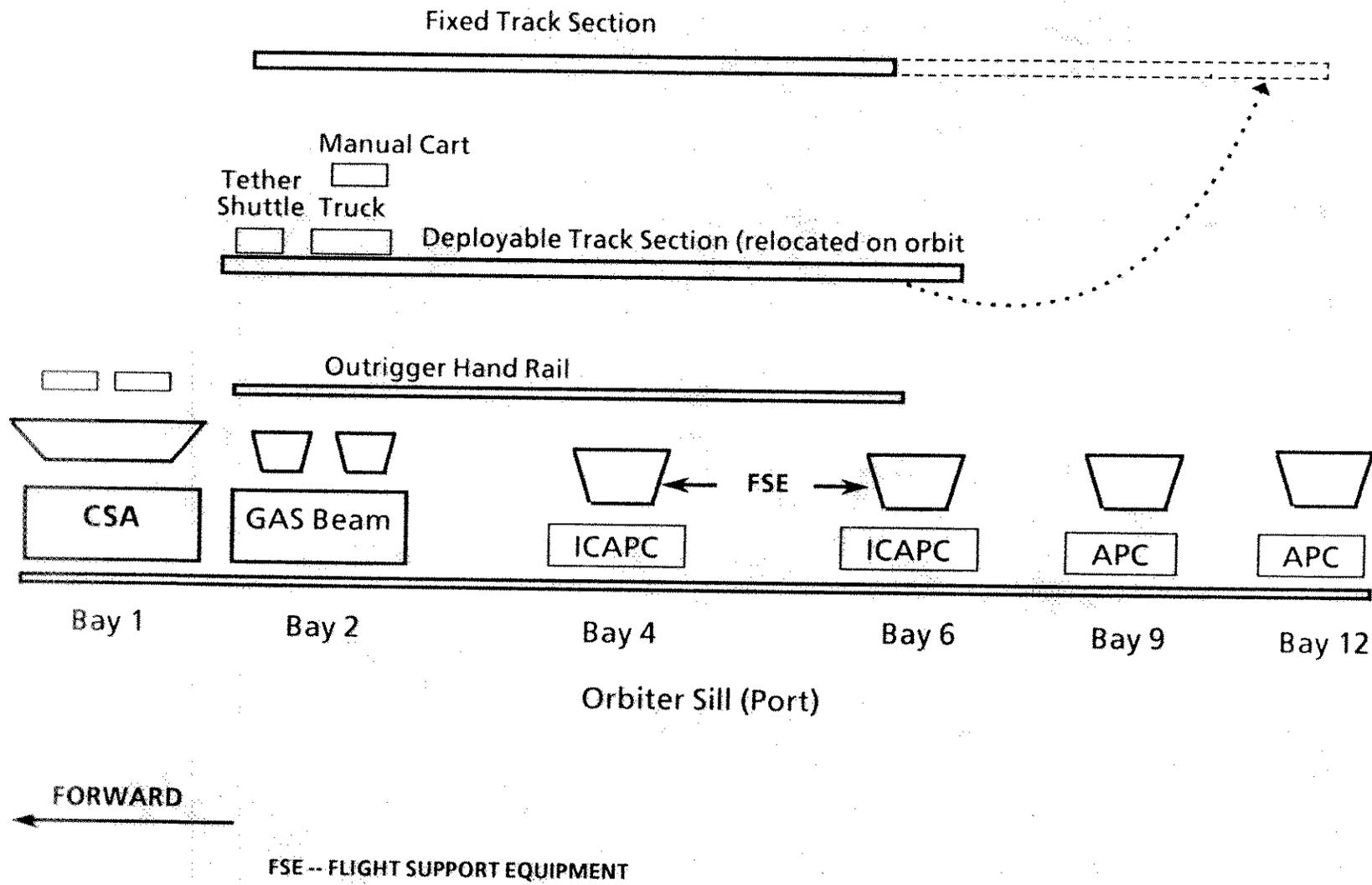
- **EVALUATE TECHNIQUES FOR ACCESSING A WORKSITE**
 - **NON-RIGID TRANSLATION AID FOR CREW AND SMALL EQUIPMENT**
 - **MANIPULATOR FOOT RESTRAINT**
 - **VELOCITIES**
 - **ACCELERATORS**
 - **RIGIDITY**

- **OBTAIN SSF DESIGN DATA**
 - **TRANSLATION RATES**
 - **CREW LOADS INDUCED INTO CETA CART AND RAILS**
 - **CREW LOADS APPLIED AT A WORKSITE**
 - **CREW LOADS INDUCED INTO STRUCTURE**

**STS-37
LAUNCH CONFIGURATION**



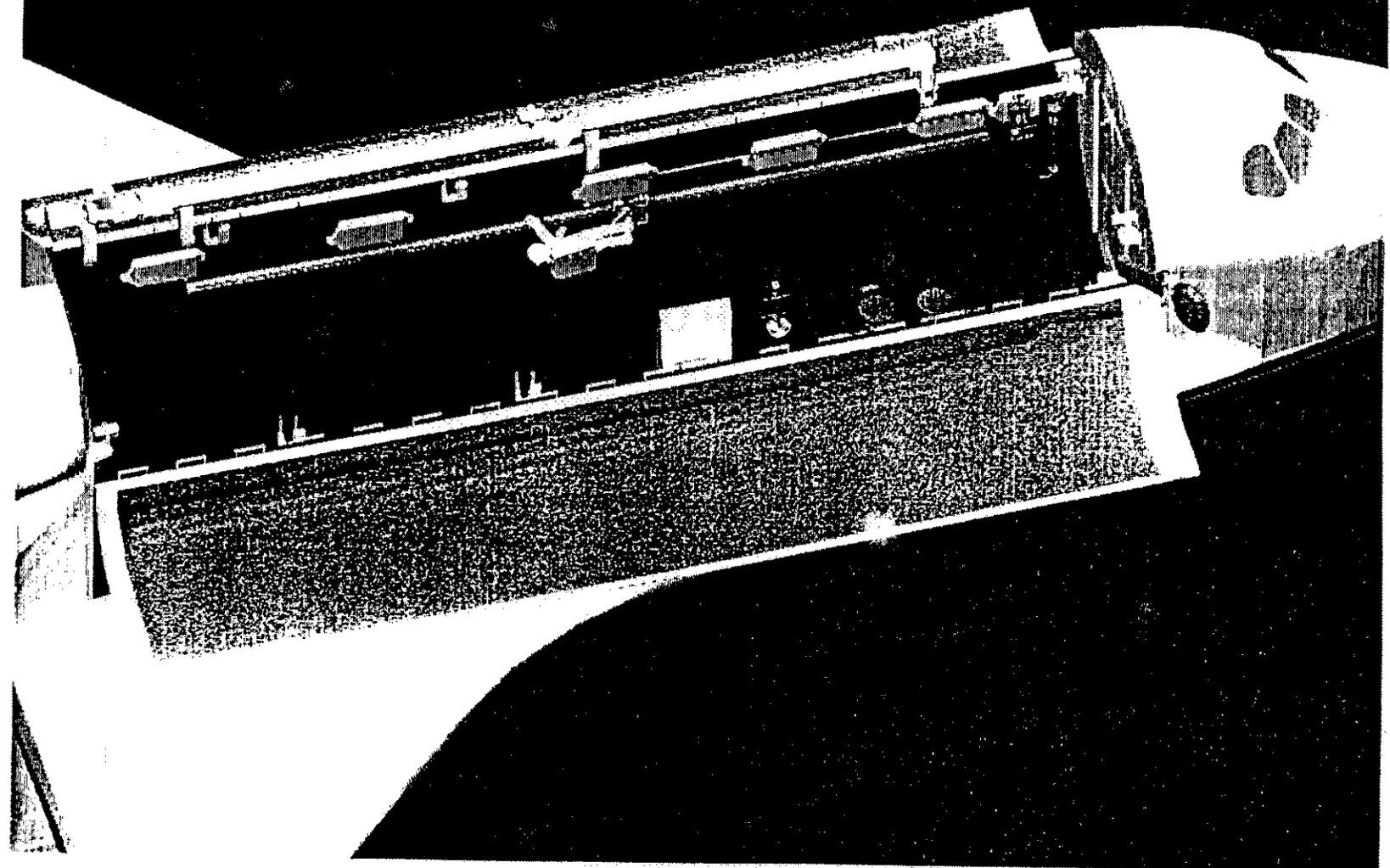
CETA FLIGHT EXPERIMENT Hardware Schematic



CETA FLIGHT EXPERIMENT OBJECTIVES

- **EVALUATE ALTERNATE TECHNIQUES AND EQUIPMENT FOR PROPELLING THE CETA CART:**
 - **MANUAL (HANDS ON RAIL)**
 - **MONORAIL/TRACK**
 - **DUAL (ONE TRACK PLUS ONE HANDRAIL)**
 - **TRIPLE (ONE TRACK PLUS TWO HANDRAILS)**
 - **MECHANICAL (HANDS ON PUMP LEVER)**
 - **ELECTRICAL MOTOR (HAND OPERATED GENERATOR)**

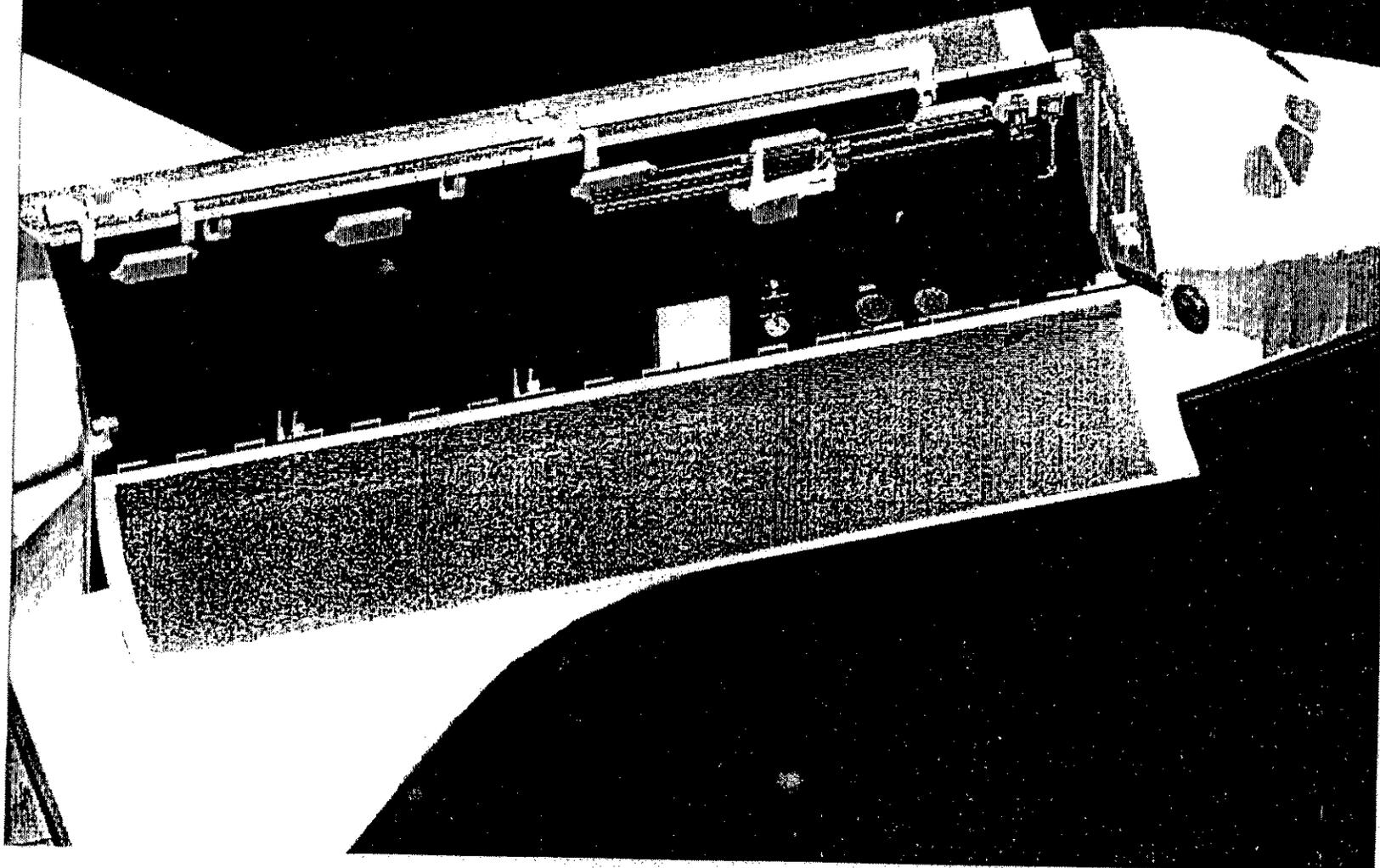
STS-37
EVA ON MANUAL CART - CETA DEPLOYED

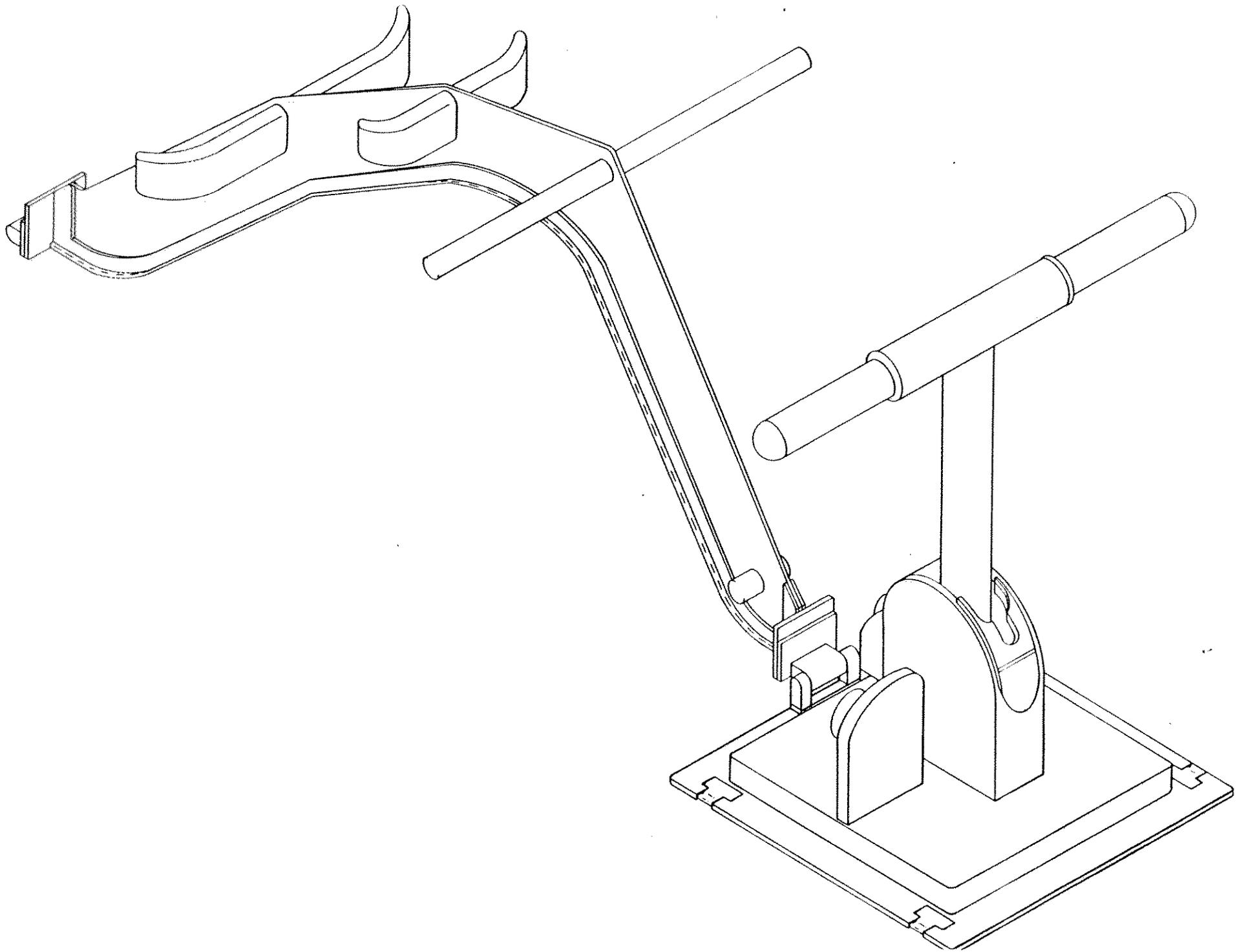


CETA FLIGHT EXPERIMENT OBJECTIVES (CONTINUED)

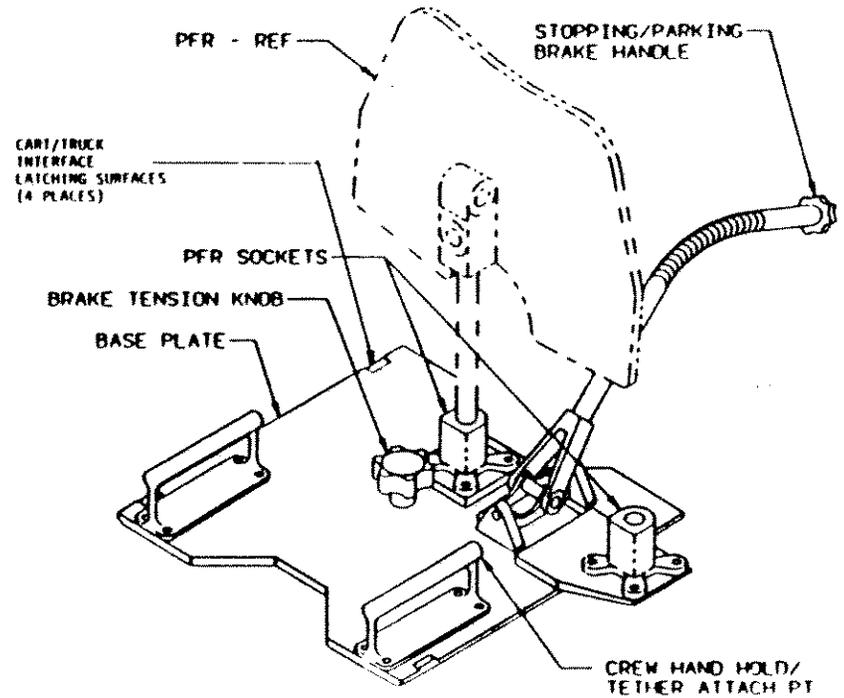
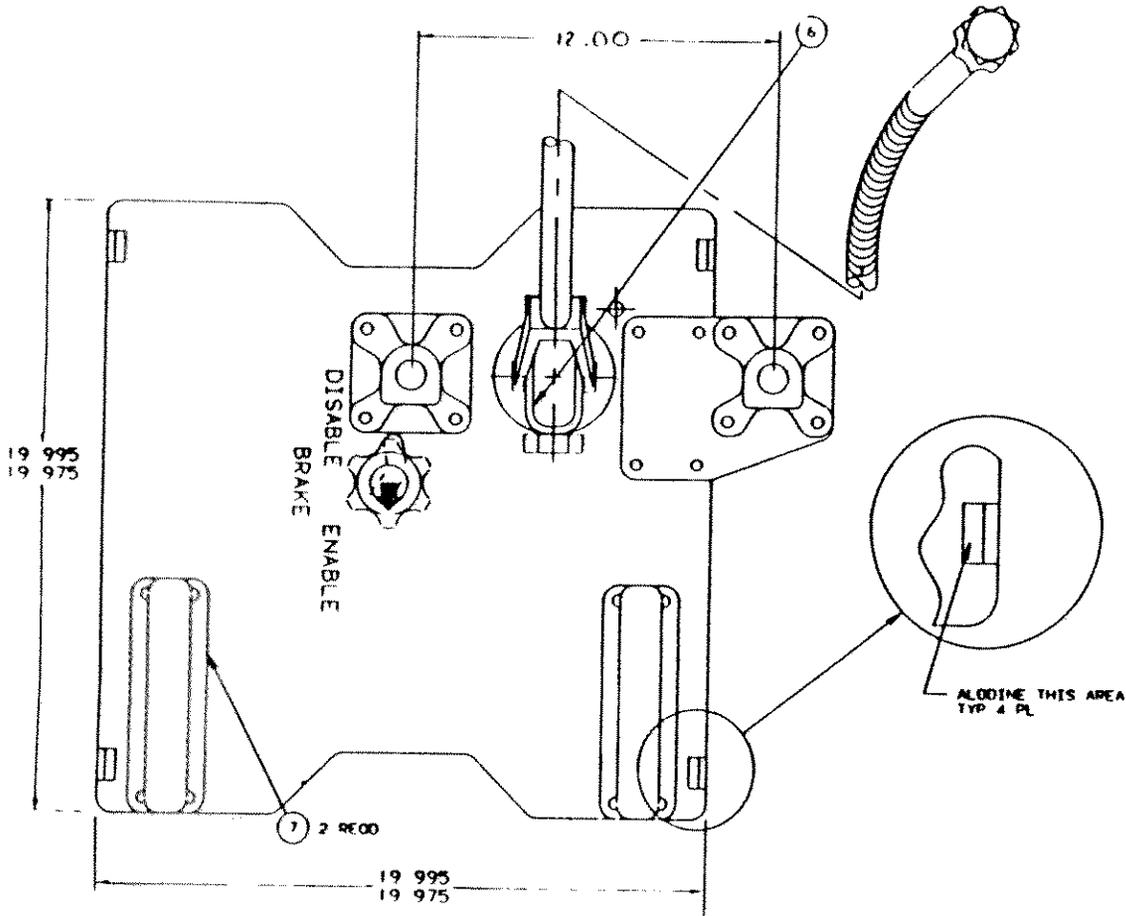
- **EVALUATE ALTERNATE TECHNIQUES AND EQUIPMENT FOR RESTRAINING CREW ON THE CETA CART:**
 - **FOOT RESTRAINTS**
 - **LEG RESTRAINTS**
 - **WAIST RESTRAINTS**
 - **NO RESTRAINTS (EXCEPT SAFETY TETHER)**
- **OBTAIN SSF DESIGN DATA ON:**
 - **CREW LOADS INDUCED INTO TRUCK AND RAILS**
 - **TRANSLATION RATES**

STS-37
EVA ON MANUAL CART





MANUAL CART DESIGN PLAN AND ISOMETRIC VIEWS

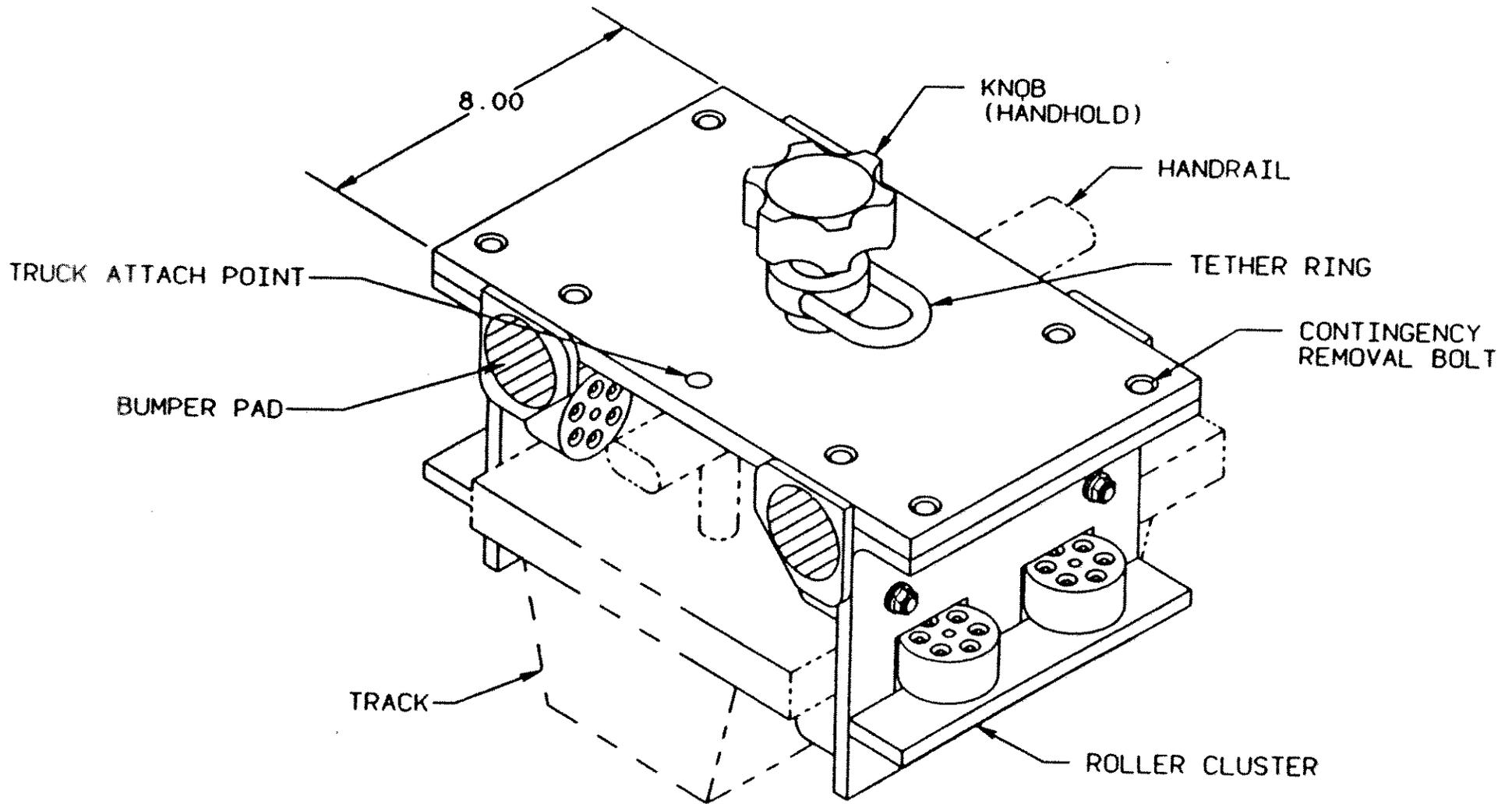


— Space Station Freedom

McDonnell Douglas • GE • Honeywell • IBM • Lockheed

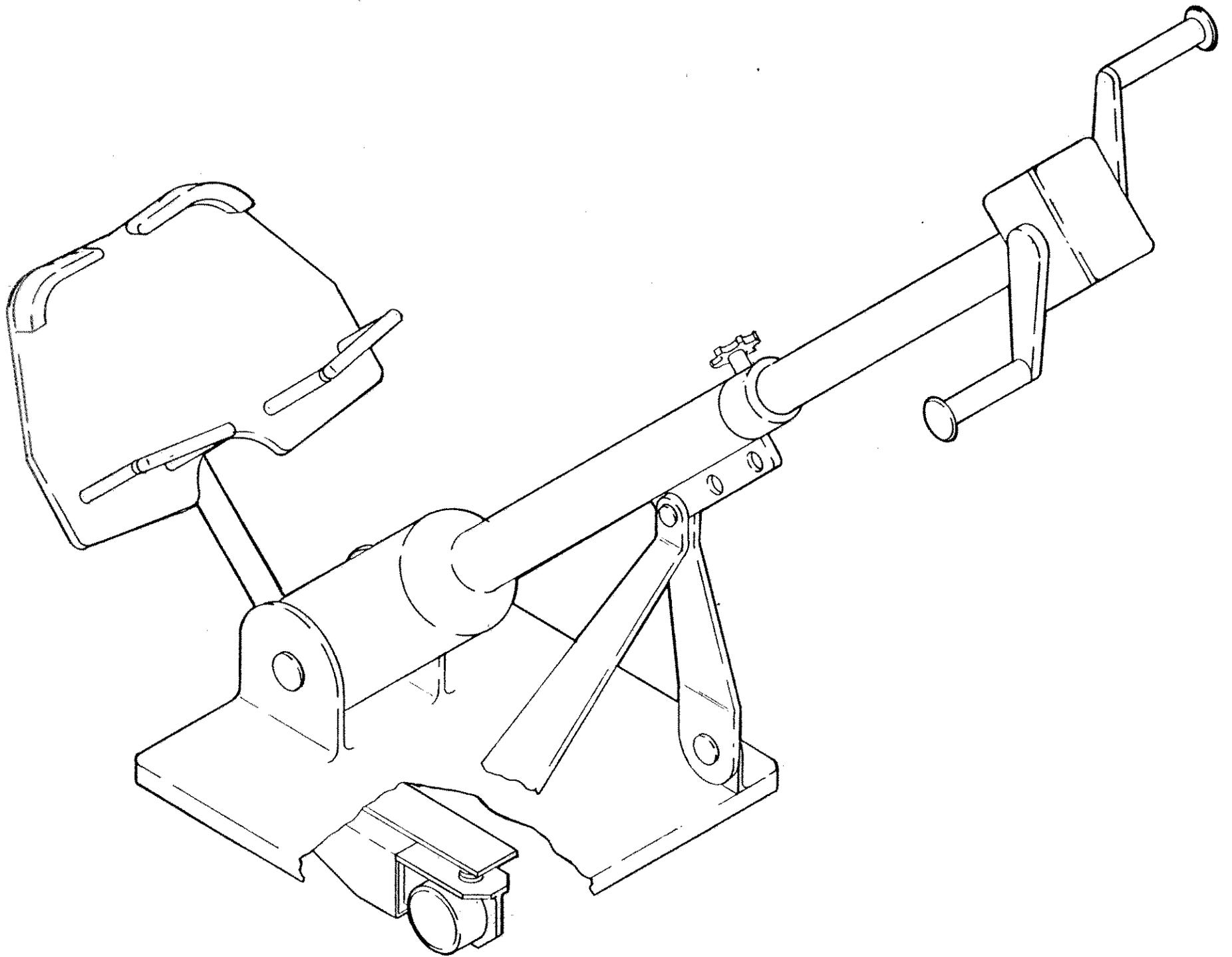
CETA FLIGHT EXPERIMENT - TETHER SHUTTLE

ISOMETRIC VIEW



— Space Station Freedom

McDonnell Douglas • GE • Honeywell • IBM • Lockheed





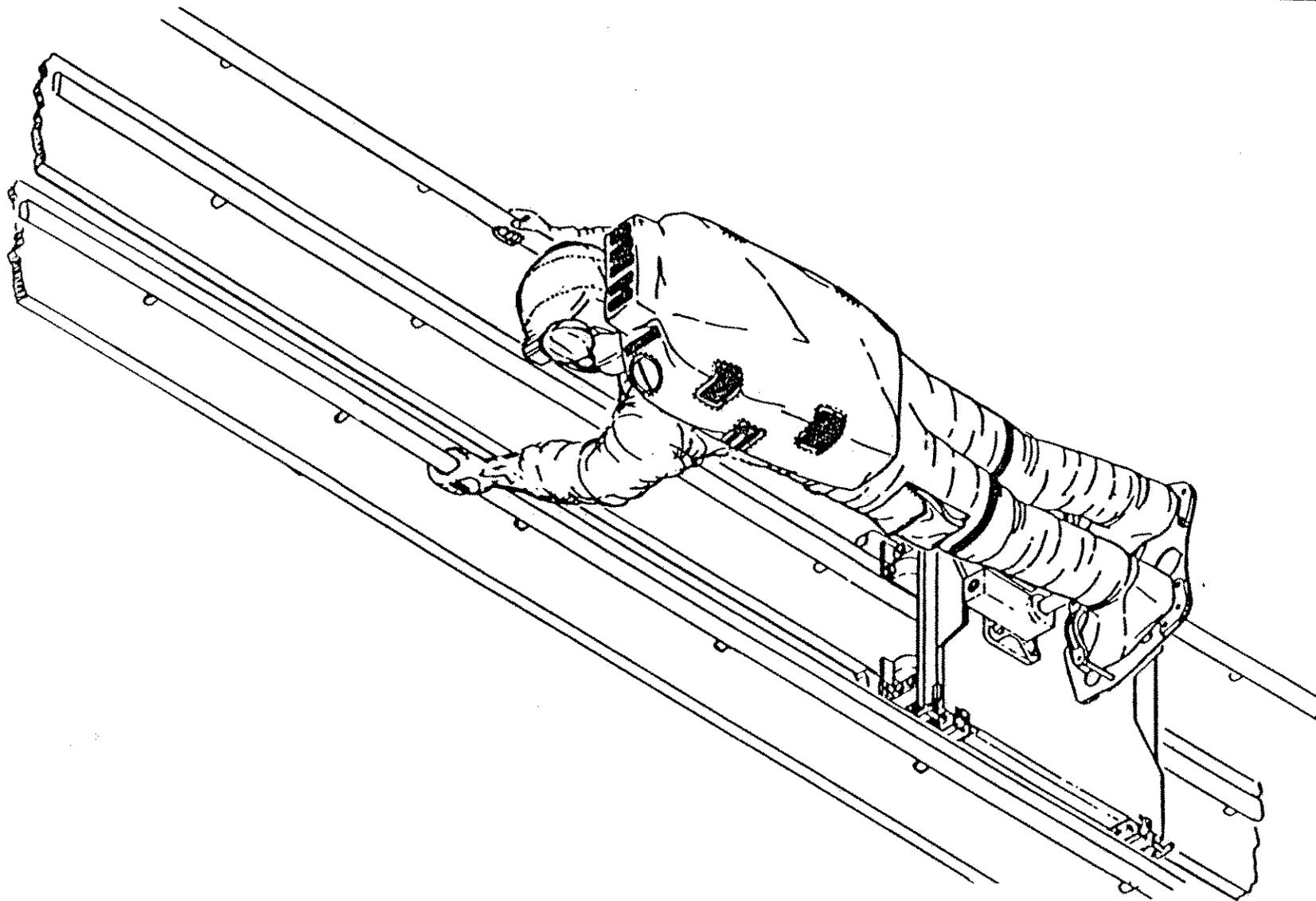
Johnson Space Center - Houston, Texas

EDFE CDR

CREW AND THERMAL SYSTEMS DIVISION

C. E. WHITSETT

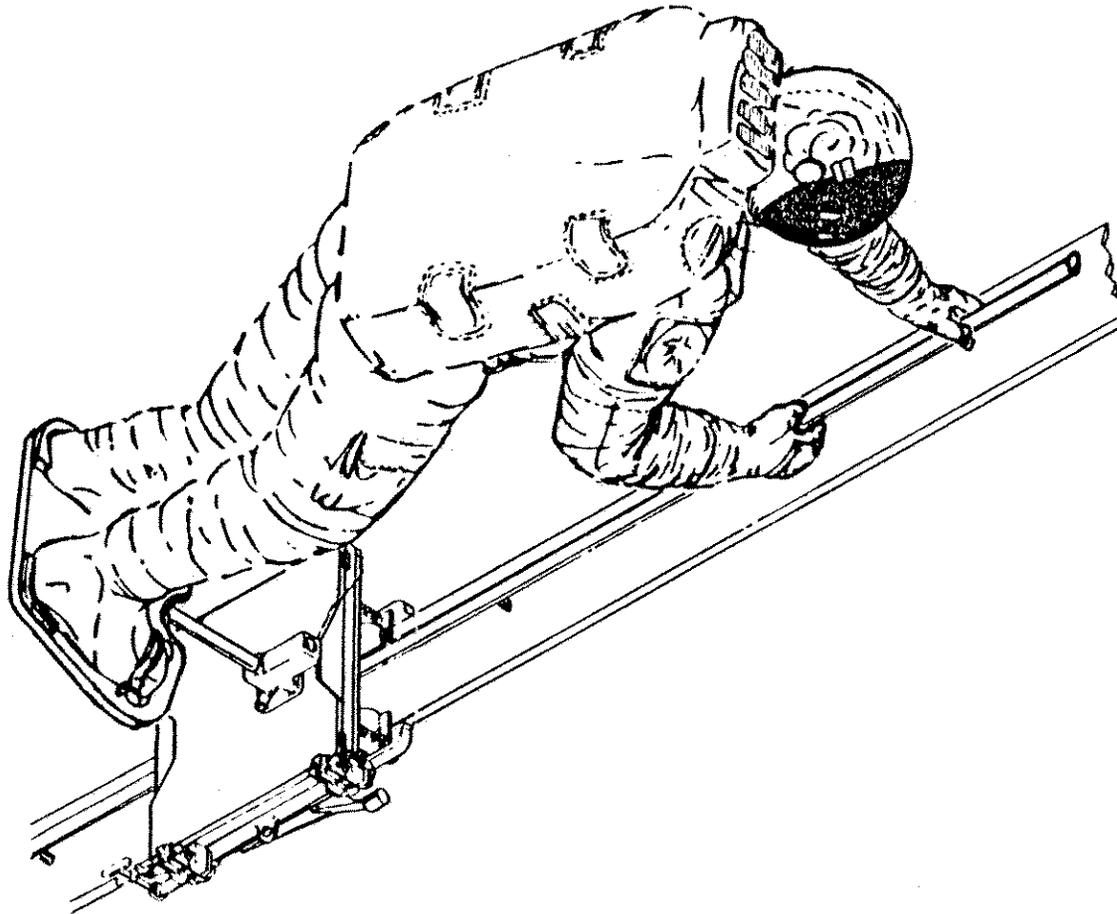
10/4/89





Johnson Space Center - Houston, Texas

EDFE CDR	CREW AND THERMAL SYSTEMS DIVISION	
	C. E. WHITSETT	10/4/89



CREW LOADS INSTRUMENTED PALLET (CLIP) OBJECTIVES (DTO-1203)

- **EVALUATE EVA CREW APPLIED AND INDUCED LOADS DURING TYPICAL EVA TASKS**
 - **STATIC AND DYNAMIC LOADS CREW CAN APPLY (INSTRUMENTED FOOT RESTRAINT)**
 - **FORCES AND TORQUES AS A FUNCTION OF POSITION/RESTRAINT**
 - **FOOT RESTRAINT INGRESS/EGRESS, KICK LOADS**
- **OBTAIN CREDIBLE SSF DATA FOR UPDATING AND VALIDATING DATA BASE, FOR CALIBRATING GROUND TEST PROTOCOLS, AND FOR DEVELOPING ANALYTICAL MODELS**

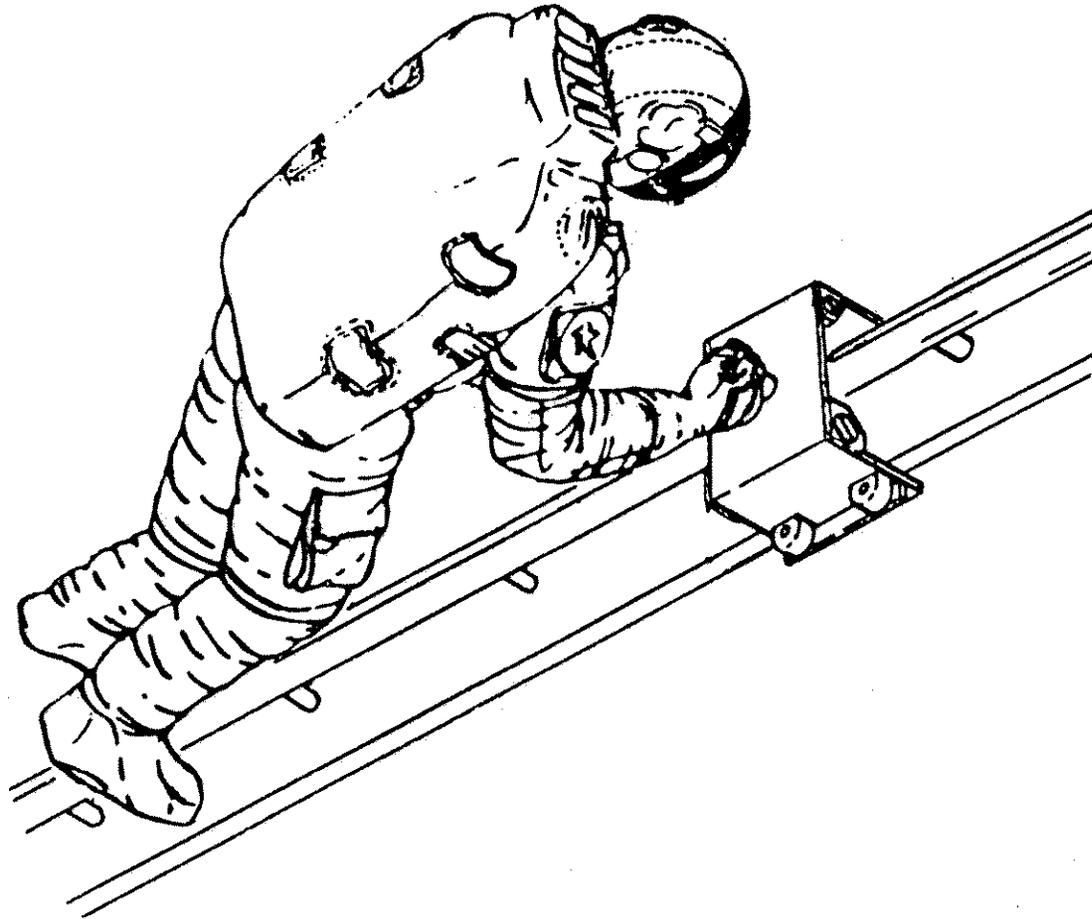


EDFE CDR

CREW AND THERMAL SYSTEMS DIVISION

C. E. WHITSETT

10/4/89



EVA TRANSLATION EVALUATION (ETE) OBJECTIVES (DTO-1202)

- **EVALUATE MANUAL TRANSLATION TECHNIQUES USING SIMPLE TRANSLATION AIDS (HANDRAILS AND ROPES)**
- **EVALUATE POWERED CREW POSITIONING DEVICES USING THE STS RMS MFR TO SIMULATE THE SSF ASSEMBLY WORK PLATFORM ASTRONAUT POSITIONING SYSTEM (APS)**
- **OBTAIN SSF DESIGN DATA FOR EVA SYSTEM REQUIREMENTS DEFINITION, TECHNIQUE DEVELOPMENT, AND EQUIPMENT DESIGN.**



**ROBOTIC APPLICATIONS WITHIN THE
STRATEGIC DEFENSE SYSTEM**

Presented at the

**SATELLITE SERVICES WORKING GROUP
MEETING #22**

29 NOV. 1989

**MR. DALE NUSSMAN
Dynamics Research Corporation**



ROBOTIC APPLICATIONS WITHIN THE SDS

PRESENTATION CONTENT

Part I - SDS Supportability Analysis & Its Implications to Robotics

- **Potential Benefits of Robotics To The Strategic Defense System**
- **SDS Supportability Analyses & Findings Relative To Robotics**
- **SDS Space Assets Support System (SASS) Concept**

Part II

- **SDS Robotics Program: An Initiative Within An Initiative**
- **Task Order 32, "SDS Robotics Program"**

Concluding Remarks

- **SDS & Robotics - Exciting Times Ahead**

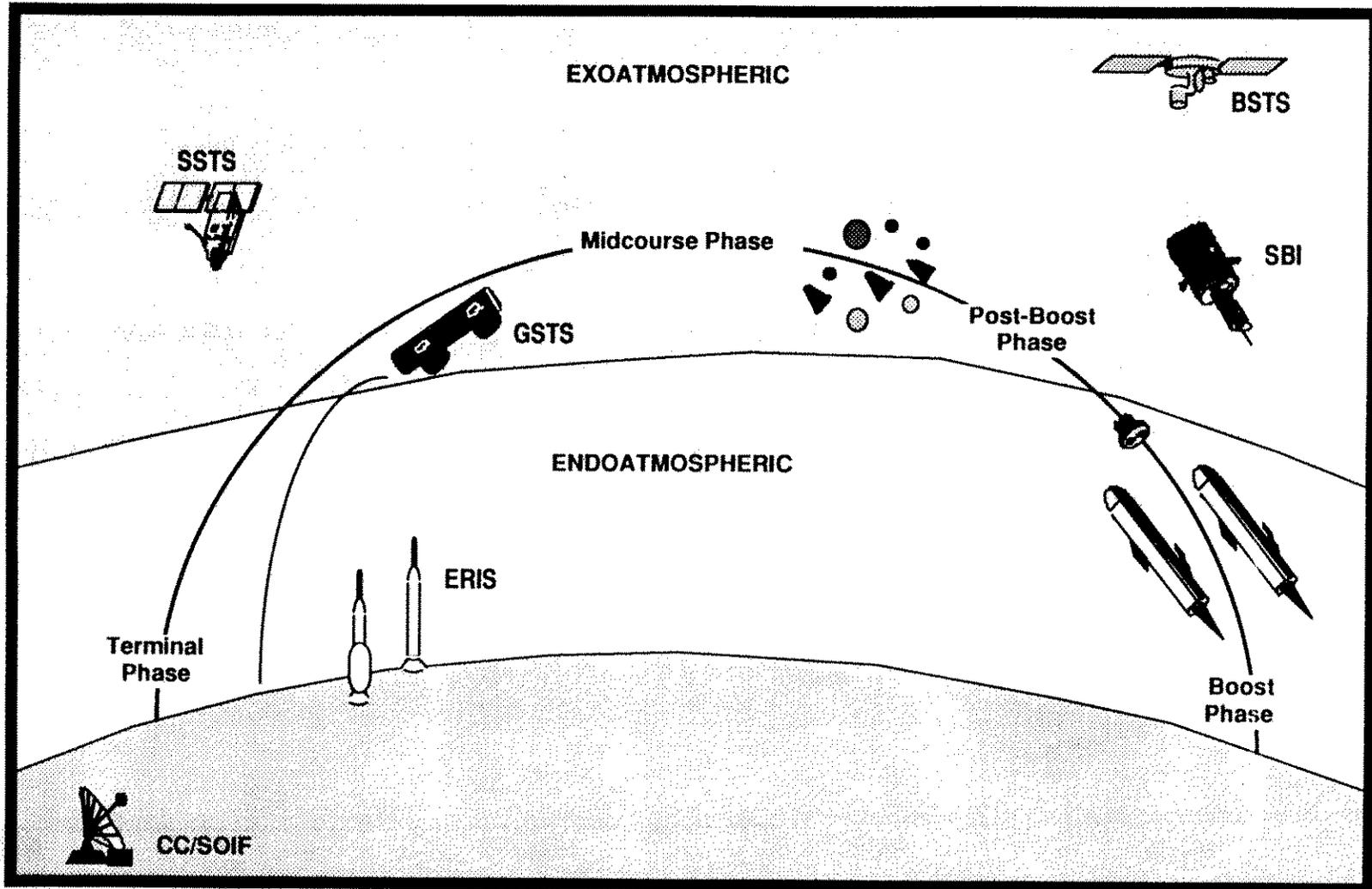


DISCLAIMER

The Views & Opinions Expressed During This Presentation Are Solely Those Of The Authors And Do Not Necessarily Reflect The Views & Opinions Of Others, Including The Strategic Defense Initiative Organization (SDIO).



SDS ARCHITECTURE



W-4099/2-TC

W-7193/2-PM



POTENTIAL BENEFITS OF ROBOTICS TO THE SDS

Producibility

- SDS Space Systems - \$ And Schedule
- SDS Ground Systems - \$ And Schedule

Supportability

- Maintenance
- Servicing
- Pre-Planned Product Improvements (P³I)
- Potential Cost Savings
- Increases In Reliability, Availability, Lifetime

Operations

- Assembly
- Deployment/Retrieval
- Reboost/Deorbit
- Tumbling SAT. Stabilization
- Contingency Operations
- Hazardous Operations
- Debris Removal



LSA TASKS PERFORMED

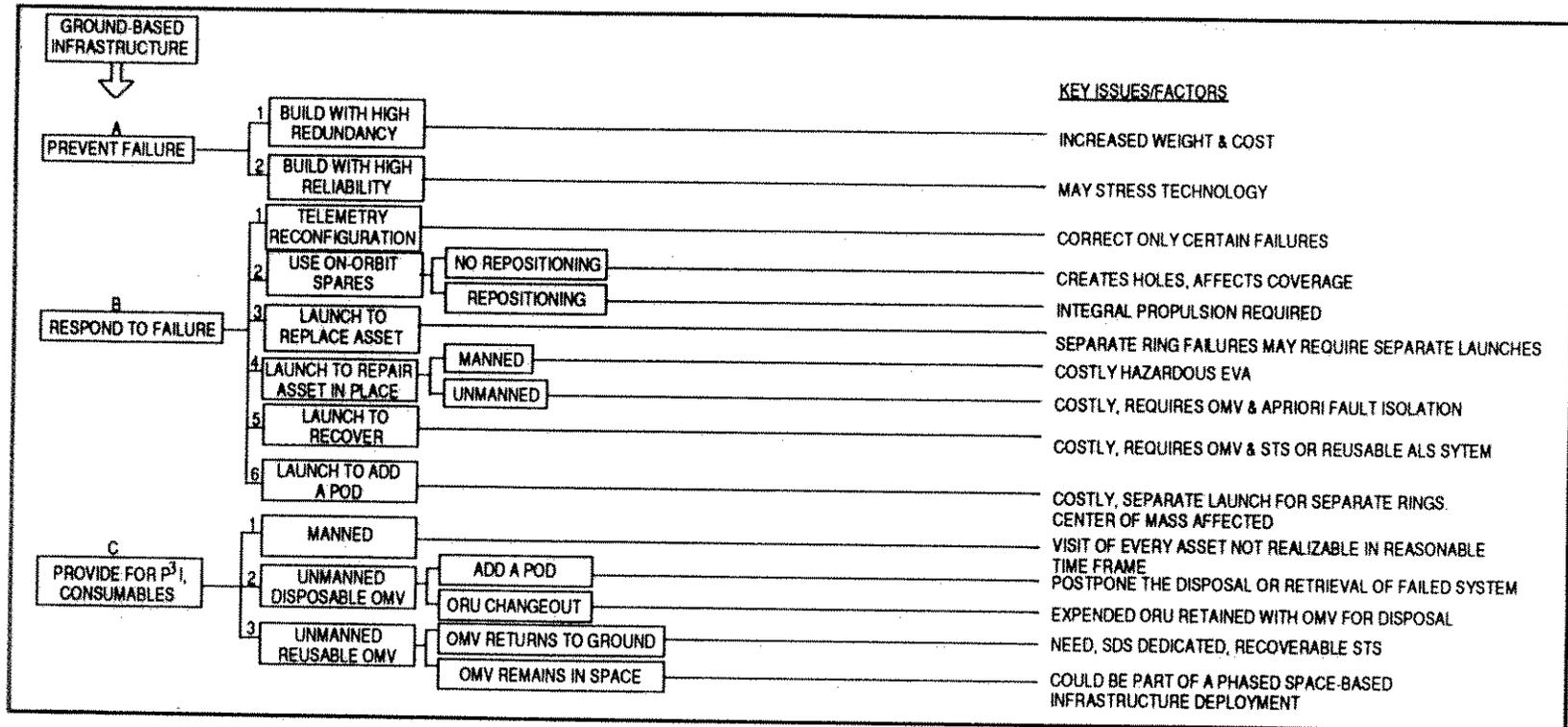
- Task 201, Use Study
- Task 202, Standards and Standardization
- Task 203, Baseline Comparison
- Task 204, Technological Opportunities
- Task 205, Supportability Design and Constraints
- Task 301, Functional Requirements
- Task 302, Supportability Alternatives
- Task 303, Tradeoff Analyses
- Task 501, Supportability Test, Evaluation, and Verification

Note: For additional information, see AIAA Paper 88-4707-CP, "Logistics Support Analysis and The Strategic Defense System," by E. Coady, D. Grover, and G. Parten of DRC, presented at The Second (AIAA/Sole) Space Logistics Symposium, Oct 3-5, 1988.



SUPPORT ALTERNATIVES FOR SPACE ASSETS - CONCEPT TREE

Concept A. Ground-Based Infrastructure



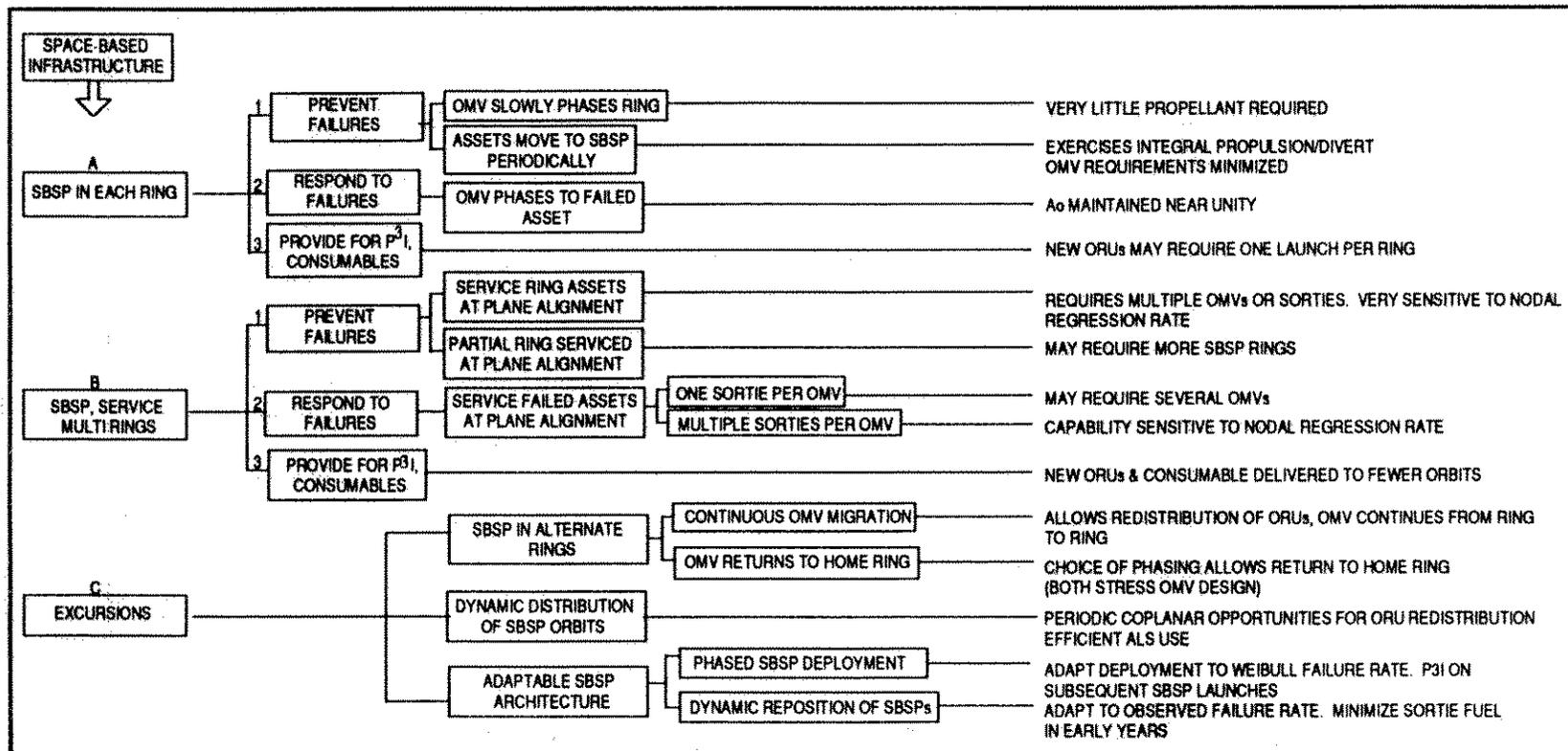
W-5083/2-RF

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SUPPORT ALTERNATIVES FOR SPACE ASSETS - CONCEPT TREE (Cont'd)

Concept B. Space-Based Infrastructure



W-50832-RF



LSA TASK 302 - SYSTEM SUPPORTABILITY ALTERNATIVES

- **Subtasks**
 - **Identify Supportability Design Requirements**
 - **Determine Feasible Support System Alternatives**
 - **Identify Software Support Alternatives**
- **Results/Recommendations**
 - **Make Satellite Sub-Systems Modular and Compatible With Robotic Maintenance and Servicing**
 - **Conduct Tradeoff Analyses of On-Orbit Support Alternatives**
 - **Ensure Support Plan Alternatives Include Disposal of On-Orbit Assets**
 - **Ensure Launch Capability and Capacity Are Sufficient To Deploy and Support Space Based Assets**



LSA TASK 303 - SYSTEM TRADEOFF ANALYSIS

- **Subtasks (Related To Space Robotics)**
 - **Conduct Tradeoff Analyses of Space-Based System Support Alternatives**
 - (1) **Direct Launch of Replacement Assets**
 - (2) **Support Platform in Each Operational Ring**
 - (3) **Support Platforms in Nodal Regression**
 - (4) **Support Platforms in Plane and Regressing**



RELATIVE LIFE-CYCLE COSTS FOR SERVICING BOTH LEO AND MEO ASSETS

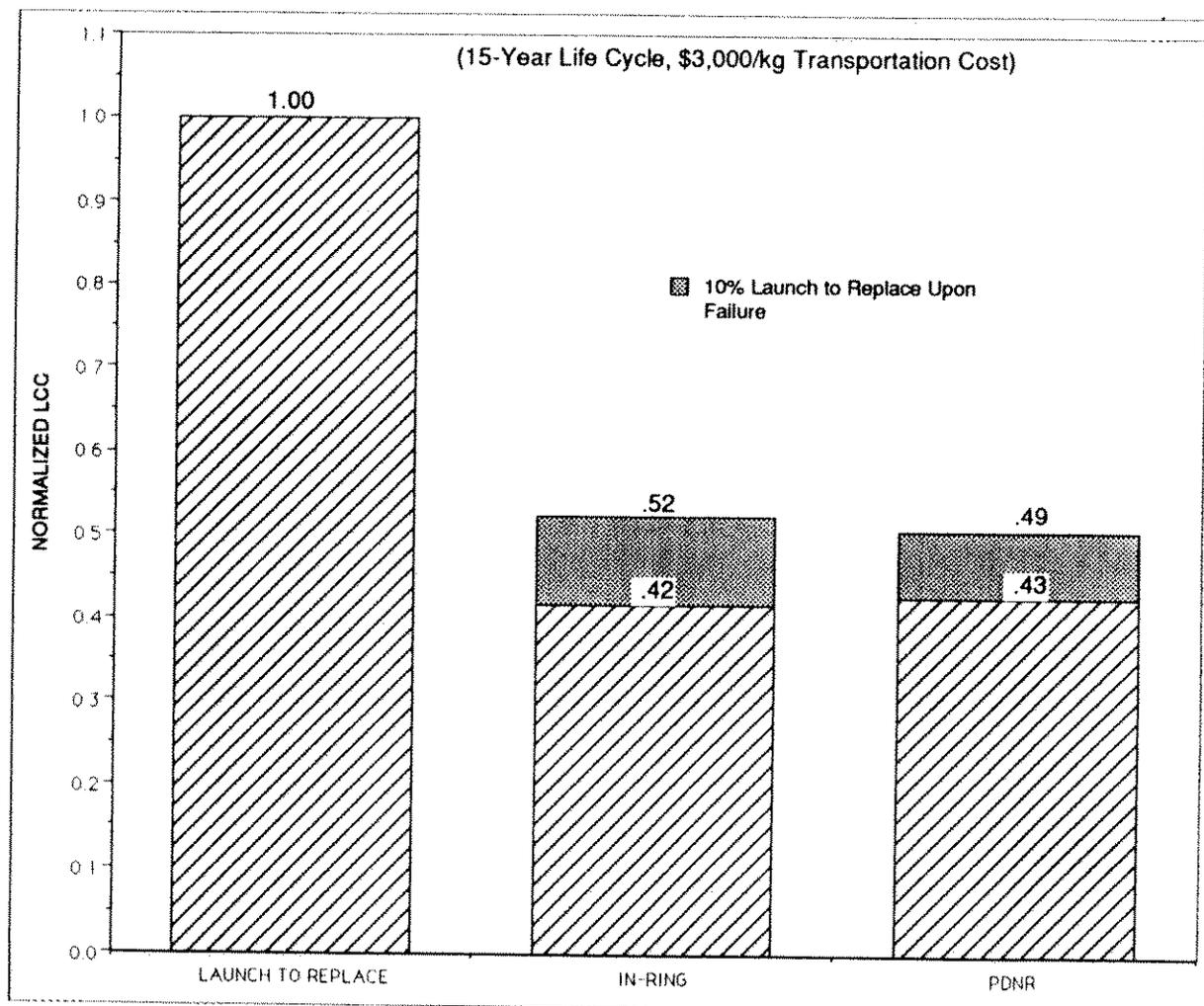
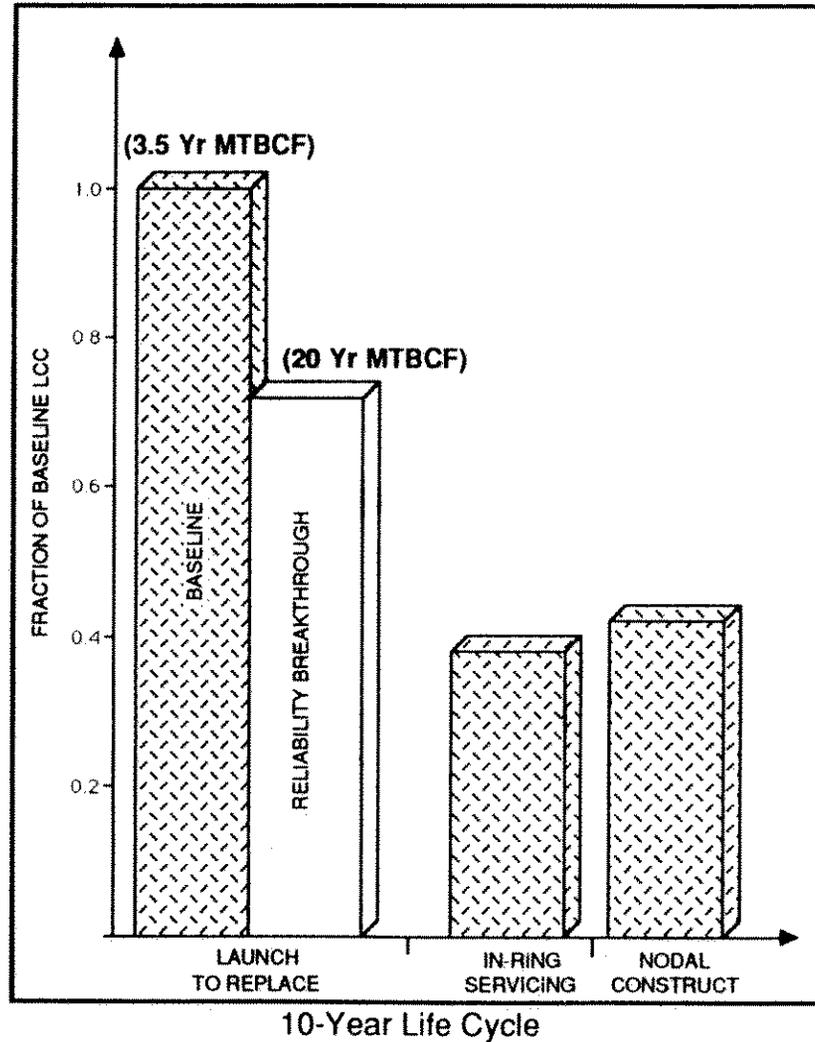


FIGURE 5 RELATIVE LIFE-CYCLE COSTS

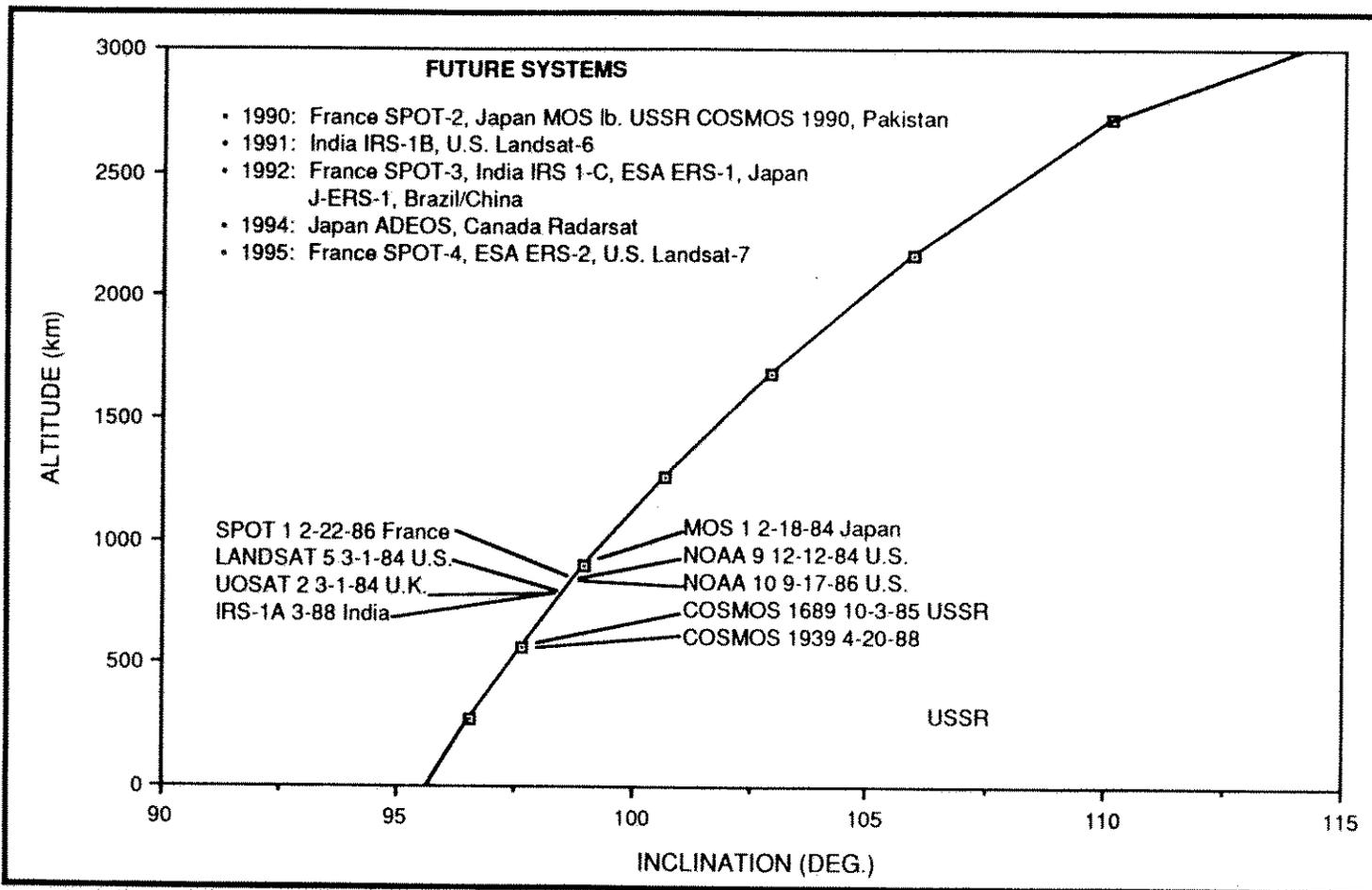


COMPARATIVE LIFE-CYCLE COSTS FOR A LARGE LEO CONSTELLATION





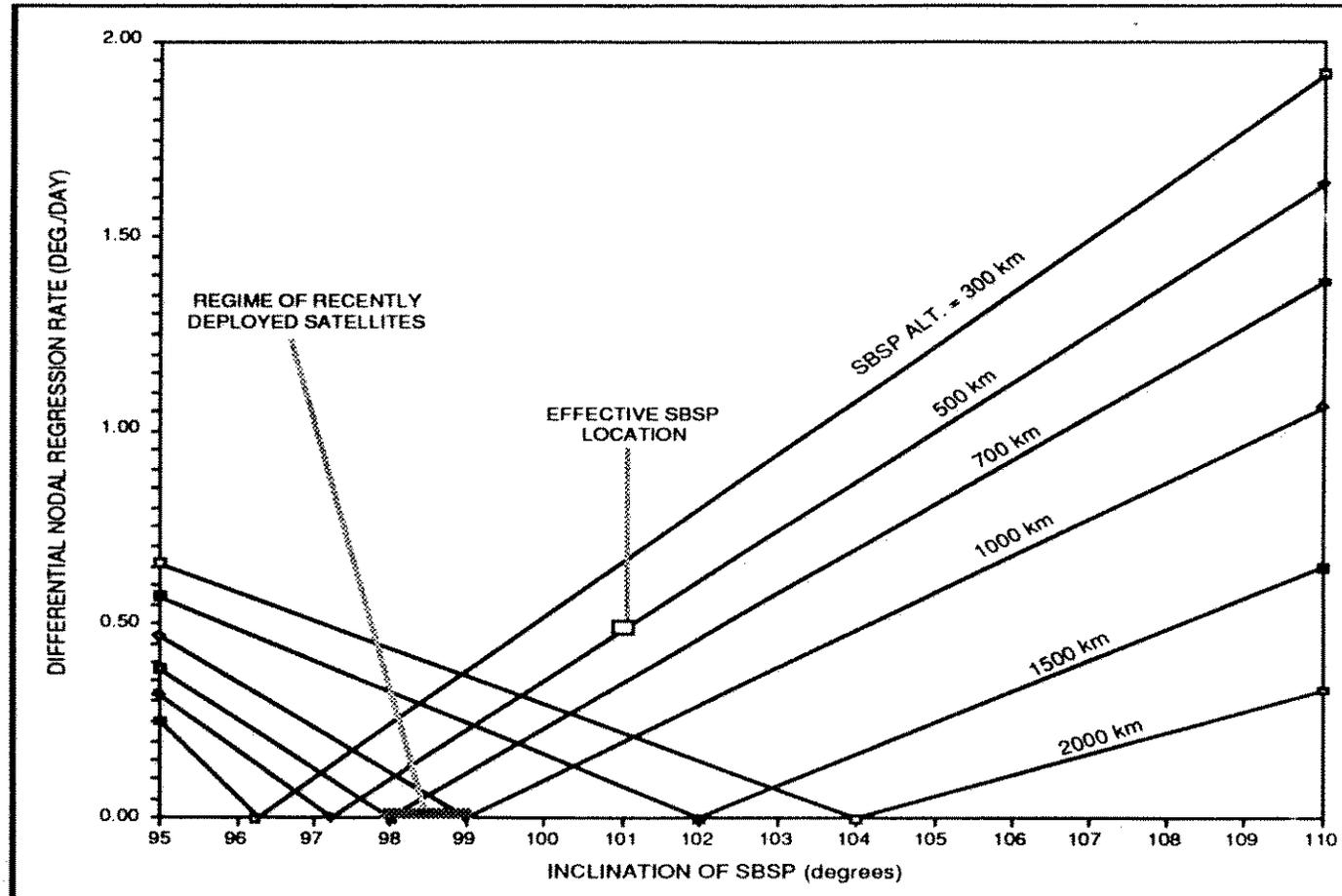
CURRENT AND PLANNED SS MISSIONS



Note: For additional information, see AIAA Paper AIAA-89-5069, "Optimizing Design Factors and Support Concepts to Reduce Space Operations Costs," by W. Robertson, J. Sliney, and T. Misencik of DRC, presented at the "AIAA/NASA Symposium on the Maintainability of Aerospace Systems, 26-27 July 1989.



2 YEAR S/C REVISIT POSSIBLE WITH 1 SBSP



Note: For additional information, see AIAA Paper AIAA-89-5069, "Optimizing Design Factors and Support Concepts to Reduce Space Operations Costs," by W. Robertson, J. Sliney, and T. Misencik of DRC, presented at the "AIAA/NASA Symposium on the Maintainability of Aerospace Systems, 26-27 July 1989.



LSA TASK 303 - SYSTEM TRADEOFF ANALYSIS (Cont'd.)

- **Results/Recommendations**
 - **All Support Alternatives Require Satellite System MTBF Greater Than 3 Years (SSTS 7-Yr MTBF) To Achieve Nominal Cost and A_c Goals**
 - **Model Runs of the Different Support Alternatives Confirmed Excess Cost Associated With PM**
 - **Optimum Figure of Merit (FOM) for Large LEO Constellation Achieved With In-Ring Support Both for LCC and O&S**
 - **Optimum FOM for Small Constellation in MEO Was In-Ring for LCC but Nodal Regression for O&S**
 - **Tradeoffs of the Excursion Alternatives-Appared That Combination of In-Plane and Regressing Servicers Optimize Support Cost and Resource Consumption in Relation to A_c**
 - **Analysis Suggested Modular SBSP With Modules Designed for 3.5-Year Service Life**



CONCLUSIONS OF SPACE ASSETS SUPPORTABILITY ANALYSES

- **On-Orbit Support Is Feasible and Cost Effective for Selected SDS Assets**
- **Highly Accurate and Reliable BIT/BITE Will Be Required**
- **Modularity and Standard ORU Sizes and Interfaces Will Be Required**
- **Appropriately Designed Spacecraft Can Be Serviced Robotically**
- **Supportability Assessment Should Be Integral to the T&E Process**



SO-O-O-O,

**AS A RESULT OF OUR (& OTHER) STUDIES,
WE FEEL THAT . . .**

WHAT THE SDS NEEDS IS . . .



A FEW GOOD ROBOTS . . .

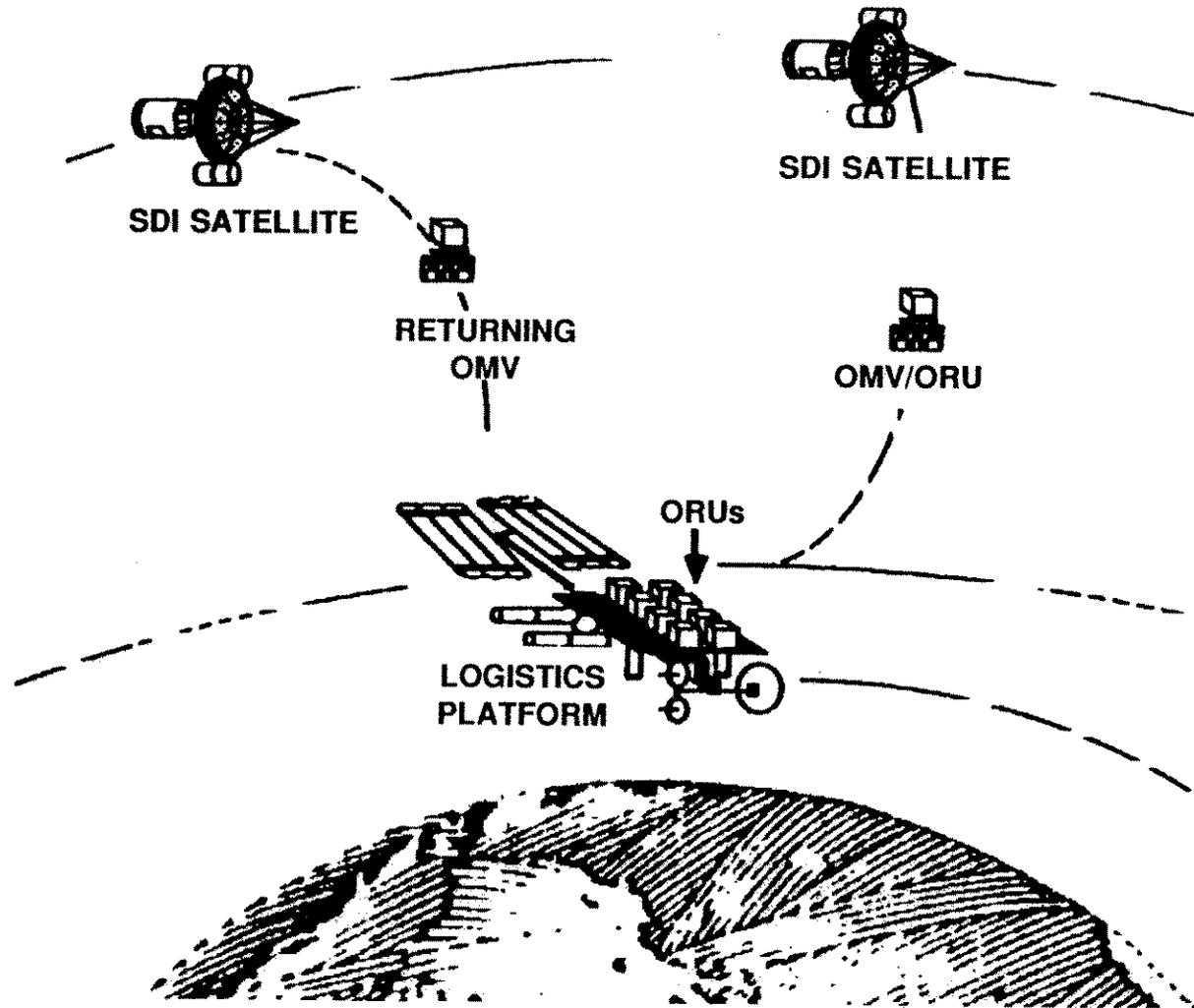
A-N-D

A REAL GOOD

SPACE ASSETS SUPPORT SYSTEM

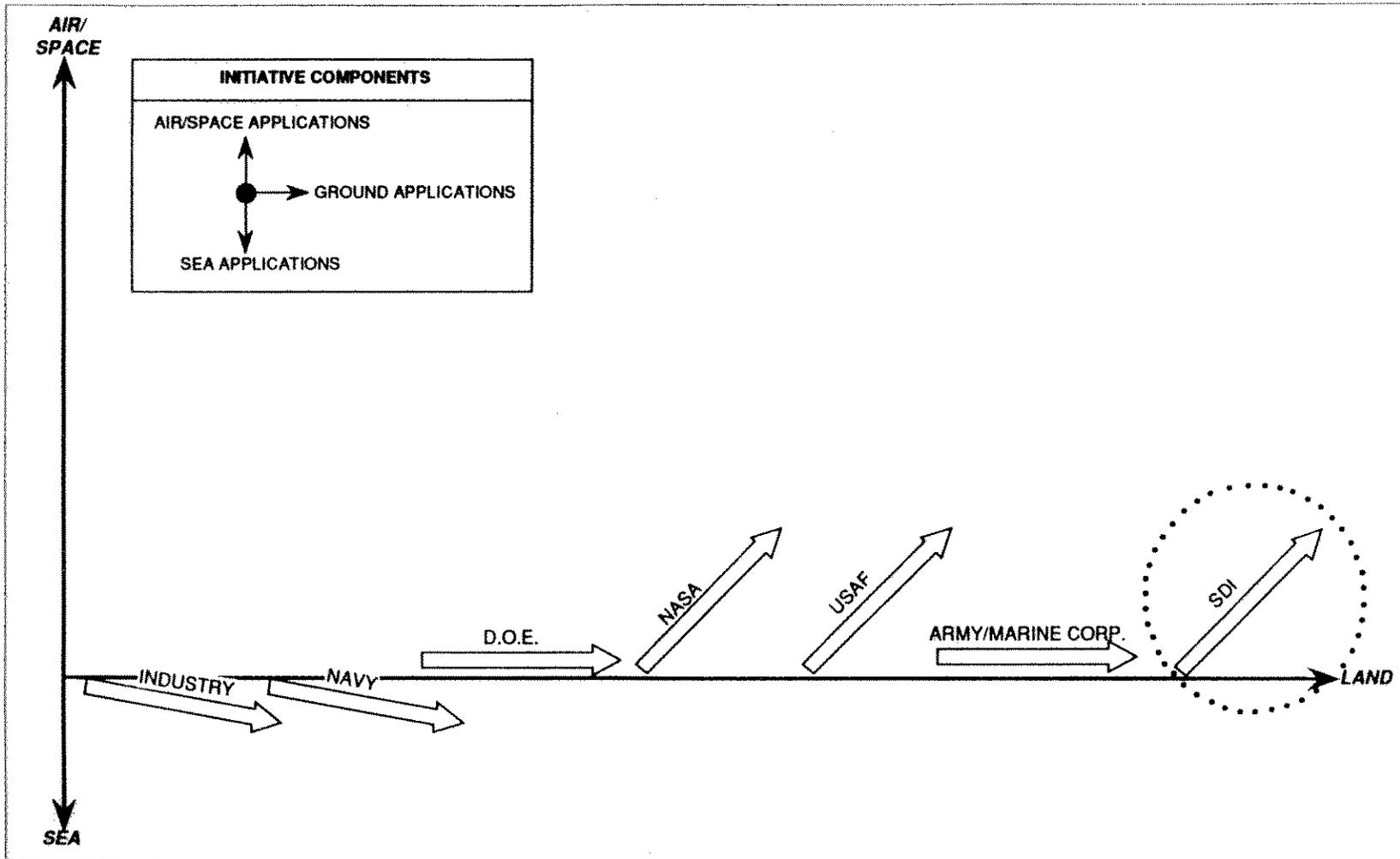


POSSIBLE "MATURE" SASS CONCEPT





RELATIVE ORIENTATION OF ROBOTIC INITIATIVES & THRUSTS



W-6350/1-LTH

W-6352/1-LTH



TASK ORDER 32 - STRATEGIC DEFENSE SYSTEMS ROBOTICS PROGRAM

SCOPE

- **Subtask 1 - Technology Assessment**
- **Subtask 2 - Video Tape**
- **Subtask 3 - Requirements Document**
- **Subtask 4 - Timed Phased Implementation Plan**
- **Subtask 5 - Program Management Agreement (PMA) Form**

STAFFING

- **Team Effort**
- **Team Members**
 - **BDM International, Inc., Team Leader**
 - **Dynamics Research Corporation**
 - **Science Applications International Corporation**
 - **W.J. Schafer Associates, Inc.**



OBJECTIVES & BACKGROUND

- **Principal Objectives Of Technology Subtask:**
 - **Status**
 - **Potential Applications**

- **Background:**
 - **1st Of 5 Subtasks**
 - **Multi-Contractor Team (DRC Tech Lead)**
 - **Two Month Effort**
 - **All Milestones & Deliverables On Time**

- **Products:**
 - **Volume I - Technical Report**
 - **Volume II - Appendices A & B (Robotics Programs/Surveys)**
 - **Volume III - Raid Data Base Survey Sheets**



PRINCIPLE AREAS ADDRESSED

- **Critical Robotic Technologies**
- **Status Of Robotic And Robotic-Related Programs**
- **Initial Assessment Of Potential Robotics Applications To SDS Support**
- **Technology Maturity & Readiness**
- **Robotic System-Level Issues**
 - **Supportability**
 - **Testability**
 - **Standardization**
 - **Safety**
- **Applicability Of Modil Concept To Robotics**



SUMMARY

- Over 80 Findings/Conclusions Relative To Robotics Technology
- Some Of The More Salient Findings/Conclusions Of The Technology Assessment Include:
 - SDS SUPPORTABILITY - High Payoff Opportunities For Space Elements
 - GRAPPLING/REFUELING - Nearest Term Applications With High Potential Payoffs
 - ROBOTIC PROGRAM CO-OPERATION/LEVERAGE - Excellent Opportunities Exist
 - ROBOTIC SYSTEM RESILIENCY - Subject Is Not Being Adequately Addressed
 - ROBOTIC AUTONOMY - Telerobots Appropriate For Near-Term Applications
 - CRITICAL TECHNOLOGIES - More Emphasis Needed For Human & System Integration



SUMMARY - CONT'D

- **TRANSFERABLE DoD TECHNOLOGY** - Examples Include Army's Field Materials Program & Navy's AUSS Project
- **ROBOTIC SYSTEM ANALYSES** - Supportability/Tradeoff Analyses Needs To Be Conducted For Potential SDS Robotic Systems
- **MODIL APPLICABILITY** - Concept Is Applicable To Development Of Robotic Technology For SDS Manufacturing, Operation, And Support



VIDEOTAPE SOURCES

- **THE SDS ROBOTICS VIDEOTAPE INCLUDES:**
 - **State-Of-The-Art Research Footage**
 - **Illustrations From SDIO**
 - **Historical And Stock Footage**
 - **Animation And Graphics**
 - **An Interview With An SDS Authority**

- **Typical Sources:**
 - **AIAA**
 - **Aviation Week**
 - **Case Western Reserve**
 - **MIT**
 - **NASA**
 - **NIST**
 - **RIA**
 - **Robotics Research Corp.**
 - **Rockwell International**
 - **SME/RI**
 - **TRW**
 - **Univ. Of Michigan**
 - **Univ. Of Minnesota**



SUBTASK 3 ROBOTICS REQUIREMENTS DOCUMENT

- **Principle Objectives:**
 - **Identify And Define Technology Requirements**
 - **Assess Current Robotics Requirements**

- **Products:**
 - **Robotics Requirements Document, Including:**
 - **Requirements Allocation Sheets**
 - **Inputs Into Time-Phased Implementation Plan**

ON-GOING EFFORTS IN CRITICAL TECHNOLOGIES

SECTORS	CONTROL			SENSORS			ACTUATORS				HUMAN INTERFACE			INTEGRATION	
	Servo Control	Obstacle Avoidance	Hierarchical	Internal	External	Vision	Prime Movers	End Effectors	Materials	Configurations	Displays	Hardware	KBS*	Computer	Programs
DOD															
USAF		●			●	●		●			●	●	●	●	●
USA		●			●	●					●	●	●	●	
USN		●			●	●					●	●	●	●	
USMC			●		●	●					●	●		●	
DARPA	●	●		●	●	●	●	●	●					●	
GOVERNMENT															
NASA	●					●		●	●	●	●	●		●	●
NST			●								●	●		●	●
ORNL		●	●		●			●	●		●	●		●	
ACADEMIA															
CMU	●	●	●	●	●	●	●	●				●			
MIT	●	●		●	●		●	●	●						
Stanford	●	●			●	●						●			
RPI			●								●			●	
U. of Michigan						●			●			●			
UT at Austin			●		●		●	●	●	●	●	●		●	
U. of Wisconsin					●	●		●	●	●	●	●			
INDUSTRY															
Robot					●	●	●	●	●	●	●	●		●	
Auto			●		●	●		●	●	●	●	●		●	
Electronic					●	●		●	●	●	●	●		●	



REQUIREMENT ALLOCATION SHEET INFORMATION CONTENT

- **Title (Proposed Candidate Robotic Application)**
- **Application Availability (Near Term or Far Term)**
- **Application Regime (Space or Ground)**
- **Potentially Impacted SDS Elements**
- **Objective**
- **Summary Functions Of Application**
- **Related Efforts**
- **Scope Of Effort (For Each Of 5 Robotic Technology Areas, i.e. Sensors, et.al.)**
- **Summary Statement Of Work**
- **Estimated Period Of Overall Task Performance**
- **Estimated Level Of Overall Effort (Total Man-Months)**
- **Leading Activities (Identification Of Work Within Various Sector)**
- **Candidate Approaches (Methodologies To Accomplish Work)**
- **Estimated Risk Level**

EXAMPLE

NOTE: EXAMPLE SHOWS
PAGE 1 OF 4 PAGES

REQUIREMENT ALLOCATION SHEET

UPDATE DATE: May 1989
TITLE: ORU Changeout-Near Term
APPLICATION AVAILABILITY: Near Term
APPLICATION REGIME: Space

POTENTIALLY IMPACTED SDS ELEMENTS:

PHASE I/NEAR TERM

BSTS
 SSTS
 SBI

 SSS
 SSS Unmanned Spt Platform

 GBI
 GBR
 GSTS
 HEDI
 ALS
 SDS Ground Launch Equipment
 SDS Site Operations

FUTURE/FUTURE GENERATIONS

BSTS - FG
 SSTS - FG
 SBI - FG
 SBL
 NPB
 SSS
 SSS Unmanned Spt Platform
 SIREN
 GBI
 GBR
 GSTS
 HEDI
 ALS
 SDS Ground Launch Equipment
 SDS Site Operations

OBJECTIVE:

Provide robotic technology application engineering and development to support ORU changeout in space. To integrate efforts with NASA, USAF and SDS developments for satellite servicing.

SUMMARY FUNCTIONS OF APPLICATION:

The effort covered by this RAS would result in hardware, software, demonstrations, and/or development of enabling technology that would permit performance of the following functions in the application availability timeframe and regime above.

Grasp, unload, then replace ORUs containing electronics, liquids, or gases. Electronic ORUs could be replaced as routine maintenance to provide consistent performance, upgrade to enhanced capabilities, or replenishment of consumed items such as batteries. ORUs containing liquids or gases would be replaced as propulsion, cryogenic, or power generation systems consume the contents. ORUs can range in weight from 50 to approximately 500 pounds. ORUs can be configured as rough cubes 3 feet long on a side or they can be smaller. Tracks and asymmetries to help mate the ORU to the satellite can be assumed.

The effort would be controlled from a ground station using human and computer control.



REQUIREMENT ALLOCATION SHEETS IN-SPACE ROBOTICS APPLICATIONS

- **ORU Changeout**
- **Interceptor Vehicle Reload***
- **Contingency Manipulation**
- **Satellite Stabilization**
- **Calibration And Nonintrusive Inspection****
- **Assembly**
- **Reboost/Remove****
- **Nuclear Reactor Removal***

*** Near Term Capability Is Not Envisioned**

****Future Capability Through Evolutionary Growth**



REQUIREMENT ALLOCATION SHEETS GROUND ROBOTIC APPLICATIONS

- **Site Security**
- **Non-Intrusive Inspection Of Missiles**
- **Missile Harvest, Transport, And Reload***
- **Hazardous Material Handling/Hazardous Environment Operations**
- **Launch Operations**

*** Future Capability Through Evolutionary Growth**



SDS & ROBOTICS - EXCITING TIMES AHEAD

- **Over 20 Years Has Passed Since The 1st Manned & Unmanned USA Space Robotic Initiatives**
- **A 1960's Commitment To Teleoperated Robotic Servicing Would Have Resulted in Multi-Billion Savings of Space Assets (Skylab, Satellites, Other)**
- **With Past Rises & Falls of Space Robotics, Momentum Is Finally Building For A Robotics "Space Permanence"**
- **SDIO Will Add To This Momentum Since It Has A Vested Interest In The Development Of Both Space & Ground Robotic Systems**
- **SDIO Is Developing A Robotics Program & Is Supporting A Joint NASA/DoD/SDIO Satellite Servicer Demonstration CIRCA 1993-95**

CONSIDERATIONS FOR HUMAN-MACHINE INTERFACES IN TELE-OPERATIONS

C. Newport/Ocean Systems Engineering, Inc.

TOPICS

Considerations for Human-Machine Interfaces

- INTRODUCTION
- HUMAN FACTORS AFFECTING OPERATOR EFFICIENCY
 - Environment of the Teleoperator and Operator Interfaces.
- PHYSICAL AND ENVIRONMENTAL FATIGUE FACTORS
 - Operational Stress, Eye Strain, Extremes in Temperature, Excessive Noise, Body Fatigue, Boredom, and IVA Lighting.
- HUMAN-MACHINE INTERFACES
 - General Console Layouts, Hand Controllers, and Master Arms.
- CONCLUSIONS AND RECOMMENDATIONS
 - Operator Environment and Physical Interfaces.

INTRODUCTION

- Subsea teleoperations experience is a large database of operational experience available for study.
- Design configurations for subsea robotic equipment, like space hardware, are driven by environmental concerns.
- An examination of the subsea robotics field can help identify significant issues with regard to operational environments and teleoperator/system interfacing.
- Human factors/lessons learned by subsea telerobotic control console layouts are directly applicable to space robotic operations.

HUMAN FACTORS AFFECTING OPERATOR EFFICIENCY

- Environment of the Teleoperator:
 - Operator comfort and the duration of teleoperations.
- Operator Interfaces:
 - -Visual and mechanical feedback to the teleoperator. (e.g., video and graphics displays, force reflection, indicator/status lights).
 - -Physical interfaces between the teleoperator and the robotic workstation (e.g., handcontrollers, pan/tilt controls, large-scale master arms).

PHYSICAL AND ENVIRONMENTAL FATIGUE FACTORS

- Operational Stress:
 - Generated by task difficulty, operational time limitations, extended durations of concentration, and partially operable equipment.
- Eye Strain:
 - Caused by improperly sized video monitors, video flicker, distortion, and an improper seat/restraint to monitor relationship.
- Extremes in Temperature:
 - Created by control consoles, power transformers, the local environment, and a lack of ventilation.
- Excessive Noise:
 - Caused by ECU equipment, and nearby unrelated support gear.

PHYSICAL AND ENVIRONMENTAL FATIGUE FACTORS

- **Body, Joint, and Hand Fatigue:**
 - Created by using large-scale masters, miniature joysticks, and the seating/restraint to console relationship.
- **Boredom:**
 - Usually caused by repetitive work tasks, excessive time on operations, a lack of sleep, and minimal time off shift.
- **IVA Lighting:**
 - Can contribute to problems with glare on video monitors, and adversely affect operator eyesight.

HUMAN-MACHINE INTERFACES

General Console Layouts

- Portable Consoles:
 - Possible use on the Aft Flight Deck of the Orbiter.
 - Have the advantage of small size, but can be damaged and consume valuable operations time during set-up.
- Free Standing Consoles:
 - Possible use in Space Station Cupolas.
 - Use up more space than portable consoles, but can have better overall capabilities due to the greater number of available work functions.
- Commonality between space and subsea applications:
 - Both workstation applications require the use of video monitors, system diagnostics, and operator interfaces (e.g., hand controllers and/or master arms).

HUMAN-MACHINE INTERFACES

Hand Controllers and Master Arms

- Large Scale Masters:
 - Have the advantage of intuitive control and force reflective capabilities, but also contribute significantly to arm fatigue. They also require a large IVA work envelope for operation.
- "Mini" Masters:
 - Have the advantage of a minimal IVA work envelope, but usually lack a force reflective capability and a kinematic configuration similar to the slave arm.
- "Bang-Bang" Joysticks:
 - Can only be used with rate arms, but generally offer robust construction, an extremely small IVA work envelope, and good reliability.
- Proportional Joysticks:
 - Can be used for end point control with resolved rate type manipulators. They can be comfortable or fatiguing to use, depending upon their physical size.

CONCLUSIONS

Environmental

- GENERAL CONCLUSIONS:

- The local environment of the teleoperator has a significant and measurable effect on the efficiency of doing remote work tasks. Steps must be taken to guarantee that the environment of the operations location is favorable to practical work.

- SPECIFIC RECOMMENDATIONS:

- Temperature: The amount of heat generated by power equipment and control consoles should be taken into account when determining heating/cooling/ventilation requirements.

- Noise: Both the expected noise levels and long term operator comfort should be considered when selecting communications headsets for teleoperations. Obviously, the noise levels should be kept as low as is practical.

CONCLUSIONS

Environmental-Specific Recommendations

- Body and Hand Fatigue: All hand controllers, if possible should incorporate hand rests to relieve muscle tension during operation. In addition, operator seating/restraints should be highly adjustable, with regard to their orientation with the control console, and general configuration. There should be sufficient IVA free volume surrounding the operator restraint to allow for body flexing (especially the legs) during extended operations.
- Operator Restraints: Teleoperations restraints should hold the operator securely during force reflection operations and be referenced to the zero-G neutral body posture.

CONCLUSIONS

Environmental-Specific Recommendations

- Operational Stress: Task difficulty should be taken into account when scheduling rotations for teleoperations personnel. Some rough guidelines are listed below:
 - Complex Manipulative Tasks: 30-60 Min.
 - Average Workloads: 60-120 Min.
 - Supervisory Operations: 120-240 Min.

- Eye Strain: Video monitors used for teleoperations should be at least 9" in size and incorporate standard controls for brightness and contrast. In addition, the IVA work environment should offer indirect lighting of low to medium intensity. The distance from the video monitor to the operator's eyes should be no less than about 3/4 arm length.

CONCLUSIONS

Physical Interfaces

- GENERAL CONCLUSIONS

- Visual and mechanical interfaces are the operator's only physical link with the equipment they are operating. Therefore, it is of the utmost importance to establish a compatible interface between the senses of the human operator and the variety of robotic system inputs.

- SPECIFIC RECOMMENDATIONS

- Control Consoles: Portable control consoles that have to be unstowed and set-up for operations should be avoided, if possible. Free standing, or dedicated teleoperations consoles should be installed in areas where there is a minimum of IVA traffic or congestion; i.e., a specific location should be dedicated for teleoperations work.

CONCLUSIONS

Control Consoles

- Video Monitors: If IVA space allows, there should be a 1:1 relationship between the number of cameras and video monitors. However, if this is not possible, the video switching system should be designed to reduce operator confusion (as to what camera is being displayed on the monitor).
- Pan/Tilt/Focus Controls: Should be integrated into hand controllers as much as is practical to aid productivity.
- Functional Design: Controls for each subsystem should be unique to that system. There should be obvious differences in the design of controls used for different purposes.

CONCLUSIONS

Physical Interfaces-Specific Recommendations

- Master Arms: Large-scale master arm controllers can be fatiguing to the operator during extended use. As a result, the nature and duration of manipulative operations should be considered when identifying these types of controllers for use.
- Joysticks: Should be sized depending upon the expected duration of use with miniature joysticks being used on a short term basis only. All hand controllers, whether they be rate, or proportional should incorporate some form of arm or hand rest/restraint.
- Operator Interface/Manipulator Relationship: Arm controllers should be kinematically equivalent to their respective manipulators. In other words, the camera/manipulator and video monitor/controller relationships should be as physically identical as is practical.

CONCLUSIONS

Physical Interfaces-Specific Recommendations

- Standardization: The configuration of all hand controllers and console functions should be standardized with respect to method of operation; e.g., the controllers do not have to be a similar design, but should operate in an identical manner, with all related functions located in the same relative positions.
- Ancillary Functions: Controllers should incorporate sufficient ancillary functions (such as camera pan, tilt, zoom, and focus), so that the teleoperator can activate most system functions without removing their hands from the controls.

CONSIDERATIONS FOR HUMAN-MACHINE INTERFACES IN TELE-OPERATIONS

TOPICS

HUMAN FACTORS AFFECTING OPERATOR EFFICIENCY

Local environments and physical interfaces.

PHYSICAL AND ENVIRONMENTAL FATIGUE FACTORS

Operational stress, eye strain, temperature, excessive noise, body fatigue, boredom, and IVA lighting.

HUMAN-MACHINE INTERFACES

Portable consoles, dedicated workstations, master arms, "mini"masters, "bang-bang rate controllers, and proportional joysticks.

CONCLUSIONS - ENVIRONMENTAL

Temperature, noise, body fatigue, operator restraints, operational stress, and eye strain.

CONCLUSIONS - PHYSICAL INTERFACES

Visual and mechanical interfaces, portable workstations, dedicated control consoles, video monitors, camera pan and tilt controls, system functions, masters arms, proportional joysticks, and workstation configurations.

INTRODUCTION

The telerobotics field is wide ranging and encompasses work in several disciplines. Some of the typical uses of telerobotics systems today are in underwater inspection and work operations, inspections of nuclear power plants, the operation of remotely piloted vehicles (airborne RPVs), and the disposal of unexploded ordnance. But of all the contemporary applications of telerobotics, the subsea field is certainly one of the most diverse uses of telerobotics technology. As a result, the subsea field offers one of the most varied databases of operational experience for study, regarding all aspects of operator interfacing with robotic hardware.

Underwater telerobots must be designed specifically with the environment in mind. Both in space and underwater, the challenges to the designer are significant if they are to provide equipment that can accomplish the desired remote task on a cost effective basis. It is also not surprising that the existing subsea operator interfaces look very similar to their proposed space counterparts, given the similarities of the design drivers for both environments.

The designer of telerobotics workstation interfaces for the space environment faces much the same problems as anyone developing equipment for the underwater environment. The consoles must be compact, and capable of supporting remote work on a 24 hour basis. In addition, the console interfaces must be compatible with the operator, so they can work for extended periods with minimal fatigue. Also, consoles designed for both environments must offer the capability of positioning the robotic work system and operating its manipulators. Consequently, an examination of the subsea robotic field can help pinpoint areas of concern with regard to operational environments and the interfaces between the teleoperator and the work system.

The human factors related to remote work tasks must also be considered. Robotic work systems are hardware designed to be operated by humans. As a rule, humans work more efficiently if the local environment is comfortable and without distractions. The same will be true of space based teleoperations. Therefore, the human factors and lessons learned by the design and operation of subsea telerobotic control consoles are directly applicable to space robotic operations. Most subsea robotics workstations incorporate many of the basic functions required of both on-orbit and ground-based space robotic control stations.

FACTORS AFFECTING OPERATOR EFFICIENCY

The efficiency of the human-machine interface is determined by two factors: the operator's local environment and the compatibility of the workstation to operator interface.

The teleoperator is affected by their local environment as is any individual attempting a task requiring high degrees of concentration. Factors such as the ambient temperature, noise levels, seating orientation, and the mental state of the individual will take on a more important role than in less demanding situations. In addition, the length of time that the operator is required to concentrate his attention on remote tasks will greatly influence the onset and degree of operator fatigue.

The physical interfaces between the operator and console also influence the practicality of doing remote work. All too often, the designers of robotic work consoles will not consider the physical movements required by the teleoperator to control remote vehicles and manipulators. The operations console must be looked at as the physical link between the operator and the robotic system; i.e., the path through which all of the operator's senses must receive visual and physical feedback from the robotic system, and the point of physical contact by which they direct the movement of the remote work system. This link, if flawed in any way, will degrade the ability of the teleoperator to communicate with the robotic system.

PHYSICAL AND ENVIRONMENTAL FATIGUE FACTORS

There are several ways a teleoperator is affected by the local environment. Some of these concerns relate to the actual physical environment, while others have to do with the nature of the remote work being attempted. Operational stress is generally created by situations where the work task is extremely difficult, whether it be because the robotic system is being operated outside of its capabilities or has experienced some type of failure. Typically, even if manipulators or related equipment are only partially operational, the job will continue because of cost or criticality concerns. This type of situation is very trying for the operator because they are attempting a task outside of the nominal method of operation. However even with a fully operational system, complex work tasks can take their toll on the operator due to the required amount of concentration. Consequently, the onset and level of operator fatigue is directly related to task complexity. Manipulator operators can "burn out" after only 30 minutes during difficult operations, whereas in other cases with less demanding tasks, they can function productively for several hours.

Eye strain is another problem with extended teleoperations. Usually, the degree to which this is a factor is related to the length of operations, and the size and quality of the video image. Fuzzy or partially out of focus pictures can be irritating to look at for any length of time. Also, the speed with which the camera focus motors operate can contribute to this problem by making it difficult for the operator to get a clear picture on the video monitor. In this type of situation, considerable time is wasted as the camera lens continually runs past the optimum focus point by either being too near or too far. Cameras fitted with zoom lenses are notorious for this focusing problem.

As with any work environment, the ambient temperature must be comfortable and within the proper range of humidity. This concern is not only for comfort because most robotic system microprocessors (as with most electronic equipment), only operate within definite temperature ranges. Related equipment such as high voltage transformers can dissipate tremendous amounts of heat, sometimes in an area located near the operator. These factors must be taken into account when specifying environmental control units and ventilation requirements for the teleoperations area.

Excessive noise is also a problem in the teleoperations work area. Occasionally, minimal consideration is given to the type of ancillary equipment operating near the control console. A high ambient noise environment enhances fatigue and also places unreasonable demands on the communications system.

PHYSICAL AND ENVIRONMENTAL FATIGUE FACTORS

Body, joint, and hand fatigue is caused in several ways. First of all, any extended operations with large scale master arms (over 45 minutes), can result in arm fatigue. During the use of a master controller, the operator's arm muscles are constantly in contraction and extension as they attempt to position the slave arm. This, in itself, is not a serious problem. However, the level of concentration required during the task is passed down to the operator's arm, inducing a higher level of muscle tenseness than would normally be present. As indicated above, this is greatly influenced by the amount of visual concentration required to do the task. Generally, the problem manifests itself in the form of a very tight grip on the hand grip of the master arm. Like general operator fatigue, arm fatigue is directly driven by the difficulty of the remote task. Extended operations with miniature joystick controllers is also a problem. Hand fatigue is quite common during long term use of small proportional controllers (similar to the ones used in "Pong" games).

Body fatigue is created by the operator's seating position at the control console. Unfortunately, little thought is normally put into the design of operator's seating configuration and the amount of leg room available. Regardless of the type of restraint in use, for the operator to concentrate their attention on the job at hand, they must be comfortable and have room to stretch. However, extended zero-G operations will be a new application for teleoperator seating/restraint concepts.

Long term repetitive teleoperations work, as a rule, can be somewhat boring. Once the initial fascination of the operation wears off, operator boredom will normally speed up the onset of fatigue, with the result that teleoperators can literally fall asleep at the console. This is particularly true during jobs where the work involves primarily supervision and little operator interaction with the equipment. The only way to combat the problem is to rotate operators on a frequent basis and vary their job requirements.

The lighting conditions in the operations area is also a concern. Improperly placed or excessively intense lighting can cause glare on the video monitors making them difficult to see. All too often, personnel not directly connected with the job can frustrate and distract the operator by switching on nearby lights at the worst time. For example, the writer was trying to follow a lift line with a Remotely Operated Vehicle (ROV), during a deepwater operation under low visibility conditions. An individual opened the door to the control van (where the workstation was located), spilling bright ambient light onto the pilot's video monitor. The teleoperator immediately lost sight of the line and much time was wasted surfacing the vehicle and starting all over again.

HUMAN-MACHINE INTERFACES

General Console Layouts

Telerobotic workstations come in a variety of configurations, but they all have a common purpose: to act as a two way conduit of operator inputs and robotic system feedback. Generally, the typical teleoperations console can come in two designs: a small portable workstation that is installed and used as needed, or a dedicated console that is permanently mounted in a specific operations area.

Portable consoles have been in use the subsea telerobotics field for over a decade and can range from small suitcase sized units to ones that are hand-held. The hand-held controllers normally encompass the basic system functions and are integrated with a separate video display. The larger portable consoles are similar, but usually contain the surface or upside system electronics. The primary problem with these types of consoles is that they must be set up before use and are very prone to damage if they are accidentally bumped in the process. Most of the internal electronics associated with these units are delicate and not capable of withstanding significant abuse. In addition, the time needed to prepare the robotic system for operation can consume valuable operations time. The other problem is that because of the console or controller's small size, some compromises are usually made with regard to the configuration of the robotic system functions. In other words, the quality of the operator interfaces can be degraded because of space or size limitations.

Dedicated consoles offer more flexibility, from the operational standpoint, because they have more console surface area onto which to mount the system functions; i.e., they can be optimized for the most compatible operator interface. The dedicated console will also make it possible to install "operator friendly" components such as larger video monitors (some dedicated to a single camera), larger sized hand controllers, and system diagnostics. In addition, since the consoles are permanently mounted in a specific location, they are not subject to any physical abuse, and can enable the creation of a single-purpose area for teleoperations. However, the down side is that dedicated consoles require more IVA volume for installation and sometimes eliminate the possibility of using the area for other purposes.

HUMAN-MACHINE INTERFACES Hand Controllers and Master Arms

Hand controllers are a direct physical interface point between the teleoperator and the workstation. Consequently, their design can have a significant impact on the overall compatibility of the control console. Large scale master controllers, as indicated earlier in this paper, can contribute to operator arm fatigue during extended use. However, that is only one potential problem. While the large scale master does offer intuitive control and force reflective capabilities, they do require a large IVA work envelope for use. This can drive the interior design of the operations area in an undesirable way, in that it increases the free-volume requirements for the location. In addition, the masters can at times be delicate contraptions that are easily damaged, and require somewhat elaborate stowage schemes to keep them out of the operator's way when they are in use. While master arm indexing can reduce the volume required for use, this feature can detract from the primary advantage to using a large scale master in the first place; that the master kinematically represents the current position of the slave manipulator.

"Mini" masters represent a departure from their large scale counterparts in that they offer a kinematic replication of the scale arm, albeit on a smaller scale. Like the larger masters, they are subject to breakage and stowage problems. Unfortunately, there are not yet any commercially available "mini" masters with force reflection.

"Bang-bang" rate controllers are limited in capability in that they can only be used with rate manipulators. However they are generally simple in construction, highly reliable and offer an extremely small IVA work envelope. Another advantage to rate controllers is that they give the operator the opportunity to do manipulative work on a part task basis because the arm automatically freezes when the operator removes his hands from the controller. While the same could be said of large scale and "mini"master controllers, the rate controller offers this capability as an inherent function of its design.

Proportional joysticks can be used for end point control with resolved rate type manipulators. Depending upon their physical size and design, they can be comfortable or fatiguing to use. Typically, these types of hand controllers are integrated with controls for ancillary functions such as camera pan, tilt, focus, and zoom. While this is a desirable feature, it can sometimes get out of hand. There are only so many functions an operator can memorize on one control stick, and while it is highly desirable to incorporate multiple functions on one controller, there should not be so many that the operator has trouble memorizing the individual functions, or can accidentally actuate a function during normal operations.

CONCLUSIONS

Environmental-Specific Recommendations

There are several conclusions that can be derived from the information presented in this paper, but one is obvious: the local environment of the teleoperator has a significant and measurable effect on the efficiency of doing remote work tasks. As a result, steps must be taken to guarantee that the environment of the operations location is favorable to practical work.

Some of the recommendations that will aid in the above goal are as follows: While it seems like a logical concern, the temperature of the telerobotics operations area is a factor that is often overlooked. The operations location must be comfortable to the teleoperators or they will have difficulty concentrating on the job at hand. The amount of heat generated by control consoles themselves is sometimes minor, but related support equipment can radiate large amounts of energy (this is of particular concern if ventilation within the operations area is lacking). The designer must consider these facts when specifying the requirements for environmental control equipment. In addition, the expected environment of the exterior of the control area, must be considered with respect to any external influences (direct sunlight, radiation, etc.).

High noise levels in the operations area can also cause problems, especially with regard to communications. A high ambient noise level will drive headset needs in an undesirable manner. Communications headsets should be able to be selected on the basis of their comfort and clarity, not sound isolation properties. Finally, as with temperature, excessive sound levels will increase the onset of operator fatigue.

CONCLUSIONS

Environmental-Specific Recommendations

Body and hand fatigue will become a significant negative influence during any extended teleoperations. But how much of a factor it becomes will be determined in part by the design of IVA restraints and hand interfaces. As a result, there are specific areas of concern that can be dealt with to reduce fatigue problems. First of all, hand controllers should incorporate some form of hand or forearm rest to help relieve operator muscle tension. For the proportional joystick, possibly some type of padded area (similar to an arm rest on a chair) that the operator can place his arm against would be beneficial. In the microgravity environment, it may be necessary to supply some flexible restraint to hold the arm against the rest during operations. Obviously, any type of force reflection system will demand some form of restraint if the teleoperator is to have any hope of "feeling" mechanical feedback generated by the master arm.

Operator restraints should be highly adjustable, with regard to their orientation with the control console, and general configuration. The restraint should be flexible enough to fit a wide range of operations personnel (this is especially true during any operations involving force reflection, since the operator will measure the physical feedback while using the restraint as a stop). In addition, there should be sufficient IVA free volume surrounding the operator restraint to allow for body flexing (especially the legs) during extended IVA operations.

CONCLUSIONS

Environmental-Specific Recommendations

Operational stress will be a driving force behind the onset of operator fatigue during teleoperations. This stress can manifest itself in several ways but primarily, it will be related to task difficulty. Highly complex manipulative operations, especially those that involve work on the borderline of system capabilities, will be extremely fatiguing to operations personnel. For example, if a manipulator has an end point positioning accuracy of plus or minus 1", and the arm is being used to assemble components that have .90" clearance around them, then clearly, it is going to be a difficult time for the arm operator (especially if the components have been designed without alignment guides). Consequently, in these types of situations the operators should be changed out on a frequent basis.

The number of degrees of freedom the operator is required to operate can also influence operational stress levels. Typically, pilots of subsea robotics systems have been able to do simultaneous operations such as combined vehicle and manipulator operations at mid-water. However, such accomplishments were normally under good conditions using only 3 - 4 DOF arms. This maximum DOF issue is one that requires further study.

Job stress is also related to how well the robotic system is operating. Equipment that experiences excessive down time will frustrate teleoperations personnel because they will spend more time repairing the equipment than operating it.

The quality and type of video monitors influence productivity by contributing to operator eye strain. Individuals doing teleoperations do not just "look" at video monitors, but must examine and understand the visual information on the screen. Trying to do this with a degraded video image is difficult, at best. Some basic suggestions are that video monitors used for teleoperations should be at least 9" in size, and incorporate standard controls for brightness, contrast, and sharpness. In addition, the IVA work environment should offer indirect lighting of variable intensity. The distance from the video displays to the operator's eyes, as a general guideline, should be no less than about 3/4 arm length.

CONCLUSIONS

Physical Interfaces

Visual and mechanical interfaces are the teleoperator's only physical link with robotic equipment. Therefore, it is of the utmost importance to establish a compatible interface between the senses of the human operator and the robotic system inputs. Some specific recommendations are listed below:

Portable workstations that have to be set up or installed before use should be avoided, if it is at all possible. The types of compromises made in portable designs are sufficient to render them undesirable for extended teleoperations use. A far better arrangement is the design of a workstation permanently installed into a "teleoperations work area". This will enable the teleoperator to do the job at hand in the most compatible environment possible.

However, in situations where it is absolutely impossible to create a dedicated area, such as in the Orbiter's aft flight deck, then any portable workstations should be highly adjustable, with regard to the installation point and mounting angle, so the teleoperator can customize the operator to workstation interface.

CONCLUSIONS

Control Consoles

Telerobotic workstations should be configured to act as the operator's reference point to the robotic system. First of all, if possible, there should be a dedicated video monitor for each camera. This will enable the teleoperator to instantly view the entire visual range surrounding the telerobot, without confusion as to what camera they are viewing. Of course, given the space limitations on-orbit, this may be impractical. A compromise would be to use video multiplexing so that the teleoperator can examine multiple video images on one video monitor. The goal should be to make sure the teleoperator knows which video image is being generated by what camera.

The mechanical orientation of manipulator controls should mimic the configuration of the telerobot as much as is feasible. For example, if the robotic system has two arms, then there should be two separate controllers instead of one controller with a selection switch.

Camera pan and tilt controls should also follow the same practice; i.e., there should be a separate controller for each camera. Ideally, pan and tilt controls should be incorporated into hand controllers so the teleoperator can operate the manipulator and camera controls without diverting their attention from the video monitor.

System functions should be unique and configured based upon their function. For example, the switches used to turn lights off and on should be of a different design than the ones that control system power. Ideally, the console should not need labels on all of the controls for the operator to know their functions. Overall, a customized function layout will reduce errors and enhance compatibility. The console should be ergometric so that the operator can easily reach all of the system's functions without constant body movements. This feature will reduce body fatigue.

In general, the concept behind a telerobotic console should be to design for functionality, compatibility, and practicality. The foremost thought that should be behind the design of the console is that the workstation is the teleoperator's hands and eyes at the worksite.

CONCLUSIONS

Physical Interfaces-Specific Recommendations

The type of manipulative operation and the design of the manipulator system should be the determining factors with regard to the configuration of arm controllers. While large scale master arm controllers can be very beneficial to teleoperations, they will cause arm fatigue if used for extended periods. Steps should be taken to ensure the availability of sufficient operations personnel for an acceptable rotation schedule during extended or complex manipulative work tasks. In addition, any full-scale masters installed in a robotic workstation should be capable of stowage during periods of non-use.

Proportional hand controllers should be sized in relation to expected task duration. Generally, if sufficient IVA console space is available, medium sized joysticks (that can be grasped by the entire hand), should be employed.

The designer should strive to make the hand controllers reflect the physical configuration of the manipulator system. In other words, the arm controllers should be referenced to the video monitor screen as a representation of how the subsystems are physically related at the worksite. The most important aspect is the video camera to end effector relationship. If the robotic system is configured with the video camera in the middle of two manipulators, then the two arm controllers at the workstation should be mounted on either side of the video monitor. The work station should represent the remote work system as much as is practical.

CONCLUSIONS

Physical Interfaces-Specific Recommendations

Standardization of teleoperator interfaces will aid operational efficiency by reducing learning requirements between different robotic systems. There are several ways that standardization can be applied to physical interfaces, but the most obvious solution, such as using identical controllers for several applications, is not necessarily the best; operator interfaces do not have to look alike to be standardized!

There are a multitude of telerobotic vehicles in use today in the subsea field, and outside of the individual manufacturers, there is little or no standardization. But what has been learned in the past decade of teleoperations is that standardization is more related to method of operation than appearance.

Some underwater remote vehicles are controlled by two joysticks while others can be driven with one. It all depends upon how the control subsystems are configured and the preferences of the manufacturer (some seem to prefer a one over a two stick arrangement). Field personnel who take over control of a vehicle with no prior experience on a particular system can usually learn the functions fairly quickly, especially if the operator is highly experienced. However, standardization of the operator interfaces would certainly reduce the amount of time it takes to learn a particular robotic system.

Robotic system controls should be standardized with respect to function and mode of operation. The key is to guarantee that identical physical movements are required of the operator to achieve a particular result. A standard typewriter is an excellent analogy. There are many varieties of typewriters, but in most designs, the keys (the separate letters, that is), are always in the same place. The typist can then learn one interface pattern, then have the ability to use all typewriters. The reason this is so important is that the teleoperator references all of their resultant actions (the physical movements they see on the video monitor) to specific movements at the workstation. The operator knows that if he moves a control in a certain direction, he will see a corresponding result on the video screen. This results in a "learned relationship" between action and reaction. This relationship is what is learned by the operator, not the shape, size, or color of the hand controller. As a result, systems that operate outside of this database of information have to be relearned all over again so the operator can develop a new action/reaction relationship. This process wastes time. Hence, the relative dynamic relationship between the operator and the controller is what should be standardized, not the physical design of the controller.



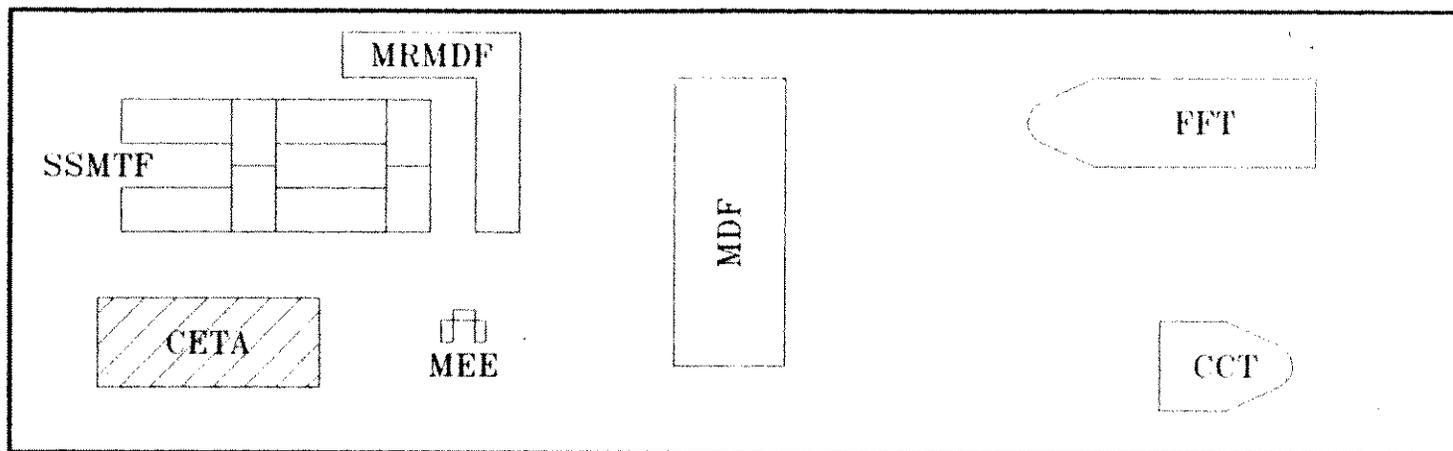
SATELLITE SERVICES SYSTEM WORKING GROUP

MEETING #22

JOHNSON SPACE CENTER

BUILDING 9A-B

NOVEMBER 29, 1989



BUILDING 9A-B

- | | | |
|-------|--|--------------------------------|
| CETA | - CETA HARDWARE | BOB TREVINO |
| MEE | - MAGNETIC END EFFECTOR
MOCKUP OF FLIGHT DEMO | LEO MONFORD |
| SSMTF | - SPACE STATION FREEDOM | LANCE BEAUCHAMP |
| MRM | - MOBILE REMOTE MANIPULATOR | FRANK EADES / SCOTT MORGAN |
| FFT | - FULL FUSELAGE TRAINER | BOB JOHNSON / ROBERT WESTERMAN |

MOBILE REMOTE MANIPULATOR DEVELOPMENT FACILITY

MAN-SYSTEMS DIVISION
NASA - JOHNSON SPACE CENTER
HOUSTON, TEXAS

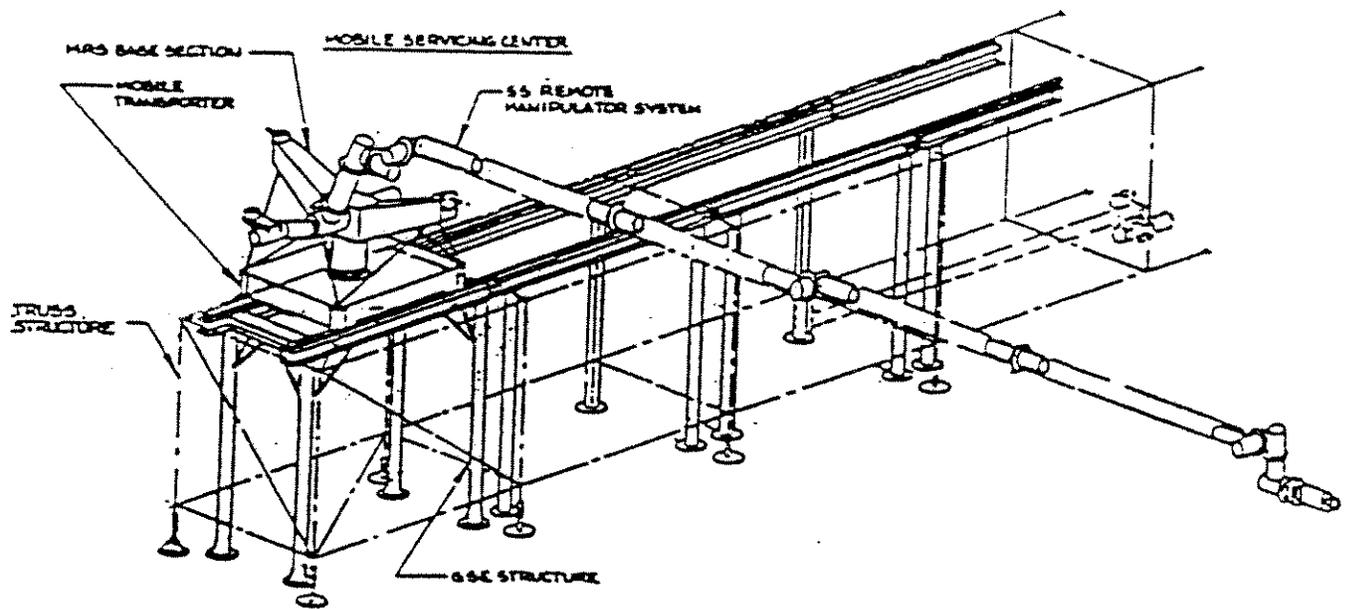


Figure 1.0 MANNED REMOTE MANIPULATOR MOCKUP

MOBILE REMOTE MANIPULATOR MOCKUP

INTRODUCTION

NASA Johnson Space Center maintains an Astronaut training facility and public viewing area in Building 9A-B. This building includes a conceptual Mockup of the Mobile Remote Manipulator (MRM). The purpose of the MRM Mockup is:

- * Evaluate physical magnitude and envelope required for MRM trainer
- * Support SSRMS reach and positioning engineering evaluations
- * Provide public viewing and information

This MRM Mockup is based upon design information obtained from McDonnell Douglas/ASTRO and SPAR Corporations.

MOBILE REMOTE MANIPULATOR MOCKUP DESCRIPTION

The MRM Mockup located in Building 9B Highbay consists of a 5 Meter Truss, Ground Support Equipment (GSE), a Mobile Transporter (MT), a Mobile Remote Servicer Base System (MBS), a Space Station Remote Manipulator System (SSRMS) and a Special Purpose Dextrous Manipulator (SPDM).

The GSE, MT, MBS and SSRMS are designed to accomodate a maximum static payload of 500 lbs.

The Mobile Remote Servicer (MRS) which consists of the MT, MBS and SSRMS has the capability to translate North/South and East/West on linear bearings attached to rails mounted on the GSE structure.

The SSRMS is a faithful replication of the flight envelope reconfigurable at one degree increments about each of the seven joints. (1. Shoulder Roll, 2. Shoulder Yaw, 3. Shoulder Pitch, 4. Elbow Pitch, 5. Wrist Pitch, 6. Wrist Yaw, and 7. Wrist Roll).

The SPDM is a static Class III C Soft Mockup for volumetric reference only.

Weights of Components:

*GSE	2439 lbs
*MT	2422 lbs
*MBS	3160 lbs
*SSRMS	2521 lbs
*SPDM	105 lbs

The MRM Mockup was installed during the early Summer of 1989. The static load testing of the MRS took place during September 1989. The MRM Mockup will be used for Reach, Positioning and Field of View Evaluations.

MRMDF FUNTIONAL TRAINER

INTRODUCTION

Johnson Engineering Corporation is a contractor to the National Aeronautics and Space Administration (NASA) Man-Systems Division, Mockup and Trainer Section, providing crew station support services for the United States Space Program. A requirement of the program is to provide crew training articles for the Mobile Remote Manipulator Development Facility. The information contained within this document will present an overview of the Space Station Mobile Remote Servicer Functional Training System.

**MOBILE REMOTE MANIPULATOR DEVELOPMENT FACILITY (MRMDF)
DESCRIPTION**

The MRMDF will be composed of a full-scale, high fidelity replica of the flight Space Station Mobile Servicing System (MSS), a full scale flight truss structure (10 bays), a simulated operator's control station, a computer facilities complex, and a load carrying ground support equipment (GSE) structure. This system shall be located in Building 9B at the NASA/JSC, Houston, Texas.

The purpose of the MRMDF will be to provide the capability to support flight MRS mobility design, truss design, partial truss deployment, module interface design, module docking procedure development, closed-circuit television location and usage development, payload retention system design, payload design, and payload handling.

MOBILE REMOTE SERVICER

The MRS will be composed of 3 major subassemblies; 1) the Mobile Transporter (MT), 2) the MRS Base System (MBS) and 3) the Space Station Remote Manipulator System (SSRMS). The MRS will be a hydraulically actuated computer controlled device which will incorporate an 8 degree of freedom (DOF) capability. The SSRMS will be a 7 DOF robotic manipulator. The SSRMS will be mounted to the MBS. The MBS will be mounted onto the MT. The MT shall provide the last degree of freedom for the total 8 DOF requirement.

MOBILE TRANSPORTER

The Mobile Transporter will consist of 3 major structural elements; 1) the upper base assembly, 2) the turntable assembly, and 3) the lower base assembly. A self contained hydraulic power supply, control electronics, and computer interface hardware will be mounted on the MT structure. Additionally, the MBS will be attached to the upper base of the MT.

The Mobile Transporter will have the capability to translate along the Ground Support Equipment (GSE) truss structure to position the SSRMS as required for SSRMS actuation and positioning during training sessions.

MRS BASE SYSTEM

The MRS Base System will be a structural assembly which will be capable of supporting the dynamic and static loads experienced from the articulation of the SSRMS which will be mounted to the MBS. Additionally, the MBS will incorporate interface components to accommodate mounting of grapple fixtures, utility harnesses, hydraulic lines, EVA tool mounts, and EVA workstation, a Special Purpose Dextrous Manipulator (SPDM), inflatable payloads and closed circuit television cameras and related umbilicals.

The MRS Base System structure will be the primary interface between the MT and the SSRMS.

SPACE STATION REMOTE MANIPULATOR SYSTEM

The SSRMS is the functional core of the Mobile Remote Services Training System. The SSRMS will consist of a 57.8 foot long robotic manipulator. The SSRMS shall be a hydraulically actuated computer controlled 7 DOF manipulator arm. The 7 DOF arm will be composed of 7 joints; 1) shoulder roll, 2) shoulder yaw, 3) shoulder pitch, 4) elbow pitch, 5) wrist pitch, 6) wrist yaw, and 7) wrist roll.

The manipulator arm will be symmetrical about the elbow joint. The shoulder and wrist assemblies will be functionally and dimensionally equivalent assemblies.

The wrist assembly will be designed to accommodate a latching end effector assembly which will be utilized to grasp payloads via a grappling fixture. The end effector device will be a hydraulically or electrically actuated computer controlled device.

The SSRMS shall be designed to lift a maximum payload of 500 lbs.

MRS HYDRAULIC SYSTEM

The MRS MT and SSRMS assemblies will be actuated and articulated via a closed loop computer controlled hydraulic power system. The core of the hydraulic power system will be a hydraulic power supply (HPS) which is to be mounted on the MT.

The HPS will consist of a pressure and flow compensated centrifugal pump, a supply plumbing system, a return plumbing system, a pressurized reservoir assembly and associated control equipment. The HPS will supply hydraulic fluid to the hydraulic actuators and motors on the MT and SSRMS assemblies.

The HPS will respond to inputs initiated from the computer control system.

The SSRMS will utilize hydraulic actuators and motors at each of the 7 DOF joints. These actuators will be designed to fit within the flight volumetric flight envelope of the SSRMS. The actuators and motors will be geared as required to produce the performance rates of the The Flight Article.

MRS CLOSED CIRCUIT TELEVISION SYSTEM

The MRS system will incorporate a closed circuit television (CCTV) system to be utilized during training operations and provide visual positional feedback to the MRS system trainers and operators.

The CCTV system will consist of cameras mounted on the MT, MBS, and SSRMS, plus CCTV monitors and a CCTV control console to be located within the MRS control station.

The CCTV monitors will provide the MRS operator, MRMDF test conductor, and astronaut trainers with real time visual feedback of training operations.

The CCTV control console will incorporate all controls required to select and adjust the CCTV cameras.

SPACE STATION AND GROUND SUPPORT EQUIPMENT TRUSS STRUCTURES

The MRS functional system will be interfaced to a GSE truss structure. The primary role of the GSE truss structure will be to provide structural support rigidity and integrity to mount the MRS assembly. The GSE truss will be capable of supporting the static and dynamic loads experienced by the translation of the MT and the articulation of the SSRMS.

The GSE truss structure will be housed within the cubic volume enclosed by the space station flight truss structure. This volume is a 5 meter cube. The GSE truss structure will be designed to interface with the space station truss structure assembly.

The GSE truss structure will be mounted in the new building 9A/C facility.

The GSE truss structure assembly will consist of 10 bays.

MRS OPERATORS CONTROL CONSOLE

The MRS system will incorporate an operators console/training workstation. The operator's console design will be a functional replica of the space station article. The operators console will be housed within a replication of a space station nodal unit. The operator's console will incorporate controls and displays required for articulating and monitoring the MT and SSRMS movements. The primary means of MT and SSRMS control inputs will be a translational and a rotational hand controller. The control console will also house the CCTV monitors.

The operator's control console will be linked via a fiber optic data transmission system to the MRMDF computer complex and the MRS closed loop control system sensors and feedback components.

MRMDF COMPUTER COMPLEX

The MRMDF Computer Complex will be the core of the control system for the MRMDF system. The complex will be located in a three story tall structure which will be designed and outfitted to accommodate computer equipment. The MRMDF Computer Complex will be sectioned into 3 functional areas; 1) 1st floor host computer room, 2) 2nd floor computational/maintenance terminals and 3) 3rd floor test director's console.

HOST COMPUTER EQUIPMENT

The MRMDF system will be controlled, monitored, and interfaced by a dual redundant host computer and associated peripherals. The host equipment will include:

- *Programmable Logic Controller
- *(2) Core Host mainframe computational units
- *Hard disks
- *Floppy disks
- *Magnetic tape devices
- *Printers
- *CRT's and keyboards
- *Plotters
- *19" utility cabinets
- *Maintenance and debug equipment

The host computer system will read input from the operator's console and displays on a real time basis. The computer will then process the inputs and produce control output signals to the MT and SSRMS control devices (i.e. servo valve drive cards). This system will be closed loop to monitor position, torque, and rate sensors at the MT and SSRMS actuator devices. These monitored signals will be fed back to the host computer and processed for control corrections.

COMPUTATIONAL/MAINTENANCE TERMINALS

The MRS system will require maintenance terminals and associated equipment to routinely monitor and status the integrity and functionality of the MRS computer systems and their interfaces. The equipment required in this functional arm shall include:

- *Software workstation
- *Disk drives (2)
- *Printers (2)
- *Tape drives (2)

MRS TEST DIRECTOR CONSOLE

The MRS system will be operated and controlled from the Test Director Console when not in the training mode of operation. The MT and SSRMS will be initially activated at the Test Director Console. The Test Director Console will contain all controls and displays required to operate and monitor the hydraulic power system. The console shall also incorporate controls and displays to status operations of the operator's control console and provide real time status from the MT and SSRMS operations. A maintenance communications system control center and CCTV system control console shall also be components of the Test Director Console.

One of the real time status subsystems to be housed in the Test Director's Console shall be a three dimensional graphic simulation of the SSRMS functional movements and positions.

The Test Director Console shall function as the central MRS system control and monitoring station.

MILESTONES (FUTURE)

*Product Description	Fall 1989
*Award Contract (Design and Development)	Midsummer 1990
*PDR	Spring 1991
*CDR	Summer 1991
*Fabrication	Fall 1991
*Test and Evaluation	Fall 1992
*Training	Spring 1993

JSC BUILDING 15 TOUR MANNED SYSTEMS TELEROBOTICS LABORATORY

NOVEMBER 29, 1989

J. LEGENDRE/ NASA-JSC

MAN-SYSTEMS TELEROBOTICS LABORATORY

PHOTO # S89-48718

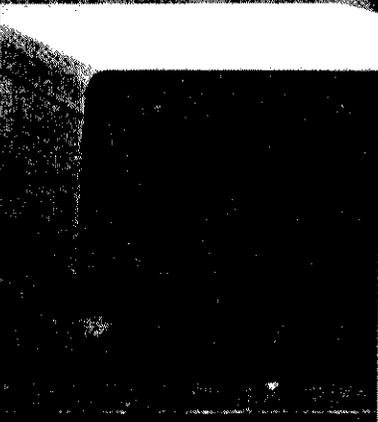
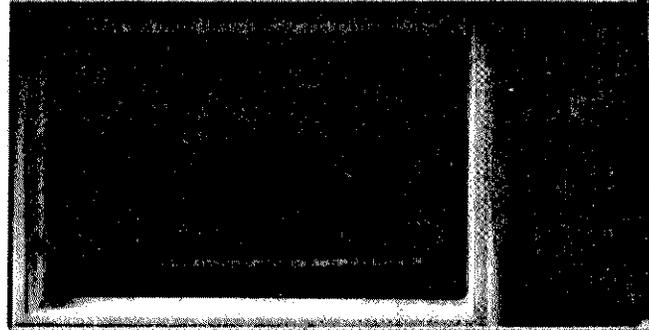
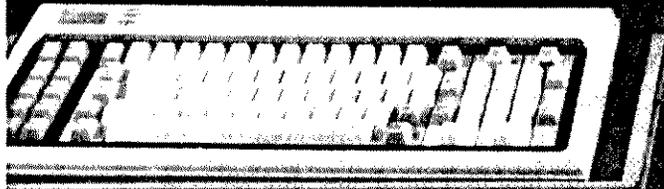
- Digital image processing
 - quarter screen real-time displays
 - 4 separate active camera inputs
 - ability to zoom individual views



National Aeronautics and
Space Administration

8 6 9 - 4 8 7 1 8

Lyndon B. Johnson Space Center,
Houston, Texas 77058



MAN-SYSTEMS TELEROBOTICS LABORATORY
PHOTO # S89-48719

- Digital image processing
 - split screen capability
 - overall and close-up views on one monitor
 - third view on separate monitor



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MAN-SYSTEMS TELEROBOTICS LABORATORY
PHOTO # S89-48720

- Digital image processing
 - showing circular inset of region-of-interest
 - inset can be moved to any part of screen
 - inset can be zoomed separately



National Aeronautics and
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589-48720

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MAN-SYSTEMS TELEROBOTICS LABORATORY

PHOTO # S89-48721

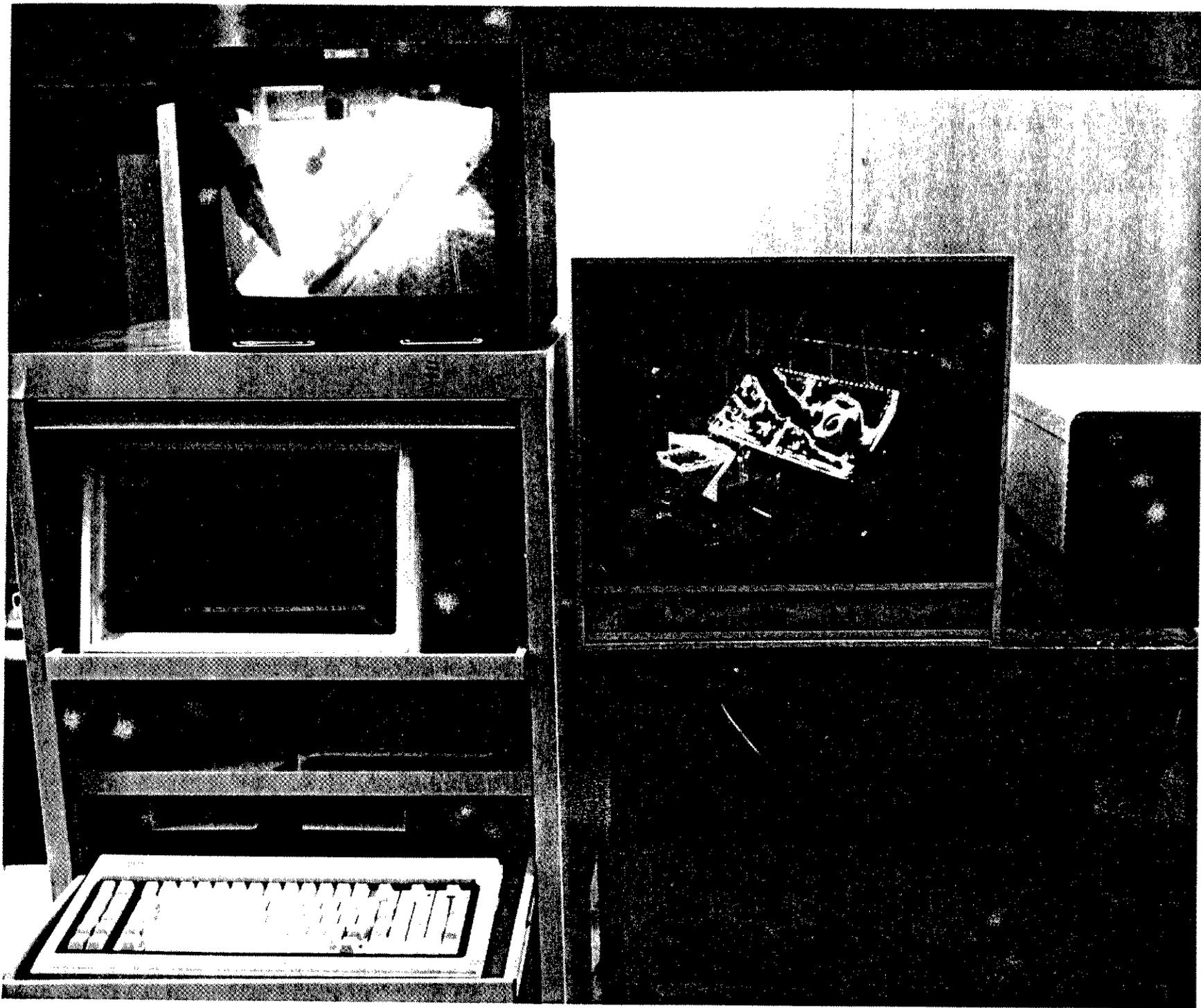
- Digital image processing
 - edge detection and enhancement
 - various filters and algorithms can be implemented
 - feature extraction for future semi-autonomous operation



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MAN-SYSTEMS TELEROBOTICS LABORATORY
PHOTO # S89-48722

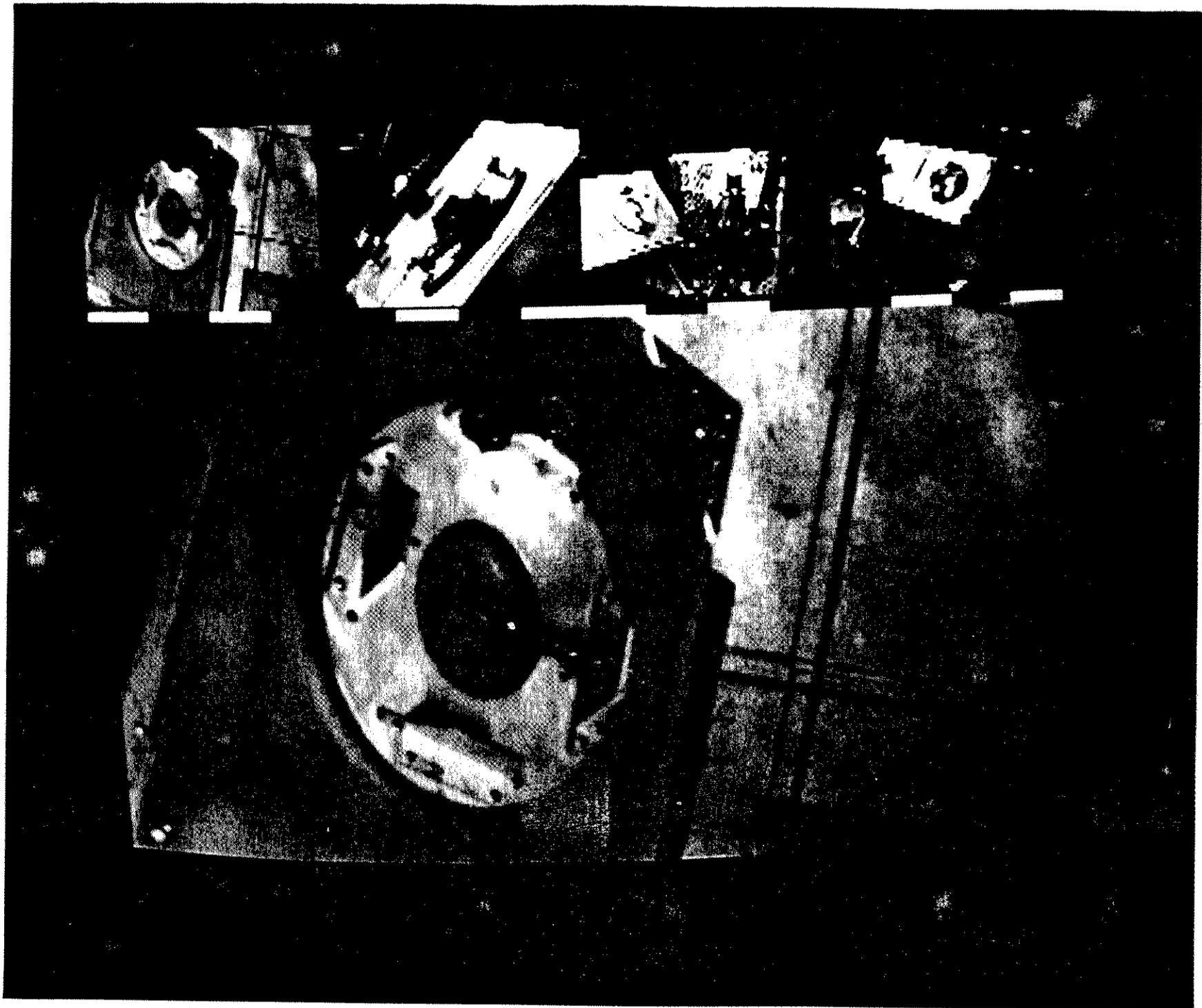
- Digital image processing— close up of monitor
 - "menu" strip showing 4 separate real-time camera inputs on top
 - 1st image is shown full size on bottom of screen
 - capability to select full size view by touch menu



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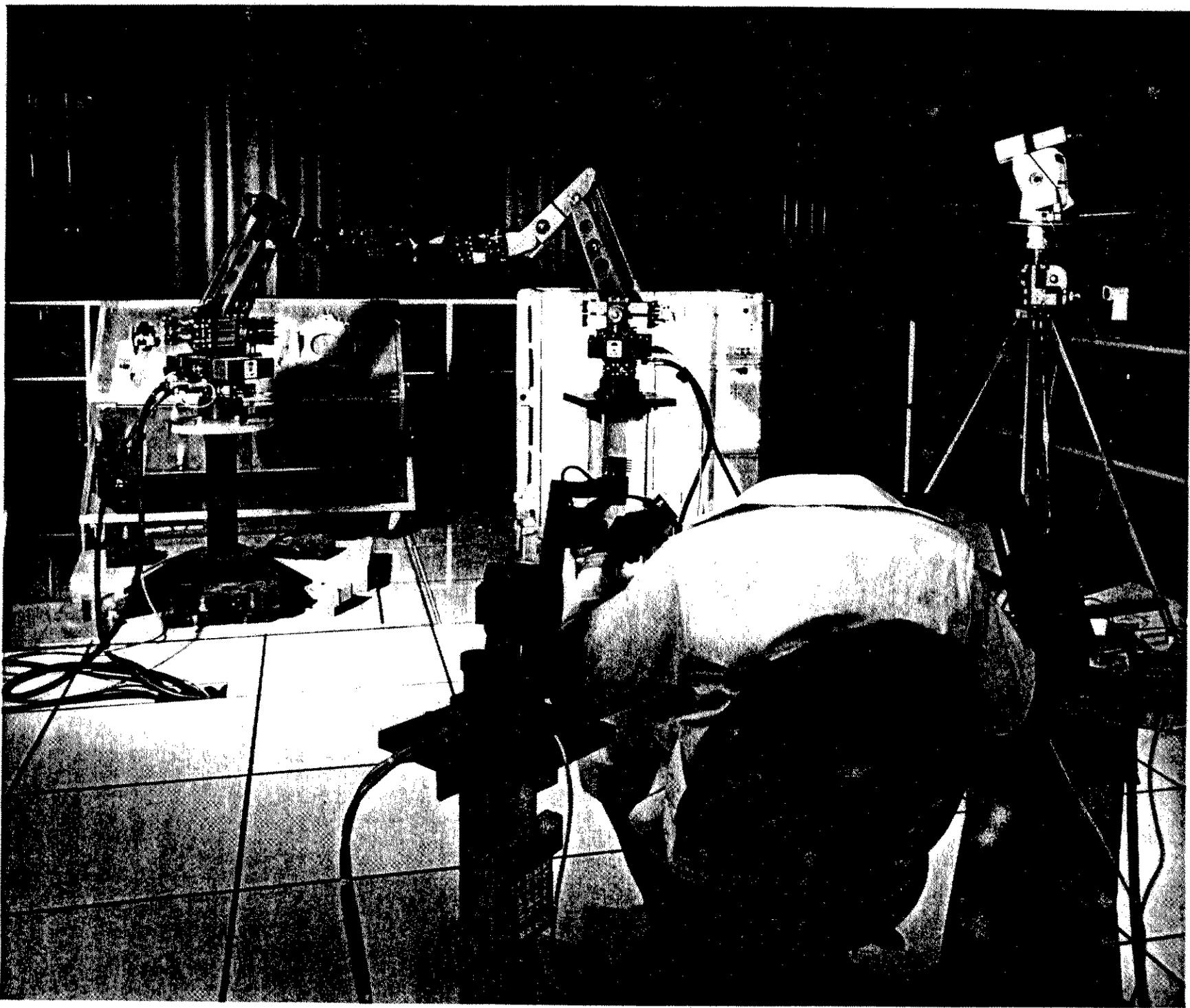
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PHOTO # S89-48723

- Dual arm force-reflecting manipulator system
- Dual miniature master controllers for operator
- Space Station tasks mockups
- Moveable camera views for the operator



MAN-SYSTEMS TELEROBOTICS LABORATORY

PHOTO # S89-48724

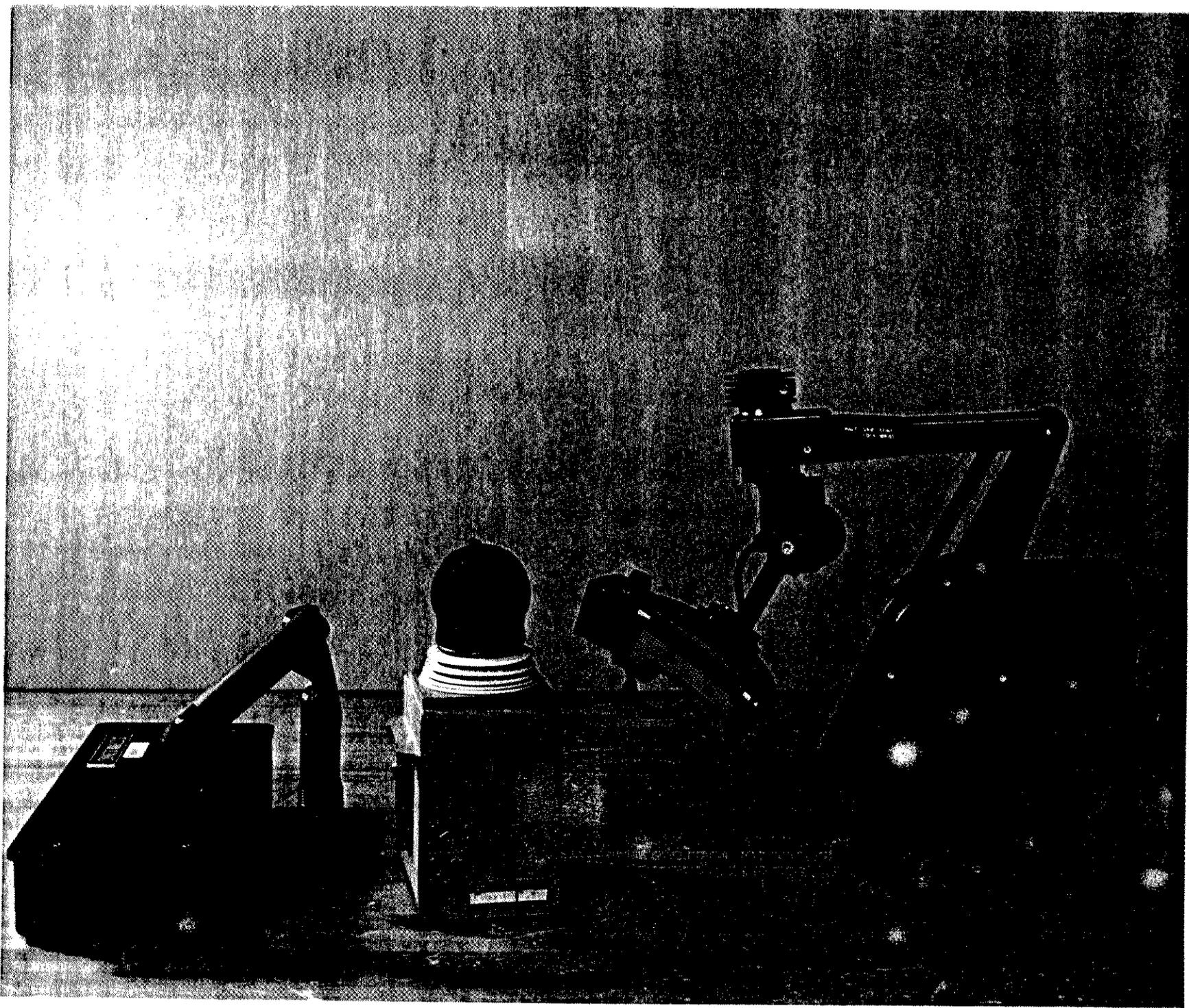
- 6 degree-of-freedom hand controllers
 - left: Schilling miniature master position controller
 - center: CAE rate input joystick
 - right: Kraft miniature master position controller



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MAN-SYSTEMS TELEROBOTICS LABORATORY
PHOTO # S89-48725

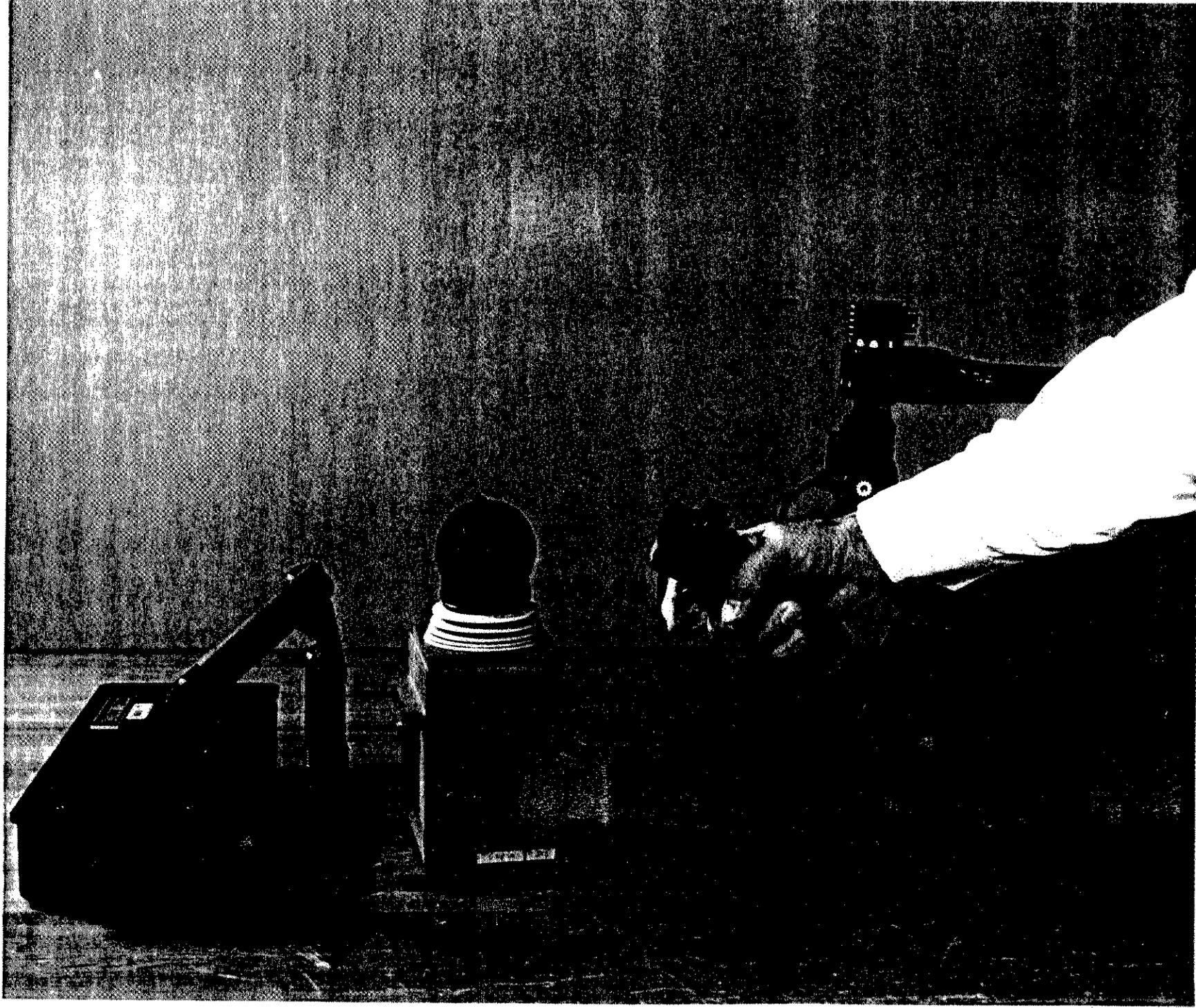
- 6 degree-of-freedom hand controllers
 - left: Schilling miniature master position controller
 - center: CAE rate input joystick
 - right: Kraft miniature master position controller



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MAN-SYSTEMS TELEROBOTICS LABORATORY

PHOTO # S89-48726

- Operator wearing head-slaved camera tracking system
- Master control station with camera feedback from test area
- Master control station contains real-time control computers for allowing rapid switch-out of hand controllers



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