D3

CREW STATION DESIGN

JAMES L. LEWIS

JOHNSON SPACE CENTER

SPACECRAFT CREW STATION DESIGN EXPERIENCE

CRITICAL PROBLEM AREAS FOR THE FUTURE

SOLUTIONS

CREW STATION

DISPLAYS AND CONTROLS SYSTEM
LAYOUT/VOLUME
REACH AND VISION
GALLEY
PERSONAL HYGIENE
FACILITY HYGIENE
SLEEP STATION
STOWAGE
RESTRAINT SYSTEMS
WASTE COLLECTION
TRASH MANAGEMENT
LOGISTICS MANAGEMENT
SCHEDULING
ACOUSTIC ENVIRONMENT
THERMAL ENVIRONMENT
CONSUMMABLES: FOOD, WATER, ATMOSPHERE
COMMUNICATIONS
LIGHTING AND VISIBILITY
INFORMATION MANAGEMENT

No author added comments to charts.

PROGRAMMATIC LIFE OF A CREW STATION

PROPOSAL

PRELIMINARY DESIGN

DESIGN

MANUFACTURING

TEST AND CHECKOUT

OPERATIONS

- <u>PRECLUDED IN EARLY DESIGN STAGES</u>
  - CAMERA MOUNTS
  - TELEPRINTER
  - TEXT/GRAPHICS SYSTEM
  - CREW COMPARTMENT EXPERIMENTS
  - CREW SIZE
  - INFLIGHT MAINTENANCE
- <u>DEFERRALS</u>
  - SLEEP COMPARTMENTS
  - GALLEY
  - PERSONAL HYGIENE STATION
  - PRIVACY CURTAIN
  - STOWAGE COMPARTMENTS
  - WET TRASH STOWAGE
  - OPERATIONAL SEATS
- <u>LATE DISCOVERIES</u>
  - DFI
  - EJECTION SEATS
  - FLASH EVAPORATOR WATER TANKS
  - HUD
- <u>GROWTH</u>
  - FOOD
  - FLIGHT DATA FILE
  - CLOTHING
  - EVA CONTINGENCY EQUIPMENT
  - STUDENT EXPERIMENTS
  - CAMERA EQUIPMENT
  - INFLIGHT MAINTENANCE

MODULARIZED ORBITER CREW COMPARTMENT

- o GALLEY
- o AIRLOCK
- o SLEEPING QUARTERS
- o HYGIENE STATION
- o LOCKERS
- o DISPLAY AND CONTROL CONSOLES
- o DRY TRASH COMPARTMENT
- o WET TRASH STOWAGE
- o OPERATIONAL SEATS

PROBLEM AREAS

TRAINING

LOGISTICS

ONBOARD SCHEDULING

INFORMATION MANAGEMENT

"RUT" SYNDROME

RESTRAINT SYSTEMS

SOLUTIONS

GOOD DATA BASE
- ACCURATE
- COMPREHENSIVE
- REAL TIME INTERACTIVE
- LOW USER OVERHEAD
- REQUIRED USE

CREW STATION DEFINED AND ORGANIZED AS A SYSTEM

SYSTEM ADVOCATE

DEVELOP THE MOST COST EFFECTIVE
MEANS FOR UTILIZATION OF HUMAN
RESOURCES IN SPACE

DEVELOP A

DYNAMIC MODEL OF MAN AND HIS ENVIRONMENT

AND COST EFFECTIVE METHODS OF

UTILIZING THE MODELS IN DESIGN AND OPERATIONS

PROGRAM THRUST

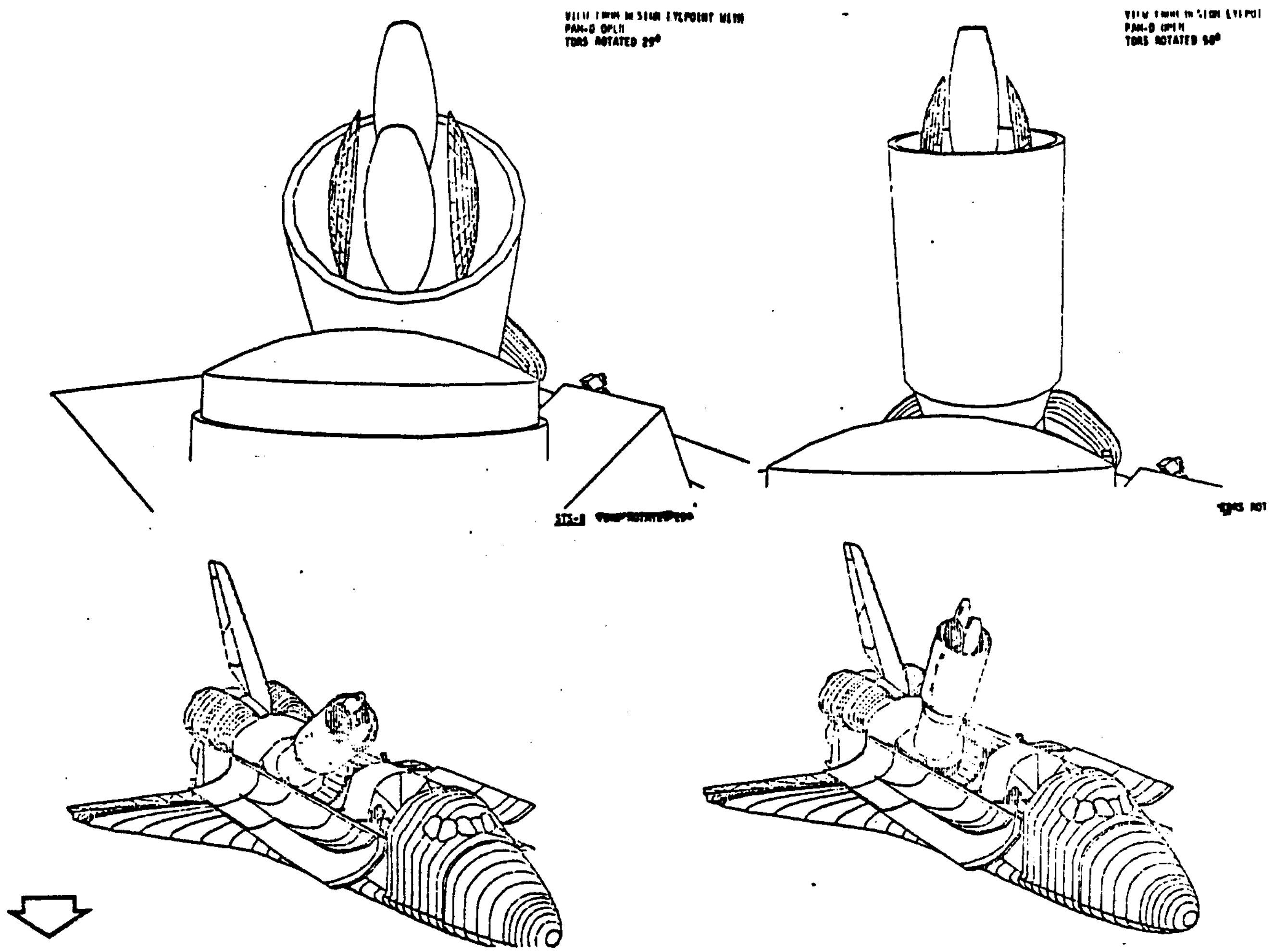
MODEL MAN STATIC DYNAMIC ANTHROPOMETRICALLY PHYSIOLOGICALLY COGNITIVE MODEL WORKSTATION STATIC DYNAMIC MODEL ENVIRONMENT STATIC DYNAMIC	DATA ACQUISITION & REPRESENTATION	PREDICTIVE MODEL DEVELOPMENT	SYSTEMS OPTIMIZATION

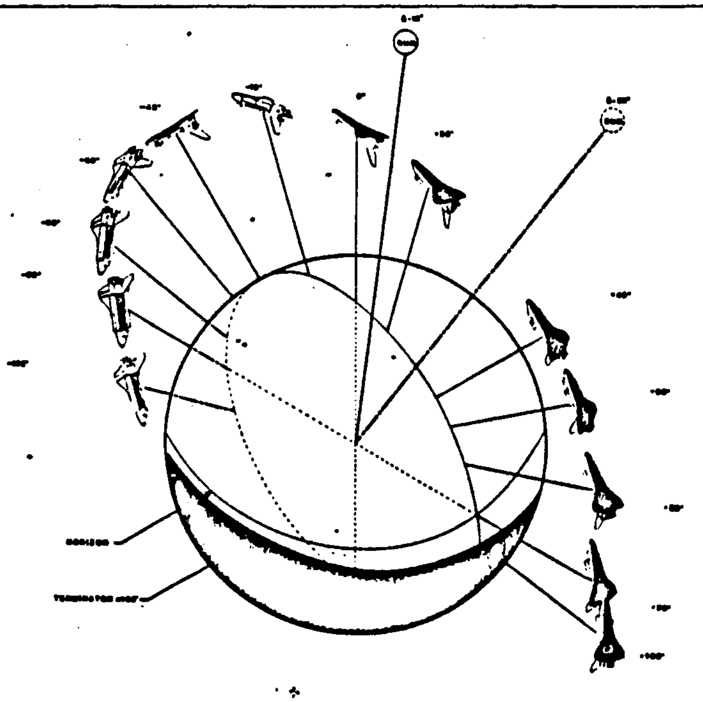
DESIGN PERFORMANCE LABORATORY

THE DPL IS AN INTERACTIVE COMPUTER BASED FACILITY USED IN THE DESIGN AND EVALUATION OF CREW COMPARTMENTS CONTROL STATIONS AND EQUIPMENT.

OPERATOR STATION DESIGN SYSTEM

- 3D DESIGN OF D&C PANELS, STRUCTURE, PAYLOADS (PANEL LAYOUT AUTOMATED INTERACTIVE DESIGN-PLAID)
- GRAPHICS OUTPUT OF OPERATOR OR OTHER VISUAL IMATES
- VISUAL CONFLICT ASSESSMENT
- OPERATOR REACH ASSESSMENT (CREW ASSESSMENT OF REACH-CAR)
- FLIGHT OPERATIONS PROCEDURE GRAPHICS AIDS
- ANTHROPOMETRIC STATISTICAL ANALYSIS



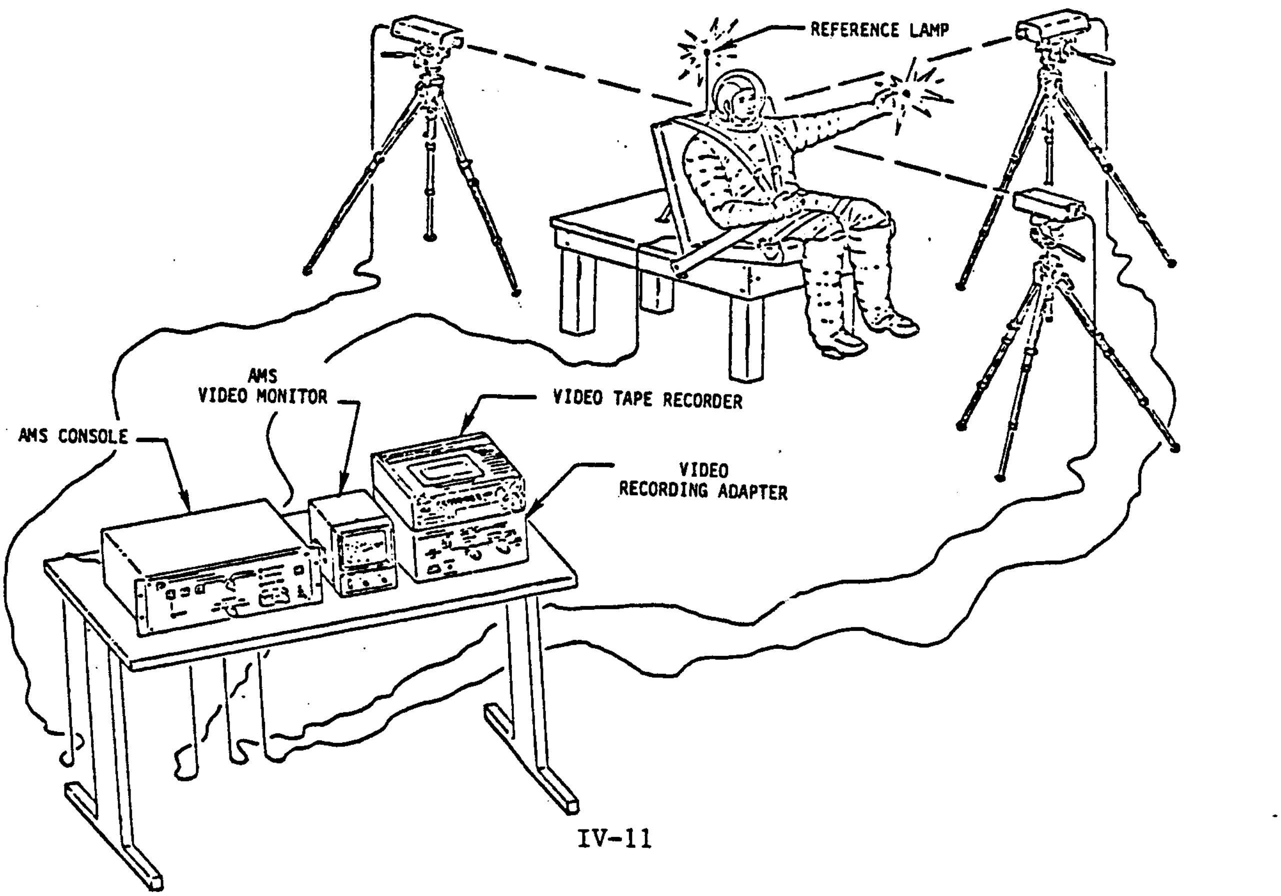


RMS OPERATIONS-SUN ANGLE FOR STS 2-3

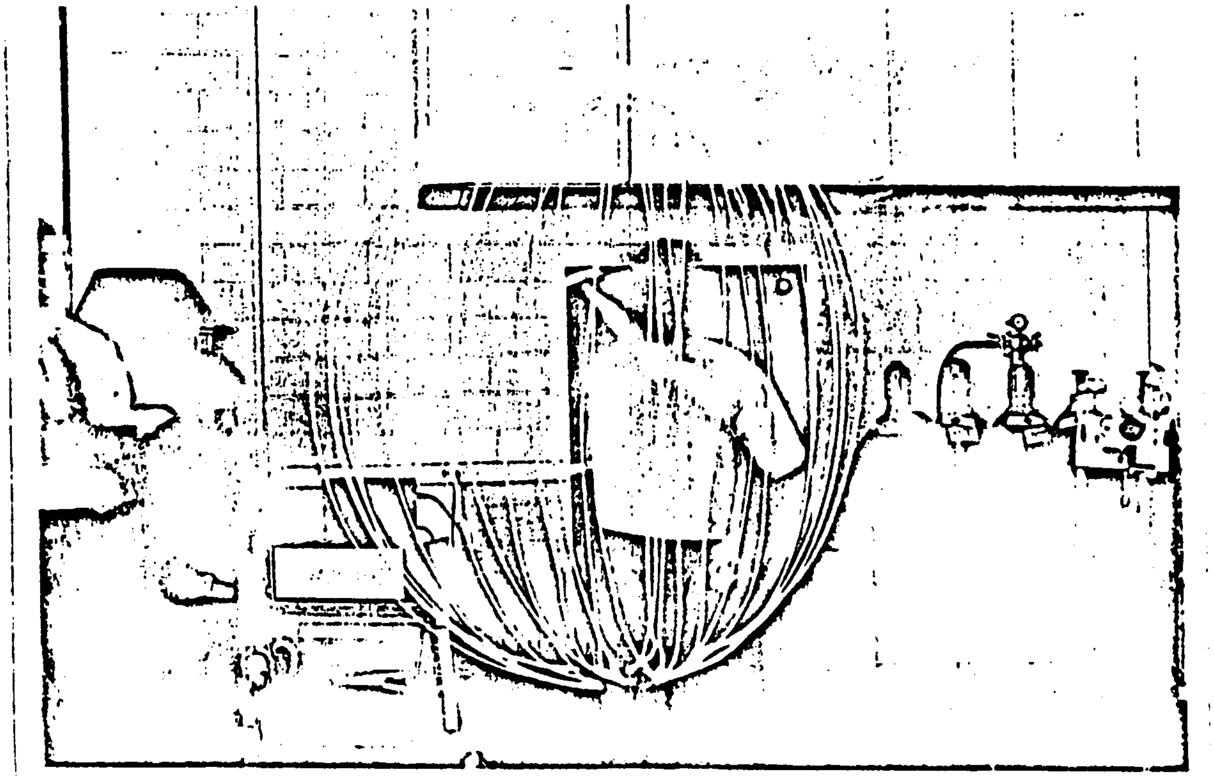
ANTHROPOMETRIC MEASUREMENT LABORATORY

- STATIC ANTHROPMETRY
- DYNAMIC ANTHROPOMETRY: KINESIMETRY, STRENGTH
- DIGITAL DATA ACQUISITION

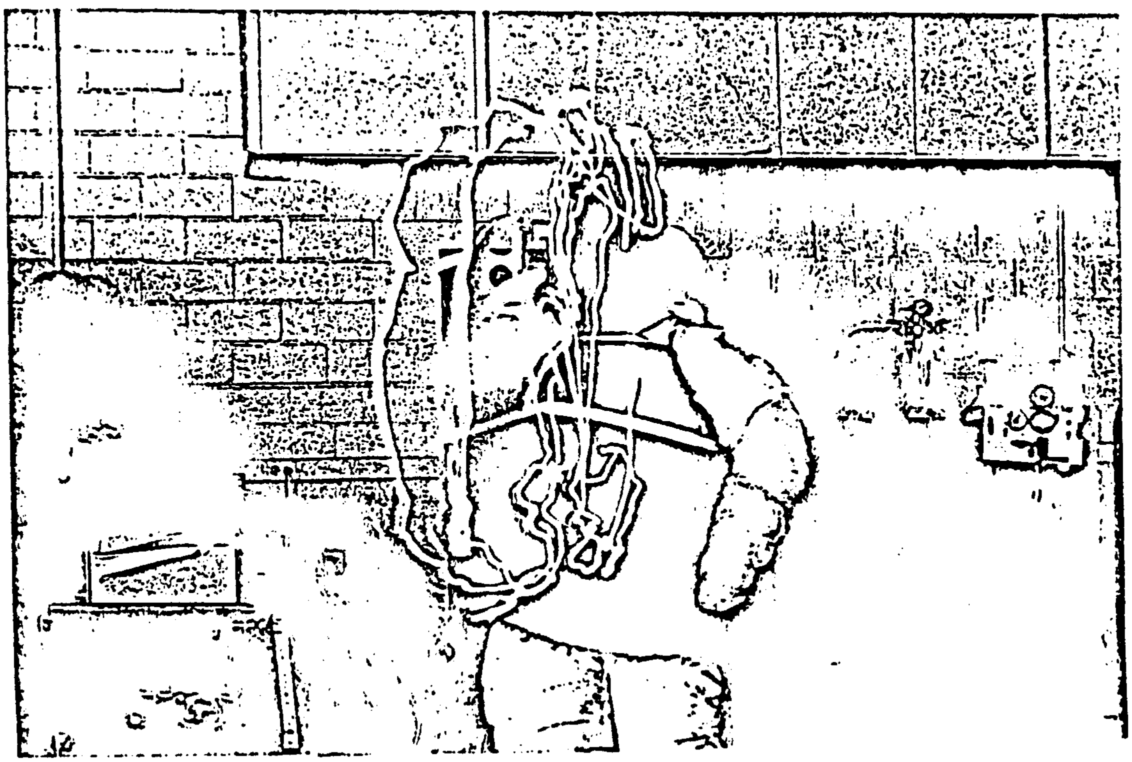
MODIFIED VIDEO RECORDING AMS SYSTEM



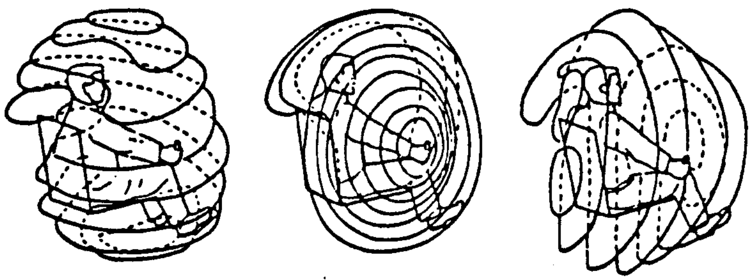
MAXIMUM SHIRTSLEEVE
RIGHT HANDED RESEARCH VOLUME

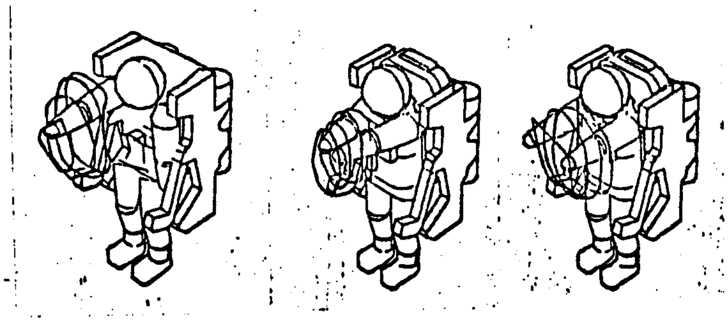


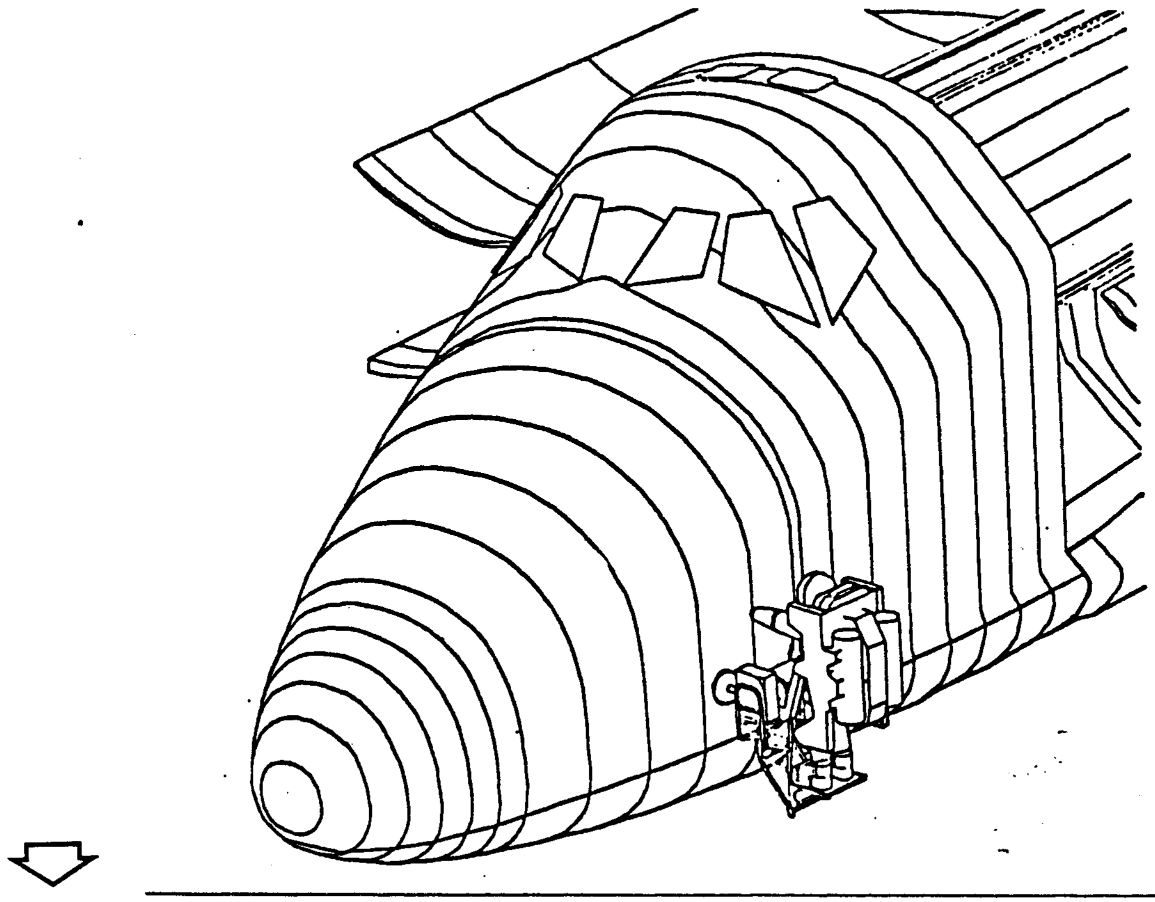
MAXIMUM PRESSURIZED
RIGHT HANDED REACH VOLUME
3.8 PSID

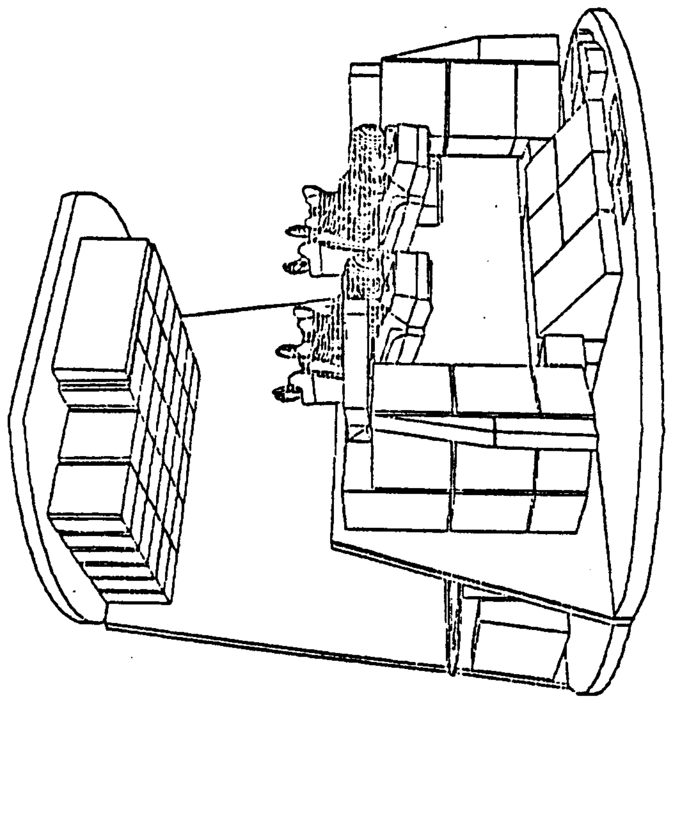


ANTHROPOMETRIC MEASUREMENT SYSTEM
ORTHOGONAL REACH PLANES









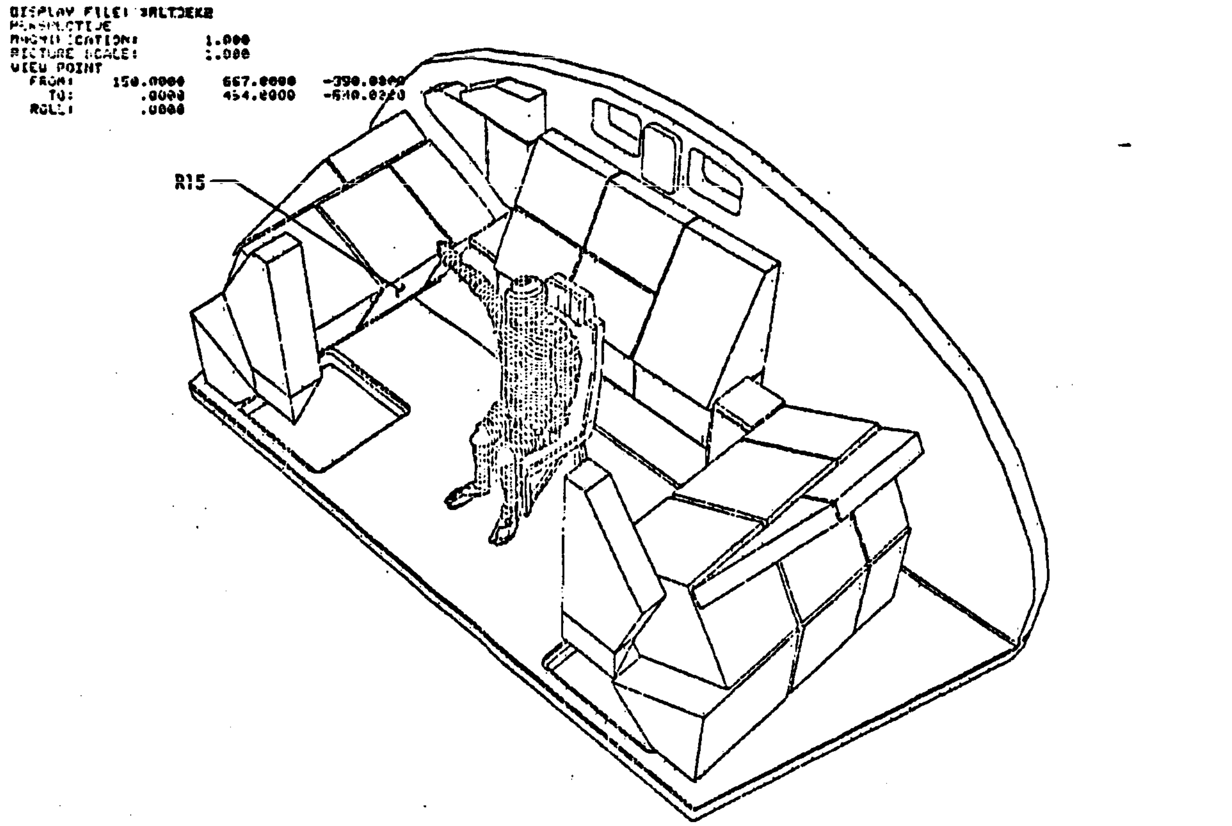


FIGURE 5: HIDDEN LINE VIEW OF TEST CONFIGURATION

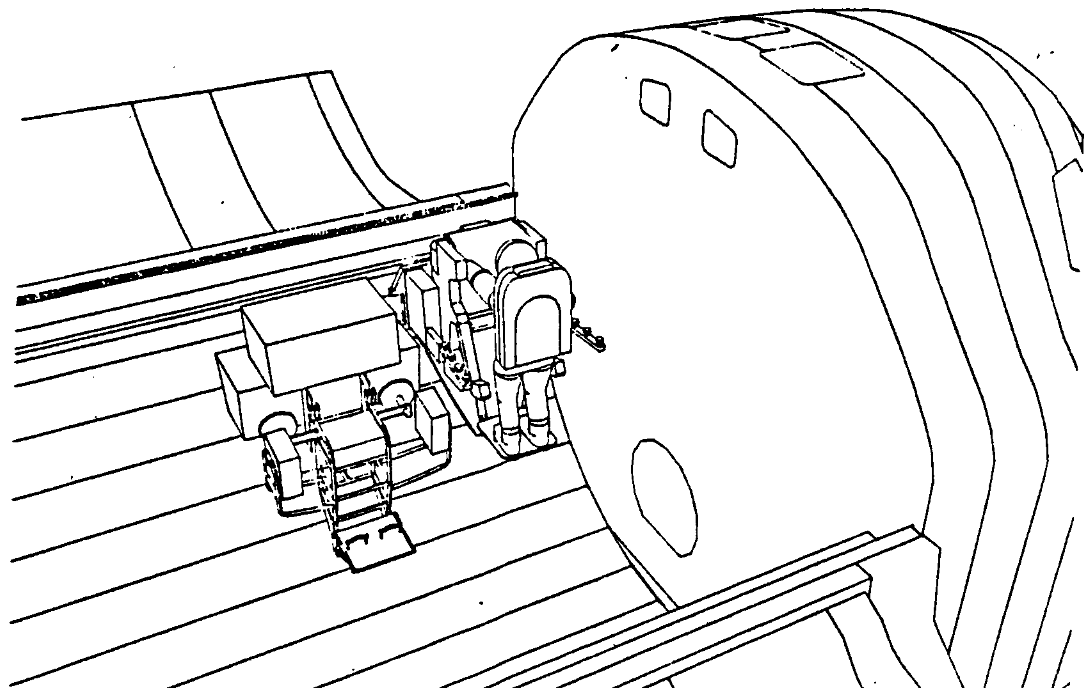


FIGURE 7.

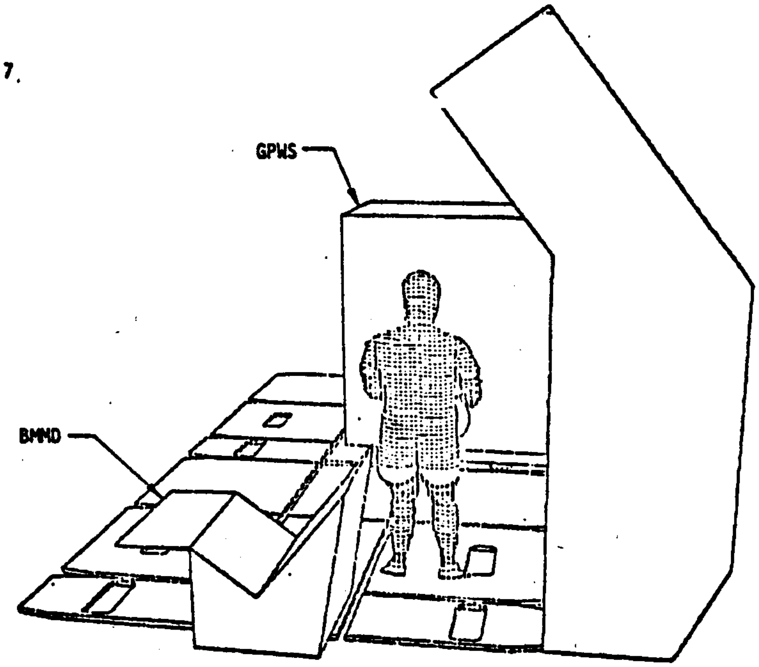
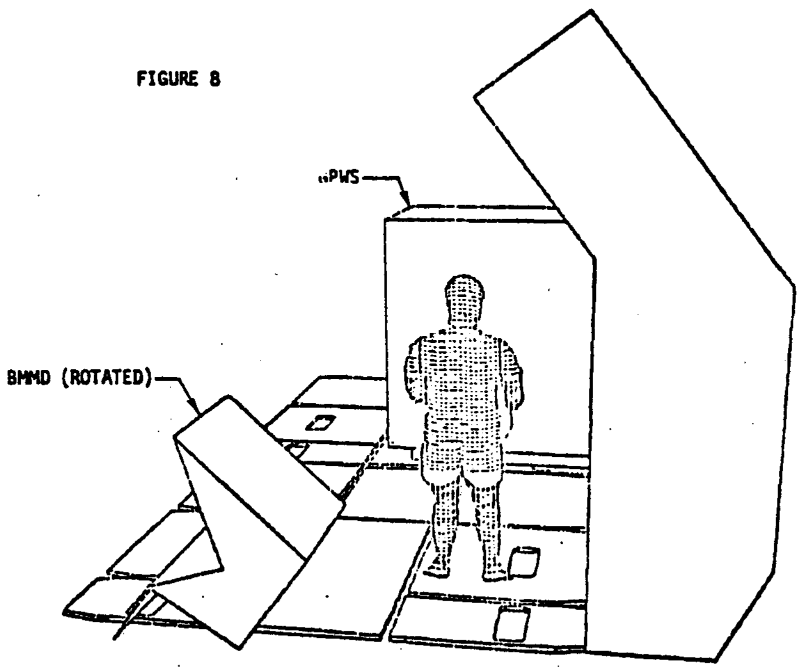
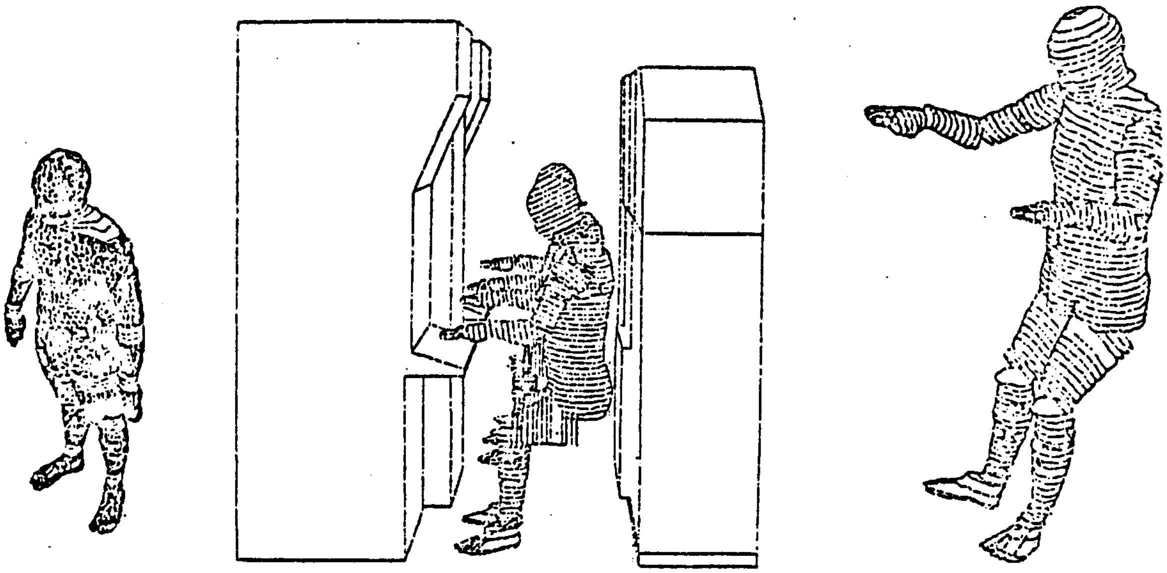


FIGURE 8

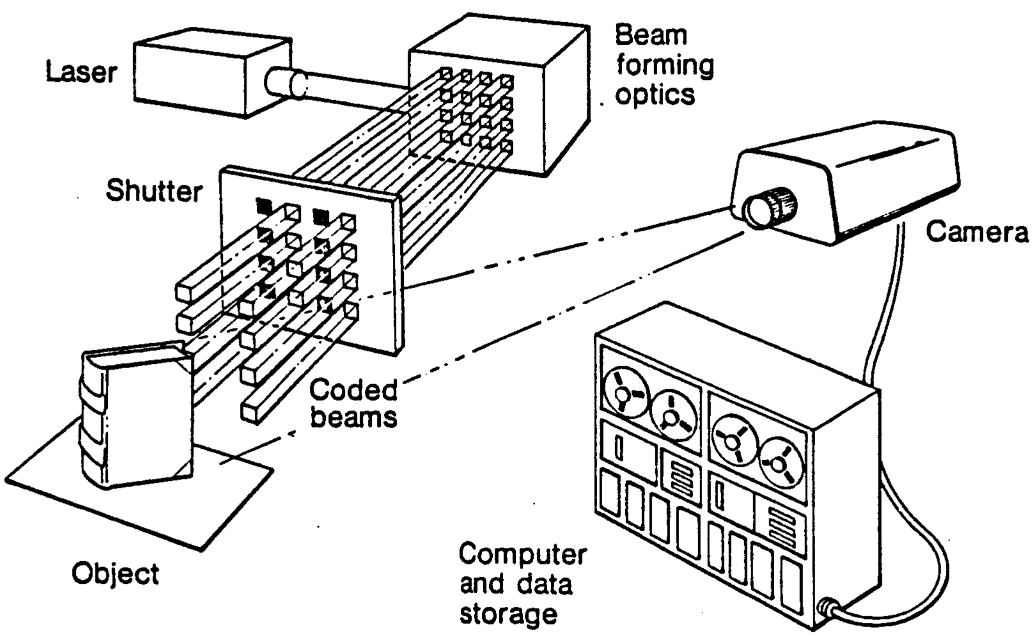




NASA

S-81-10781

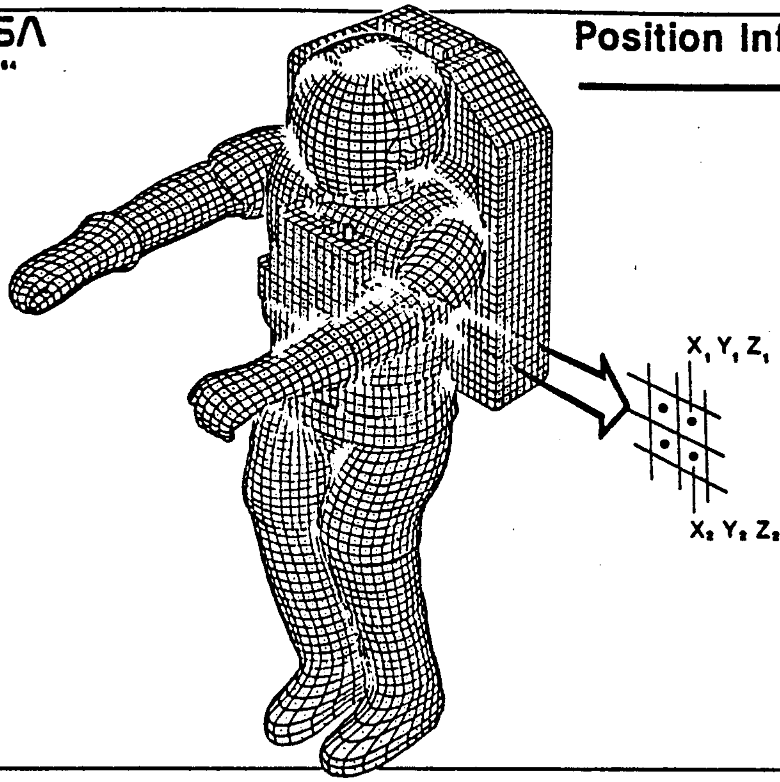
Topographic Mapping Data Aquisition



NASA

S-81-10764

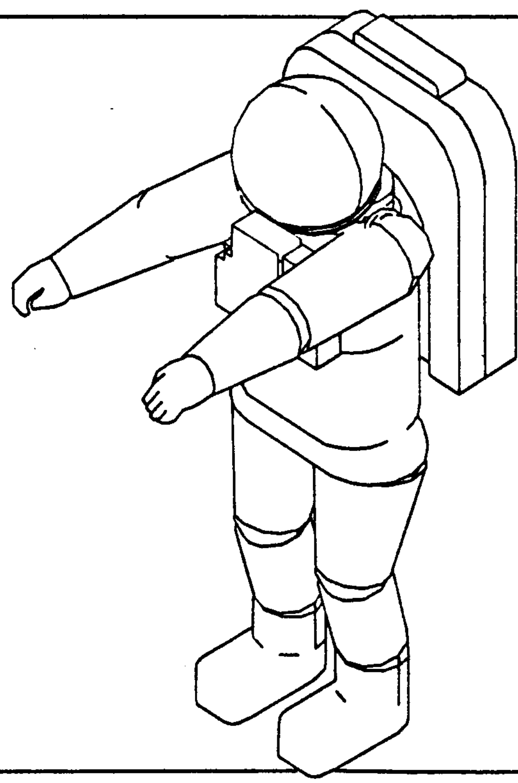
Position Information

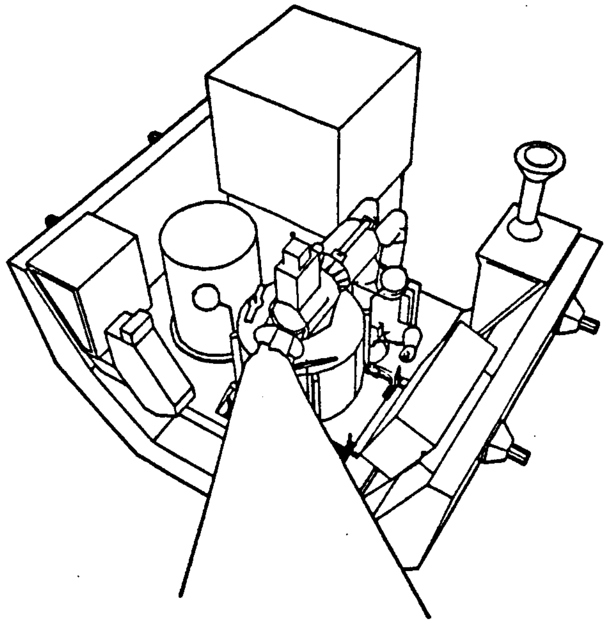


NASA

S-81-10760

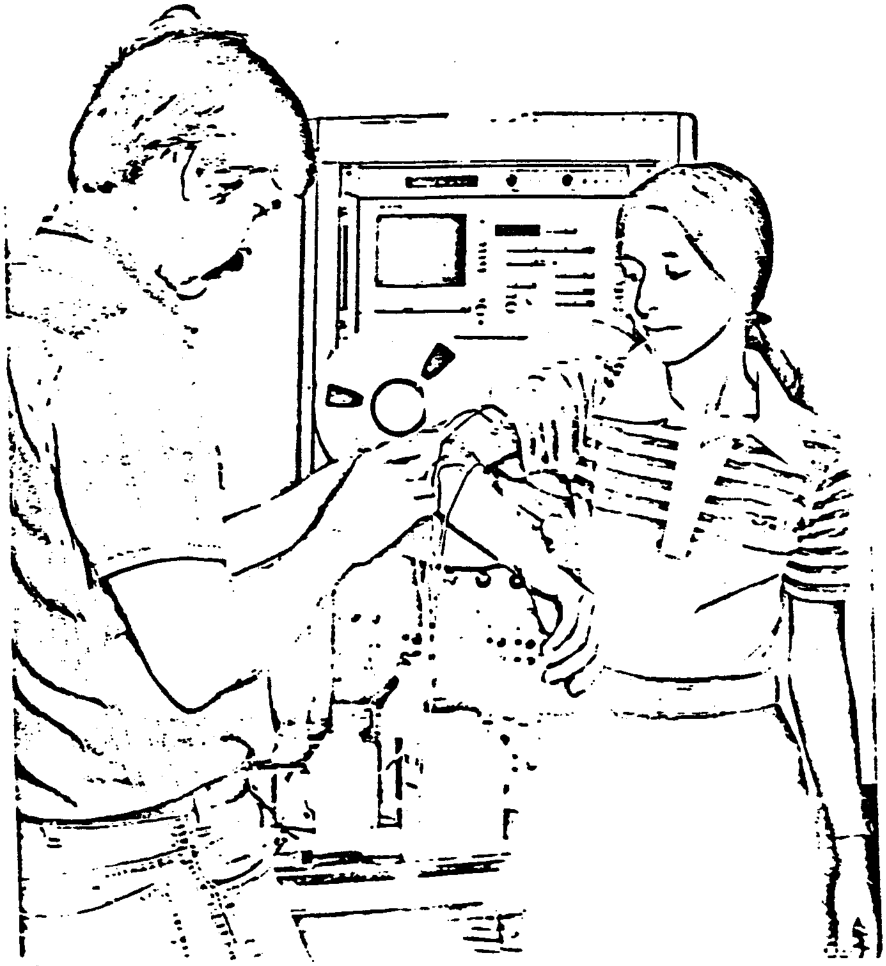
Computer Graphics Reconstruction

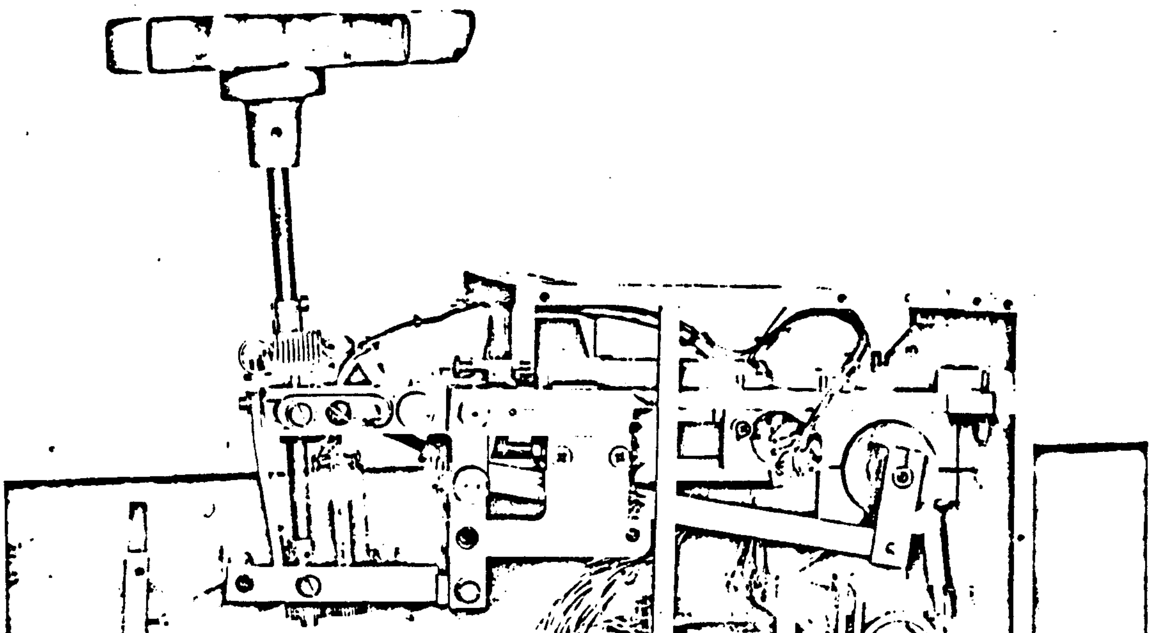




CONTROLLER DESIGN REQUIREMENTS SYSTEM

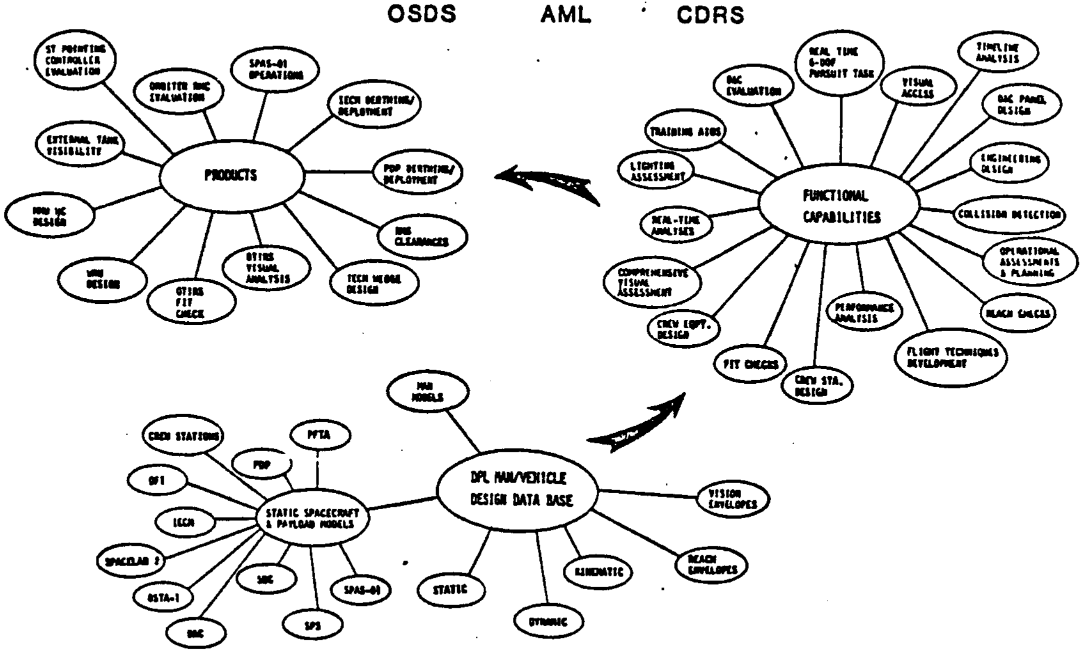
- MAN-IN-THE LOOP SIMULATOR
- TWO VEHICLE TRACKING/PURSUIT TASK
- CONFIGURABLE VEHICLE CONTROL SYSTEM
- UNIVERSAL CONTROLLER INTERFACES
- FLEXIBLE D&C INTERFACES





DESIGN PERFORMANCE LABORATORY

OSDS AML CDRS



OPERATOR STATION DESIGN SYSTEM

PLAID:
A 3D INTERACTIVE GRAPHICS MODELING SYSTEM

ADDITIONAL SOFTWARE MODULES

OPERATIONAL	IN-WORK	PLANNED
CAR II	BUBBLEMAN	COLOR
REACH	ANVIL 4000	STRENGTH
	SLAM	LIGHTING
		GROUP
		CUBITS

DATA ACQUISITION INTERFACES

OPERATIONAL	IN-WORK
ANTHROPOMETRY	ANTHROPOMETRIC
STATIC	DYNAMIC
KINEMATIC	TOPOGRAPHIC MAPPING
GONIOMETRIC	

EXTRAVEHICULAR ACTIVITY (EVA) -

EXTENDING THE DIMENSIONS OF THE SPACE SHUTTLE

HARLEY L. STUTESMAN
CREW SYSTEMS DIVISION
NASA, JOHNSON SPACE CENTER

FREDERICK A. KEUNE
UNITED TECHNOLOGIES
HAMILTON STANDARD DIVISION
HOUSTON, TEXAS

BACKGROUND

From the very beginning of the manned space program, the inventory of existing space vehicles included pressure suits not unlike those used in high altitude aircraft. These suits were used as a backup to the capsule's pressurized cabin. The mid 1960's provided a volatile political backdrop in the form of a space "race" with the USSR and a quick response was needed to a Russian space walk performed by Cosmonaut Aleksey Leonov on Voskhod II in March of 1965. A crash program was initiated to upgrade these existing high altitude suits in order to improve their reliability so that a United States astronaut could venture outside of a vehicle on an umbilical linked to the craft's environmental control system. The end result of this rapid response program occurred on June 6, 1965 when astronaut Edward H. White, II left the protective environment of Gemini IV spacecraft cabin and ventured into earth orbital space. This "stunt" became an important step forward in the role that man plays in the United States space program.

Later Gemini missions demonstrated extravehicular activity to be an important tool for performing mission enhancing tasks while in earth orbit. These successes, which were largely concurrent with Apollo program planning, helped to shape not only lunar EVA's but the science of all extravehicular activity still to come.

The overall success of the Apollo program speaks for itself but the details of that success - that is the hugely successful lunar EVA's - were the result of the technical excellence of the Apollo Extravehicular Mobility Unit (EMU). This system was a hybrid of past and present combining a specifically designed suit which still had the capability for cabin pressurization backup and a completely independent and portable life support system. The most significant testimony given to the system during the 288 man hours of lunar exploration activity by the Apollo astronauts was that once they were outside the space craft and on the lunar surface, they never thought about the Apollo EMU again. (See Figure 1.)

EVA played its most dramatic role in the Skylab Program. During the launch phase of Skylab I, the payload lost a meteoroid shield and one of two solar array panels and jammed the remaining panel. At first it was thought that all was lost, but as a result of careful planning and ten (10) EVA's involving more than 82 man hours of orbital activity, the Orbiter Workshop was repaired and all planned pre-launch objectives were completed. (See Figures 2 and 3.) The EVA tasks were many and varied but their success and the flexibility it provided the Skylab Program resulted in EVA becoming a baseline activity for the Space Shuttle Program.

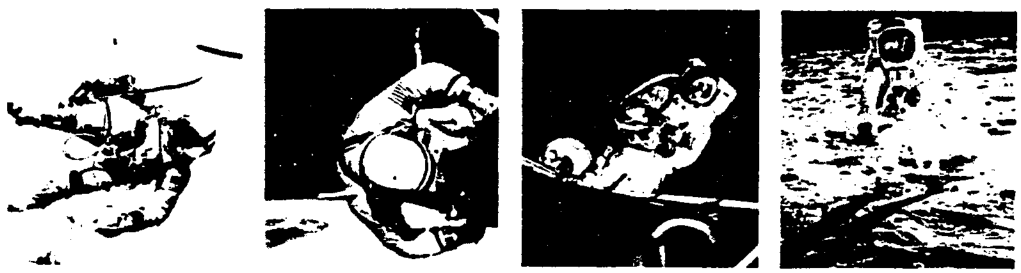
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center

NASA-S-72-3932-V

NASA EVA EXPERIENCE

GEMINI 4	GEMINI 9 THROUGH 12	APOLLO 9	APOLLO 11 THROUGH 17



ASTRONAUT ED WHITE	ASTRONAUT ALDRIN	ASTRONAUT SCHWEICKART	ASTRONAUT ALDRIN

FIGURE 1

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston Texas 77058

NASA-S-74-4103

SKYLAB CLUSTER (+Z VIEW)

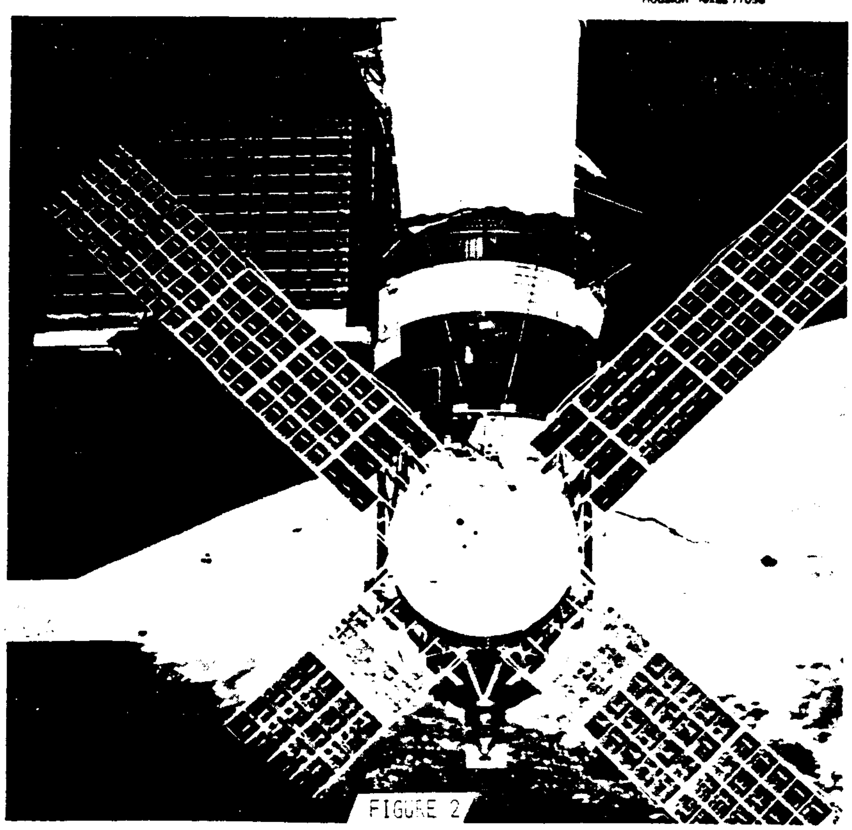


FIGURE 2

Extravehicular Activity (EVA) is defined as any activity requiring a crewmember to don an Extravehicular Mobility Unit (EMU) and leave the pressurized confines of a spacecraft. A description of the three basic classes of EVA follows.

Planned EVA - Activities planned prior to launch for support of selected Orbiter or payload operations.

Unscheduled EVA - Activities not planned, but which may be required to support Orbiter or payload operations.

Contingency EVA - All EVA activities required to effect a safe return of the Orbiter and crew.

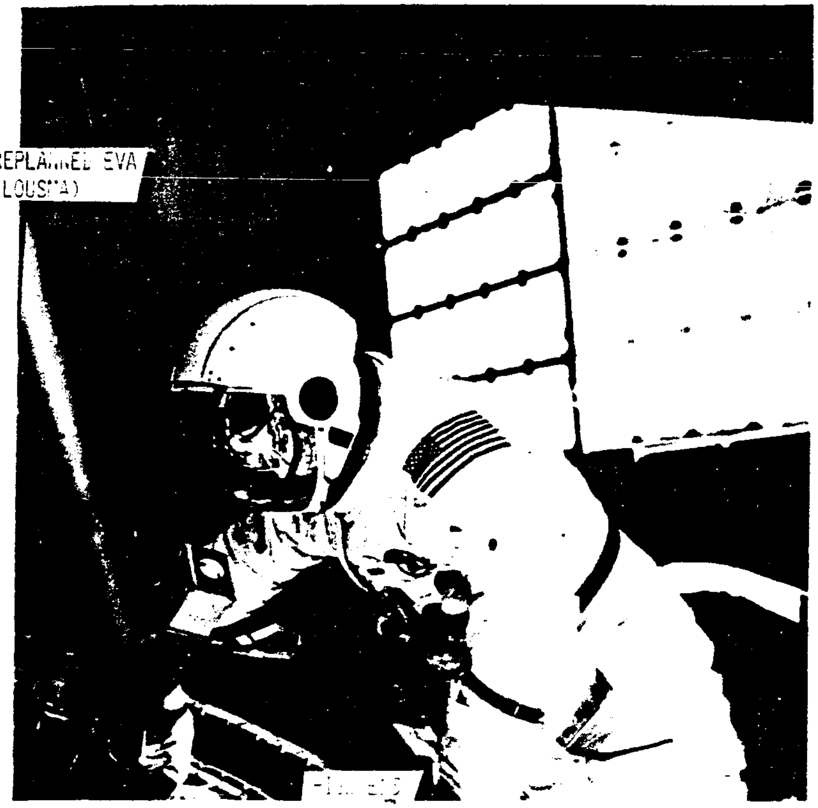
The National Aeronautics and Space Administration (NASA), in its Shuttle Space Transportation System program, is currently preparing to deliver to orbit payloads that will vary considerably in design and purpose. The payload may be a laboratory housing single biological cells or housing several scientist astronauts. It may be an entire astronomy observatory or a "small" component of a mammoth solar power station. EVA can provide sensible, reliable and cost-effective servicing operations for these payloads because EVA gives the payload designer the options of orbital equipment maintenance, repair and replacement without the need to return the payload to Earth or, in the worst case, to abandon it as useless space junk. Having EVA capability can help maximize the scientific return of each mission.

SHUTTLE EMU

The Shuttle Extravehicular Mobility Unit (EMU) is the system which makes available the use of the most versatile tools known to man - the human hand and eyes - in the hostile environment of space. (See Figure 4.) To work in space the crewman should have reasonable comfort and be mobile enough for the task at hand.

The most important factors in laying out design criteria for an EVA system are mobility, comfort, operability, visibility, waste management, mission suitability, weight and cost. A quick review of the list shows that five of the eight parameters are human-factor related. The mobility required of a suited crewman is strictly related to his ability to perform specifically assigned tasks. In Mercury and Gemini, for example, there was no need for walking so the capability to walk in a pressurized suit was not included as a design requirement, thus simplifying the suit leg design.

SKYLAB PREPLA...EL EVA
(JACK LOUS..A)



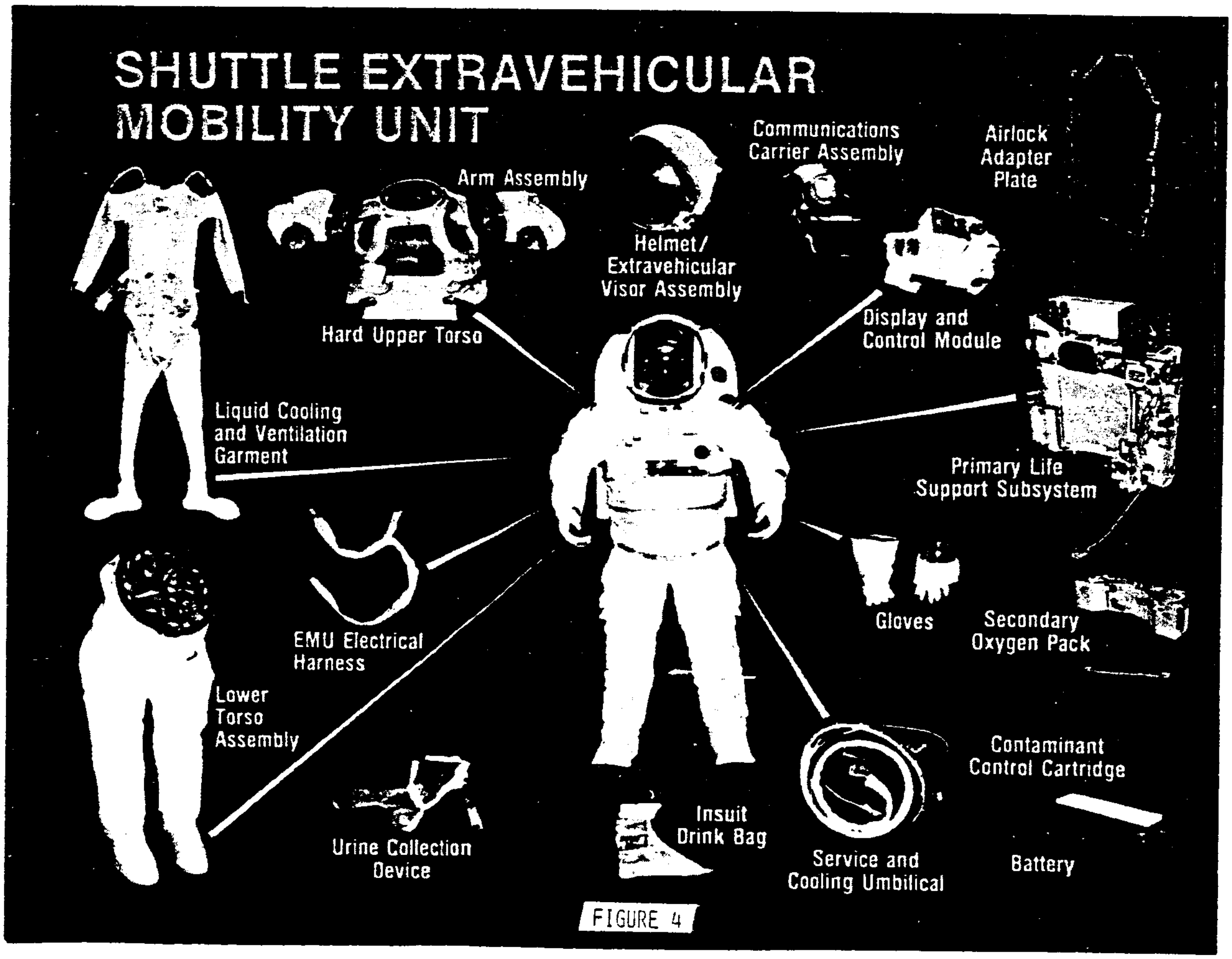


FIGURE 4

In Apollo, walking capability was a primary requirement and the legs of the suit had to be completely redesigned to provide knee, hip, and ankle mobility. Later Apollo flights also required waist mobility which would allow the crewman to sit down and drive the lunar rover. It was clear from the outset that Shuttle EVA requirements would call for maximum mobility from the waist up. The space suit that has evolved for Shuttle employs metal bearings to accommodate rotational motion at the waist, shoulder, wrist and arm. These bearings provide much lower torque and greater range than had been available in the past. Providing mobile joints where bending is required is a greater challenge. The torque and forces required to bend a suit element are generated because bending the joint causes an internal volume change. For example, the volume change associated with bending a knee joint 90° without a mobility element is 242 in^3. This would require a force of 1040 in/lbf. Compare this to the volume change in the current Shuttle suit knee joint of 2.8 in^3 which requires only 12 in/lbf to bend the joint. The wrist and finger joints or mobility elements are tucked fabric joints and the remaining suit joints (elbow, waist, and knee) are flat pattern construction. These joints are much superior to early rubber convoluted joints which had the problem of requiring a subtantial force to hold the bent joint in position. See Figure 4A.

The best mobility elements and bearings are useless unless the bending or twisting axis corresponds precisely with the respective physiology of the crewmans body. Physical comfort in a pressurized suit requires a near perfect anthropomorphic fit. The Mercury, Gemini, Apollo and Skylab programs used space suits which were custom fit for the crewman and provided a degree of comfort which allowed the crewman to perform hard physical labor for up to three seven-hour periods in less than three days. (See Figure 5.) Custom space suits were deemed impractical and economically unfeasible for The Shuttle Program due to the larger size of the astronaut corps and the fifteen-year required lifetime. Consequently, the Shuttle suit incorporates provisions for modular sizing. The cost trade off favors the Shuttle modular system over the Apollo custom approach since the total equivalent suit inventory for Shuttle is approximately forty units for a population of approximately eighty astronauts compared to more than 100 custom space suits required for only thirty Apollo astronauts. The Shuttle modular sizing system allows suits to be assembled which fit a population from the smallest female astronaut to the largest male with a minimum of hardware. (See Figure 6.) The most complex and expensive part of the Shuttle space suit is the Hard Upper Torso (HUT). The sizing system provides five HUT sizes from extra small to extra large. Vernier sizing of the arms and legs is incorporated with sizing insert system which assures that the elbow and knee elements bend at the crewman's joints.

SPACE SUIT : MOBILITY ELEMENTS

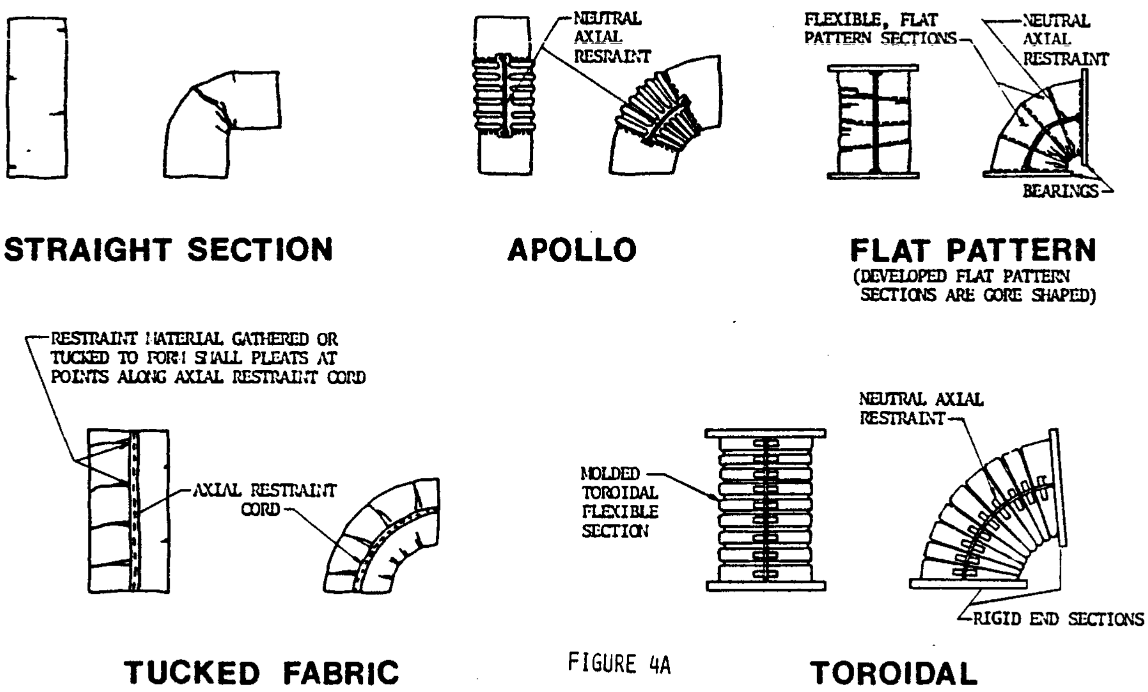


FIGURE 4A

NASA-S-71-2028-S

SUIT DEVELOPMENT IN CREW SYSTEMS DIVISION

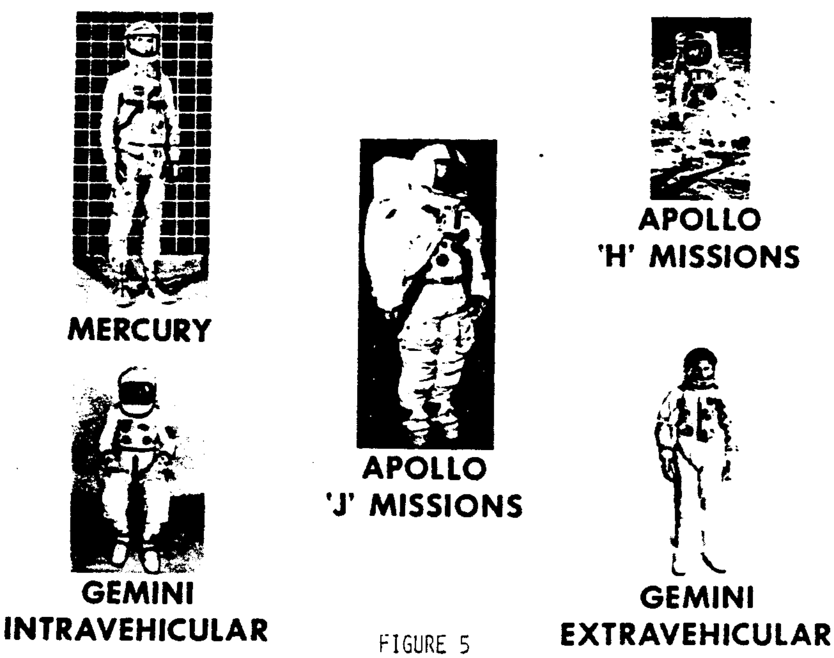


FIGURE 5

As might be imagined, glove mobility is the single most important factor in space suit design. This dexterity is also the most difficult to achieve. Glove development has been a continuing process from the beginnings of manned space activity and a significant program is still underway to develop improved Shuttle glove mobility. As can be seen in Figure 7, the combinations of sizing elements are almost limitless. The penalty for this capability is in the labor required to build up and tear down the suit to fit different crewmen between flights or ground exercises.

A significant benefit resulting from the modular sizing system is an improvement in the ease of suit donning and doffing. The HUT, Arms, and life support system are integrated on the ground prior to flight, and installed inside the Orbiter on the airlock wall. To don the EMU, the crewman steps into the "trouser-like" Lower Torso Assembly (LTA) and moves upward into the HUT. Mating halves of the waist body seal disconnect are then connected and locked. This design and procedural approach to suit donning permits, for the first time, truly unassisted self-donning by crewman in the flight environment. On previous programs, the single piece, fabric pressure suit with its awkwardly located dual zippers, coupled with the difficulty of positioning the suit during donning, made self-donning marginal.

Translational mobility was a requirement in the zero-G condition of earth orbit in the Gemini, Skylab, and Apollo Programs and is still required for the current Shuttle program. This linear movement is accomplished by the use of handholds in strategic locations which are incorporated into the design of the particular space vehicle. However, free space translation totally independent of the orbiting space vehicle has not been available until now. Development of a Manned Maneuvering Unit (MMU) was initiated during the Skylab program and has continued until the present time. The MMU and the resultant capability for free space translation are now a reality and this capability is planned activity on the STS-8 mission and is available for all subsequent Shuttle flights. See Figure 8.

Provisions for controlling the environment within the space suit have a great deal of bearing on overall EMU design. The Gemini and Skylab EVA crewmen were provided life support by the spacecraft environmental control systems through an umbilical and therefore carried no portable life support system on the space suit. (A short duration back-up life support system was incorporated on the suit for emergencies.) This allowed locating the controls and displays on the front of the suit for easy viewing and operation. (See Figures 9 and 10.) In Apollo, however, a completely portable system was required which made front mounting of the life support system impossible because of

SHUTTLE EMU SPACE SUIT ASSEMBLY

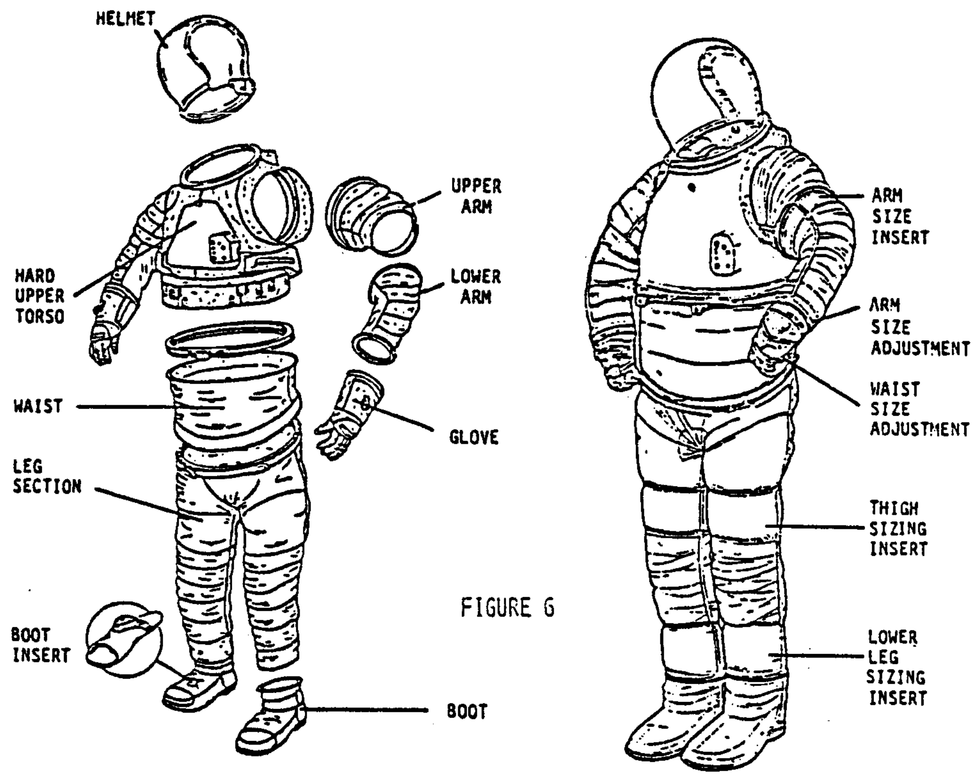
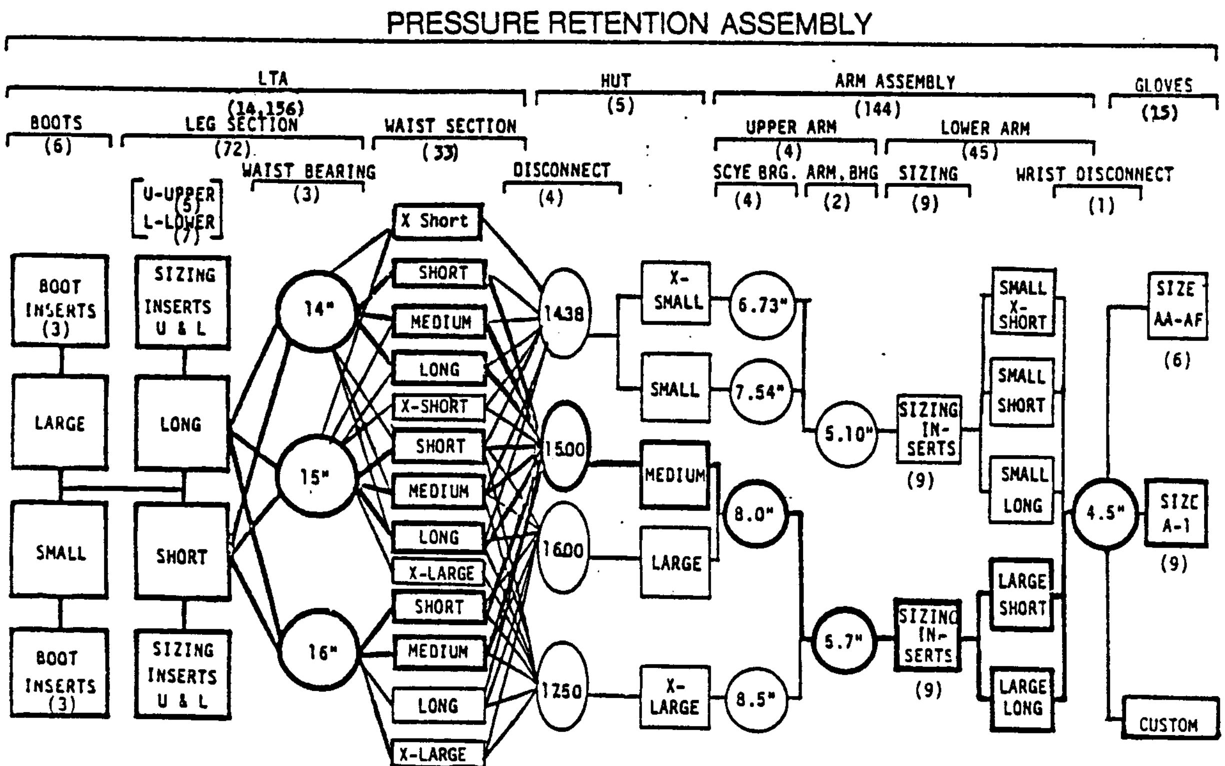


FIGURE 6

SPACE SUIT SIZING SYSTEM

8/82



( ) Qty Possible Sizes

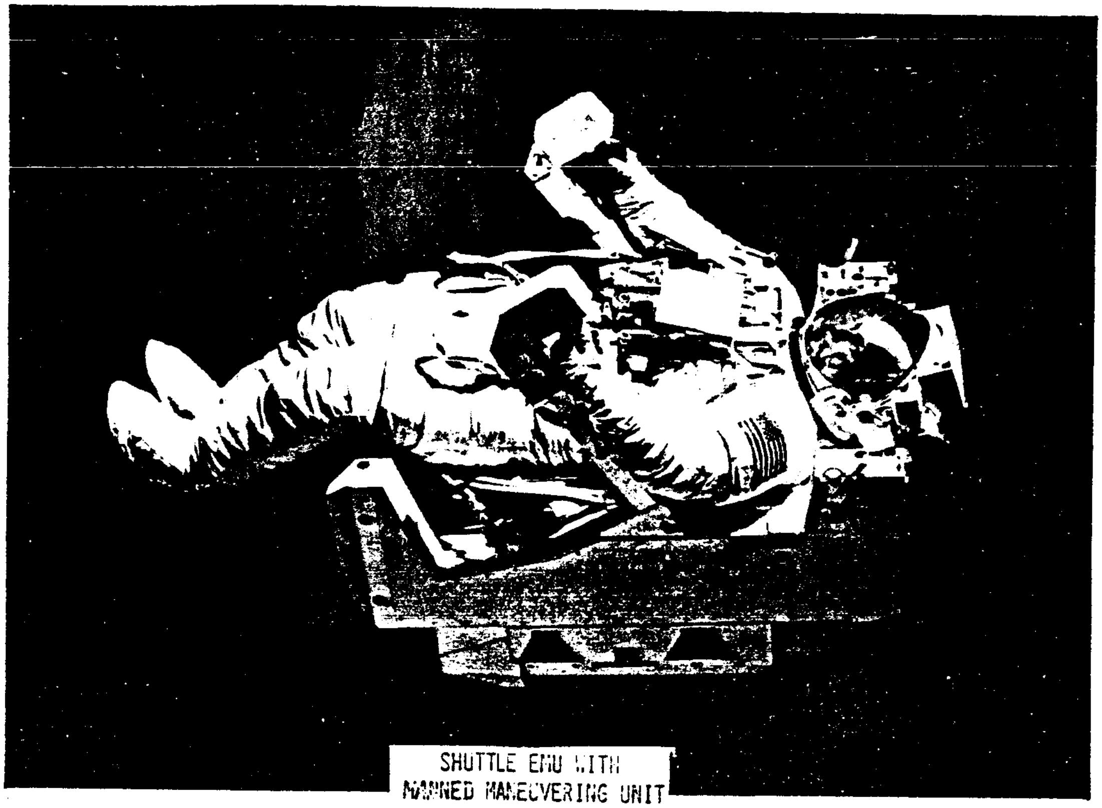
FIGURE 7

its size. Since the two major elements of the system, the suit and the Portable Life Support System (PLSS), were assembled on the lunar surface, a compromise was required. While electrical controls could be front mounted, all mechanical and radio controlls of the Apollo PLSS were located on the lower corners of the backpack. (See Figures 11 and 12.) Apollo flight crews required a considerable amount of training to operate these controlls by "feel". This was a constant source of irritation and frustration. In Shuttle a change in program requirements helped solve the problem.

All NASA programs to date have used the space suit as a spacecraft backup pressure enclosure. This required the crewman to wear the suit in the spacecraft seat during launch, re-entry or other hazardous spacecraft operations. As a result, integration of the suit and the life support systems was not possible. The Shuttle Orbiter incorporates other backup systems, and consequently the space suit is only required for extravehicular operations. Therefore, the Shuttle EMU is an integrated ensemble (i.e., the EMU is not assembled in space). The advantages are that all controls are located on the front of the suit, donning and doffing operations are simplified, and inflight checkout of the EMU is reduced.

In early space suit design and in high altitude aircraft pressure suits a rotating helmet with a small movable visor was provided to allow visibility. This system worked but was very confining and mechanically complex. Visibility in current space suit design is provided by enclosing the head in a clear lexan bubble type helmet. Lexan is not optically perfect but is extremely tough and easy to form. The crewman can rotate his head inside the helmet to the full natural range of head movement. Vision correction, if required, is provided by either wearing normal glasses or if the crewman uses only reading glasses, with a "stick on" Fresnel lens in the helmet which provides accommodation for viewing the controls and displays.

Comfort can be a very subjective factor and a real frustration for designers. Discomfort in a space suit can range from minor annoyances to painful blisters or thermal exhaustion. The first EVA activities on Gemini were done using space suits which provided only gas cooling. (See Figure 13.) It was quickly learned that any strenuous physical activity in the space suit resulted in unacceptable sweating and thermal heat storage in the body. Thermal comfort has been easily accommodated since the Apollo Program with long underwear lined with plastic tubes through which water is pumped at a temperature controlled by the crewman. In addition, cool dry air is also circulated to remove moisture and CO_2. (See Figure 14.) Body comfort during heavy physical activity is accomplished by providing a good suit fit and



SHUTTLE EMU WITH
MANNED MANEUVERING UNIT
FIGURE 8

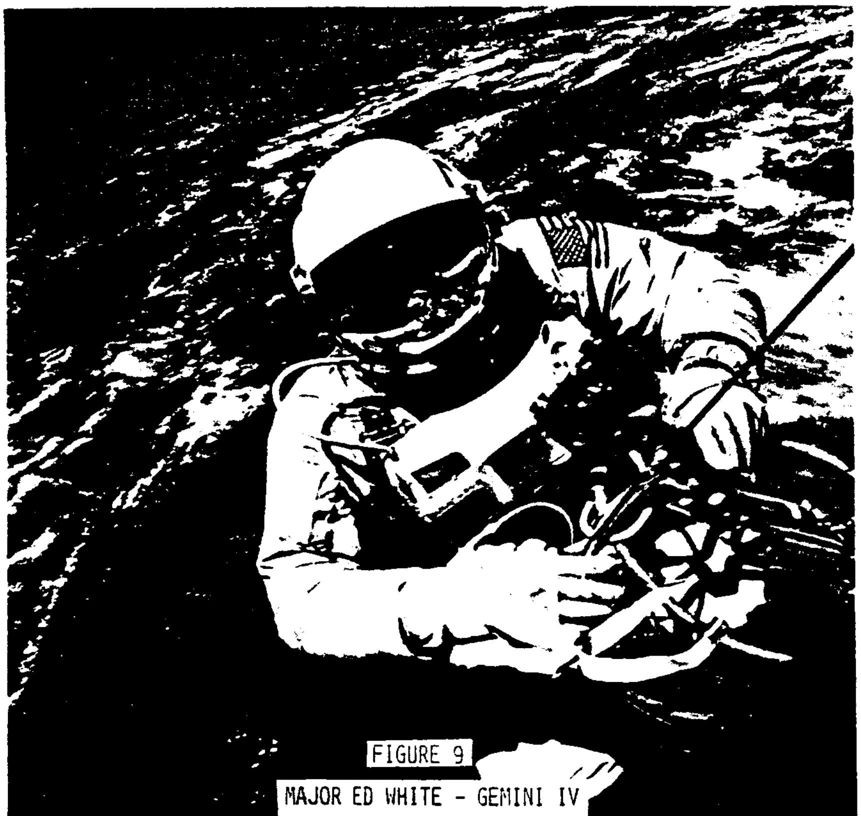


FIGURE 9
MAJOR ED WHITE - GEMINI IV
EVA EQUIPMENT

by adding pads where necessary. This design for comfort should not be limited to zero-G operations. It is an important design consideration to remember that with all of the interface testing, hardware evaluations, water immersion exercises, and altitude chamber tests, it is estimated that 95% of FMU manned activity is conducted at one-G.

Other comforts provided for in the Shuttle FMU are a sealed drink bag located in the helmet area and operated by the mouth and a high nutrition food stick. These provisions are particularly important during a strenuous seven-hour EVA.

The ability to urinate becomes another comfort issue during long EVA's. For suited male crewmen urination is easily accommodated with a fitted cuff over the penis connected to a storage bladder by a tube. However, in the case of suited females, no such direct system could be developed. Presently, the female urination system consists of layered, form-fitted pants which contain an absorptive powder. This powder combined with layers of absorbent material is individually fitted into the pants which are sealed at the waist and thighs. This system has proven itself to be both effective and comfortable.

There are a multitude of EVA accessories which either enhance normal EVA (i.e. lights, TV, etc.) or are designed for specifically assigned tasks (i.e. payload bay door closure tools, safety tethers, etc.). (See Figure 15 and Table 16.)

In summary, the changes which have resulted from this evolution are major in both the suit and life support system areas, and the Shuttle EMU represents the total experience and the best thinking of the project personnel who have long been associated with EVA systems. Although yet to be flight proven, the Shuttle hardware has already withstood vigorous ground-level testing; and there is no doubt that the Shuttle EMU will fulfill all of its operational needs throughout the Shuttle era.

SHUTTLE EVA

Each Orbiter mission will provide the equipment and consumables required for three two-man EVA operations, each lasting a maximum of seven hours. Two of the EVAs will be available for payload operations and the third retained for Orbiter contingency EVA. Additional excursions may be added with the added consumables and equipment weights allotted to the particular payload being supported.

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NASA-S-74-4649

EXPERIMENT INSTALLATION

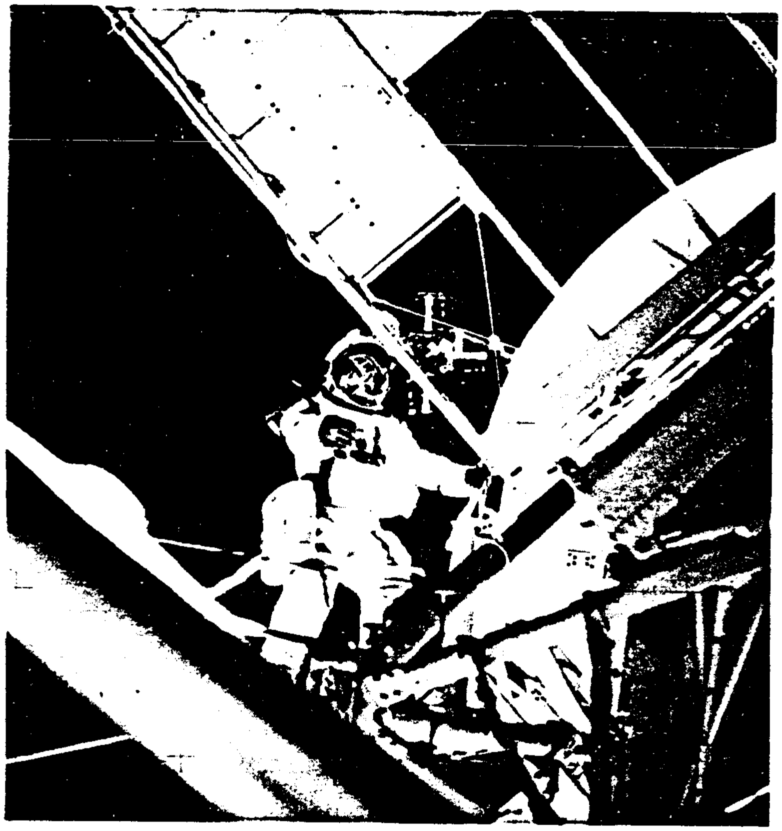

FIGURE 10

SKYLAB EVA EQUIPMENT
JACK LOUSMA

NASA National Aeronautics and Space Administration

NASA AS12-47-6919

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FIGURE 11

The EVA system is the Space Shuttle baseline astronaut rescue system. Currently, it is the only means that can guarantee, for potential failure modes, transfer of the crew from a stranded Orbiter to a rescuing spacecraft. This capability relies upon the EMU as the basic life sustaining element, supported by other elements of the EVA system. Studies are currently in progress at NASA to determine the optimum rescue techniques and procedures.

The ability to effect EVA provides the crew with an inflight autonomous inspection or repair capability that increases both crew safety and the probability for mission success. In addition, EVA provides considerable operational flexibility for payload-related mission enhancement. Table 17 presents several examples of the wide range of payload-related EVA applications.

Manned involvement in orbital servicing or construction tasks produces requirements which should be addressed during the formulation stage of a specific mission. This is accomplished by defining the human role and identifying the servicing/construction operations an EVA astronaut is expected to perform. Once identified, the procedures necessary to perform the operations can be defined and astronaut training and simulations can be addressed. Simulation timeline data can be used to create profiles to the accuracy required for EVA planning.

Safety consideration such as astronaut thermal exposure and post-EVA activities propose no overbearing restrictions when planning a mission if accounted for during the front end of a program.

As a greater number of satellites are designed for on-orbit servicing, the operations required to maintain a satellite will become more widely used. At the present time, servicing is planned for appendage deployment, replacement of modules and recharging of hydraulic systems. Module replacement is concerned with power supply components such as electrical batteries and assorted electronics assemblies. (See Figures 18 and 19.)

On-orbit servicing or construction operations will be most effectively enacted if EVA considerations are incorporated during the actual design phase of the satellite. The level of EVA task complexity capability can be identified through EVA task simulations and WIF tank tests. Replacement components, elimination of redundant backup systems and component location are all factors which can be incorporated during the design stage.

NASA

FIGURE 12

NASA-S-78-12051

OPEN LOOP SYSTEM

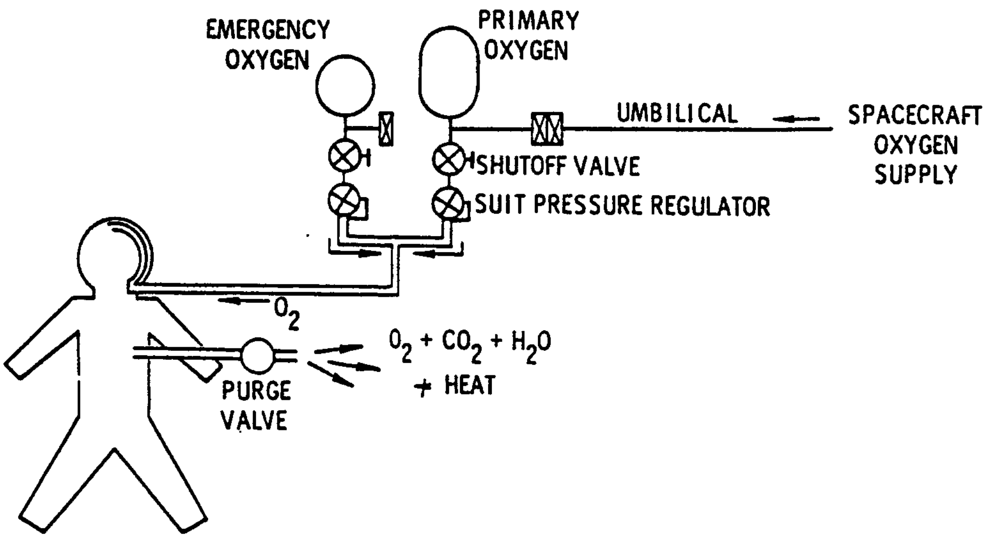

FIGURE 13

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CLOSED LOOP SYSTEM

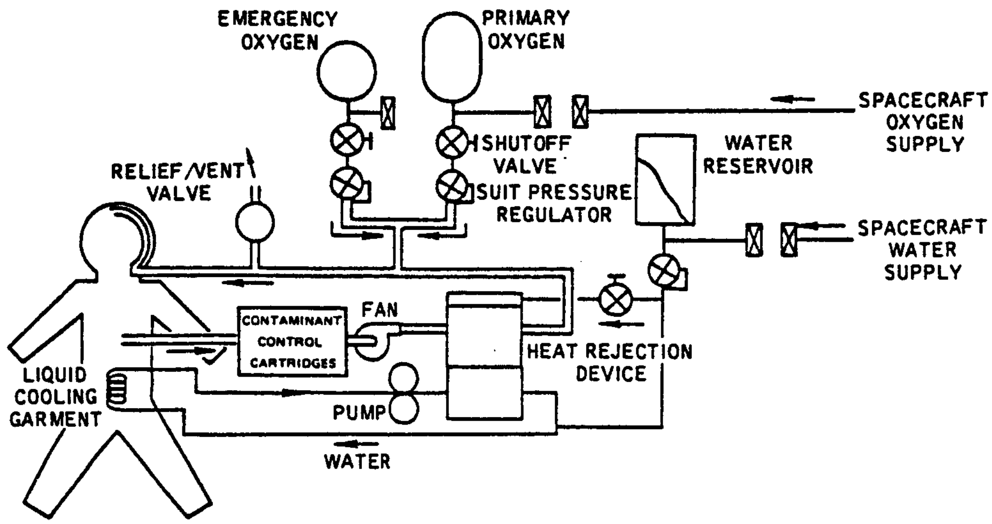

FIGURE 14

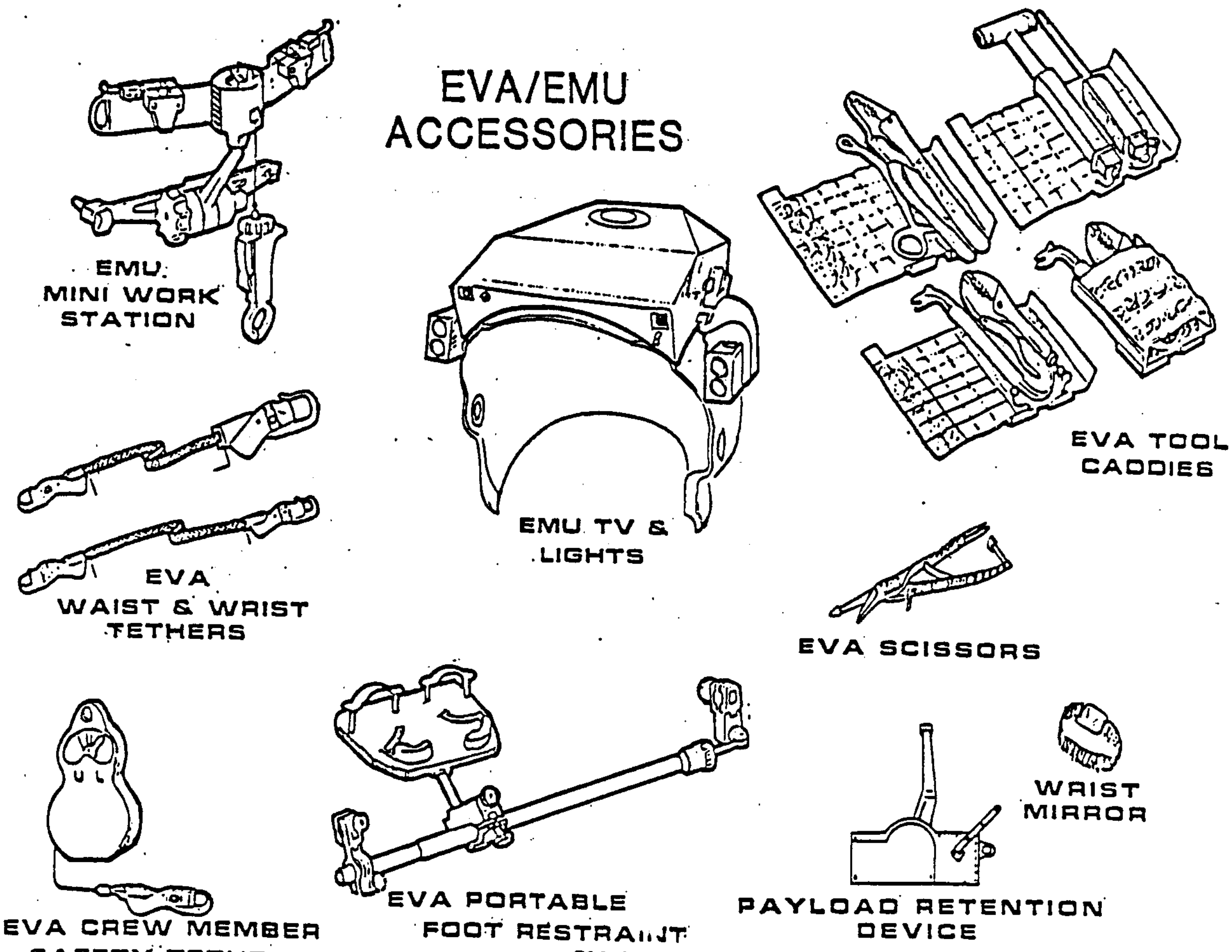

FIGURE 15

EMU Description

The acronym EMU stands for Extravehicular Mobility Unit. The EMU is a pressurized, mobile anthropomorphic enclosure which provides an EVA crewperson with essential life support, protection from the hostile space environment, communications with the Orbiter and/or other EVA crewmembers, and status monitoring of life support functions. Specific life support functions provided by the EMU are:

1. control of space suit pressure
2. suit atmosphere revitalization, including

   a. replenishment of oxygen consumed due to leakage and crewman metabolic activity, and
   b. removal of water vapor, CO_2, and trace contaminants from the suit atmosphere, and

3. rejection of heat generated by crewperson metabolic activity and equipment and heat leaked into the EMU from the environment.

The EMU consists of two major subsystems, the Space Suit Assembly (SSA) and the Life Support Subsystem (LSS). Each of these are made up of several components called Contract End Items or CEIs. These are depicted in Figure 4.

There are ten SSA CEI's. These are described briefly below:

1. The Liquid Cooling and Vent garment (LCVG) is worn underneath the Space Suit. It contains liquid cooling tubes through which chilled water flows for cooling the crewperson and ventilation ducts which distribute oxygen flow throughout the suit.

2. The Communications Carrier Assembly (CCA) is a headset containing microphones and receivers for radio communications.

3. The Urine Collection Device (UCD) consists of adapter tubing, storage bag and disconnect hardware for emptying urine.

4. The Hard Upper Torso (HUT) is the structural mounting interface for several major EMU CEI's - PLSS, DCM, Arms, LTA, Helmet/EVVA, and EEH. It also provides oxygen and water interface connections for the LCVG.

EVA EQUIPMENT INVENTORY	CREW SYSTEMS DIVISION	
	H L STUTESMAN	8/24/82

CREW PROVISIONS	ORBITER ACCOMMODATIONS	EVA TOOL KIT
SPACE SUITS	AIRLOCK	ADJUSTABLE WRENCH
PORTABLE LIFE SUPPORT	HANDHOLDS	RATCHET DRIVES/SOCKETS
EMU LIGHTS	FOOT RESTRAINTS	END WRENCHES
EMU TV	SLIDEWIRES	SOCKET WRENCHES
MINI WORK STATION	TETHERS	SPANNER WRENCHES
HOT PAD GLOVES	WENCHES	EXTRACTOR
COMMUNICATION CAP	STOWAGE	PRY BAR
WRIST MIRROR	EMU RESERVICING	FORCEPS
WATCH	MMU	FLIERS
TOOL CADDIES		SNATCH BLOCKS
SCISSORS		HAMMER
		PROBE
		VICE GRIP

TABLE 16

TABLE 17 EVA APPLICATIONS - PAYLOAD SUPPORT*

- Inspection, photography, and possible manual override of payload systems and mechanisms
- Installation, removal, and transfer of film cassettes, material samples, protective covers, and instrumentation
- Operation of equipment, including standard or special tools, cameras, and cleaning devices
- Cleaning of optical surfaces
- Limited connection, disconnection, and stowage of fluid and electrical umbilicals when saved
- Replacement and inspection of modular equipment and instrumentation on the payload or spacecraft
- Remedial repair and repositioning of antennas and solar arrays
- Activating/deactivating or conducting extravehicular experiments
- Providing mobility outside the cargo bay and in the vicinity of the Orbiter using manned maneuvering units (MMU's)
- Mechanical extension/retraction/jettison of experiment booms
- Removal/reinstallation of contamination covers or launch tiedowns
- Transfer of cargo
- Large space station construction
- On-orbit satellite servicing

* Extracted in part from JSC 10615 EVA Description and Design Criteria

5. The Lower Torso Assembly (LTA) contains pants and boots for the EMU with hip, knee and ankle mobility joints.

6. Arms (Left and Right) contain shoulder and elbow mobility joints, a wrist bearing, and a quick disconnect for the Glove.

7. Gloves (Left and Right) contain wrist and finger mobility joints.

8. Insuit Drink Bag (IDB) mounts inside the HUT just below the crewperson's chin and provides a drinking water supply.

9. The Helmet is a pressurizable polycarbonate "bubble" which attaches to a neck ring in the HUT and provides visibility and distribution of oxygen ventilation flow.

10. The Extravehicular Visor Assembly (EVVA) consists of two transparent visors which reflect infrared radiation (body heat) back into the EMU and attenuate solar glare. The EVVA also has three shades which the crewperson can deploy to further reduce glare.

LSS CEI's are described below:

1. The Primary Life Support Subsystem (PLSS) provides life support functions, status monitoring and communication for a seven-hour EVA in a "nominal thermal environment".

2. The Secondary Oxygen Pack (SOP) provides a 30-minute emergency supply of oxygen in the event of a failure of the PLSS.

3. The Display and Controls Module (DCM) is a chest-mounted pack which provides controls for EMU operation, a 12-character LED status display, and a purge valve for emergency mode operation.

4. The EMU Electrical Harness (EEH) transmits electrical signals to and from the CCA and Operational Biomedical System (OBS - the harness which senses EKG signals).

5. The Contaminant Control Cartridge (CCC) is an expendable lithium hydroxide and activated charcoal canister used for CO_2 and odor removal.

6. The Battery provides electrical power for the EMU during EVA.

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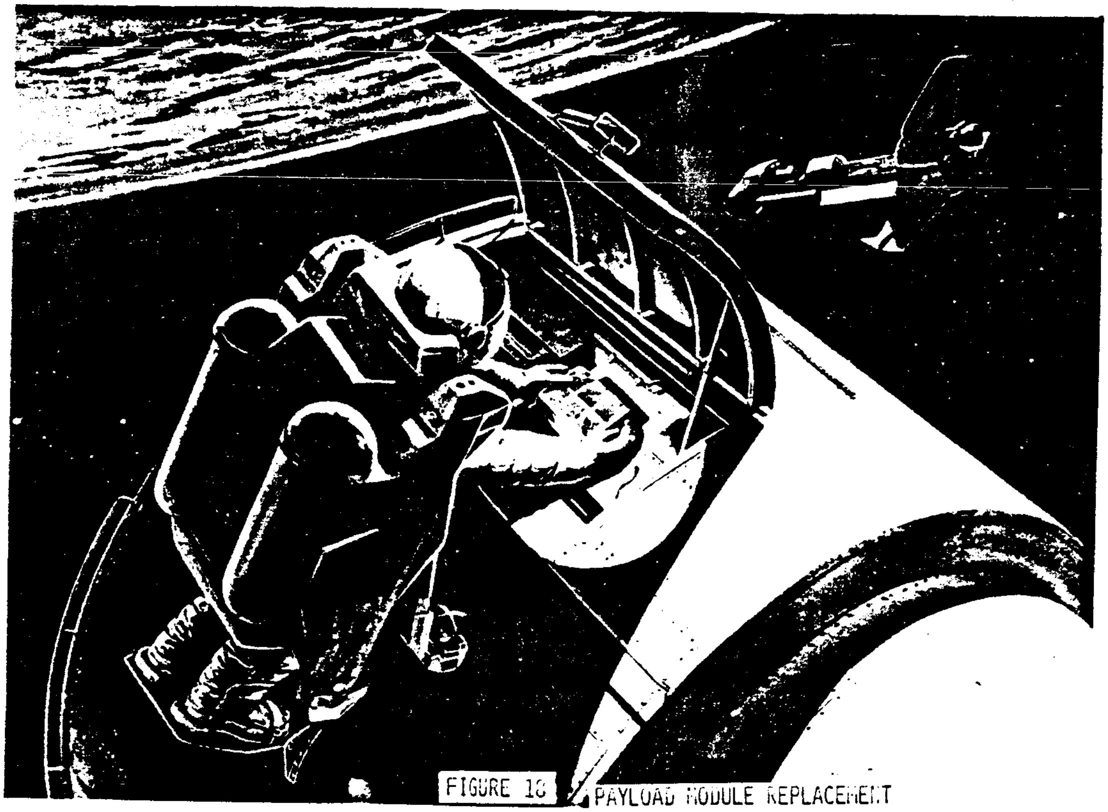

FIGURE 18 PAYLOAD MODULE REPLACEMENT BY EVA

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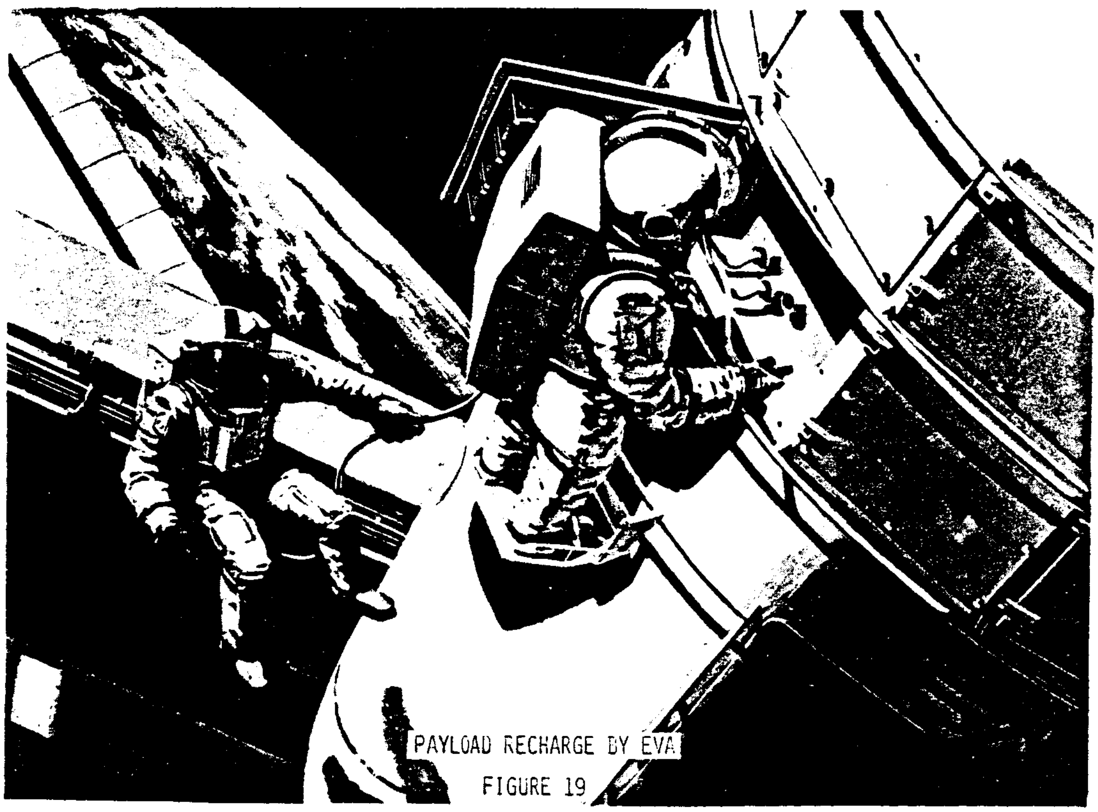


PAYLOAD RECHARGE BY EVA

FIGURE 19

7. The Service and Cooling Umbilical (SCU) provides an electrical and fluid interface between the vehicle and EMU for IV operations and on-orbit recharge. It is permanently mounted to the vehicle but can be connected to and disconnected from the DCM by the crewperson.

8. The Extravehicular Communications System (EVCS) is a radio (furnished as GFE to the EMU) which mounts inside the PLSS and provides communications and transmission of EKG signals.

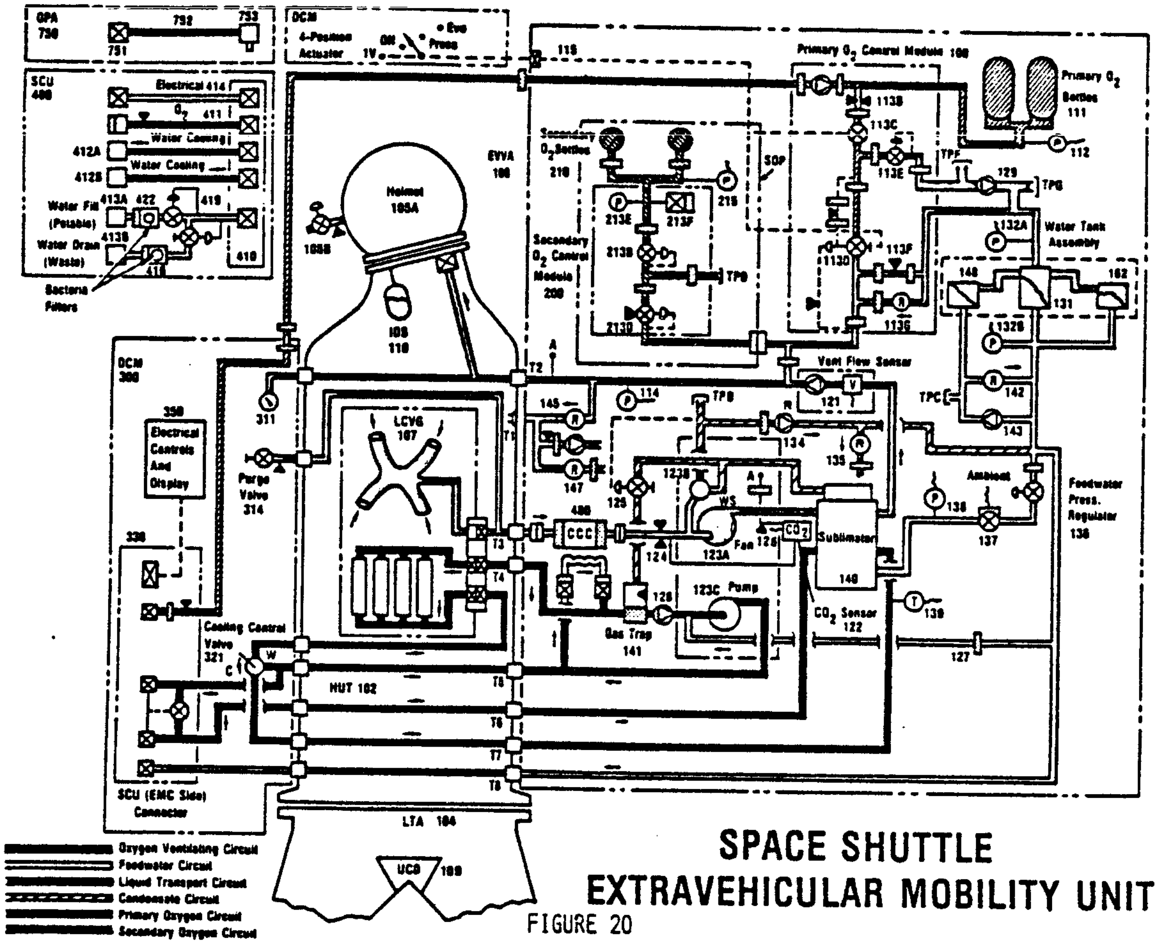
9. The Airlock Adapter Plate (AAP) is a frame, mounted to the airlock wall, in which the EMU is retained when not in use.

In order to describe the operation of the EMU, it is necessary to refer to the color schematic of Figure 20.

The EMU operates in two modes, EVA (SCU disconnected) and IVA (SCU connected). The EVA mode will be described in detail below. The IVA mode will be described by noting the manner in which it differs from EVA operation.

During EVA operation, make-up oxygen for metabolic consumption and suit leakage is stored in two primary oxygen bottles (items 111), initially at 900 + 50 psi. Make-up oxygen flows to the CO_2 vent loop (solid yellow lines) via the 113C shut-off valve and the 113D regulator. In the EVA mode, the 113D regulator controls vent loop pressure to 4.3 psi.

A fan, item 123A, drives oxygen ventilation flow of about 6 scfm around the vent loop. Make-up flow joins the ventilation flow just downstream of the item 121 vent flow sensor and check valve. Vent flow is then ducted through the back of the HUT into the helmet where it washes CO_2 out of the ora-nasal area and flows to the extremities of the suit. It returns to the PLSS via ducts in the LCVG. CO_2 is removed from the vent flow by chemical reaction with lithium hydroxide in the CCC and trace contaminants are adsorbed by activated charcoal. Vent flow passes through the fan and through a heat exchanger, called a sublimator, where it is cooled. Water condensed in the sublimator is sucked, along with some oxygen, to a rotating drum water separator (item 123B) where the water is separated from the oxygen by centrifugal force. Separated water is returned to the feedwater loop (solid blue lines) via a check valve (item 134), and separated oxygen is returned to the fan inlet. Ventilation flow from the sublimator then passes through the vent flow sensor and check valve assembly (item 121), completing the vent loop circuit. A pressure gage (item 311) on the DCM gives the crewperson a visual readout of



SPACE SHUTTLE EXTRAVEHICULAR MOBILITY UNIT

FIGURE 20

suit pressure. A small bleed flow of vent loop gas goes from point A (suit inlet) through a CO_2 sensor (item 126) and back to the fan inlet to provide constant monitoring of suit inlet CO_2 concentration to the Caution and Warning System.

A 30-minute emergency oxygen purge flow capability is provided by the SOP (orange, cross-hatched lines). Oxygen at 6000 psi is stored in two spherical bottles. In the event of a system failure, the crewperson may activate SOP purge flow by opening one of the EMU purge valves. The items 213B and 213D regulators will open and control vent loop pressure to 3.25 to 3.55 psi. Flow from the SOP enters the vent loop downstream of the vent flow sensor and check valve. The check valve prevents SOP flow from going back through the sublimator. SOP flow goes through the helmet to the suit extremities and back through the LCVG vent ducting to point T3 where, instead of reentering the PLSS it goes overboard (to space vacuum) through the item 314 purge valve on the DCM. Should the 314 purge valve freeze up or become blocked, a back-up purge valve (item 105B) is provided on the helmet.

There are three additional valves in the oxygen vent loop which are connected via a monifold to the inside of the space suit at point T1 on the schematic. The item 145 valve is used to check out the SOP prior to EVA. The item 147 valve is a negative pressure relief valve which allows ambient air flow into the suit during emergency airlock repressurization. This prevents rapidly rising airlock air pressure from exceeding suit pressure sufficiently to collapse the suit and injure the crewperson. The valve between the items 145 and 147 is a positive pressure relief valve which prevents suit pressure from exceeding 5.3 psi in the event of a failure of one of the PLSS or SOP pressure regulators.

Rejection of metabolic and equipment heat loads and environmental heat leak is accomplished in the sublimator by utilizing latent heat required for sublimation of ice to the vapor state. Expendable water (feedwater) is forced into a porous metal plate exposed to space vacuum. An ice layer forms on top of the porous plate and heat transferred from both the oxygen ventilation loop and the liquid transport loop (solid red lines) to the porous plate sublimates the ice.

The feedwater loop (solid blue lines) provides expendable water to the sublimator and controls pressure in the liquid transport loop. Feedwater stored in bladders in three water tanks (items 148, 131 and 162) is pressurized by oxygen from the primary oxygen circuit (cross-hatched yellow lines). The item 113E regulator maintains a pressure of 15 psi on the back of the bladders. A constant, very small bleed of oxygen always flows through the 113F orifice to the vent loop. The item 113G relief valve protects the water tanks from overpressurization in the event of failure of the 113E regulator.

The feedwater pressure regulator, item 136, controls pressure to the sublimator porous plate to approximately 2.7 psia. A solenoid shut-off valve, item 137, controlled by the crewperson via a switch on the DCM, permits water flow to the porous plate when opened.

The bulk of the expendable feedwater is contained in the items 131 and 162 tanks. The item 148 tank contains a 30-minute reserve supply of feedwater. When the items 131 and 162 tanks are empty, pressure in the feedwater system drops. This is sensed by the Caution and Warning System which warns the crewperson that he has 30 minutes to return to the airlock. The drop in feedwater pressure also causes the item 142 relief valve to open, initiating flow from the reserve tank. The check valve, item 143, permits the reserve tank to be recharged with feedwater after EVA.

The bulk of cooling for the crewperson is provided by the liquid transport loop. Starting at the pump (item 123C) water flows through the PLSS and HUT to a point just upstream of the DCM cooling control valve (item 321). Depending upon the valve setting selected by the crewperson, any percentage of the flow from the pump ranging from zero to 100 percent may pass through the valve, thus bypassing the sublimator. That flow which does not go through the valve returns to the sublimator where it is chilled. The return flow from the sublimator rejoints the flow which bypassed the sublimator at the cooling control valve. The total flow then enters the LCVG where it cools the crewperson and returns to the PLSS. A small parallel flow loop shown providing cooling to the CCC has been deleted from the EMU. Water flow then passes through a gas trap where gas bubbles along with some water flow (about 11 pph) are removed and sent to the water separator via a valve (item 125) which opens only when water separator water outlet pressure reaches a preset level. The bulk of transport water flow returns to the pump through a check valve (item 128).

Water bled out of the transport loop at the gas trap is recirculated through the feedwater loop and reenters the transport loop between the pump and check valve. If a large gas bubble were trapped in the pump at the time of pump start up, water transport flow might never be initiated. Should this occur, the crewperson can manually open the 125 valve forcing this recirculation to occur. Water reentering the transport loop between the check valve and the pump would be forced by the presence of the check valve to go through the pump, thus clearing the gas bubble and priming the pump.

Electric power to drive the motor which turns the fan, water seperator and pump as well as to operate the transducers, the Caution and Warning System and the EVCS is provided by a battery, not shown on the schematic.

IVA mode operation is similar to the EVA mode described above, except that:

1. The SCU is connected to the DCM (items 410 and 330 mate) and cooling is provided by a heat exchanger in the vehicle water transport loop rather than by the sublimator. In this mode, the cross-over valve between the transport lines in the item 330 connector is closed by the mating of the SCU to the DCM and transport loop water is forced to flow through the SCU,

2. electric power is supplied by the vehicle via the SCU,

3. excess condensate produced by the crewman's sweating is dumped to the vehicle waste water system via a regulator in the SCU, and

4. suit pressure is controlled to 0.65 psi by the item 113D regulator instead of 4.3 psi.

The EMU can be recharged between EVA's. Oxygen and feedwater are supplied by the SCU, as is current to recharge the EMU battery. The CCC is removed and a fresh CCC wwith unexpended lithium hydroxide is installed. If desired, the battery can also be changed out instead of being recharged.

TELEOPERATION IN SPACE

NEW CHALLENGES IN THE DEVELOPMENT OF SPACEBORN MAN-MACHINE SYSTEMS

ANTAL K. BEJCZY
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

OVERVIEW

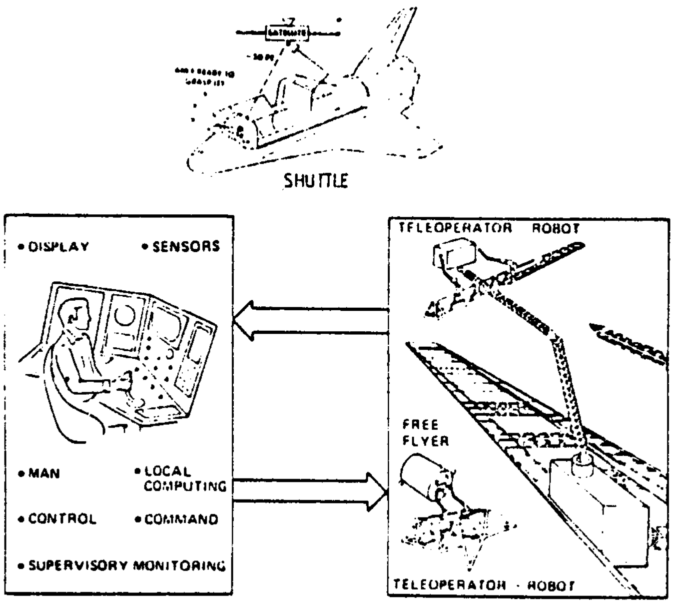
- TELEOPERATOR HUMAN INTERFACE TECHNOLOGY
- GENERIC HUMAN FACTORS ISSUES AND R&D TOPICS
- ONGOING ADVANCED R&D WORK

The scope of applications includes Shuttle-based, TMS and Space Station related teleoperation. The key R&D issues are highlighted as centered around man's involvement in teleoperation: sensors, controls, commands, displays, computers and supervisory monitoring.

The R&D issues in teleoperation can be subdivided into three groups. From a human factors viewpoint, the man-machine interface represents the central group of issues since the interface is a shared boundary between man and machine. It is noted that the m/m interface may involve different technical issues dependent upon the operator's location: (i) the operator is in space or (ii) the operator is on earth.

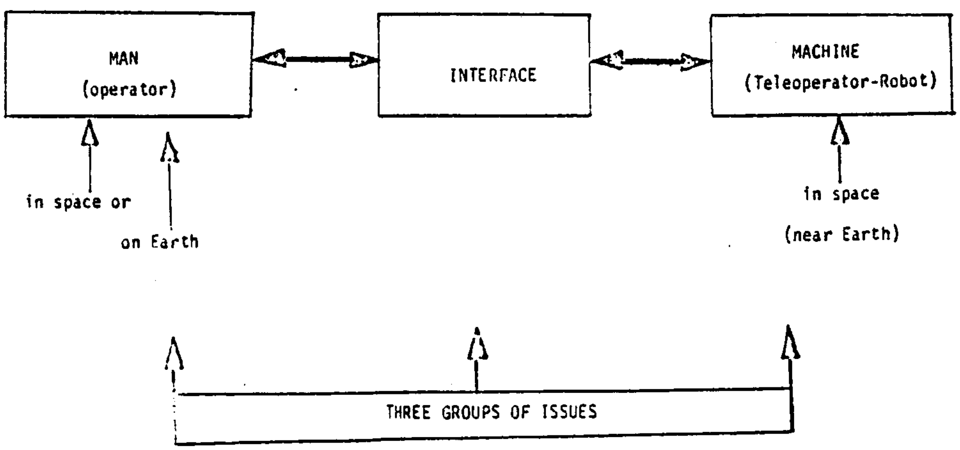
TELEOPERATION IN SPACE

SCOPE OF APPLICATIONS AND ACTIVITIES



BASIC SYSTEM DEFINITION

TELEOPERATORS ARE MAN-MACHINE SYSTEMS EXTENDING AND AUGMENTING MAN'S CAPABILITIES



The statements are self-explanatory. The main point is that teleoperator human interface technology is a relatively new field which involves different technical disciplines. The level of this technology determines the operator's "telepresence" capabilities in teleoperation.

The m/m interface problem in an operator centered view shows the operator "squeezed" between the information feedback and control input devices, and highlights the human capabilities involved in teleoperation. The essential statement is that (i) the operator has limited capabilities in a real-time control environment, and (ii) the operator's information receiving capabilities are much broader than his control output capabilities. In m/m communication, the fundamental human control output capabilities reside in the hand.

TELEOPERATOR HUMAN INTERFACE TECHNOLOGY

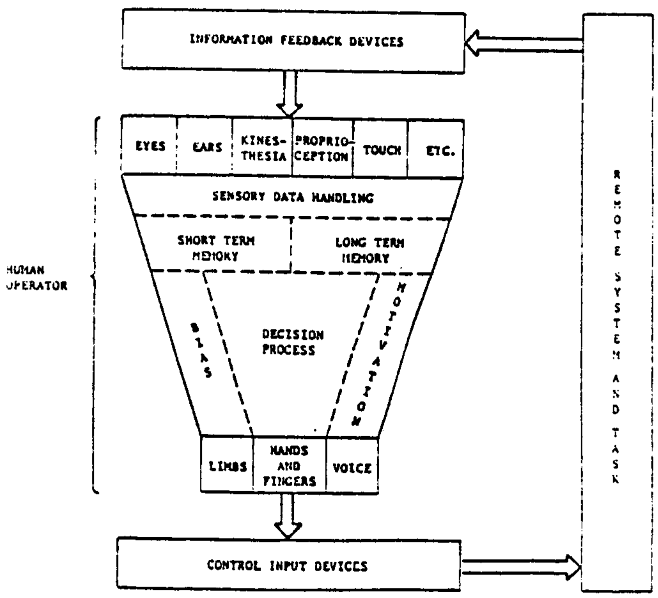
WHAT
- A RELATIVELY NEW TECHNOLOGY INVOLVING DIFFERENT DISCIPLINES: SENSOR INSTRUMENTATION, COMPUTER SYSTEMS, DISPLAY ENGINEERING KINEMATICS & DYNAMICS ANALYSIS, CONTROL SYSTEMS, HUMAN ENGINEERING, PSYCHOMETRICS, KINESIOLOGY, ANTHROPOMETRICS, ETC.

WHY
- MAN-IN-THE-LOOP OPERATION BEST PROVIDES THE USE OF HUMAN SKILL AND INTELLIGENCE IN BOTH MANUAL AND HIGH-LEVEL DECISION MAKING CONTROL, SUPERVISING DISTRIBUTED COMPUTER CONTROL SYSTEMS

GOAL
- AN OPTIMAL, INTEGRATED TELEOPERATOR HUMAN INTERFACE DESIGN, PERMITTING MAXIMUM PERFORMANCE EFFICIENCY BY THE REMOTE HUMAN OPERATOR IN A COMPLEX MULTI-TASK ENVIRONMENT
- PERFORMANCE EFFICIENCY AS MEASURED BY
  - (A) EXTENT OF PERCEPTIVE & COGNITIVE INFORMATION TRAFFIC AND OF COMMAND/CONTROL DEMANDS
  - (B) EFFECTIVENESS OF INFORMATION REPRESENTATION TO OPERATOR
  - (C) EFFECTIVENESS OF COMMAND/CONTROL COMMUNICATION BY OPERATOR
  - (D) OVERALL OPERATOR-SYSTEM RESPONSE TIME
  - (E) ACCURACY AND TIME OF TASK PERFORMANCE

THE INTERFACE

AN OPERATOR CENTERED VIEW



CONCLUSIONS:

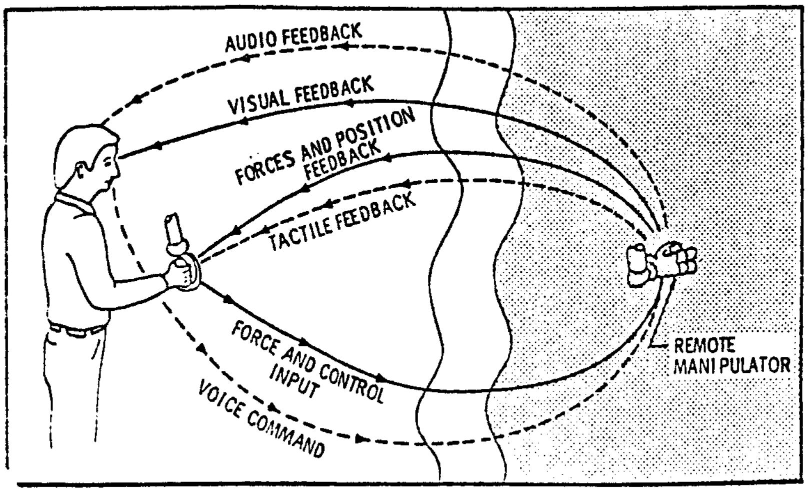
- HUMAN IS ESSENTIAL
- HUMAN PRESENCE IS BIDIRENCTIONAL
- HUMAN IS LIMITED AND ASSYMETRIC IN I/O HANDLING
- HUMAN NEEDS AIDS
- HUMAN PRESENCE SHOULD BE OPTIMIZED

The m/m interface problem ("telepresence") in teleoperation can be highlighted by relating it to the human input/output channels and channel capacities.

The m/m interface problem from an equipment and components viewpoint represents the challenge of finding an optimal configuration and sensible integration of interface elements, matching and optimizing the human capabilities. A key problem area is the utilization of sensory information which supplements and/or extends the visual information for control.

THE INTERFACE

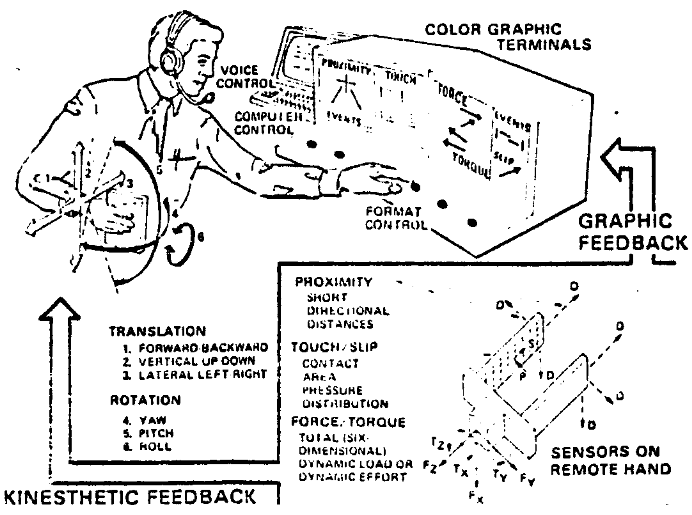
A HUMAN I/O CHANNEL VIEW



CHALLENGE: OPTIMAL USE OF HUMAN I/O CHANNELS

THE INTERFACE

AN EQUIPMENT AND COMPONENTS VIEW



CHALLENGE: OPTIMAL CONFIGURATION AND INTEGRATION

It is emphasized that the development of "telepresence" devices and techniques should be paralleled with the development of data base and models to understand and quantify human performance when advanced "telepresence" devices and techniques are employed in teleoperation.

This list of performance studies is centered around the evaluation of human capabilities under varying task and varying information/control conditions. The main purpose of the performance studies is to develop human factors guidelines for the design of advanced "Integrated Space Teleoperator Controls."

R&D ISSUES AND TOPICS

- DEVELOPMENT OF DEVICES AND TECHNIQUES WHICH PROVIDE ENHANCED AND EFFICIENT SENSORY FEEDBACK ("TELEPRESENCE) TO THE HUMAN OPERATOR
  - GENERALIZED KINESTHETIC-PROPRIOCEPTIVE M/M INTERFACE
  - INTEGRATED AND TASK-REFERENCED DISPLAYS OF VISUAL & NON-VISUAL SENSORY INFORMATION
  - INTERACTIVE MANUAL-COMPUTER/SENSOR CONTROL OF MANIPULATIONS
- DEVELOPMENT OF DATA BASE AND MODELS FOR QUANTIFYING HUMAN PERFORMANCE IN SENSOR-AND COMPUTER-AUGMENTED INFORMATION AND CONTROL ENVIRONMENT OF SPACE TELEOPERATOR SYSTEMS, WITH PARTICULAR EMPHASIS ON:
  - KINESTHETIC-PROPRIOCEPTIVE M/M COUPLING
  - MANUAL AND SYMBOLIC M/M COMMUNICATION
  - PERCEPTIVE/COGNITIVE PROCESSES IN REAL-TIME DECISION MAKING AS A FUNCTION OF ALTERNATIVE PRESENTATIONS OF CONTROL TASKS
- DEVELOPMENT OF HUMAN FACTORS GUIDELINES FOR THE DESIGN OF ADVANCED "INTEGRATED SPACE TELEOPERATOR CONTROLS"

R&D ISSUES AND TOPICS (CONT'D)

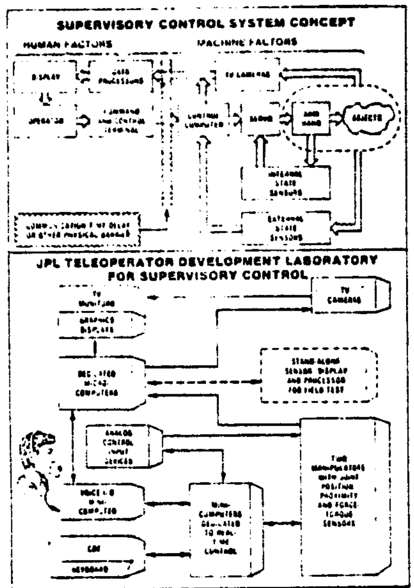
PERFORMANCE STUDIES OF PARTICULAR INTEREST

- TIME-CONSTRAINED CAPABILITIES OF A SINGLE OPERATOR
- OPERATOR'S PERCEPTIVE/COGNITIVE LIMITS UNDER VARYING TAKS CONDITIONS
- OPERATOR'S INFORMATION ASSIMILATION RATE AND CAPACITY
- UTILITY OF ALTERNATIVE HUMAN PERCEPTIVE AND COMMAND/CONTROL MODALITIES
- HUMAN ENDURANCE AS A FUNCTION OF CONTROL I/O LOADS
- NUMBER OF OPERATORS REQUIRED FOR A GIVEN CONTROL STATION/TASK SCENARIO
- EFFECT OF SYSTEM RESPONSE TIME ON OPERATOR'S PERFORMANCE (COMMUNICATION TIME DELAY & DATA HANDLING RATE)
- EFFECT OF SPACE ENVIRONMENT (WEIGHTLESSNESS, VISUAL CONDITIONS, ETC.) ON OPERATOR'S PERFORMANCE

The supervisory control block diagram shows the functional role of the various technical components. Operator "in series" with control computer means that the operator is the source of continuous (analog) commands to the system. The commands are, however, functional commands that hare transformed by the computer into appropriate joint motor drive commands. Operator "in parallel" with control computer means that the operator only provides intermittent commands to the system. In between operator inputs, the computer is the source of continuous commands to the system.

This viewgraph summarizes the JPL advanced teleoperator technology development goals and the corresponding development activities.

ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT AT JPL



ORGANIZATIONAL CONCEPT
EXPERIMENTAL FRAME
LABORATORY COMPONENTS

WORK ROOM

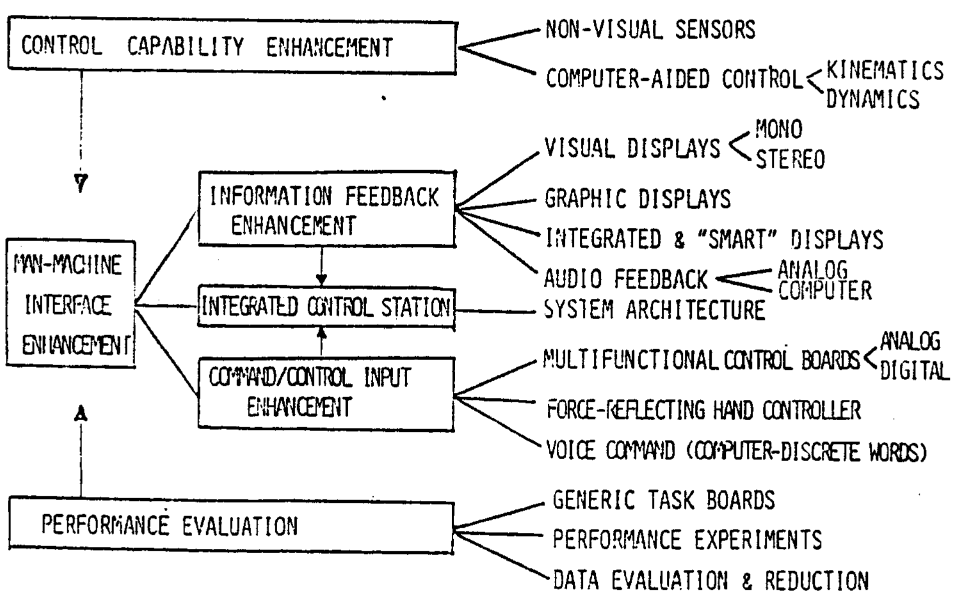
- HUMANOID SLAVE ARM (O)
- "CURV" LINKAGE ARM (O)
- PARALLEL JAW HANDS (O)
- SWINGING HAND (O)
- HUMANOID HAND (O)
- STEREO TV CAMERAS (O)
- MONO TV CAMERAS (O)
- PROXIMITY SENSORS (O)
- TOUCH SENSORS (B-O)
- FORCE/TORQUE SENSOR (O)
- SLIPPAGE SENSORS (B-O)
- MINICOMPUTER, INTERDATA M70 (O)
- CONTROL PROGRAMS (O)
- MINICOMPUTER, NOVA 2 (O)
- MICROPROCESSOR, CROMEMCO Z-2 (O)
- DISC MEMORY (O)
- FAST LINE PRINTER (O)
- PDP 11/40 MINICOMPUTER (O)
- MINICOMPUTER, INTERDATA 8/16 (D)
- PUMA 600 ROBOT ARM (D)

REMOTE CONTROL STATION

- EXOSKELETON MASTER ARM (O)
- UNIVERSAL CONTROL PANEL (O)
- CONVERTIBLE HAND CONTROLLER (O)
- TV, PAN TILT, ZOOM CONTROL (O)
- STEREO / MONO TV DISPLAYS (O)
- AUDIO AND VISUAL DISPLAYS FOR FOUR PROXIMITY SENSORS (O)
- VISUAL DISPLAY FOR DIRECTIONAL SLIPPAGE SENSORS (B-O)
- VISUAL DISPLAY FOR MULTIPOINT PROPORTIONAL TOUCH SENSOR (O)
- FORCE/TORQUE SENSOR VISUAL DISPLAY (O)
- TELETYPE AND CRT FOR COMPUTER COMMAND (O)
- VOICE COMMAND SYSTEM (O)
- VOICE FEEDBACK SYSTEM (O)
- COLOR GRAPHIC TERMINAL (O)
- FORCE-REFLECTING POSITION HAND CONTROLLER (O)

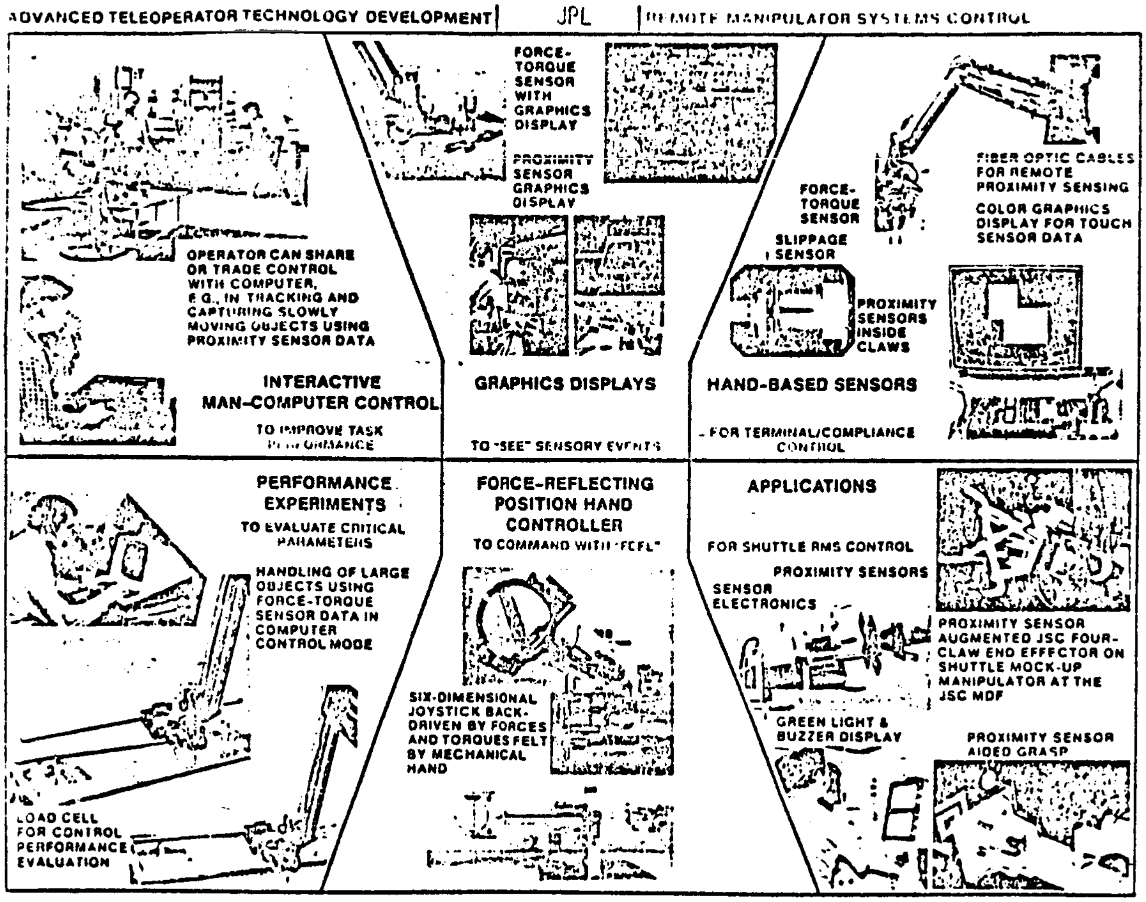
NOTES: (O): OPERATIONAL; (B): BENCH MODEL; (D): DEVELOPMENT

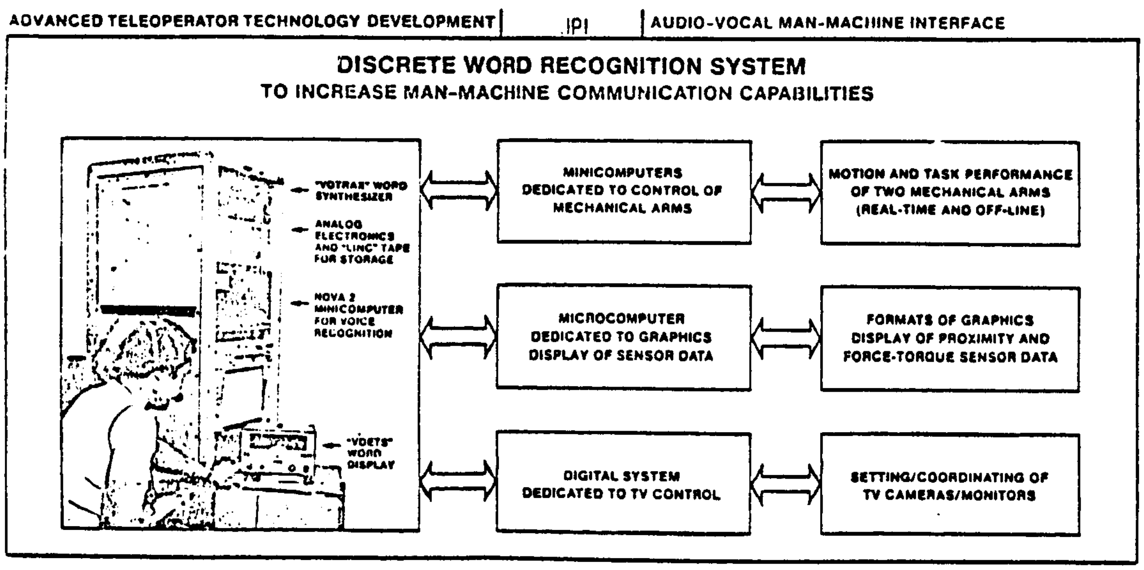
ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT AT JPL



This viewgraph presents a graphic summary overview of the JPL activities in advanced teleoperator technology development.

This viewgraph summarized accomplishments in advanced teleoperator technology development at JPL.


ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT
JPL
REMOTE MANIPULATOR SYSTEMS CONTROL
OPERATOR CAN SHARE OR TRADE CONTROL WITH COMPUTER, E.G., IN TRACKING AND CAPTURING SLOWLY MOVING OBJECTS USING PROXIMITY SENSOR DATA
INTERACTIVE MAN-COMPUTER CONTROL
TO IMPROVE TASK PERFORMANCE
FORCE-TORQUE SENSOR WITH GRAPHICS DISPLAY
PROXIMITY SENSOR GRAPHICS DISPLAY
GRAPHICS DISPLAYS
TO "SEE" SENSORY EVENTS
FIBER OPTIC CABLES FOR REMOTE PROXIMITY SENSING
COLOR GRAPHICS DISPLAY FOR TOUCH SENSOR DATA
FORCE-TORQUE SENSOR
SLIPPAGE SENSOR
PROXIMITY SENSORS INSIDE CLAWS
HAND-BASED SENSORS
- FOR TERMINAL/COMPLIANCE CONTROL
PERFORMANCE EXPERIMENTS
TO EVALUATE CRITICAL PARAMETERS
HANDLING OF LARGE OBJECTS USING FORCE-TORQUE SENSOR DATA IN COMPUTER CONTROL MODE
LOAD CELL FOR CONTROL PERFORMANCE EVALUATION
FORCE-REFLECTING POSITION HAND CONTROLLER
TO COMMAND WITH "FEEL"
SIX-DIMENSIONAL JOYSTICK BACK-DRIVEN BY FORCES AND TORQUES FELT BY MECHANICAL HAND
APPLICATIONS
FOR SHUTTLE RMS CONTROL
PROXIMITY SENSORS
SENSOR ELECTRONICS
PROXIMITY SENSOR AUGMENTED JSC FOUR-CLAW END EFFECTOR ON SHUTTLE MOCK-UP MANIPULATOR AT THE JSC MDF
GREEN LIGHT & BUZZER DISPLAY
PROXIMITY SENSOR AIDED GRASP


ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT
JPL
AUDIO-VOCAL MAN-MACHINE INTERFACE
DISCRETE WORD RECOGNITION SYSTEM
TO INCREASE MAN-MACHINE COMMUNICATION CAPABILITIES
"VOTRAX" WORD SYNTHESIZER
ANALOG ELECTRONICS AND "LINC" TAPE FOR STORAGE
NOVA 2 MINICOMPUTER FOR VOICE RECOGNITION
"VOETS" WORD DISPLAY
MINICOMPUTERS DEDICATED TO CONTROL OF MECHANICAL ARMS
MOTION AND TASK PERFORMANCE OF TWO MECHANICAL ARMS (REAL-TIME AND OFF-LINE)
MICROCOMPUTER DEDICATED TO GRAPHICS DISPLAY OF SENSOR DATA
FORMATS OF GRAPHICS DISPLAY OF PROXIMITY AND FORCE-TORQUE SENSOR DATA
DIGITAL SYSTEM DEDICATED TO TV CONTROL
SETTING/COORDINATING OF TV CAMERAS/MONITORS

Self Explanatory

Start of Appendix A

SUMMARY OF ACCOMPLISHMENTS IN ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT AT JPL

- SENSORS:
  - PROXIMITY
  - FORCE-TORQUE
  - TACTILE
  - SLIP
- CONTROLS:
  - ANALOG
  - COMPUTER
  - INTERACTIVE
  - SENSOR-GUIDED
- M/M INTERFACE:
  - FORCE-REFLECTING HAND CONTROLLER
  - MULTIFUNCTIONAL CONTROL DEVICES
  - GRAPHICS DISPLAYS
  - VISION DISPLAYS
  - INTEGRATED DISPLAYS
  - COMPUTER-BASED AUDIO-VOCAL
  - INTEGRATED CONTROL STATION
- EQUIPMENT:
  - THREE MANIPULATORS
  - TWO MINICOMPUTERS
  - FIVE MICROPROCESSORS
  - ETC., SEE SEPARATE
- TASK BOARD
- PERFORMANCE EXPERIMENTS AT JPL
- SIMULATED SHUTTLE RMS PERFORMANCE EXPERIMENTS AT JSC MDF
  - 1978, PROXIMITY SENSOR - SIMPLE DISPLAY
  - 1980, PROXIMITY SENSOR-ADVANCED DISPLAY
  - 1981, VOICE CONTROL OF TV & MONITORS
  - 1982, FORCE-TORQUE CONTROL
- M/M INTERFACE DEVELOPMENT AND DESIGN STUDIES
- STATE-OF-THE-ART STUDIES
- UNIVERSITY COOPERATION (UCLA, UCB, USC, UNIV. OF ARIZONA & UNIV. OF FLORIDA)
- STIPENDIATS FROM ABROAD (NORWAY, FRANCE)

1. TECHNICAL GOALS AND ACCOMPLISHMENTS ARE ILLUSTRATED ON VIEWGRAPHS; SEE APPENDIX A.
2. BIBLIOGRAPHY IS GIVEN IN APPENDIX B.

APPENDIX A

TECHNICAL GOALS & ACCOMPLISHMENTS

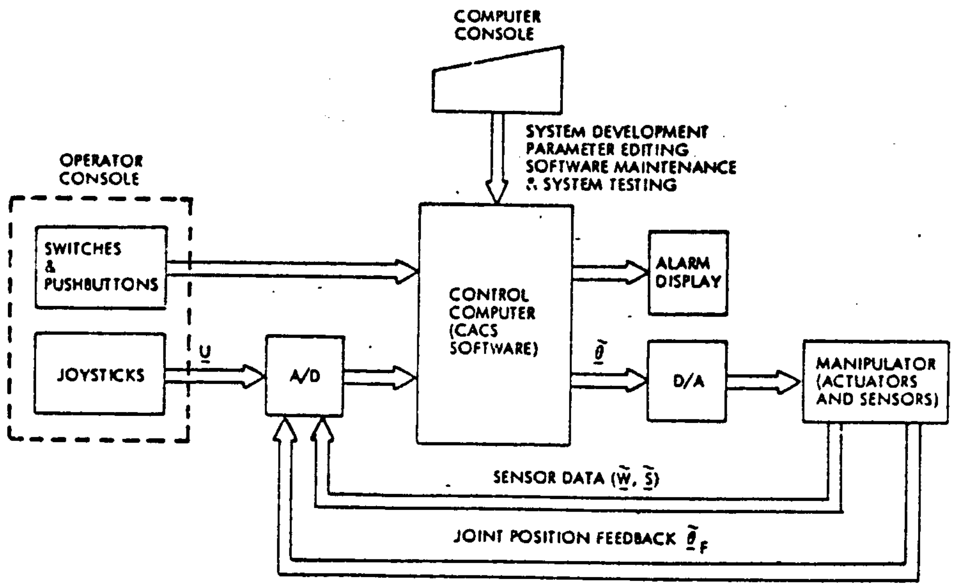
EXAMPLES

Interactive manual and automatic control for tracking and capturing slowly moving targets aided by proximity was developed in a pilot project at JPL using the JPL/CURV manipulator as a feasibility demonstration "vehicle." The general idea is to provide an interactive manual/automatic control capability so that the operator can decide on-line when and at what level the automatic control should be activated or, eventually, deactivated. The block diagram shows the data flow in this interactive manual/automatic control system. Note in this diagram that exteroceptive (proximity and force-torque) sensor information is looped through the computer directly together with the operator's manual (joystick) commands. Note also in the diagram that the operator uses switches addressed directly to the computer to select the appropriate automatic control functions referenced to proximity or force-torque sensor data which then work together with the operator's manual (joystick) commands. The manual joystick commands are also addressed to computer programs in resolved positions or resolved rate control modes.

The block diagram shows the interactive manual/automatic operation and system state sequences as they relate to the selected example of tracking and capturing targets moving slowly in a horizontal plane. The operator can select an all-the-way automatic control once the proximity sensors' sensing range has reached the tracking plane under manual control of the manipulator. Or, he can first select any other automatic control action signified by the square boxes in the diagram. After completion of the selected automatic action, the operator can select any other sequentially meaningful automatic operation, or continue the remaining operation manually. In the last case, the system state attained earlier automatically will be maintained automatically during the subsequent manual control for the remaining part of the operation. At any time, the operator can retain full or partial manual control by simple switch turn on/off.

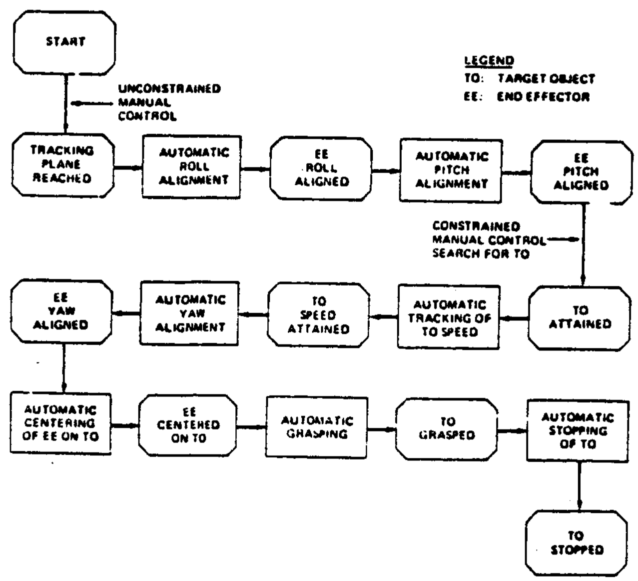
TECHNICAL GOALS AND ACTIVITIES EXAMPLE

DATA FLOW IN INTERACTIVE MANUAL/COMPUTER SENSOR-REFERENCED CONTROL



TECHNICAL GOALS AND ACTIVITIES EXAMPLE

INTERACTIVE MANUAL/AUTOMATIC TRACKING/ GRASPING CONTROL OPERATIONS SEQUENCE



This flowchart summarizes the program/function hierarchy and menu developed at the University of Arizona under a JPL contract in 1978/79. The computer programs are aimed to study and evaluate the practical implications of coordinated transfer of control between human operator and computer routines at appropriate stages of the task.

The presently available computer programs provide the following capabilities for the control of the JPL/Ames Antropomorphic Master-Slave Arm: (a) permit transfer of control from the master arm to the computer and back via TTY; (b) determine for any arm configuration the location and orientation of the end effector in world space; (c) solve for joint angles corresponding to locations and orientations of the end effector specified in Cartesian world frame; (d) enable the operator to command from the TTY a move to a position expressed in Cartesian base frame; (e) permit the operator to command increments in location and orientation of the end effector in Cartesian world, hand-based, or display-based reference frames.

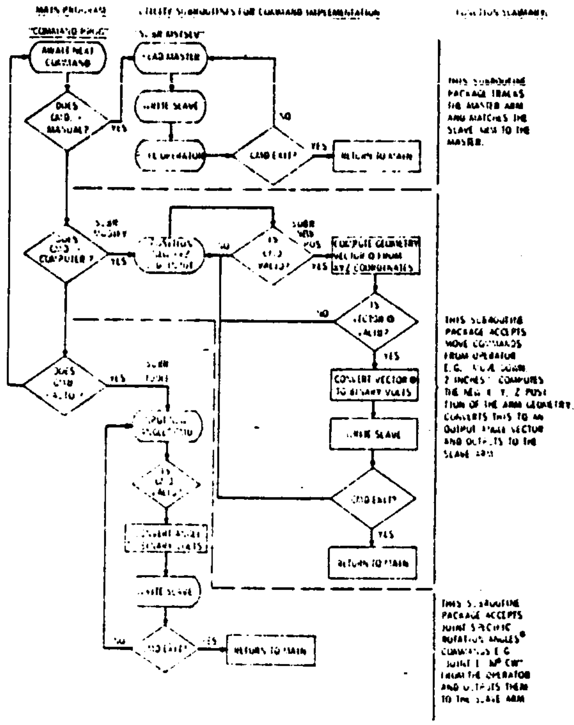
The force-reflecting position hand controller is a general purpose six-dimensional control input device which can be back-driven by forces and torques sensed at the base of the end effector of a remotely controlled mechanical arm. The device is general purpose in the sense that it does not have any geometric/kinematic relation to the mechanical arm it controls and from which it is back-driven.

The force-reflecting position hand controller is a fundamental development tool serving two purposes: (1) advancing the state of the art in dexterous remote manipulation which requires force feedback; (2) investigating and evaluating critical performance parameters related to kinesthetic man-machine coupling in remote manipulator control, e.g., stress and motion resolution sensed by the human muscular system.

The positional control relation between this hand controller and mechanical arm is established through real-time mathematical transformation of joint variables measured at both the control device and mechanical arm. Likewise, the forces and torques sensed at the base of the end effector are resolved into appropriate hand controller joint drives through real-time mathematical transformations to give to the operator's hand the same force-torque "feeling" that is "felt" by the end effector on the remote mechanical arm, e.g., working with a wrench held by the remote mechanical hand will give nearly the same kinesthetic feeling to the operator as a wrench held by his own hand.

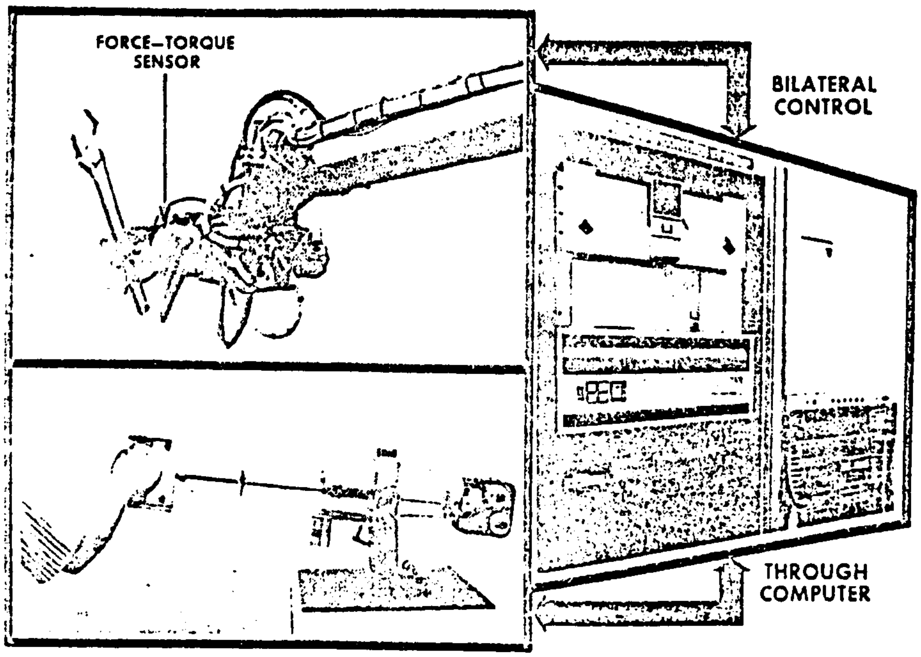
TECHNICAL GOALS AND ACTIVITIES EXAMPLE

INTERACTIVE MASTER/ COMPUTER CONTROL



TECHNICAL GOALS AND ACTIVITIES EXAMPLE

FORCE-REFLECTING POSITION HAND CONTROLLER OVERALL SYSTEM IMPLEMENTATION AND APPLICATION



The pictures show display formats related to the object encounter regime control events. In these displays, the hand is shown schematically together with four bars indicating the distances sensed by the four proximity sensors integrated with the mechanical "fingers." The bar lengths are proportional to the sensed distances. At the bottom of the two lower right displays the required corrective control is shown. The error is much easier to see from the automatically monitored error bars than it is from comparing the relative lengths of the sensed distances visually or from examining the scene in a TV view.

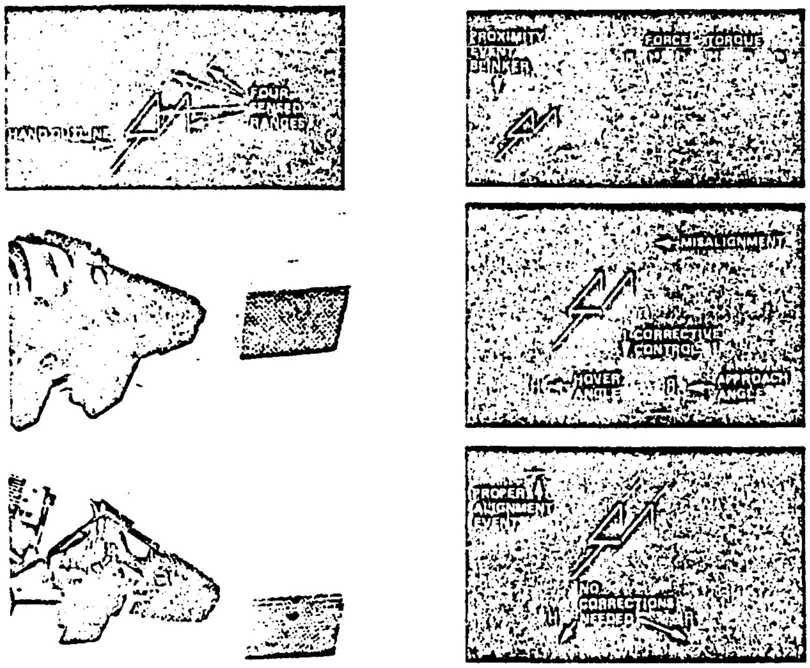
The upper right picture shows a combined ("dual") display of both proximity and force-torque sensor data, together with the "proximity event" blinker. This display is related to a task scenario which requires the simultaneous monitoring of both proximity and force-torque sensor information.

The new graphics displays are aimed to investigate techniques by which the operator's perceptive/cognitive workload can be reduced.

The new Advanced Teleoperator Development Laboratory established in 1978 doubles the size of the old one. The cables interconnecting the various equipments are carried under the elevanted floor in the central part of the laboratory where the new control station is located.

TECHNICAL GOALS AND ACTIVITIES EXAMPLE

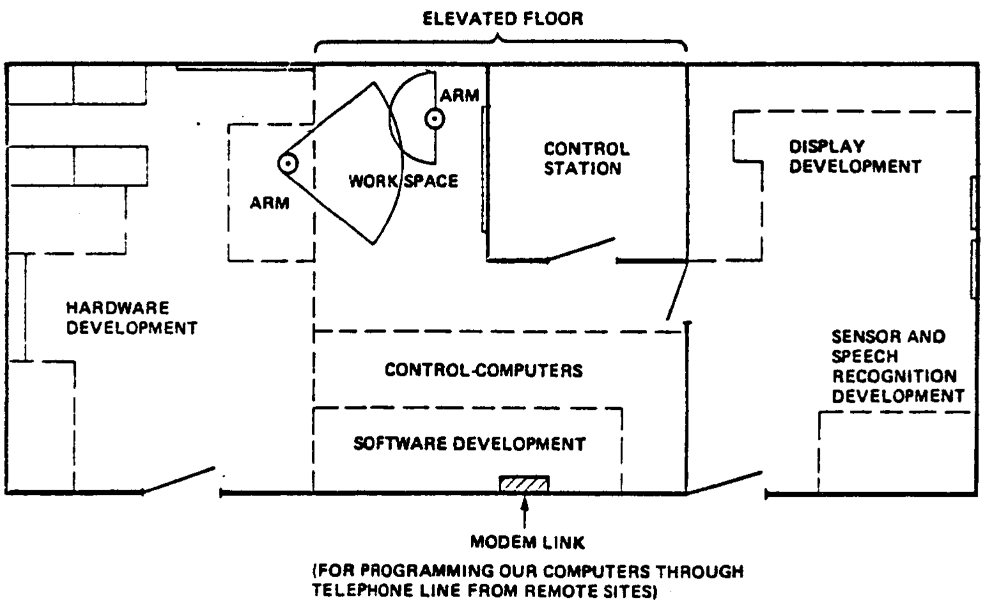
EVENT-DRIVEN DISPLAYS FOR PROXIMITY SENSOR DATA



TECHNICAL GOALS AND ACTIVITIES EXAMPLE

TELEOPERATOR LABORATORY

(52' by 22' AREA)



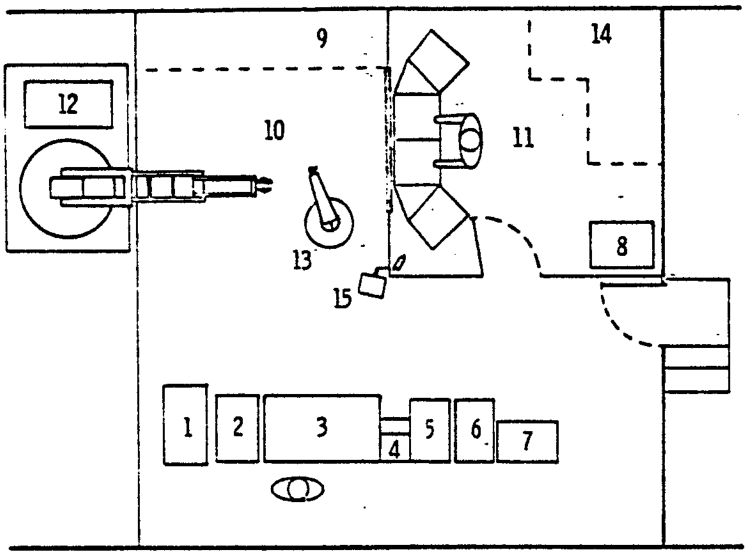
The teleoperator laboratory can be divided into four major areas: (1) the control station, (2) the manipulator workspace, (3) the test director's stand, and (4) the processing section. This figure shows the relationships of these areas and their associated equipment.

The console panels are divided into primary, secondary, and non-essential control/display areas. The specific allocations were established on the basis of efficient man-machine interaction. To give some examples, the graphics and status monitors were placed close together and to the top of the control console so that they can be addressed with equal ease under director or remote viewing. The two audio speakers were physically separated so that spatial sound clues can be perceived. The light bar was given preferential location between the viewing area and the control console for position identification of high priority states. The control inputs were placed within easy reach to avoid unnecessary strain or awkward positioning of the operator, etc.

The integrated control station has a modular structure aimed to experiment with new implementation concepts matching the needs of a hybrid analog/symbolic control/information environment.

TECHNICAL GOALS AND ACTIVITIES EXAMPLE

CONTROL STATION IN RELATION TO WORKROOM

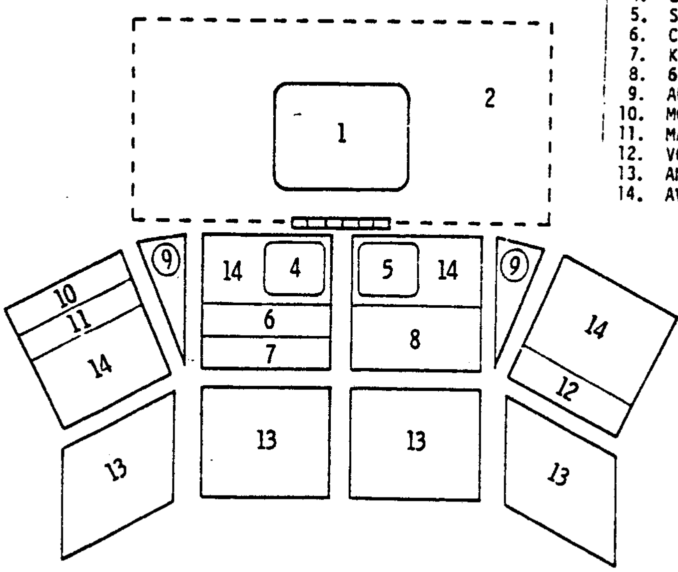


1. AMES SERVO CONSOLE
2. CURV CONTROL CONSOLE
3. TEST DIRECTOR'S STATION
4. TELETYPE
5. INTERDATA M70
6. INTERDATA 8/16E
7. HIGHSPEED PRINTER
8. VOICE COMMAND COMPUTER
9. TASK STORAGE AREA
10. MANIPULATOR WORKSPACE
11. CONTROL STATION
12. CURV VEHICLE AND ARM
13. AMES ARM
14. INTERFACE STORAGE AREA
15. CONTROL STATION MONITOR

TECHNICAL GOALS AND ACTIVITIES EXAMPLE

CONTROL STATION DETAILS

1. STEREO VIEWING MODULE
2. DIRECT VIEWING WINDOW
3. LIGHT BAR
4. GRAPHICS DISPLAY
5. STATUS DISPLAY
6. CAMERA CONTROL PANEL
7. KEYBOARD UNITS
8. 6 DOF JOINT CONTROL PANEL
9. AUDIO ALERT AND COMMUNICATION PANEL
10. MONITOR SELECTION PANEL
11. MANIPULATOR SELECTION PANEL
12. VOICE CONTROL PANEL
13. AMPLIFIER AND POWER SUPPLY PANEL
14. AVAILABLE PANEL SPACE



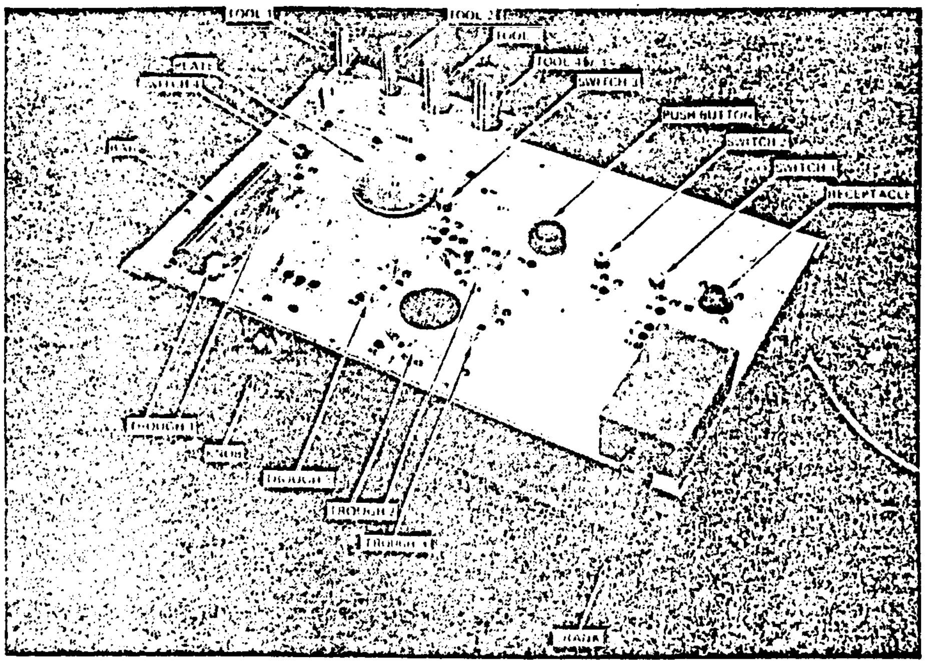
The task board has been designed and built at SRI International under a JPL contract. It is instrumented for seven different tasks, some with a variety of tolerance tools and movement distances. Each contact point is equipped with microswitches to detect the raising of a tool or the touching at contact. The receptacle has a light spring-loaded plunger that follows the tool as it descends. The status of the micro-switches can be recorded on a paper tape automatically for subsequent computer-based performance evaluation of the control experiments.

The task board has already been used for seven different experimental tasks performed under the same JPL contract quoted above: Peg-in-Hole Task; Push-Button Task; Plate-Touch Task; Knob-Turn Task; Crank-Turn Task; Pick-and-Place Task; and Bar-Transfer Task. The experiments involved the use of two arms; the Ames Antropomorphic Master-Slave Arm at SRI (without force feedback) and a Model H Force-Reflecting Master-Slave Arm at Lawrence Berkeley Laboratory. The task board has been copied by Grumman Aerospace Company for control experiments. The original task board at JPL is now being used for a ULCA PhD dissertation work.

This viewgraph shows a proximmity sensor system developed at JPL for control experiments using the full-scale simulated Shuttle manipulator at JSC. The sensor system and experiments aimed at providing concepts of sensor-aided control. This sensor system helps the operator of the 16-m long manipulator find the proper final depth positioning and pitch and yaw alignments of the four-claw end effector relative to the grapple fixture of a payload near or within the grasp envelope where visual perception of depth, pitch and yaw errors are poor.

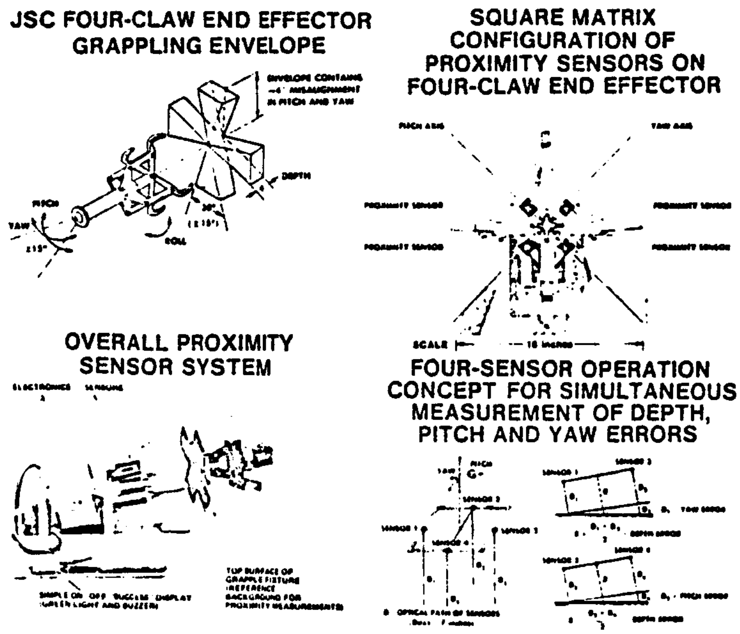
TECHNICAL GOALS AND ACTIVITIES EXAMPLE

TASK BOARD FOR CONTROL EXPERIMENTS WITH/WITHOUT FORCE FEEDBACK



ACCOMPLISHMENTS EXAMPLE

PROXIMITY SENSOR SYSTEM FOR SHUTTLE RMS EXPERIMENTS AT JSC MDF



The pictures illustrate operational ground tests conducted with the proximity sensor and simple "go-no go" display system and JSC under realistic payload handling conditions to grasp static and to capture moving targets. Altogether 112 test runs have been performed by four operators. With the simple "go-no go" display the operators achieved the capture of a slowly moving target every time.

The new graphics and numeric displays developed for the proximity sensor system integrated with the JSC Four-Claw End Effector give more detailed information to the operator to fine-control the grasp of a target. The tests conducted at the JSC MDF were aimed to evaluate the utility of this type of detailed control information displays under realistic payload handling conditions utilizing the Shuttle mock-up manipulator.

The new displays show the operator the values of depth, pitch and yaw errors referenced to end effector axes, in addition, to indicating whether the combination of these three errors will allow a successful grasp. Showing the actual values of these errors will aid the operator to fine-control the grasp.

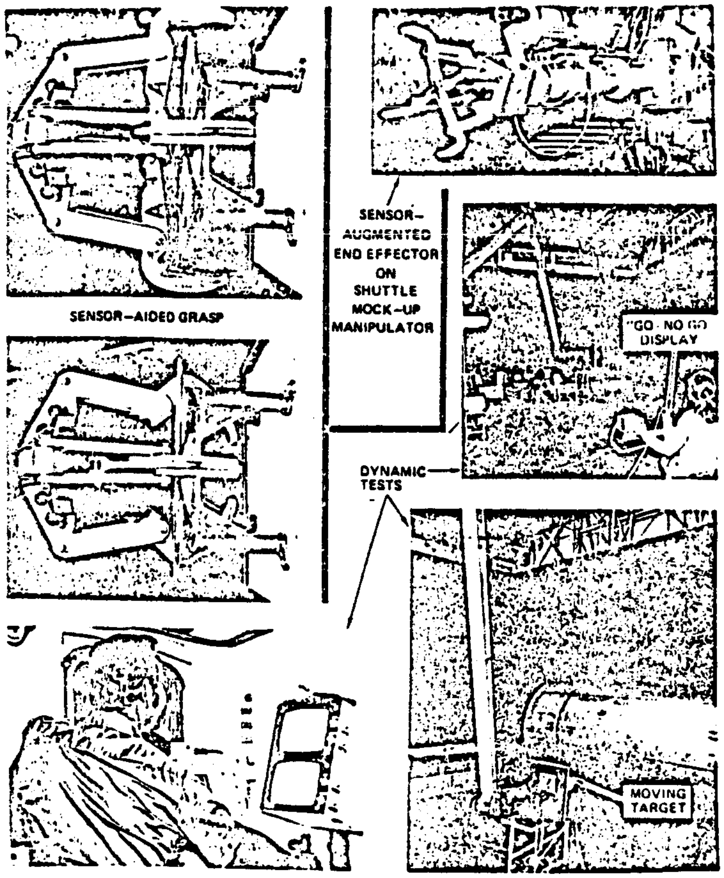
The graphic display resolution is 0.5 cm per display element in depth, and 1 degree per display element in pitch and yaw errors. The quantitative value of each error bar is increasing away from the center green lamp. Hence, zero error for each bar is at the center of the display. This focuses the operator's attention to a single "goal point" on the display towards which all error bars should be decreased and where the "green light" should be on for successful grasp. Note that depth error is indicated with two identical bars converging in a parallax-type view arrangement towards the center green lamp.

The graphic display also contains a tone generator for both "success tone" (when the center gree lamp is on) and a "warning tone" (when the target reaches or leaves the sensing range).

The numeric display resolution is 0.25 cm in depth and 0.5 deg in angular errors. The numeric display can also be applied to performance evaluation by the use of a set/reset switch. This switch can also be connected to the grasp control circuit permitting an automatic registration of depth, pitch and yaw errors at the moment when the operator decides to grasp a target.

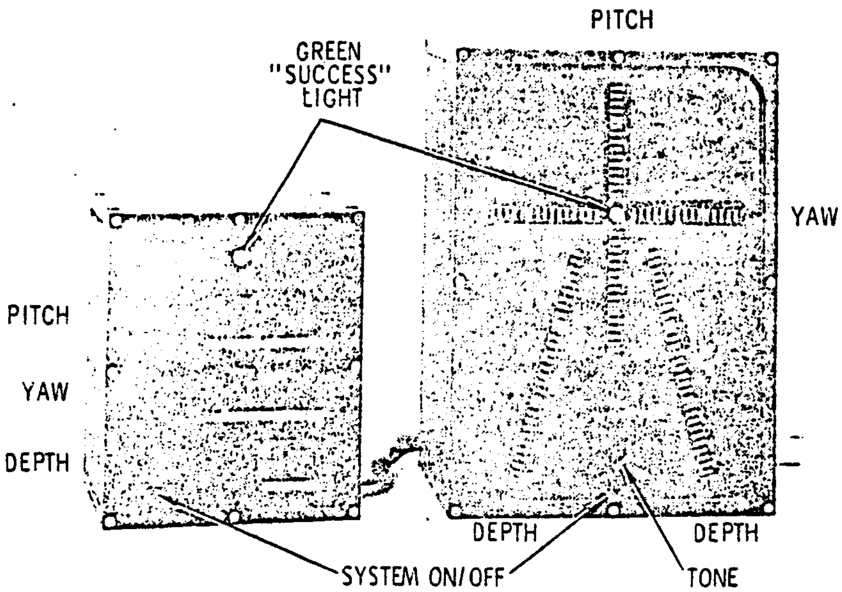
ACCOMPLISHMENTS
EXAMPLE

PROXIMITY SENSOR
AIDED GRASP
TESTS AT JSC MDF



ACCOMPLISHMENTS EXAMPLE

NEW NUMERIC AND GRAPHICS DISPLAYS FOR PROXIMITY
SENSORS INTEGRATED WITH JSC FOUR-CLAW END EFFECTOR



These test data are related to the task of positioning the grasp plane of the end effector at 0.2 inches from the grapple fixture of a static payload. As seen, the use of the sensor and advanced display system improved the accuracy by more than a factor of two.

These test data are related to the capture of a slowly moving target. In the average, the accuracy improved by a factor of two when more detailed display information was available to the operators. But take note of the performance variations between individuals. For operator no. 3, the simple "go-no go" display was more helpful in achieving better performance than the advanced display.

ACCOMPLISHMENTS EXAMPLE

PROXIMITY SENSOR AIDED CONTROL OF SHUTTLE RMS AT JSC MDF

SUMMARY OF STATIC TEST DATA

	USING SENSOR DISPLAYS		WITHOUT SENSOR DISPLAYS	
	AVERAGE RANGE ERROR (IN.)	GREEN SUCCESS LAMP "ON"	AVERAGE RANGE ERROR (IN.)	GREEN SUCCESS LAMP "ON"
27 TRAINING RUNS	0.23	NO DATA	0.48	NO DATA
27 FINAL RUNS	0.075	100%	0.2	63%

ACCOMPLISHMENTS EXAMPLE

SUMMARY OF DYNAMIC TEST DATA

PROXIMITY SENSOR AIDED CONTROL OF SHUTTLE RMS AT JSC MDF

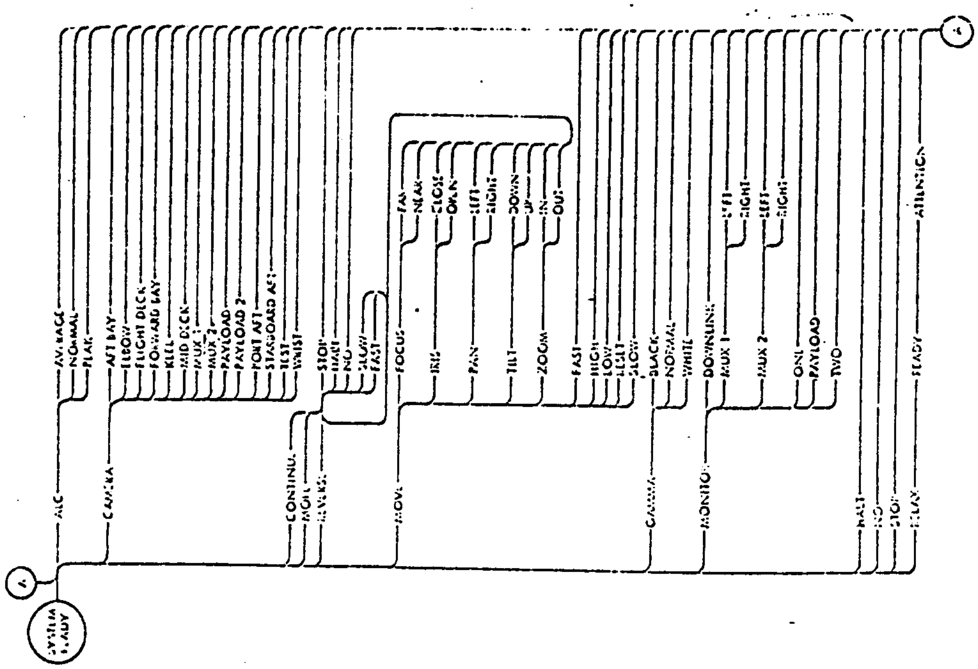
	USING GRAPHIC AND NUMERIC SENSOR DISPLAYS	USING ONLY "GREEN LAMP" SENSOR DISPLAY	WITHOUT SENSOR DISPLAYS
OPERATOR	AVERAGE RANGE ERROR (IN.)	AVERAGE RANGE ERROR (IN.)	AVERAGE RANGE ERROR (IN.)
NO. 1, 6 RUNS EACH	0.4	1.3	1.4
NO. 2, 6 RUNS EACH	0.5	0.8	1.1
NO. 3, 6 RUNS EACH	0.9	0.5	1.0
TOTAL OF 18 RUNS	0.6	0.9	1.2

The feasibility and utility of controlling the Space Shuttle TV cameras and monitors by voice commands has been investigated utilizing a discrete word recognition system. The system can be trained to the individual utterances of each operator. The system developed at JPL utilizes a commercially available discrete word recognizer, and is interfaced to the TV camera and monitor controllers of the Shuttle mock-up manipulator at JSC, using an M6802 microprocessor. The use of voice commands allows the operaotr to effectively press the control buttons of the Space Shuttle TV cameras and monitors by voice while he manually controls the Shuttle manipulator. Several different combinations of vocabulary words both with and without syntax restrictions were developed and tested. This figure shows a vocabulary with a multilevel syntax.

This figure shows a TV camera and monitor control vocabulary without syntax. The words are "natural" in the sense that they closely follow the names or functions of the keyboard buttons and switches. The operators perferred this vocabulary.

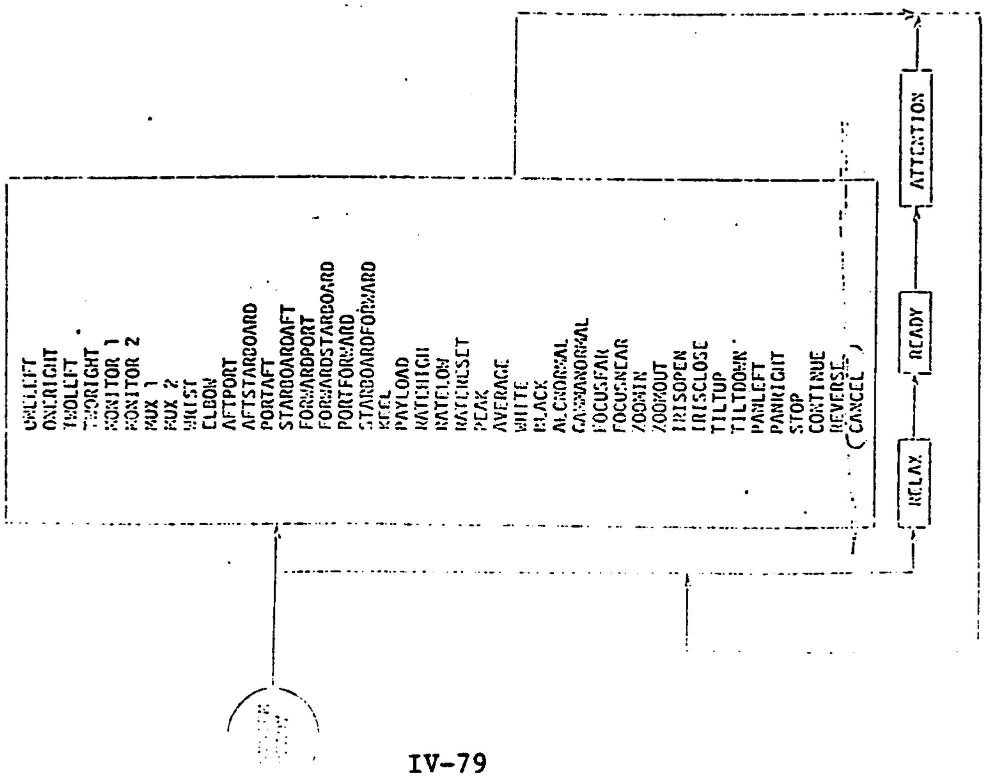
ACCOMPLISHMENTS EXAMPLE

VOICE CONTROL OF SHUTTLE TV CAMERAS / MONITORS



ACCOMPLISHMENTS EXAMPLE

VOICE CONTROL OF SHUTTLE TV CAMERA/MONITOR SYSTEM



An experimental force-torque sensor, claw and display system has been developed and integrated with the simulated full-scale Space Shuttle RMS at JSC. The sensor system provides data on the three orthogonal forces and three orthogonal torques acting at the base of the claw. This vugraph shows the overall sensor-claw display system configuration.

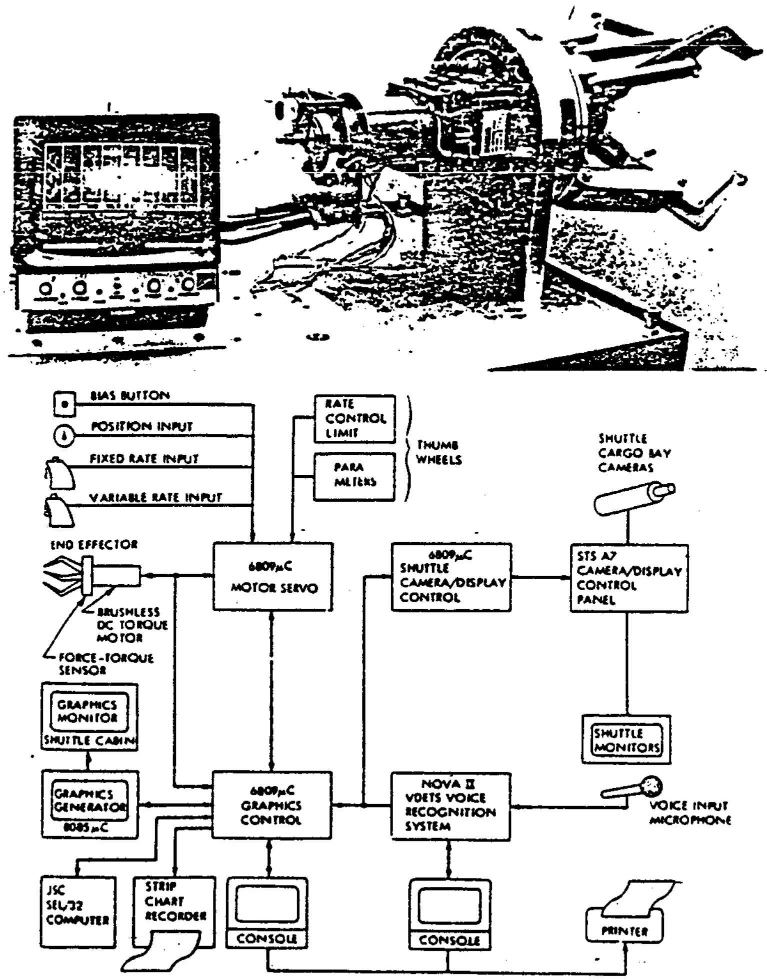
The experiment system contains the following man components and capabilities:

a) Two force-torque sensors; one is operating in the 0 to 100 lb (0 to 445 N) range, the other is the 0 to 200 lb (0 to 890 N) range.
b) A servo-controlled end effector drive system using a brushless DC torque motor in position or rate control mode; the rate control can be proportional or preselected fixed rate control.
c) An interchangeable three-claw and four-claw end effector, interfaceable to both force-torque sensors.
d) A computer graphics terminal. The graphics display is programmable for alternative scales and formats, the selection of which can be controlled manually or by a computer-recognized voice command.
e) A network of dedicated microcomputers supporting the sensor data handling, the control of end effector drive system, the graphics display and the voice command system.
f) Control input peripherals for position, fixed rate and variable rate control of the end effector.
g) An eight-channel analog chart recorder for recording sensor data and end effector status for performance evaluation.

The forces and torques measured by the sensor at the base of the claws were displayed to the operator on a 9-inch B/W monitor in graphics format. This monitor was mounted to the right of the TV monitors as shown in the pictures. The graphics display generator used in the present experimental system has a resolution of 512 by 512 pixels and is capable of displaying up to eight colors. The initial format chosen for displaying forces and torques is a very simple "bar chart" display, and a rotating two dimensional vector. At the bottom of the screen are horizontal bars indicating the position of the claw. As the claw is closed the bars extend toward the center of the screen. When the claw is fully closed, it appears as a solid horizontal bar on the display. Beneath the force/torque bar chart display appears the last word recognized by the voice recognition system. The word blinks if the voice system is active.

The basic RMS control was manual using two three-dimensional hand controllers for RMS control in resolved rate control mode: one hand controller (left hand) controls the three translational components of RMS end effector motion, the second hand controller (right hand) controls the three rotational components of RMS end effector motion. The on-off switch, which controls the opening and closing of the RMS end effector, was replaced with a linear potentiometer arrangement providing proportional rate control capability for opening and closing the claws. The direct visual and TV information sources and the basic RMS control are Shuttle baseline arrangements. The graphics display and the proportional claw control were specifically developed for the force-torque control experiments.

ACCOMPLISHMENTS EXAMPLE
FORCE-TORQUE SENSOR-CLAW-DISPLAY SYSTEM FOR
SHUTTLE RMS CONTROL EXPERIMENTS AT JSC MDF



ACCOMPLISHMENTS EXAMPLE
FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF
-OPERATORS USE GRAPHICS DISPLAY OF SENSOR DATA-

Two sets of control experiments were performed using force-torque sensor information. The first set of experiments involved the use of a task board equipped with "tools" and "modules" as shown in the pictures.

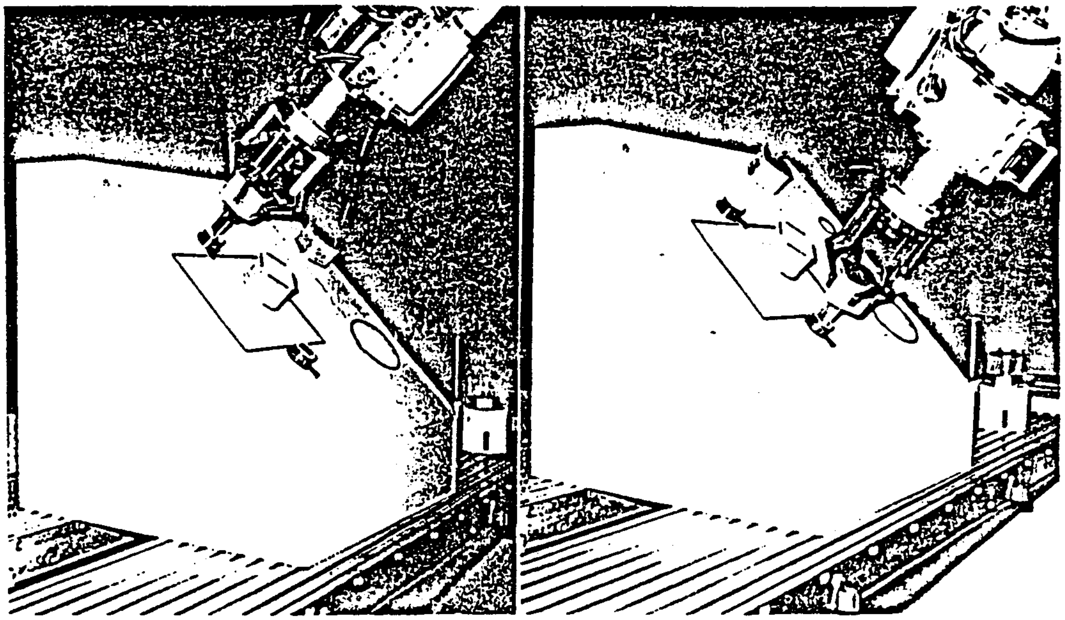
The "tool" and "module" handling task board was placed in the bay of the Shuttle mock-up, about 8 meters (25 feet) from the Shuttle cockpit. The task board contained (a) a box, (b) a keyed cylinder, (c) a screwdriver, and (d) a square-base wrench. The operator's task was to remove the "modules" from their retaining holes in the task board and insert them back to their holes. The removal and insertion of one of the modules required the use of "tools" which also were placed in retaining holes in the task board. All insertion tolerances on the task board were 6 mm (0.25 inches).

The pictures show "module" insertion and removal using force-torque sensor information. The insertion and removal tasks are risky since jamming can easily occur. Jamming occurs when the force applied in the direction of insertion or removal no longer causes the insertion or removal to proceed. In general, jamming is caused by moving the direction of the applied force outside certain bounds.

ACCOMPLISHMENTS EXAMPLE

FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF

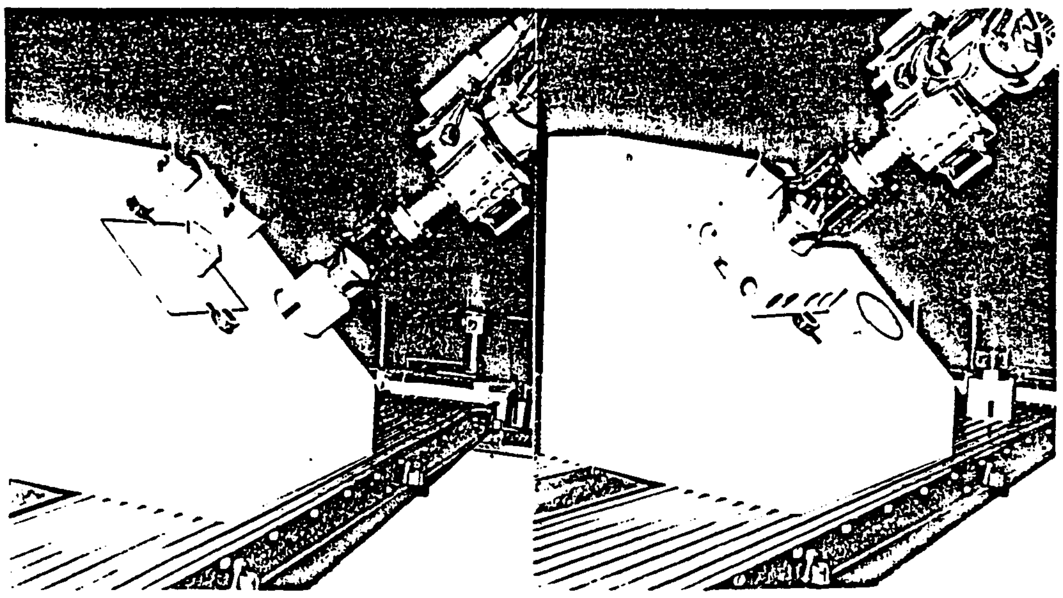
-TOOL HANDLING-



ACCOMPLISHMENTS EXAMPLE

FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF

-MODULE HANDLING-



The table shown here lists the full sequence of subtasks involved in the "tool" and "module" handling tests when the main task was to reinsert the moduels back to their retainers in the task board. During these tests, the operators had access to all three information sources: direct vision, TV cameras/monitors and graphics display of force-torque sensor information. The data shown in the table should be interpreted as indicative regarding the distribution of performance times among the subtasks. Note also the spread of performance times (max. and min. time) for a subtask. The large spread of performance times is essentially caused by three factors: (i) the initial error when contact is established, (ii) the operator's ability to interpret a multidimensional error vector in a given situation, and (iii) the operator's ability to respond through manual control to a multidimensional error vector.

Typical force-torque time histories recorded during the "module" and "tool" handling tests are shown in these figures. The graphics display of force-torque sensor information was most useful for preventing jamming during box and cylinder insertion, illustrated in the figures. The large amplitude variations in the F_z force shown in the upper and lower figures indicate situations where jamming could have occurred. The time history of the F_z force variations shows that the operator prevented the jamming and successfully completed the box and cylinder insertions.

ACCOMPLISHMENTS

EXAMPLE

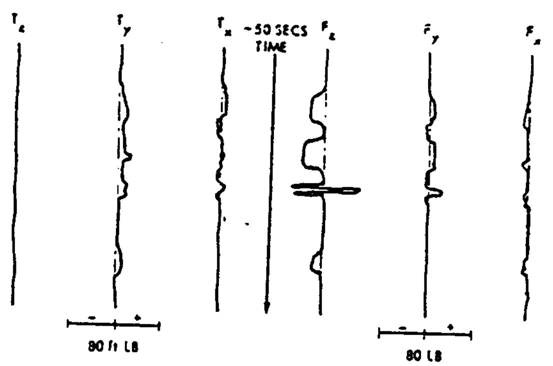
TIME PERFORMANCE DATA OF TASK BOARD "MODULE" AND "TOOL" HANDLING TESTS

	mean Δt [min:sec]	max. Δt [min:sec]	min. Δt [min:sec]
START RUN			
BOX GRAPPLED	1:19	2:12	:26
BOX MANEUVERED	3:00	5:23	1:43
BOX INSERTED	4:26	21:20	:21
RED TOOL GRAPPLED	2:03	5:03	:01
RED TOOL EXTRACTED	0:30	2:18	:07
RED TOOL MANEUVERED	2:25	4:43	:20
RED TOOL INSERTED	1:19	4:23	:01
RED LATCH CLOSED	:38	1:49	:01
RED TOOL REMOVED	:11	:59	:01
RED TOOL MANEUVERED	2:45	4:28	:17
RED TOOL INSERTED	1:14	4:26	:40
RED TOOL RELEASED	:04	:12	:01
BLUE TOOL GRAPPLED	1:38	3:34	:15
BLUE TOOL EXTRACTED	:13	:21	:02
BLUE TOOL MANEUVERED	1:27	2:59	:34
BLUE TOOL INSERTED	1:45	4:52	:10
BLUE LATCH CLOSED	:34	1:20	:10
BLUE TOOL REMOVED	:13	:21	:02
BLUE TOOL MANEUVERED	1:25	2:53	:22
BLUE TOOL INSERTED	:59	2:36	:08
BLUE TOOL RELEASED	:11	:55	:01
CAN GRAPPLED	2:41	5:16	1:19
CAN MANEUVERED	2:25	5:00	1:13
CAN INSERTED	4:20	13:48	:28
CAN RELEASED	:07	:16	:01
TOTAL TIME AVERAGE FOR PHASE B TASK	37:53	MEAN TIME COMPUTED FROM TEN TEST RUNS	

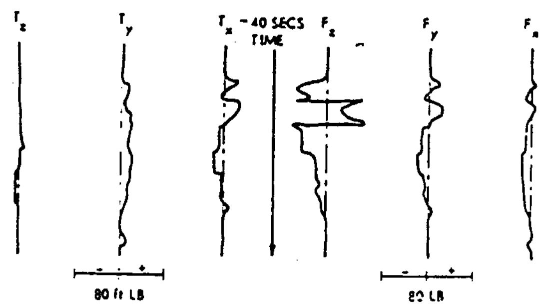
ACCOMPLISHMENTS

EXAMPLE

TYPICAL TASK BOARD PERFORMANCE DATA



CYLINDER INSERTION



BOX INSERTION

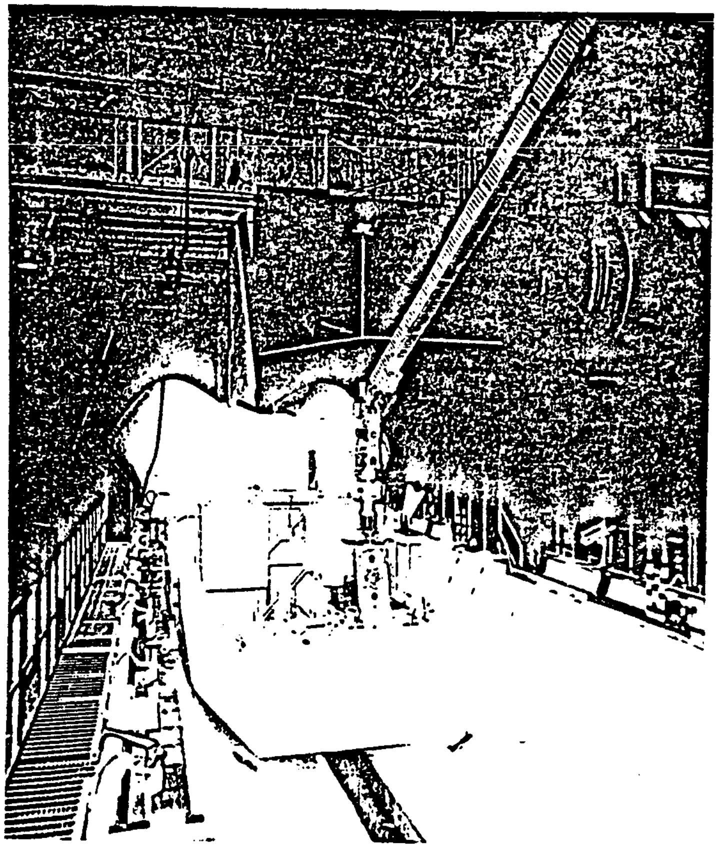
The objective of the payload berthing test was to maneuver the simulated PDP payload into a retention or latching mechanism shown in the figure. The latch assembly was placed in the bay of the Shuttle mock-up about 10 meters (30 feet) from the Shuttle cockpit. The berthing tests were performed so that the weight of the mock-up PDP payload (about 250 lb) was counterbalanced through a pulley attached to an overhead crane. In this way the only forces and torques generated at the force-torque sensor were those caused by the payload contact with the latch assembly. The counterbalance arrangement allowed all small translational and rotational movements of the manipulator necessary for the tests. The tests started with lowering the guide pins of the PDP paylaod to the point that they were almost touching the V-shaped guides of the latching mechanism.

The latching mechanism used in the payload berthing tests consists of four V-shaped guides. Two are on the forward end of the mechanism, and two are on the port side. Three microswitches are closed whenever the payload is is level and touching the bottom of the guides. Three indicators inside the flight deck area of the cockpit indicate the on-off state of the three microswitches. To latch safely requires that all three microswitches are on. This in turn requires a simultaneous contact at points A, B and C. Ideally, only a small "down" force should be acting between the payload and the latch assembly at the terminal contact, and all lateral forces and all torques should be zero or near zero. That is, the operator had to zero out a five-dimensional error vector and keep the sixth component within bounds.

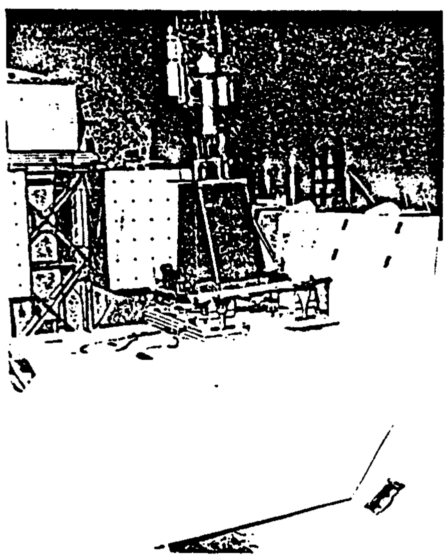
ACCOMPLISHMENTS
EXAMPLE

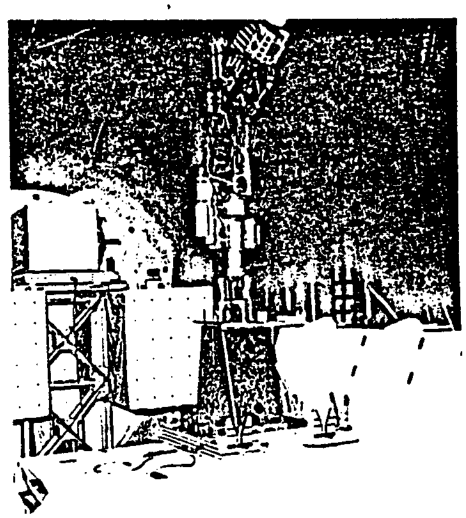
FORCE-TORQUE
CONTROL EXPERIMENTS
AT JSC MDF

PAYLOAD (PDP) BERTHING



ACCOMPLISHMENTS EXAMPLE
FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF
-PAYLOAD (PDP) BERTHING-





This table shows a few significant points:

(1) The most interesting result is that all operators consistently could perform the payload berthing without any visual feedback, relying only on graphics display of force-torque sensor information during the terminal phase of berthing when the payload guide pins were inside the V-shaped guides of the latch assembly. However, operator comments indicated the desirability of having some visual access to the RMS and task scene.

(2) The time data indicate that the force-torque sensor information may contain more relevant guidance data than the visual information during the terminal/contact phase of the payload berthing task, since the average time under condition A is shorter than under condition B.

(3) The time data also indicate that the use of more sensory information (that is the simultaneous use of visual and graphics display of force-torque sensor information) may lead to longer performance time unless the information is properly coordinated in order to ease the operator's perceptive workload. Note that the average time under condition C is longer than under condition A or B.

A typical time history of contact forces and torques recorded during payload berthing is shown here. The significant point here is that only graphics display of force-torque information was available to the operators; the window was blocked and the TV monitor was turned off.

ACCOMPLISHMENTS EXAMPLE

TIME PERFORMANCE DATA OF PAYLOAD BERTHING TESTS

Information Condition \ Operators	Operator No. 1		Operator No. 2		Overall Average Time
	max.time / min.time	mean time	max.time / min.time	mean time	
A	3:58 / 0:39	1:40	4:33 / 1:27	2:49	2:14
B	4:10 / 0:48	2:11	5:27 / 1:46	3:17	2:44
C	3:48 / 0:44	2:13	7:27 / 2:39	4:16	3:14

time in [min:sec]

A: only force-torque sensor display

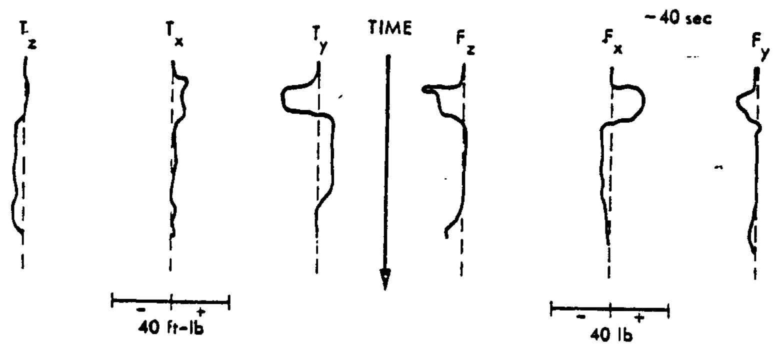
B: only visual (direct and/or TV) feedback

C: both visual and sensor display feedback

Note: each "mean time" is computed from twelve test runs

ACCOMPLISHMENTS EXAMPLE
FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF
-PERFORMANCE DATA-
-PAYLOAD (PDP) BERTHING-

- ONLY GRAPHICS



Another typical time history of contact forces and torques recorded during payload berthing. The point here is that, using graphics display of force-torque sensor information for guidance, the operators could successfully control the excess contact forces and torques during the terminal phase of the pyaload berthing task.

Another typical time hisotry of contact forces and torques recorded during payload berthing. The point here is that, without graphics display of force-torque sensor information, using only visual feedback, the operators had no idea about the magnitude and location of contact forces and torques generated during payload berthing though the latching was successfully accomplished.

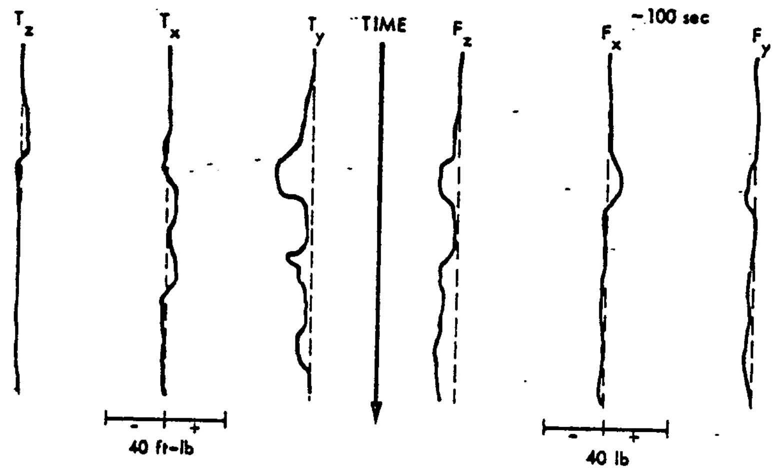
ACCOMPLISHMENTS EXAMPLE

FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF

-PERFORMANCE DATA-

-PAYLOAD (PDP) BERTHING-

GRAPHICS + DV + TV



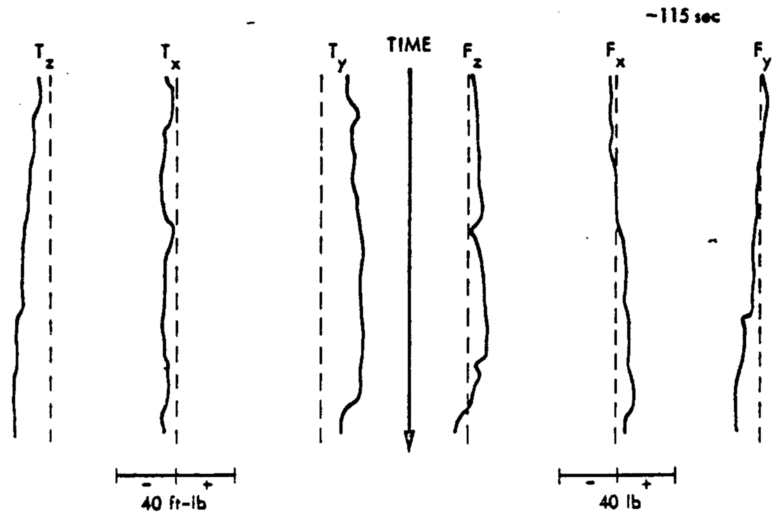
ACCOMPLISHMENTS EXAMPLE

FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF

-PERFORMANCE DATA-

-PAYLOAD (PDP) BERTHING-

ONLY DV + TV



APPENDIX B

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KENNEDY SPACE CENTER GROUND OPERATIONS

by

David C. Moja
Chief, Future Aerospace Projects Office
National Aeronautics and Space Administration
Kennedy Space Center, Florida

ABSTRACT

This paper addresses the human role in space vehicle ground operations. After a brief description of the various facets of KSC ground operations, including space vehicle control and monitor, payload and Orbiter processing, servicing, and countdown, areas that can potentially be enhanced by technological development are discussed.

INTRODUCTION

The majority of KSC ground operations functions require extensive human activity and/or interaction with computers or other equipment. In many cases, the safety and efficiency of these ground operations functions can be enhanced by new and innovative technological developments.

This paper discusses the following facets of KSC ground operations:

- Space Vehicle Control and Monitor
- Payload Processing
- Orbiter Processing
- Element Mating
- Servicing
- Countdown
- Post Landing
- Future Systems

SPACE VEHICLE CONTROL AND MONITOR

The focal point for space vehicle control and monitor is the launch control rooms where checkout, servicing, and countdown activities are managed. The Launch Processing System (LPS), which is a distributed computer system, issues commands and processes data associated with the space vehicle and ground support equipment (GSE). The LPS consists of fifteen consoles in the control room and associated equipment at all areas of Launch Complex 39. Systems and applications software, which is unique for each space mission, requires large numbers of people for computer program generation and verification. The Launch Processing System also provides capabilities for operations scheduling, problem tracking, logistics management, and configuration management.

PAYLOAD PROCESSING

Prior to installation into the Shuttle Orbiter the following payload functions are accomplished: completion of assembly, subsystem checkout, integrated/mission test, upper stage/payload mating, servicing, verification of interfaces.

ORBITER PROCESSING

Shuttle Orbiter processing takes place in the hangar-like Orbiter Processing Facility and consists of the following to prepare for the next space Shuttle mission: subsystem checkout, thermal protection system (tile) refurbishment, payload installation and interface verification, integrated mission test.

SHUTTLE ELEMENT MATING

The elements of the Shuttle are integrated together in the Vehicle Assembly Building. The following functions are performed: physical mating, connection of electrical and fluid umbilicals, and interface verification.

SPACE VEHICLE SERVICING

After the assembled space vehicle has been moved to the launch pad, the following fluid systems are serviced for launch: fuel cell cryogenics, hypergolic propellants, ammonia, nitrogen, and hydrazine.

SPACE VEHICLE COUNTDOWN

The final countdown, which takes five hours, consists of the following: cryogenic propellant loading, flight crew ingress, final checkout of systems, and verification that all systems are within specifications for launch.

ORBITER POST LANDING

Upon completion of the mission, after the Orbiter has landed, a safety check is performed to verify that the hypergolic system is not leaking toxic gases. Then, connections are made to mobile ground support equipment to provide special purges and cooling for the Orbiter. The Orbiter is then towed to the Orbiter Processing Facility and another ground turnaround cycle is initiated.

FUTURE SPACE SYSTEMS

Proposed future space systems, including the Space Station and the Orbital Transfer Vehicle, will pose additional technological challenges to enhance ground operations safety and efficiency. The Space Station will be designed with an evolutionary growth capability, and thus will require special provisions for interface verification prior to the launch of each element. Also, Space Station re-supply will pose special challenges in the area of ground logistics. The Orbital Transfer Vehicle will have to be capable of checkout and servicing both on the ground and at the Space Station. This will require special design considerations to minimize "hands-on" operations.

AREAS NEEDING IMPROVEMENT

Based on the ground operations functions discussed above, the following ground operations areas potentially can benefit from technological developments:

- Man/Machine Interfaces
- Software Generation and Verification
- Information Management
- Fault Detection and Isolation
- Hazardous Monitoring and Leak Detection
- Interface Verification

MAN/MACHINE INTERFACES

The complexity of the space vehicle and its associated Ground Support Equipment requires a large number of time critical interactions between control room operating personnel and the Launch Processing System. New methods to simplify these interactions are needed.

SOFTWARE GENERATION AND VERIFICATION

Because of varying mission requirements, major changes are made to the Shuttle and payload software programs prior to each launch. This requires a large number of man-hours for generation and verification. New techniques, possibly including machine intelligence developments, are required to simplify this function.

INFORMATION MANAGEMENT

As the space Shuttle becomes operational, new techniques will be required to provide real-time scheduling, inventory control, and configuration management functions.

FAULT DETECTION AND ISOLATION

The present Shuttle system and the proposed Space Station and Orbital Transfer Vehicle will require optimum methods for subsystem fault detection and isolation to minimize system downtime and to enhance operational efficiency.

HAZARDOUS MONITORING AND LEAK DETECTION

Because of the hazardous fluids required by space vehicle systems, new developments in remote and in situ sensing devices and the associated electronics are required. Simplicity and reliability are primary considerations in this area.

INTERFACE VERIFICATION

Significant amounts of manpower are expended during space vehicle ground operations to verify interfaces after electrical and fluid connectors have been "mated" together. New developments in both fluid and electrical connectors, to enhance safety and to minimize checkout, are required. Also, since elements of the Space Station will be launched over a period of years, a method to ensure interface compatibility of elements in space and other elements prior to launch is needed.

SUMMARY

Space vehicle ground operations functions presently require intensive human activity. Potential technological developments can enhance both the efficiency and safety of these operations.

ROBOTICS/SUPERVISORY CONTROL

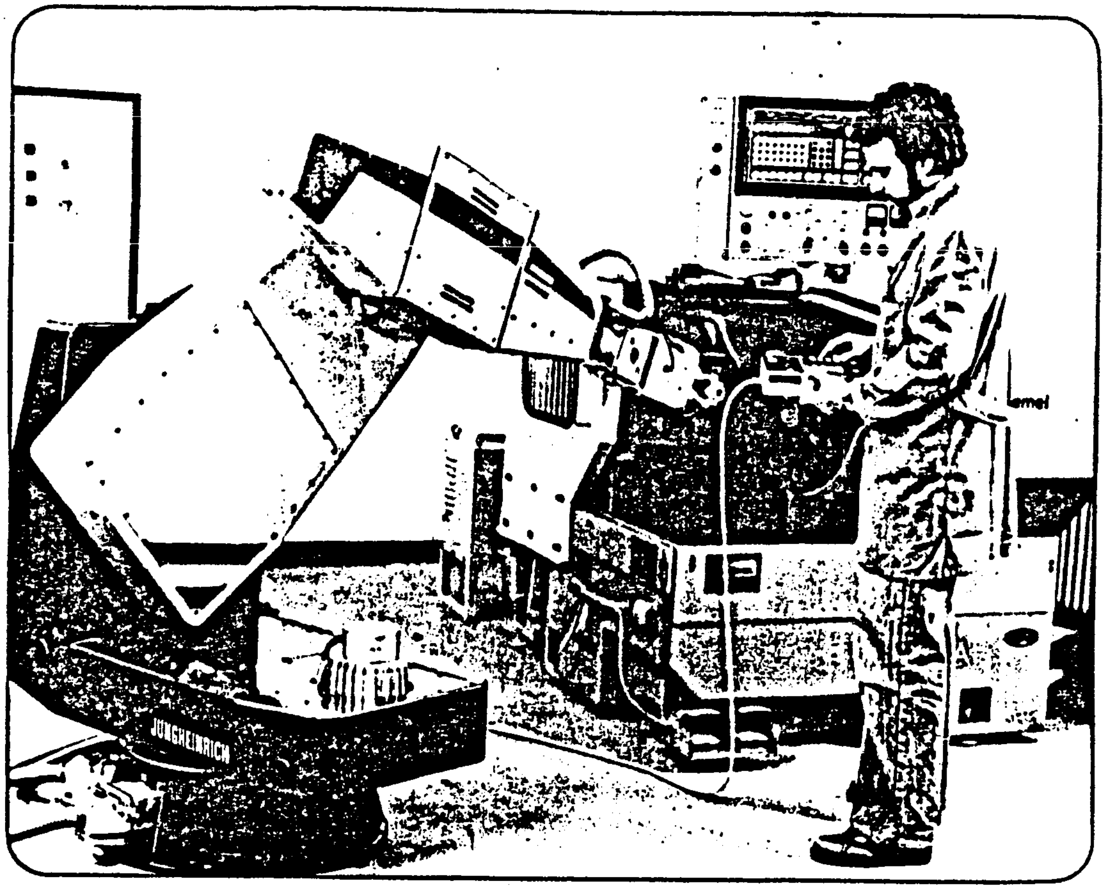
DR. EDWALD HEER

MANAGER, AUTONOMOUS SYSTEMS AND SPACE MECHANICS

JET PROPULSION LABORATORY

This is representative of the state of the art of industrial robots and the way industrial robots are programmed through teach-in or walk-through methods. Only very few off-line programming languages are in practical use today. Most have been developed and are applied in a laboratory setting. In practical applications, it is difficult to do off-line programming of robots because of lack of training of shop personnel in the art of programming, or the lack of knowledge of programmers of the requirements on the shop floor. Practically the most acceptable way of industrial robot programming is still done by teach-in or walk-through programming.

Some of the developed industrial robot programming languages and their identified characteristics for comparison



ROBOTICS AND MANIPULATORS

PROGRAMMING LANGUAGES

LANGUAGE	DEVELOPER	BASED ON	COMPUTER	COMMANDS			OBJECT DESCRIPTIONS		ARITHMETIC OPERT'NS	PROCESS OPERT'NS CONTROL
				MOTION	HAND	SENSOR REFERENCED	POSITION	GEOMETRY		
AL	STANF UN AI LAB	ALGOL	PDP-10 PDP-11/45	X	X	X		X	X	X
AUTOPASS	IBM	PL/I		X	X	X	X	X		
ALFA	GNL TELEPH & ELECTR CO		PDP-11/10	X	X	X				X
LAMA	MIT AI LAB									
MAL	UNIV MAILAND	BASIC	ITAL MC	X	X				X	X
ML	IBM		IBM/7	X	X	X			X	X
RAPT	UNIV EDINBURGH	APT	PDP-10	X			X	X		
ROCOL	UNIV LENINGRAD		ACBTM-6000	X	X				X	X
SIGLA	OLIVETTI			X						X
TL	TOYOTA		NOVA-01	X	X	X				X
VAL	UNIMATION		LSI-11	X	X				X	X
SRI-AL	SRI	FORTRAN	PDP-11/40	X						
CML	CINCINNATI MILACRON			X						X
TUB	TECH UNIV BERLIN		INTERDATA 7/16	X		X				X
ILUB	UNIV BUDAPEST			X	X	X				
HCS	NBS	FORTRAN	PDP-11/45	X	X	X	X			
DONAU-S	UNIV MAILAND	LISP		X	X	X	X			X

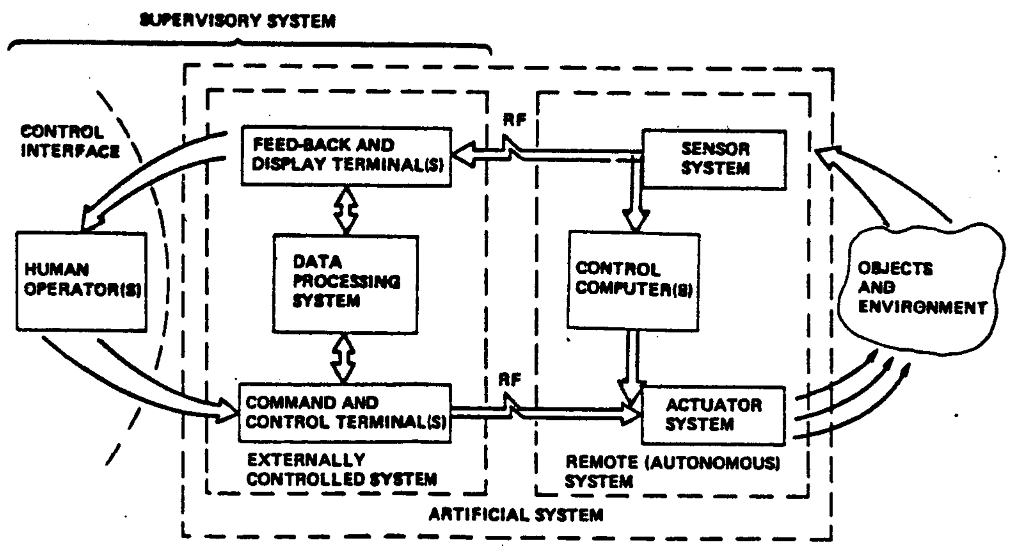
Nine industrial robot programming languages have been evaluated recently with respect to the twelve parameters identified on the left. The most widely used languages as of this date are T3 developed by Cineninaty Milacron and VAL developed by Unimation. T3 is a teach-in language and VAL is a language with off-line capabilities, but is mostly used in research laboratories.

An example of a systems operations model

ROBOT PROGRAMMING LANGUAGES COMPARISONS

LANGUAGE	PARAMETERS
AL	MODALITIES
AML	TYPE
HELP	GEOMETRIC DATA
JARS	DISPLAY
MCL	NO. OF ARMS
RAIL	CONTROL STRUCTURE
RPL	CONTROL MODES
T3	MOTION TYPES
VAL	SIGNAL LINES
	SENSOR INTERFACE
	SUPPORT MODULES
	DEBUGGING

SYSTEM OPERATIONS MODEL



Self Explanatory

Self Explanatory

AUTONOMOUS SYSTEMS TECHNOLOGY
LEVELS OF FUNCTIONAL SYSTEMS AUTONOMY

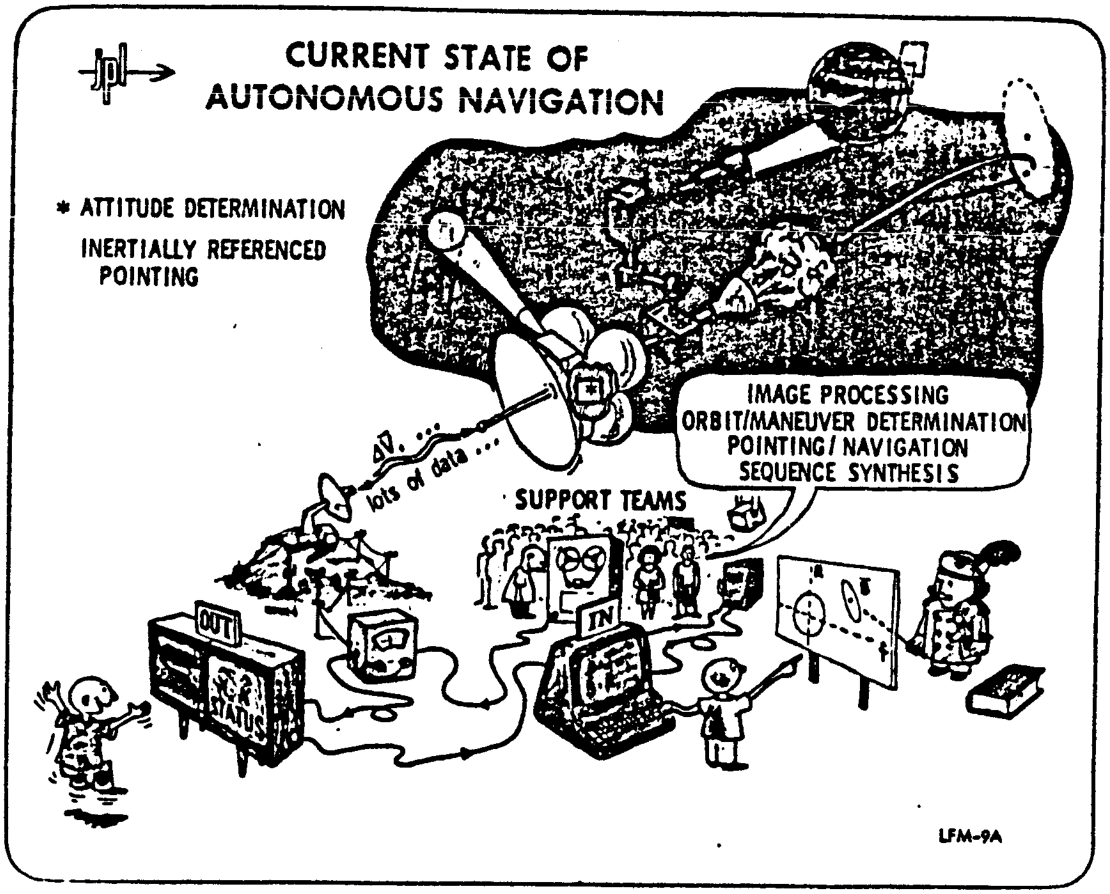
LEVEL 1	SERVO-LOOP FUNCTIONS MEETING EXTERNALLY-SET GOALS
LEVEL 2	EXECUTION OF EXTERNALLY-PLANNED SEQUENCES/PROGRAMS OF ACTIONS
LEVEL 3	ADAPTATION OF SERVO-LOOP PARAMETERS TO ACCOMMODATE ENVIRONMENTAL VARIATIONS
LEVEL 4	TOLERANCE OF SYSTEM FAULTS THROUGH DETECTION, LOCATION, AND RECONFIGURATION TO ISOLATE AND REPLACE FAULTY SYSTEM ELEMENTS
LEVEL 5	LOAD-SHEDDING TO ISOLATE LIMITED SYSTEM CAPABILITIES FROM CURRENTLY NON-ESSENTIAL TASKS
LEVEL 6	SELF-PRESERVATION OF THE SYSTEM FROM UNSAFE INTERNAL CONDITIONS AT THE COST OF REDUCING MISSION PERFORMANCE
LEVEL 7	AVOIDANCE OF EXPOSURE OF THE SYSTEM TO UNSAFE ENVIRONMENTS
LEVEL 8	MANAGEMENT OF SYSTEM RESOURCES TO ALLOCATE THEM TO INDIVIDUAL TASKS IN A WAY THAT MAXIMIZES OVERALL MISSION PERFORMANCE
LEVEL 9	VALIDATION OF EXTERNAL INSTRUCTIONS FROM SYSTEM SUPERVISORS, TO EVALUATE AND REJECT INSTRUCTIONS THAT WOULD INADVERTENTLY ENDANGER THE SYSTEM OR ITS PERFORMANCE
LEVEL 10	TASK PLANNING TO SELECT SATISFACTORY OR OPTIMAL, DETAILED PLANS FOR ACHIEVING HIGHER-LEVEL GOALS, PARTICULARLY IN THE PRESENCE OF LARGE ENVIRONMENTAL OR SYSTEM VARIATIONS

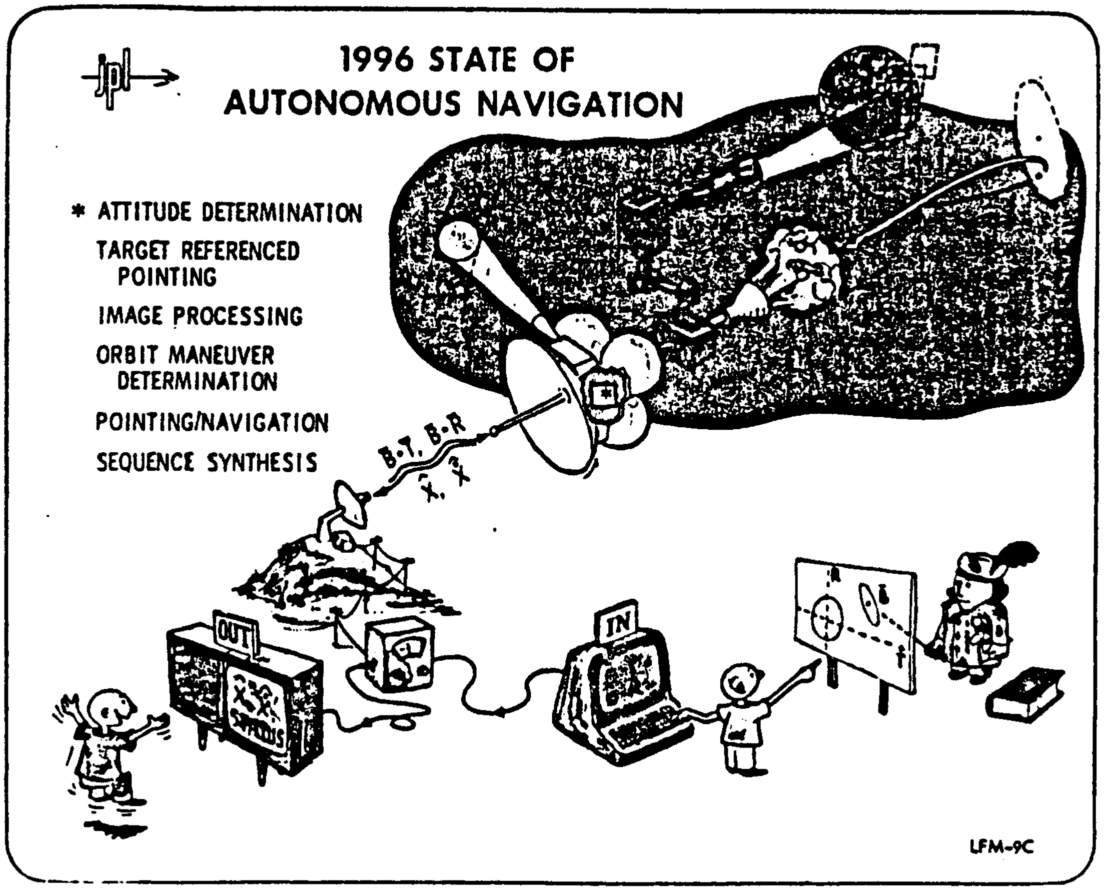
AUTONOMOUS SYSTEMS TECHNOLOGY
REASONS FOR AUTONOMOUS SYSTEMS

- REDUCE THE WORK LOAD FOR USERS AND OPERATORS OF GROUND BASED SYSTEMS, e.g., DOCUMENTATION, MAINTENANCE, MANAGEMENT
- LIMIT THE AMOUNT OF REQUIRED COMMUNICATION WITH REMOTE SYSTEMS, e.g., BECAUSE OF PLANETARY OCCULTATION, TWO-WAY LIGHT TIME, CHANGE OF DETECTION
- COMPENSATE FOR TECHNICAL LIMITATIONS OF COMMUNICATIONS WITH REMOTE SYSTEMS, e.g., LIMITED BANDWIDTH, ERROR RATE, RESPONSE TIME OF EQUIPMENT
- SUSTAIN RELIABLE PERFORMANCE OF GROUND BASED AND REMOTE SYSTEMS, e.g., FAULT TOLERANCE, SELF-MAINTENANCE

The current state of autonomous navigation and autonomous operations in space in general, is characterized by large support teams. The objective is to automate their functions either on the ground and/or on the spacecraft leading to the situation depicted in the next viewgraph.

Future state of autonomous navigation


CURRENT STATE OF AUTONOMOUS NAVIGATION
* ATTITUDE DETERMINATION
INERTIALLY REFERENCED POINTING
IMAGE PROCESSING
ORBIT/MANEUVER DETERMINATION
POINTING/NAVIGATION
SEQUENCE SYNTHESIS
ΔV, ...
lots of data ...
SUPPORT TEAMS
OUT
STATUS
IN
LFM-9A


1996 STATE OF AUTONOMOUS NAVIGATION
* ATTITUDE DETERMINATION
TARGET REFERENCED POINTING
IMAGE PROCESSING
ORBIT MANEUVER DETERMINATION
POINTING/NAVIGATION
SEQUENCE SYNTHESIS
B·T, B·R
OUT
IN
LFM-9C

The development of the required technology to effect system autonomy requires the solution of problems in automated decision making. These problems fall into a whole continuum between the highly well-structured decisions at one end and the highly ill-structured decisions at the other end and include human oriented decision-making methods and automation oriented decision making methods.

There are currently three JPL automation tools under development. These tools are known as GREAT (Graphic Representation Editing Aid Timeline program), MOVIE (Moving Observation View Interactive Editor), and DEVISER. When interconnected, these tools from a workstation which allows the user to design, plan, and integrate and analyze sequences of events in either graphic or tabular format (see Fig. 1).

The GREAT program is a general purpose graphic timeline editor which can be modified by the user to operate from different sequence file formats and which displays and/or prints the information in formats specified by the user. The S/W is very user friendly, relying mainly upon graphics tablet input for menu option selection and information manipulation.

The MOVIE program is a more specialized observation design tool which is used to compute S/C positions relative to planets and satellites, based upon high precision ephemeredies input from a central computer. This information is then used to graphically explore potential observation opportunities and to model S/C scan platform positioning and instrument shutterings as needed for observation designs.

The DEVISER program is a highly sophisticated, artificial intelligence, automated planner. Given a request for a system action or state, the initial states of the system and a knowledge base describing the system (the way it functions and rules governing its operation), DEVISER will produce a plan which will satisfy the request and all constraints (if such a solution exists).

AUTOMATED DECISION-MAKING AND PROBLEM SOLVING

PROBLEM STRUCTURE AND SOLUTION TECHNIQUES

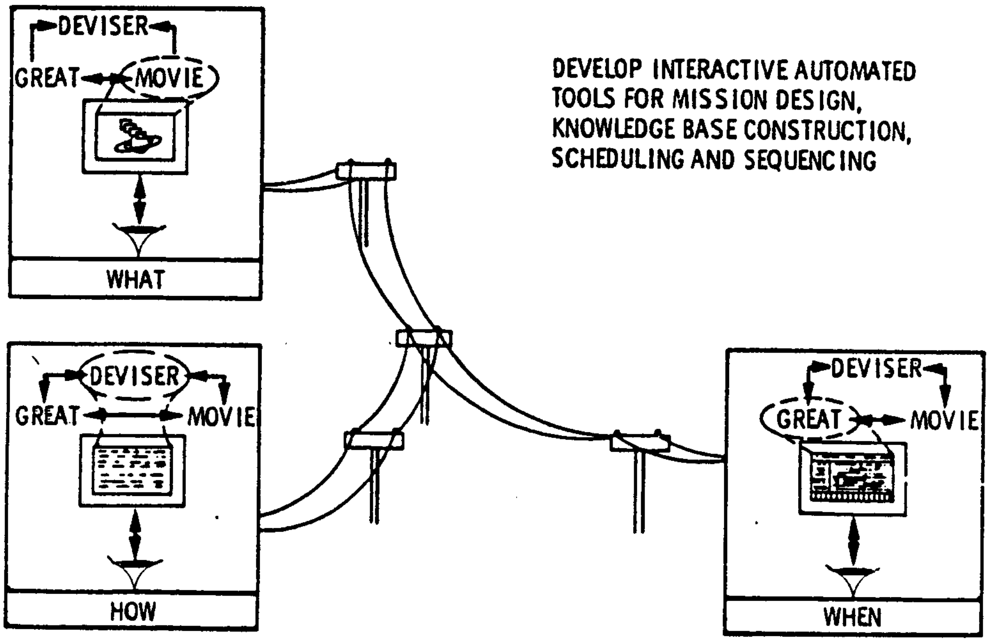
- WELL STRUCTURED PROBLEMS
  - ROUTINE, REPETITIVE DECISIONS
  - PROGRAMABLE DECISION PROCESSES
- ILL STRUCTURED PROBLEMS
  - NOVEL POLICY DECISIONS
  - NONPROGRAMABLE DECISION PROCESSES

- HUMAN ORIENTED DECISION-MAKING
  - HABIT
  - CLERICAL ROUTINE
  - STANDARD PROCEDURES
  - WELL DEFINED COMMUNICATION CHANNELS
  - JUDGEMENT
  - INTUITION AND CREATIVITY
  - RULES OF THUMB
  - SELECTION AND TRAINING OF MANAGERS

- AUTOMATION ORIENTED DECISION-MAKING
  - OPERATION RESEARCH
  - COMPUTER DATA ANALYSIS AND PROCESSING
  - HEURISTIC PROBLEM SOLVING TECHNIQUES
  - HEURISTIC COMPUTER PROGRAMS

EH-13
May 19, 1980

GRAPHIC WORK STATION DEVELOPMENT



DEVELOP INTERACTIVE AUTOMATED TOOLS FOR MISSION DESIGN, KNOWLEDGE BASE CONSTRUCTION, SCHEDULING AND SEQUENCING

Over the past two years, automated decision making tools based on machine intelligence techniques have been developed. This work contributes to the mission operations uplink process control automation efforts at JPL.

A computer program, DEVISER, has been developed and demonstrated in the laboratory. DEVISER is an automatic planner/scheduler that accepts a start state description of a system (e.g., for a spacecraft), a goal description (e.g., take pictures of the red spot of Jupiter), and the content of a knowledge base describing the physical and operational characteristics and relationships of the mission in a suitably structured form. DEVISER then develops automatically the command sequence that must be sent to the spacecraft in order to implement the desired goal. DEVISER can be operated interactively with editing capabilities. When it has difficulty to schedule a goal, it will come to the user and ask for help; the user can then alter the goal structure until an acceptable solution can be found by DEVISER.

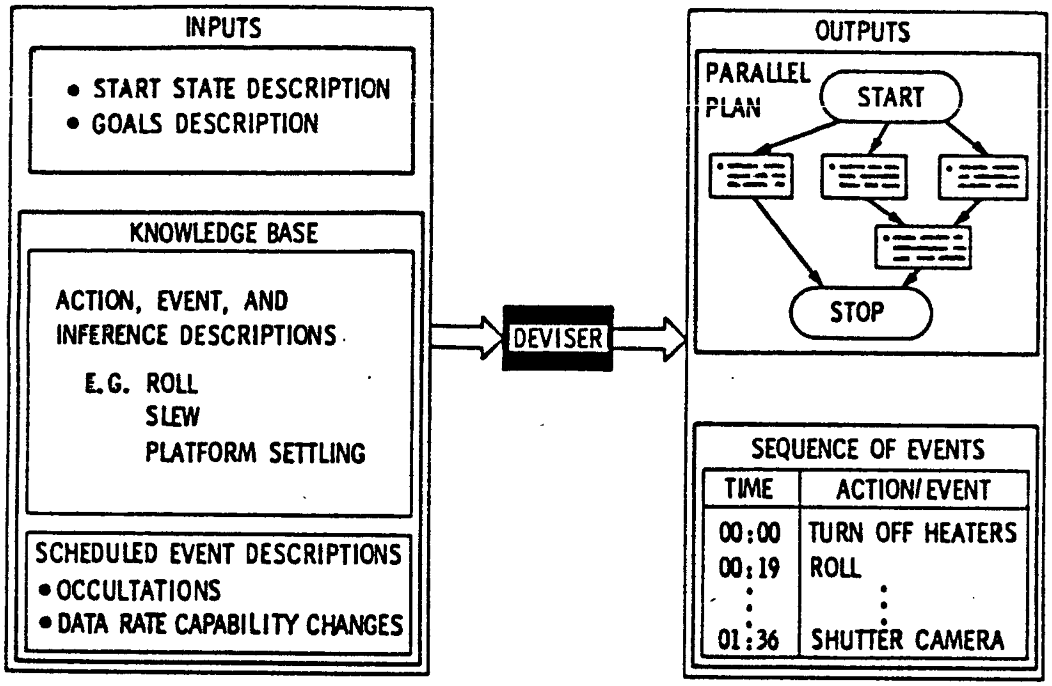
The three-dimensional object tracker breadboard system developed at the Jet Propulsion Laboratory Robotics Laboratory has demonstrated robust real-time tracking, at approximately 3 Hz, of an object having convex shape and consisting of planar surfaces. The tracker is robust in the sense that, even with a partially obscured object image, the tracking software still keeps the object in lock.

This stereo vision system consists of two charge-injection-device solid-state cameras, a pipeline image processor "IMFEX", a 188 pixels x 240 lines digitizer "RAPID", a SPC-16 minicomputer, real-time tracking algorithms, and supporting software and peripherals.

The IMFEX special-purpose real-time processing hardware detects edges of the object. The tracking software computes and stores the current states (i.e., orientation and location) of the object, predicts the future states, compares with the actual future states, and updates the prediction trends.

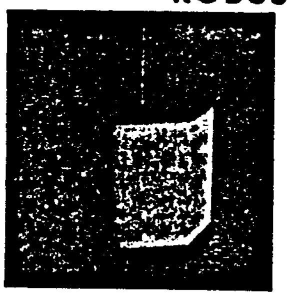
Future research and development on this tracking system will aim at improving the speed to up to 30 Hz, to accommodate objects of more complicated shapes, and to be able to perform automatic initial acquisition.

A BLACKBOX VIEW OF DEVISER



Vere
3/82

JPL ROBOTICS LABORATORY VISION RESEARCH
ROBUST REAL-TIME 3-D OBJECT TRACKER



DIGITIZED IMAGE
OF OBJECT TO BE
TRACKED

"IMFEX" R/T PROCESSING
+ TRACKER SOFTWARE

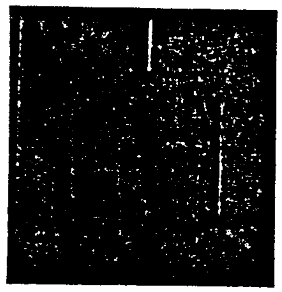
- EDGE DETECTION
- OBJECT LOCATION & ORIENTATION
- PROJECT vs ACTUAL
- ERROR TRACKING

3-D VISION SYSTEM

- 2 CID CAMERAS/GE
- "IMFEX" PIPE-LINE IMAGE PROCESSOR/JPL
- 188 x 240 "RAPID" DIGITIZER/JPL
- SPC-16 MINICOMPUTER
- REAL-TIME TRACKER SOFTWARE/JPL
- SUPPORTING SOFTWARE AND PERIPHERALS

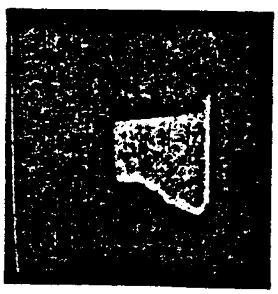
CONCLUSION

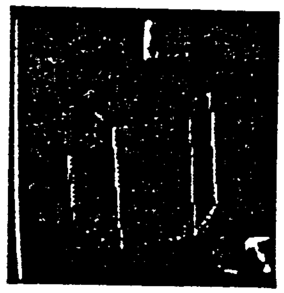
ROBUST TRACKER OVERCOMES
PARTIAL OBSCURATION AND
EFFECTS CONTINUAL R/T
TRACKING



PREVIOUS DETECTION
(FAINT LINES)
OBJECT PREDICTS
(BRIGHT LINES)
CURRENT/ACTUAL DETECTION
(DOTS)
ERROR TRACKING (DOTS
VS BRIGHT LINES)

OBJECT PARTIALLY OBSCURED

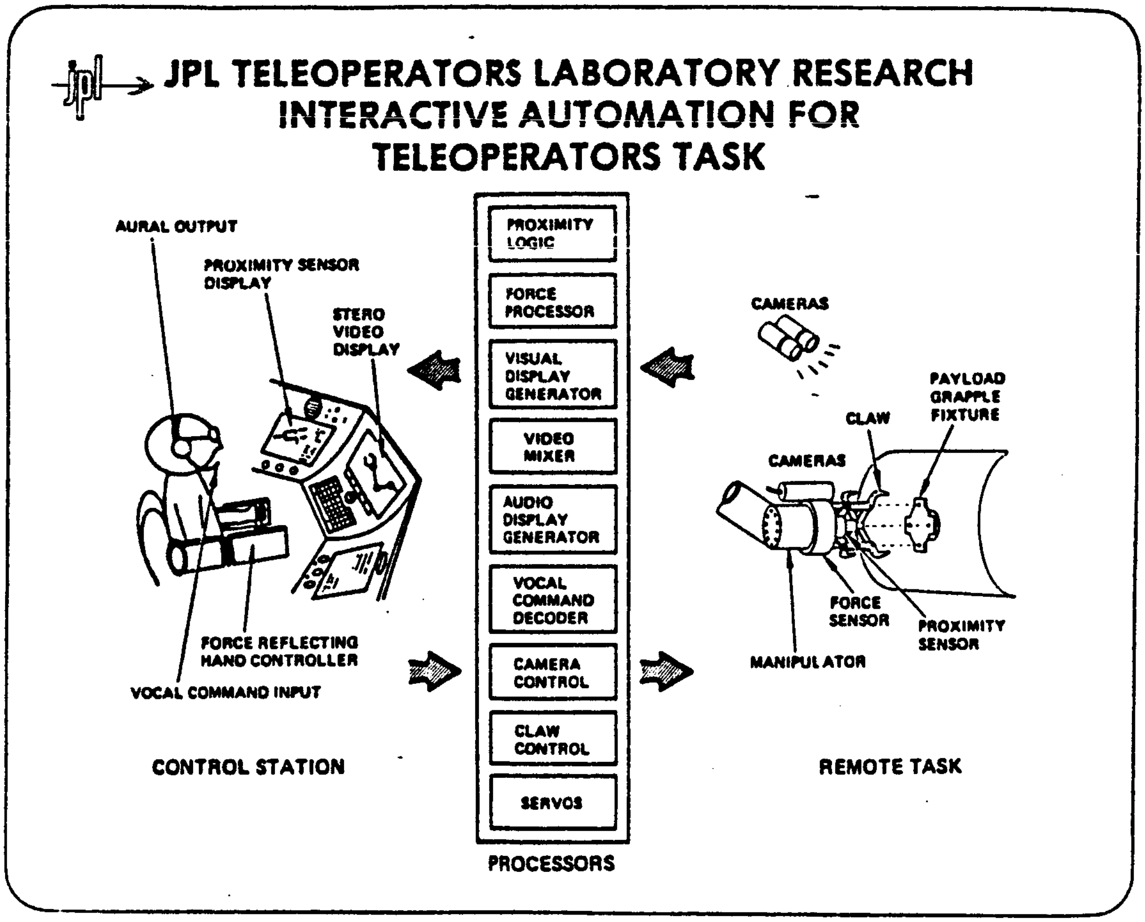


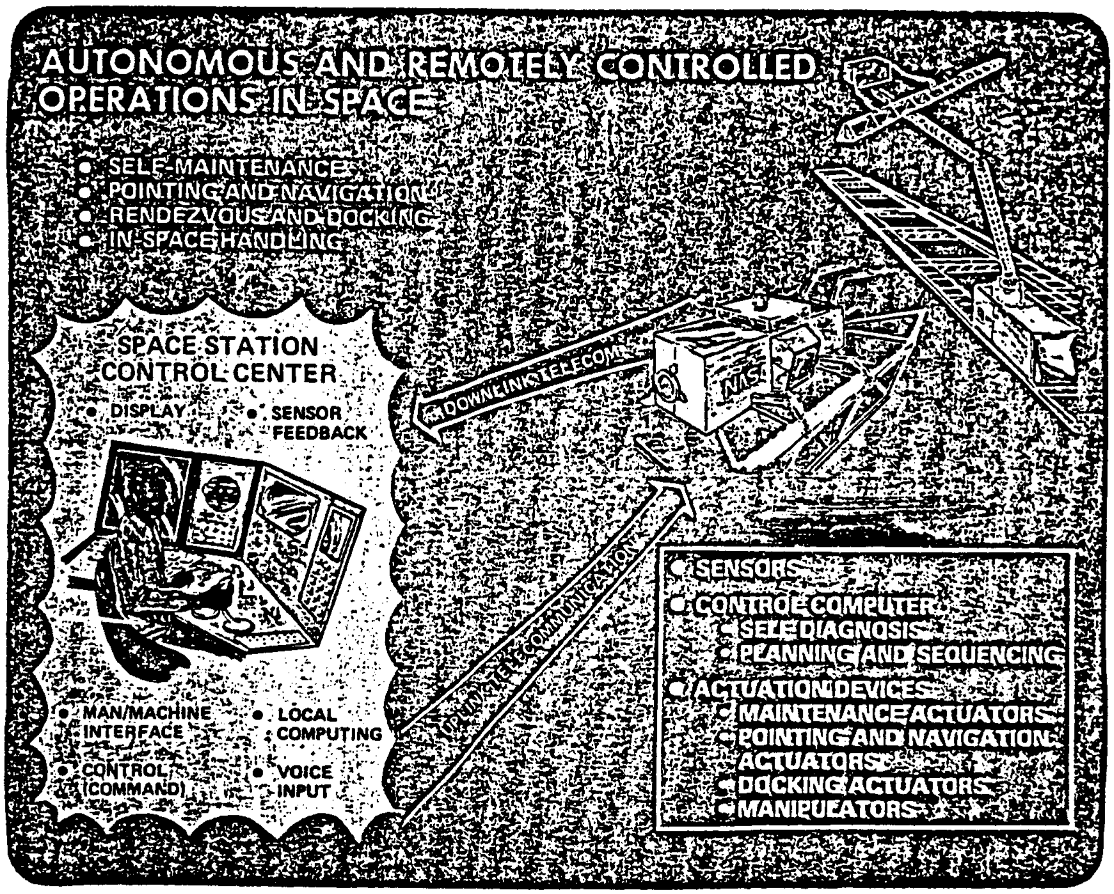


Past years of research in the Jet Propulsion Laboratory Teleoperators Laboratory have been supported by NASA, Office of Life Sciences, Johnson Space Center, and contracts with Oakridge National Laboratory (Department of Energy funds). Research and development thrusts have been in human-machine interfaces, information traffic and display, smart computer-based sensors and control systems.

FY 83 RTOP 506-54-6 work will aim at the evaluation of teleoperator control techniques such as shared manual/computer control, task frame indexing and scaling, bilateral force-reflecting hand control, and to integrate the Puma 600 manipulator arm with the existing computing facilities and control station. Integration of the vision systems in the JPL Robotics Laboratory with the manipulator systems in the Teleoperator Laboratory will be initiated.

Self Explanatory

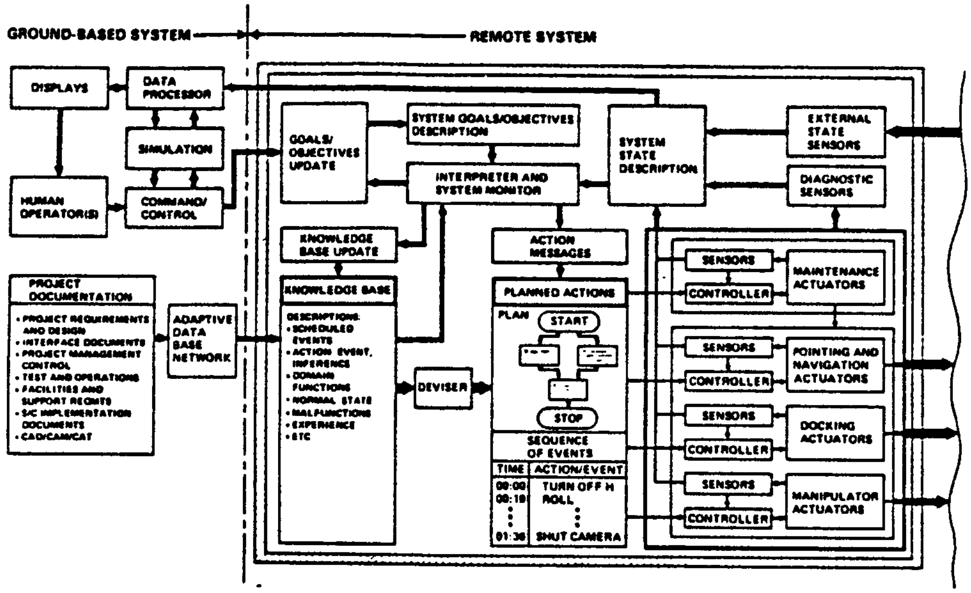

JPL TELEOPERATORS LABORATORY RESEARCH
INTERACTIVE AUTOMATION FOR
TELEOPERATORS TASK
AURAL OUTPUT
PROXIMITY SENSOR DISPLAY
STERO VIDEO DISPLAY
FORCE REFLECTING HAND CONTROLLER
VOCAL COMMAND INPUT
CONTROL STATION
PROXIMITY LOGIC
FORCE PROCESSOR
VISUAL DISPLAY GENERATOR
VIDEO MIXER
AUDIO DISPLAY GENERATOR
VOCAL COMMAND DECODER
CAMERA CONTROL
CLAW CONTROL
SERVOS
PROCESSORS
CAMERAS
PAYLOAD GRAPPLE FIXTURE
CLAW
CAMERAS
FORCE SENSOR
PROXIMITY SENSOR
MANIPULATOR
REMOTE TASK


AUTONOMOUS AND REMOTELY CONTROLLED OPERATIONS IN SPACE
• SELF-MAINTENANCE
• POINTING AND NAVIGATION
• RENDEZVOUS AND DOCKING
• IN-SPACE HANDLING
SPACE STATION CONTROL CENTER
• DISPLAY
• SENSOR FEEDBACK
• MAN/MACHINE INTERFACE
• LOCAL COMPUTING
• CONTROL (COMMAND)
• VOICE INPUT
DOWNLINK TELECOM
UPLINK TELECOMMUNICATION
NASA
• SENSORS
• CONTROL COMPUTER
• SELF DIAGNOSIS
• PLANNING AND SEQUENCING
• ACTUATION DEVICES
• MAINTENANCE ACTUATORS
• POINTING AND NAVIGATION ACTUATORS
• DOCKING ACTUATORS
• MANIPULATORS

A schematic for the architecture for supervisory system

The major technical issues

ARCHITECTURE FOR SUPERVISORY SYSTEM



AUTONOMOUS SYSTEMS TECHNOLOGY
TECHNICAL ISSUES

- APPROPRIATE LEVEL OF SPACECRAFT AUTONOMY
- OPTIMAL ALLOCATIONS OF FUNCTIONS BETWEEN MAN AND MACHINE
- EMPHASIS OF GENERAL PURPOSE VS SPECIFIC MISSION REQUIREMENTS
- SYSTEMS TECHNOLOGY VS COMPONENT TECHNOLOGY
- VALIDATION OF COMPLEX AUTONOMOUS SYSTEMS
- IMPACT OF AUTONOMOUS SYSTEMS ON FUTURE SPACE MISSIONS

Cutting Edge Technologies

AUTONOMOUS SYSTEMS

CUTTING EDGE TECHNOLOGIES

- SYSTEM ARCHITECTURES
- MACHINE INTELLIGENCE
- KNOWLEDGE ENGINEERING
- MAN-MACHINE SYSTEMS
- DECISION-MAKING TOOLS

SIMULATION AND TRAINING

PRESENTATION TO:

THE HUMAN ROLE IN SPACE WORKSHOP
AUGUST 24, 1982
LEESBURG, VA

BY JACK W. STOKES/MSFC/EL15

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WORLD OF SIMULATION

In response to the request to present to the Human Role in Space Workshop a review of Simulation and Training we have prepared the following. Since the world of simulation has grown to such expances, from paper exercises to the use of the actual equipment required for the accomplishment of some function, we will bound the scope of this discussion to man-in-the-loop simulations only. Man-in-the-loop simulations are those in which a human is an instigator and/or receiver of experience, information, or material transaction as a result of the simulation activities.

In order to further understand what simulation means to the world of aerospace, we will further break man-in-the-loop simulations into two categories, those being engineering development simulations and training simulations. Examples of each are included in the viewgraph. Of course, we will limit our discussion to those simulators and trainers compatible with space missions.

DEVELOPMENTAL SIMULATION

Engineering development in the space community may be defined as those activities required to bring a space flight idea from the conceptual stage through verification to completion of the design. As a design progresses through engineering development to completion, man-in-the-loop simulations have proven to be beneficial as both an engineering conceptual and verification tool at various stages of development.

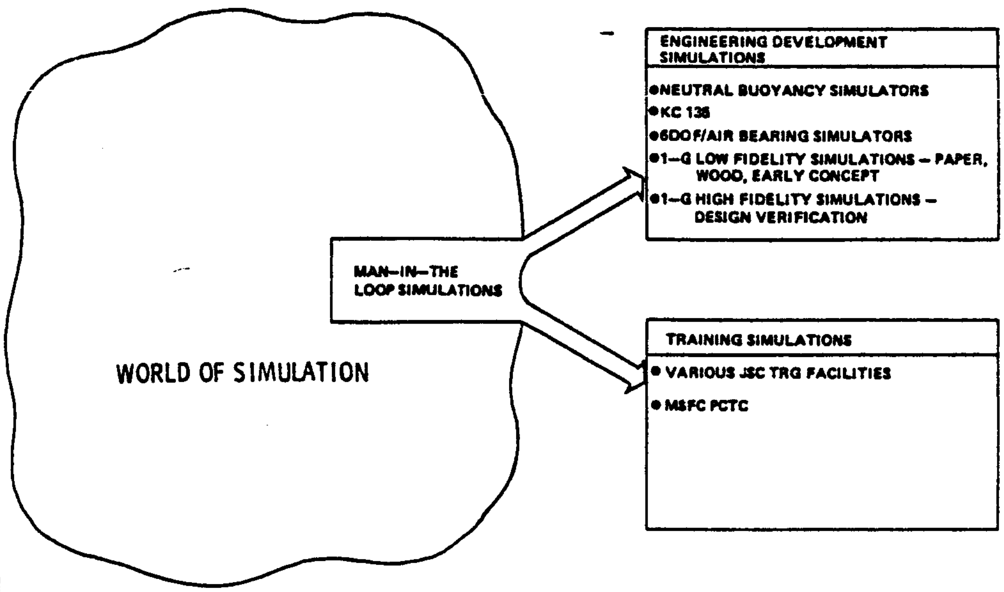
The major utility of such simulation techniques include the performance of basic man/machine research (results for human engineering standards), man/machine concept design/development, man/machine verification testing, and finally operations development. The last is usually not considered as an engineering activity per se, but supports mission preparation and completion.

Major engineering development simulation benefits include the reduction of the program and engineering cost by providing timely feedback to the design and managerial organizations for assistance and direction in design. An inadequate design can be recognized early enough so as not to impact the total program if simulation works as intended. Hence, the schedule is more likely to be met if simulation occurs at proper sequences, since no unnecessary redesign is anticipated.

Man-in-the-loop simulations, if properly used, will provide development and verification of the space hardware features and functions, thereby verifying that the item will interface with the space crewman as planned.

EL 10306

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982



[MAN–IN–THE–LOOP SIMULATIONS: SIMULATIONS IN WHICH HUMAN IS INSTIGATOR AND/OR RECIPIENT OR EXPERIENCE, INFORMATION, OR MATERIAL TRANSACTIONS AS RESULT OF SIMULATION ACTIVITIES.]

EL 10302

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

MAN–IN–THE–LOOP DEVELOPMENTAL SIMULATION

ENGINEERING DEVELOPMENT:

THOSE ACTIVITIES REQUIRED TO BRING A SPACE FLIGHT IDEA FROM THE CONCEPTUAL STAGE THROUGH VERIFICATION TO DESIGN COMPLETION

DEVELOPMENTAL SIMULATION:

REPRODUCTION/REPRESENTATION OF CONCEPTUAL OR ACTUAL OBJECT, SYSTEM, PROCESS, OR SITUATION INCLUDING MAN AS AN INTERFACE. CONCEPTUAL/VERIFICATION TOOL USEFUL AT VARIOUS DEVELOPMENT LEVELS OF MAN/SYSTEM FLIGHT DESIGN

DEVELOPMENTAL SIMULATION UTILITY:

- TO PERFORM
  - BASIC MAN/MACHINE RESEARCH
  - MAN/SYSTEM CONCEPT DESIGN/DEVELOPMENT
  - MAN/SYSTEM VERIFICATION TESTING
  - OPERATIONS DEVELOPMENT

DEVELOPMENTAL SIMULATION BENEFITS:

- REDUCE PROGRAM & ENGINEERING COSTS
- PREVENT PHASE C/D SCHEDULE IMPACTS DUE TO CREW INTERFACES
- PROVIDE DEVELOPMENT & VERIFICATION OF HARDWARE FEATURES & FUNCTIONS FOR ON–ORBIT USE

TRAINING

Training for space missions may be defined as those activities undertaken by ground and flight crewpersons to develop the skills and knowledge necessary to accurately and efficiently conduct or direct space operations; employs a variety of techniques including formal lectures, active participation in mission preparation, self directed study, and specially constructed simulations.

Training simulation likewise may be defined as an attempt to approximate the physical and circumstantial dimensions of an anticipated operating environment, e.g., a space mission.

The usefulness of training for the mission is to prepare flight and ground personnel to perform tasks/functions necessary to verify mission accomplishment. From a systems point of view, training is a technique for verifying the productivity of the human component or subsystem in the manned space system.

Benefits accrued via training include the provision of a prime or backup component in order to guarantee mission success. Training will also verify system or operator safety via operator experience and knowledge. Another benefit, though not the last, includes the reduction of crew operations times, thereby reducing operations costs.

THE ROLE OF MAN-IN-THE-LOOP SIMULATION

Man-in-the-loop simulation has a specific function in man/machine design and operations of a space system. Crew requirements including those for IVA, EVA, habitability, and, if a teleoperator or robot is to be employed, remote workstation requirements can be gleaned from man-in-the-loop simulations. Simulation can be a useful tool in the definition or delineation of crew requirements. Conceptual simulations are most beneficial here.

After the man/system requirements have been established, the design of the crew station must be addressed. Crew station is any situation or location where the crewman is expected to perform some mission operation. Activities to be considered under crew station design include orbital maintenance techniques, assembly and construction, habitability design, tools and restraint aids relative to the crew station, and payload handling techniques. It is very obvious what the role of simulation should be under this heading, as design engineers attempt to integrate the requirements with the man. Simulation can provide the most cost-efficient technique to define the crew station.

As a crew station design is accomplished, it must be verified prior to flight. Likewise, any hardware with which the crewmen will be using or interfacing must be verified.

Similarly, as the operating procedures for the crewmen are developed, they must be iteratively evaluated and verified. Simulation provides an excellent opportunity to accomplish this.

As the hardware and procedures are defined to flight readiness, the crew scheduled to fly the mission must undergo training to accomplish the mission tasks. Likewise, training must occur for the ground support network. Each individual must learn his specific task, and the mission operations personnel must be brought to an acceptable level of readiness.

EL10306

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST, 1982

TRAINING: THOSE ACTIVITIES UNDERTAKEN TO DEVELOP WITHIN GROUND AND FLIGHT CREW-PERSONS THE SKILLS AND KNOWLEDGE NECESSARY TO ACCURATELY AND EFFICIENTLY CONDUCT OR DIRECT SPACE OPERATIONS; EMPLOYS A VARIETY OF TECHNIQUES INCLUDING: FORMAL LECTURES, ACTIVE PARTICIPATION IN MISSION PREPARATION, SELF DIRECTED STUDY AND SPECIALLY CONSTRUCTED SIMULATIONS

TRAINING SIMULATION: AN ATTEMPT TO APPROXIMATE THE PHYSICAL AND CIRCUMSTANTIAL DIMENSIONS OF AN ANTICIPATED OPERATING ENVIRONMENT, e.g., A SPACE MISSION.

TRAINING UTILITY:

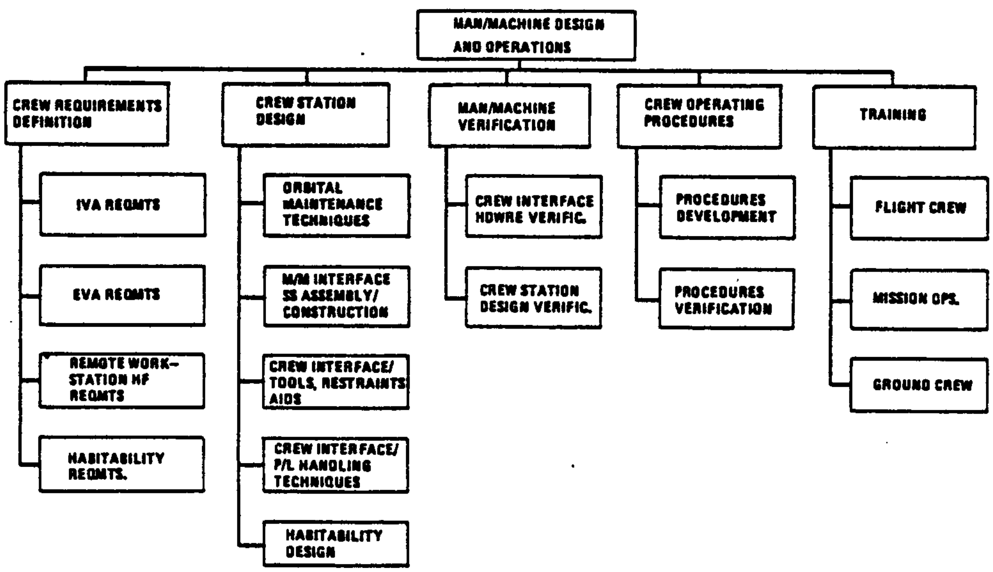
- TO PREPARE FLIGHT AND GROUND PERSONNEL TO PERFORM TASKS/FUNCTIONS NECESSARY FOR MISSION ACCOMPLISHMENT
- VERIFY HUMAN COMPONENT IN MANNED SPACE SYSTEM

TRAINING BENEFITS:

- TO PROVIDE A PRIME OR BACKUP SUBSYSTEM OR COMPONENT IN ORDER TO VERIFY MISSION ACCOMPLISHMENT
- TO VERIFY SYSTEM AND OPERATOR SAFETY VIA OPERATOR KNOWLEDGE
- TO REDUCE OPERATIONS TIMELINES, THEREBY REDUCING OPERATIONS COSTS.

ORGANIZATION: MSFC/EL15 CHART NO.:	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST, 1982

THE ROLE OF MAN-IN-THE-LOOP SIMULATION



NASA MAN-IN-THE-LOOP SIMULATION FACILITIES

An attempt has been made to list the various man-in-the-loop simulation facilities in use within NASA. We considered only those in which man is an active participant, either within the simulation medium, or as a controller. This list is not comprehensive, and is subject to interpretation relative to man's involvement. Both engineering development and training simulations are addressed, and are indicated in the second and third columns relative to their respective utility. Also indicated is the current level of use for each. This may fluctuate with time.

Should a need by industry, academia, or other government agencies be identified for a simulator, it can be provided on a priority basis (NASA, other government agencies, industry/academia) on a cost reimbursible basis.

Continued

EL 10313

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

NASA MAN-IN-THE-LOOP SIMULATION FACILITIES

FACILITY	ENGINEERING DEVELOPMENT	TRAINING	LOADING
REDUCED GRAVITY SIMULATION			
● KC135 ZERO GRAVITY AIRCRAFT, ELLINGTON AFB	X	X	HEAVY
● ARC LEARJET, CV-990	X		LIGHT
● MSFC NEUTRAL BUOYANCY SIMULATOR; 40 FT DEEP X 75 FT D.	X		HEAVY
● JSC WEIGHTLESS ENVIRONMENT TRAINING FACILITY: 78 FT X 30 FT X 25 FT		X	HEAVY
MULTIPLE D.O.F. SIMULATION			
● MSFC TELEOPERATOR/ROBOTICS SYSTEMS LABORATORY	X		TBD
● LaRC INTELLIGENT SYSTEMS RESEARCH LABORATORY	X		TBD
● JSC PAYLOAD DEPLOYMENT & RETRIEVAL SYSTEM RMS TRAINER		X	MEDIUM
● JSC AIR BEARING TABLE		X	LIGHT
● MSFC 6 D.O.F. MOTION SIMULATOR	X		LIGHT
● JSC SHUTTLE MISSION SIMULATOR – MOVING BASE CREW STATION		X	HEAVY
1–G SIMULATION			
● JSC ORBITER ONE–GRAVITY TRAINER	X	X	HEAVY
● JSC 11–FOOT ALTITUDE CHAMBER	X	X	MEDIUM
● JSC ENVIRONMENTAL CONTROL & LIFE SUPPORT SYSTEM TEST ARTICLE		X	HEAVY
● JSC ORBITER MOCKUP (PAYLOAD BAY, UPPER & MIDDECK)		X	HEAVY

EL 10307

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

NASA-MAN-IN-THE-LOOP SIMULATION FACILITIES

FACILITY	ENGINEERING DEVELOPMENT	TRAINING	LOADING
COMPUTER–AIDED 1–G SIMULATION			
● JSC CREW SOFTWARE TRAINER		X	HEAVY
● JSC ORBITER SINGLE SYSTEM TRAINER		X	HEAVY
● JSC GUIDANCE & NAVIGATION SIMULATOR		X	HEAVY
● JSC SHUTTLE MISSION SIMULATOR – FIXED BASE CREW STATION		X	HEAVY
● MSFC PAYLOAD CREW TRAINING COMPLEX		X	HEAVY
● JSC SPACELAB SINGLE SYSTEMS TRAINER		X	TBD
● JSC SPACELAB SIMULATOR		X	TBD
● JSC EXTRAVEHICULAR MOBILITY UNIT MALFUNCTIONS SIMULATOR		X	HEAVY
● JSC MISSION CONTROL CENTER		X	HEAVY
● JSC/MSFC PAYLOAD OPERATIONS CONTROL CENTER		X	HEAVY
● JPL TELEOPERATOR LABORATORY	X		HEAVY
● JPL GRAPHIC WORK STATION DEVELOPMENT FACILITY	X		HEAVY
● MSFC RENDEZVOUS & DOCKING SIMULATOR	X		LIGHT
OTHER SIMULATIONS			
● JSC SHUTTLE TRAINING AIRCRAFT (MODIFIED GULFSTREAM II)		X	N/A
● JSC T–38A MODIFIED SPEED BRAKE AIRCRAFT		X	N/A

FILE NO. ________

MSFC NEUTRAL BUOYANCY SIMULATOR (NBS)

The NBS is used as a reduced gravity simulator for man/machine studies. Neutral buoyancy simulation is a simulation technique in which all objects to be manipulated, as well as the manipulator, are balanced or neutralized so that they neither sink nor float to the surface, and prefer no specific orientation or attitude. The NBS serves as a tool for concept development and engineering verification. It provides extended simulation times (similar to the planned flight mission) and a relatively large volume for 3-D operations.

The NBS consists of a large (40-ft. deep by 75-ft. diameter, 1.3M gallons H_2O) tank supported by a recompression chamber, control room filtration/heating system, medical facility, pressure suit facility, 1-ton crane, CCTV system, and a minor shop facility. Mockups available for underwater simulation support include a Shuttle cargo bay mockup with RMS, MMU, and AFD mockups, as well as Spacelab pallet mockups, teleoperator "flying" machine, and various neutralized space hardware mockups. The NBS is located in Building 4705 at MSFC.

KC-135 AIRCRAFT

The KC-135 aircraft provides flight crews and space engineers with simulation of zero gravity for engineering evaluations, introduction to a weightless condition, and for body and equipment motion dynamics. KC-135 flying sessions are one to two hours in duration.

The KC-135 is the military version of the Boeing 707 (a four-engine jet transport aircraft) and is based at Ellington Air Force Base.

Basic training and engineering exercises in zero gravity conditions are accomplished with the KC-135 on a parabolic trajectory flight path where the weightless condition (approximately 20 seconds) occurs at the apex of the trajectory. Proficiency training for flight crews in the handling characteristics of heavy aircraft is conducted as required.

Space designers and engineers are provided an opportunity to evaluate the man/machine interface with spacecraft and EVA hardware. The technique is suitable for obtaining quantitative measurements because operational parameters (i.e., hardware mass, action/reaction forces, operator body stability, and translation techniques) can be almost identical to flight conditions. It is useful for determining unknown mass dynamics and experiencing the physiological sensation and physical reactions to zero-gravity.

EL 10309

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

REDUCED GRAVITY MAN/MACHINES SIMULATION

MSFC NEUTRAL BUOYANCY SIMULATOR (NBS)

PURPOSE: PROVIDE TECHNIQUE FOR REDUCED GRAVITY MAN/MACHINE SIMULATIONS

NEUTRAL BUOYANCY: MANIPULATED OBJECTS & MANIPULATOR NEUTRALIZED (BALANCED) – NEITHER SINK NOR FLOAT. NO PREFERRED ORIENTATION OR ATTITUDE

APPLICATION:
- MEDIUM FOR CONCEPT DEVELOPMENT & ENGINEERING VERIFICATION OF FLIGHT DESIGNS
- EXTENDED SIMULATION TIMES – SIMILAR TO FLIGHT
- LARGE SIMULATION VOLUME
- SUPPORTS 3–D OPERATIONAL SIMULATIONS

NBS DESCRIPTION:
- LOCATED IN BUILDING 4705
- TANK–40FT DEEP X 75FT DIAMETER; 1.3 M GALLONS FILTERED WATER @90F
- SAFETY – RECOMPRESSION CHAMBER, MEDICAL FACILITIES
- STUDY SUPPORT – CONTROL ROOM, PRESSURE SUIT FACILITY, CCTV SYSTEM, INSTRUMENTATION CAPABILITIES
- SUPPORT MOCKUPS – SHUTTLE CARGO BAY, RMS, MMU, AFD, SPACELAB PALLETS, TELEOPERATOR FLYING DEVICE, VARIOUS NEUTRALIZED SPACE–SIMILAR HARDWARE
- ADDITIONAL FACILITIES – 1-TON CRANE, SMALL SUPPORT SHOP, FILTRATION/HEATING SYSTEM

EL 10310

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

DEVELOPMENTAL SIMULATIONS

KC–135 AIRCRAFT

PURPOSE: PROVIDE SIMULATION OF ZERO–G FOR ENGINEERING AND TRAINING PURPOSES

PARABOLIC TRAJECTORY FLIGHT: AIRCRAFT FLIES PARABOLIC TRAJECTORY. WEIGHTLESS CONDITION OCCURS AT APEX OF PARABOLA, LASTING APPROXIMATELY 20 SEC

APPLICATION:
- PROVIDES DESIGNERS/ENGINEERS OPPORTUNITY TO EVALUATE MAN/MACHINE INTERFACE WITH SPACE HARDWARE
- PERMITS OBTAINMENT OF QUANTITATIVE ENGINEERING DATA
- PROVIDES TRAINING FOR WEIGHTLESS CONDITIONS, ZERO–G BODY DYNAMICS
- PROVIDES MANIPULATION OF RELATIVELY LARGE MASSES UNDER CONTROLLED CONDITIONS

KC135 DESCRIPTION:
- MILITARY VERSION OF BOEING 707 (4–ENGINE JET TRANSPORT) FEW WINDOWS, PADDED CARGO COMPARTMENT, CCTV, PHOTOGRAPHY
- ELECTRICAL POWER AND GAS (O_2 CO_2) AVAILABLE DURING FLIGHT

FILE NO. ________

MSFC TELEOPERATOR/ROBOTICS SYSTEMS LABORATORY

The MSFC Teleoperator/Robotics Systems Laboratory, Building 4619, is presently being developed to study and develop those technologies required for operational teleoperator and robotic flight systems. The laboratory consists of three facilities, the Robotic Evaluation Facility, the Remote Manipulator Systems R&D laboratory, and the Orbital Servicer Simulator. The Robotic Evaluation Facility will consist of a 4,000 sq. ft. floor space, mirror flatness surface, capable of supporting self-contained, radio-controlled, air-bearing-mounted test vehicles. These vehicles have modular construction and, by means of centrally located air bearing suspension units, can be assembled with six-degrees-of-freedom. Solar illumination can be supported utilizing a xeon search light and various types of video systems. This facility is to be used for identifying and verifying docking concepts, guidance, navigation and control subsystems for remotely controlled, semi-antonomous Teleoperator experiments for satellite placement and retrieval, and for the study of human factors related to their operation.

The Remote Manipulator Systems Laboratory will support the investigation and development of manipulator systems including end effectors and associated hardware. Manipulator systems will be evaluated against proposed functional requirements and for general manipulator research and development. It consists of a mounting and positioning carriage capable of handling a pair of manipulator arms, a task board, visual sensors for providing operator feedback, remote controls and displays, data handling and communications hardware, a test control and data recording and readout console, a digital controller, and support equipment.

The Orbital Servicer Simulator (OSS) is utilized to demonstrate the concept of satellite maintenance through servicing by on-orbit module replacement. The OSS facility consists of a 35 by 60 by 30 ft. volume with a raised floor. The portable control panel contains all the electronics for operating the OSS. A PDP 11/34 digital computer supports the OSS.

LaRC INTELLIGENT SYSTEMS RESEARCH LABORATORY (ISRL)

The ISRL, located at LaRC is being procured to study/develop controls and displays for efficient man/machine interface for control of remote systems. Initial efforts will concentrate on a control station design for direct teleoperator control of a Remote Orbital Servicing System (ROSS). Future research will develop an enhanced telepresence and evaluate the application of advanced technology to enhance man's capability to accomplish remote operations by increasing his supervisory capabilities for complex automated systems. The system will serve to develop/test control algorithms, theoretical models, and advanced displays.

The ISRL, located in Building 1268A, will consist of facilities to study controls, displays, crew interactions, and systems interfaces. Controllers to be evaluated include 3- and 6-DOF, force reflecting, replica, and exoskeletal. Control modes include force, rate, position, scaling and indexing, computer/manual control, and multiarm coordination. Display evaluations will include television (stereo, multiple views, position, position control, color, resolution, area of interest, data compression, reconstruction and enhancement), and computer graphics (integrated displays, data bases, and pseudo view). Man/systems interaction will be initially through switches and keyboards, with later evaluations employing touch sensitive panels, voice I/O, and friendly intelligent interfaces based on Artificial Intelligence techniques. As remote system development proceeds from teleoperator control to increased use of robotics, a hierarchical control structure will be developed and evaluated for man/machine interface with automated systems.

In the near term, laboratory experiments will be conducted to validate software modules in the Teleoperator and Robotics Systems Simulation (TRSS). A reconfigurable remote control station for ROSS will also be procured and developed.

EL10317

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME: J. W. JONES
MSFC/EL15	HUMAN ROLE IN SPACE	DATE: AUGUST 1982

DEVELOPMENTAL SIMULATIONS

MSFC TELEOPERATOR/ROBOTICS SYSTEMS LABORATORY

PURPOSE: PROVIDE A SINGLE FACILITY TO STUDY AND DEVELOP TECHNOLOGIES REQUIRED FOR OPERATIONAL TELEOPERATIONAL AND ROBOTIC FLIGHT SYSTEMS

APPLICATION:

- DEVELOP/VERIFY DOCKING CONCEPTS, GUIDANCE, NAVIGATION & CONTROL SUBSYSTEMS FOR REMOTE CONTROL, SEMI–AUTONOMOUS TELEOPERATORS
- DEFINE/DEVELOP MANIPULATOR SYSTEMS INCLUDING END EFFECTORS & ASSOCIATED HARDWARE
- DEMONSTRATE CONCEPT OF SATELLITE MAINTENANCE THROUGH REMOTE SERVICING BY ON–ORBIT MODULE REPLACEMENT

LAB DESCRIPTION:

- LABORATORY IN BUILDING 4619 HIGH BAY AREA
- ROBOTIC EVALUATION FACILITY – 4,000 SQ FT FLOOR SPACE W/SOUND–PROOF CONTROL & DISPLAY ROOM, PRECISION TEST BED, WORK/STORAGE AREA, TEST VEHICLES–SELF-CONTAINED, RADIO–CONTROLLED, ON AIR BEARINGS, POTENTIAL 6DOF CAPABILITY
- MOBILITY UNIT–PROVIDES FOR VARIOUS DOCKING MECHANISMS & VIDEO FEEDBACK SYSTEMS. TIME DELAY FOR RF & VIDEO SIGNALS
- REMOTE MANIPULATORS SYSTEMS LAB – MOUNTING & POSITIONING CARRIAGE FOR MANIPULATOR ARMS, TASK BOARD, REMOTE OPERATOR CONTROL STATION, DATA HANDLING/COMMUNICATIONS HARDWARE, DIGITAL CONTROLLER
- ORBITAL SERVICER SIMULATOR – MOCKUP OF TYPICAL FULL SCALE ORBITAL SERVICER SPACE VEHICLE, CONTROL PANEL, MODULE/SPACECRAFT INTERFACE MECHANISMS, 6DOF MECHANICAL MANIPULATOR ARM
- SUPPORT: 2 PDP–11/34 COMPUTERS, 10-TON CRANE
- POTENTIAL INTERFACE WITH MSFC 6DOF MOTION SIMULATOR

EL10314

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME: J. W. STOKES
MSFC/EL15	HUMAN ROLE IN SPACE	DATE: AUGUST 1982

DEVELOPMENTAL SIMULATIONS

LaRC INTELLIGENT SYSTEMS RESEARCH LABORATORY (ISRL)

PURPOSE: STUDY/DEVELOP CONTROLS AND DISPLAYS FOR EFFICIENT MAN/MACHINE INTERFACE FOR CONTROL OF REMOTE SYSTEMS – DEVELOP CONTROL STATION DESIGN FOR DIRECT TELEOPERATOR CONTROL OF A REMOTE ORBITAL SERVICING SYSTEM (ROSS). PERFORM TELEOPERATOR & ROBOTICS SYSTEMS SIMULATION (TRSS)

APPLICATION:

- DEVELOP REMOTE OPERATIONS SYSTEM FOR FUTURE SPACE MISSIONS (e.g., SPACE CONSTRUCTION, SUPPORT SPACE STATION)
- RESEARCH MAN/MACHINE INTERACTION IN DEVELOPMENT/TESTING OF ADVANCED CONTROLS, ENHANCED VISUAL DISPLAYS, EFFICIENT COMPLEX SYSTEMS INTERFACE
- DEVELOP/TEST CONTROL ALGORITHMS, THEORETICAL MODELS, ADVANCED DISPLAYS

ISRL DESCRIPTION

- LOCATED IN BUILDING 1268–A
- 3- AND 6- DOF CONTROLLERS – FORCE REFLECTING, REPLICA AND EXOSKELETAL
- DISPLAYS – TV: STEREO, MULTIPLE VIEWS, POSITION, POSITION CONTROL, COLOR, RESOLUTION, AREA-OF-INTEREST, DATA COMPRESSION, RECONSTRUCTION, ENHANCEMENT
  - – COMPUTER GRAPHICS: INTEGRATED DISPLAYS, DATA BASES, PSEUDO VIEW
- HUMAN FACTORS RESEARCH CONTROL STATION – SWITCHES/KEYBOARDS, TOUCH SENSITIVE PANELS, VOICE I/O, FRIENDLY INTELLIGENT INTERFACES
  - – HIERARCHICAL CONTROL STRUCTURE FOR ROBOTICS
- ROSS GROUND CONTROL STATION

FILE NO.____________

MSFC 6 DEGREE-OF-FREEDOM (DOF) SIMULATOR

The 6 DOF Motion Simulator consists of a large platform that is hydraulically driven, under computer control, in roll, pitch, and yaw rotations and X, Y, Z translations. Sufficient volume is available to mount test hardware to the platform as well as above it for docking purposes. Motion is achieved by coordinated position commands to each of six hydraulic activators between the platform and the floor.

The 6 DOF Motion Simulator, located in Building 4663, is useful for simulating both manned and remote space vehicles. It provides realistic motion to an onboard test subject, and has been used for lunar rover, space Shuttle landing, and Navy surface effect ship simulations. It also provides realistic close rendezvous and docking simulations and was used for the Skylab/TRS docking simulations.

The moving base is supported by a hybrid computer system, a test conductor's control console, and a test subjects' remote workstation housed in a Shuttle Aft Flight Deck mockup.

The Rendezvous and Docking Simulator, which can include the 6 DOF Motion Simulator, is utilized to study orbital docking and related orbital maneuvers for manual, supervisory, or autonomous spacecraft control. It can be used to simulate remote operation of a simulated spacecraft from a control range of 120,000 feet to point of contact. This simulator is housed in Building 4663.

The simulator includes a Target Motion Simulator which accommodates various scale models for simulating various distances to the target. This system is supported by a hybrid computer system.

JSC SHUTTLE MISSION SIMULATOR (SMS)

The SMS provides a full-task training in operation of the Space Shuttle Systems during all flight phases. The SMS is used to train flight crews during both phases (SMS stand alone) and integrated (SMS interfaces to the MCC) training sessions. During integrated training, the flight control team participates in the training sessions. SMS training is conducted from a simulation script that exercises both nominal and malfunction procedures for a particular flight phase. SMS sessions are two to four hours in duration.

The STS facility consists of a Moving Base Crew Station (MBCS), Fixed Based Crew Station (FBCS), instructor/operator stations, visual system, signal interface equipment, large-scale data processing complex, and a network simulation system for integrated training with the MCC. The MBCS provides a full-fidelity commander and pilot forward flight deck mounted on a six-degree-of-freedom motion base with a forward station three-dimensional visual presentation. The FBCS provides full-fidelity simulation of the Orbiter forward and aft flight deck with visual presentations. The MBCS and FBCS can operate independently and simultaneously; however, only one station can be interfaced to the MCC at any given time. The SMS also provides Inertial Upper Stage (IUS) modeling, remote manipulator system visual imaging, and a general payload model for conduct of payload operations training. Advanced and flight specific training conducted on the SMS includes all facets of the ascent, orbit, and entry flight phases. This includes training associated with prelaunch, ascent, abort, deorbit, and entry operations; on-orbit training for orbit, rendezvous, Z-axis rendezvous, docking, payload operations, and undocking and atmospheric training for terminal area energy management and approach, landing, and rollout. The SMS is located in Building 5 at JSC.

JSC ORBITER SINGLE SYSTEM TRAINER (SST)

The Orbiter SST provides part-task training in operation of the Orbiter support systems. The SST is used to train pilots, mission specialists, and selected ground support personnel in operation of the Orbiter support systems on a one-at-a-time or single system basis. SST training uses a lesson sequence of display and control familiarization, normal operating procedures, and malfunction procedures using the Orbiter checklists. Lessons are one to two hours in duration.

The SST facility consists of two student stations with colocated instructor stations, a minicomputer system, digital conversion interface equipment, and an intercom system. Each student station is a medium fidelity mock-up of the Orbiter cockpit forward and aft flight deck with interactive controls and displays. The following basic and advanced training on the following Orbiter support systems are instructed in the SST.

1. <u>Student Station 1</u>
   - o Orbital Maneuvering System/Reaction Control System (OMS/RCS)
   - o Communications (COMM)
   - o Instrumentation (INSTR)
   - o Navigational Aids (NAVAIDS)
   - o Main Propulsion System (MPS)
   - o Data Processing System (DPS)
   - o Closed Circuit Television (CCTV).

2. <u>Student Station 2</u>
   - o Electrical Power System (EPS)
   - o Environmental Control and Life Support System (ECLSS)
   - o Auxiliary Power Unit/Hydraulics (APU/HYD)
   - o Structures/Mechanical (STRU/MECH)
   - o Caution and Warning System (C&W).

The SST is located in Building 4, Room 2044, at JSC.

EL 10311

ORGANIZATION	MARSHALL SPACE FLIGHT CENTER	NAME: J. W. STOKES
MSFC/EL15	HUMAN ROLE IN SPACE	DATE: AUGUST 1982

DEVELOPMENTAL SIMULATIONS

MSFC SIX DEGREE-OF-FREEDOM MOTION SIMULATOR

PURPOSE: PROVIDE A COMPUTER-CONTROLLED SPACE MOTION SIMULATION FOR MAN/MACHINE CONTROL STUDIES

APPLICATION:
- PROVIDES REALISTIC MOTION TO ONBOARD SUBJECT, (e.g., LUNAR ROVER, SPACE SHUTTLE LANDING, NAVY SURFACE EFFECT SHIP CREW TESTING)
- PROVIDES REALISTIC MOTION & SIMULATED LOADS FOR DOCKING SIMULATIONS (e.g., TRS/SKYLAB) SUBJECT MAY BE ONBOARD OR REMOTELY LOCATED

SIMULATOR DESCRIPTION:
- LOCATED IN BUILDING 4663
- HYDRAULICALLY DRIVEN PLATFORM WITH ROLL, PITCH, YAW, AND X, Y, Z TRANSLATION CAPABILITY
- HYBRID CONTROL COMPUTER
- TEST CONDUCTOR COMMAND/CONTROL CONSOLE
- TEST SUBJECT CONTROL STATION

MSFC RENDEZVOUS & DOCKING SIMULATOR

PURPOSE: INVESTIGATE ORBITAL DOCKING & RELATED ORBITAL MANEUVERS FOR MANUAL, SUPERVISORY, OR AUTONOMOUS SPACECRAFT CONTROL

APPLICATION:
- REMOTE OPERATION OF A SIMULATED SPACECRAFT WITH RANGE OF CONTROL FROM 120,000 FT TO POINT OF CONTACT
- TARGET MOTION SIMULATOR PROVIDES FLYING CAPABILITY FROM 500 FT WITH VARIOUS SCALE TARGETS

SIMULATOR DESCRIPTION
- LOCATED IN BUILDING 4663
- MANNED REMOTE CONTROL STATION, TARGET MOTION SIMULATOR (VARIOUS SCALE MODELS & GIMBALED CAMERA
- HYBRID COMPUTER SYSTEM

EL 10330

ORGANIZATION	MARSHALL SPACE FLIGHT CENTER	NAME: J. W. STOKES
MSFC/EL15	HUMAN ROLE IN SPACE	DATE: AUGUST 1982

TRAINING SIMULATION

JSC SHUTTLE MISSION SIMULATOR (SMS)

PURPOSE: PRIMARY TRAINING FACILITY USED FOR SHUTTLE FLIGHT CREW TRAINING

APPLICATIONS:
- PROVIDES FULL–TASK TRAINING IN SPACE SHUTTLE SYSTEMS OPERATIONS
- TRAINING POSSIBLE AS STAND–ALONE OR INTEGRATED WITH MCC
- PROVIDES FULL–FIDELITY CMDR & PILOT FORWARD FLIGHT DECK
- PROVIDES IUS–MODELING, RMS VISUAL IMAGING, GENERAL P/L MODEL

SMS DESCRIPTION:
- LOCATED IN BUILDING 5
- SIMULATORS: MOVING BASE CREW STATION, FIXED BASE CREW STATION – OPERATE INDEPENDENTLY, SIMULTANEOUSLY
- SUPPORT: INSTRUCTOR/OPERATOR, STATIONS, VISUAL SYSTEM, SIGNAL INTERFACE EQUIPMENT, LARGE-SCALE DATA PROCESSING COMPLEX, NETWORK SIMULATION SYSTEM

JSC ORBITER SINGLE SYSTEM TRAINER (SST)

PURPOSE: TO PROVIDE ADDITIONAL SIMULATION CAPABILITY TO THE SHUTTLE MISSION SIMULATOR

APPLICATION:
- PROVIDE PART–TASK TRAINING IN OPERATION OF ORBITER SUPPORT SYSTEMS ON SINGLE–SYSTEM BASIS
- PROVIDE LESSON SEQUENCE OF DISPLAY & CONTROL FAMILIARIZATION, NORMAL & MALFUNCTION PROCEDURES
  LOW–COST INTERACTIVE SYSTEMS TRAINER
  PROVIDES DIRECT SUPPORT TO CLASSROOM TRAINING PRIOR TO MISSION SIMULATOR EXPOSURE

DESCRIPTION:
- PRIMARY FACILITIES: TWO STUDENT STATIONS WITH COLOCATED INSTRUCTOR STATIONS
- SUPPORT: MINICOMPUTER SYSTEM, DIGITAL CONVERSION INTERFACE EQUIPMENT, INTERCOM SYSTEM

FILE NO.

ORBITER ONE GRAVITY TRAINER (O-1G)

The O-1G trainer provides full-task training in crew systems operation, Extravehicular Activity (EVA), Orbiter ingress/egress, waste management, routine housekeeping, and maintenance operations for all flight crew members. Training on the O-1G uses a lesson sequence that begins with performing these crew activities on an individual basis and leads up to the complete activation and deactivation of the Orbiter crew systems in accordance with the flight timeline. Emergency procedures are then exercised. Trainer lessons for the O-1G are two to three hours in duration.

The O-1G trainer is a full-scale representation of the Orbiter flight deck, middeck, and midbody. The trainer has operational middeck equipment and systems, e.g., waste management, lighting, galley, sleep stations, etc. Additionally, the trainer has the airlock for the airlock/extravehicular mobility unit trainer used in support of emergency/safety training.

Advanced and flight specific training conducted in the O-1G trainer includes activation, operation, emergency procedures, and deactivation of the crew systems. During this training, the crew member will operate the photography, closed circuit television, lighting, food preparation, medical, waste management, portable oxygen systems, and equipment.

The O-1G trainer is located in Building 9A at JSC.

ORBITER MOCKUP (ORBMU) (PAYLOAD BAY, UPPER AND MIDDECKS)

The ORBMU provides full-task training for closed circuit television procedures and postlanding egress operations. ORBMU lessons are three to four hours in length.

The ORBMU is a full-scale representation of the payload bay, upper and middecks. Egress from a horizontal trainer through both the side and overhead hatches is practiced for approximately eight hours. The ORBMU is located in Building 9A at JSC.

JSC WEIGHTLESS ENVIRONMENT TRAINING FACILITY (WETF)

The WETF is used to provide part- and full-task training to flight crew members in the dynamics of body motion during the performance of planned crew activities under weight-loss conditions. The WETF provides controlled neutral buoyancy in water to simulate the condition of null gravity.

The WETF consists of a 30-foot wide by 78-foot long by 25-foot deep immersion facility supported by suit dressing rooms, medical station, water purification systems, five-ton crane, environmental monitor systems, closed circuit television, and pressure suit ballast system.

Basic training conducted in the WETF includes basic swimming, skin diving, SCUBA equipment utilization, SCUBA diving, mock-up familiarization, and suit operation certification.

The WETF is located in Building 29 at JSC.

ORBITER NEUTRAL BUOYANCY TRAINER (ONBT)

The ONBT provides full-task training to flight crew members in zero gravity EVA and emergency survival training. ONBT lessons are one to three hours in duration.

The ONBT is a full-scale representation of the Orbiter cabin middeck, airlock, and payload bay doors. The ONBT is submersed in the Weightless Environment Training Facility (WETF) to simulate zero gravity during training; however, the ONBT can be removed from the WETF for hardware familiarization training.

Advanced training conducted in the ONBT includes hardware familiarization, airlock operation, manually disconnecting radiator drive actuators and closing the radiator panel, removal of door jambs, cutting drive linkages, manual payload door closing, and closing the fore and aft bulkhead latches.

The ONBT is located in Building 29 at JSC.

EL10318

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

TRAINING SIMULATION

JSC ORBITER ONE GRAVITY TRAINER (O–1G)

PURPOSE: PROVIDE FULL–TASK TRAINING IN SHUTTLE CREW OPERATIONS

APPLICATION:
- TRAINING IN CREW SYSTEMS OPNS, EVA, ORBITER INGRESS/EGRESS, WASTE MANAGEMENT, HOUSEKEEPING & MAINTENANCE
- INCREASINGLY COMPLEX TRAINING SEQUENCE

O–1G DESCRIPTION:
- LOCATED IN BUILDING 9A
- FULL–SCALE MOCKUP OF ORBITER FLIGHT DECK, MIDDECK & MIDBODY
- CONTAINS OPERATIONAL MIDDECK EQUIPMENT (e.g., WASTE MGMT, GALLEY, SLEEP STATIONS, ETC.)
- ADDITIONALLY, HAS AIRLOCK

JSC ORBITER MOCKUP (ORBMU) (PAYLOAD BAY, UPPER & MIDDECKS)

PURPOSE: FULL–TASK TRAINING FOR CCTV PROCEDURES & POST–LANDING EGRESS OPERATIONS

APPLICATION:
- PRACTICE OF EGRESS FROM SIDE & OVERHEAD HATCHES IN HORIZONTAL TRAINER

ORBMU DESCRIPTION:
- LOCATED NEAR O–1G IN BUILDING 9A
- FULL–SCALE MOCKUP OF THE PAYLOAD BAY, UPPER & MIDDECKS

EL10319

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

TRAINING SIMULATION

JSC WEIGHTLESS ENVIRONMENT TRAINING FACILITY (WETF)

PURPOSE: PROVIDE PART- AND FULL-TASK TRAINING TO FLIGHT CREW IN BODY MOTION DYNAMICS UNDER O-G CONDITIONS

APPLICATIONS:
- PROVIDE CONTROLLED NEUTRAL BUOYANCE TO SIMULATE NULL GRAVITY CONDITION
- PROVIDE BASIC TRAINING INCLUDING BASIC SWIMMING, SKIN DIVING, SCUBA DIVING, MOCK–UP FAMILIARIZATION, AND SUIT–OPERATIONS CERTIFICATION

WETF DESCRIPTION:
- WETF LOCATED IN BUILDING 29
- 30-FT WIDE X 78-FT LONG X 25-FT DEEP IMMERSION FACILITY
- SUPPORT FACILITIES – MEDICAL STATION, SUIT DRESSING ROOMS, WATER PURIFICATION SYSTEM, 5-TON CRANE, ENVIRONMENTAL MONITOR SYSTEMS, CLOSED CIRCUIT TV, PRESSURE SUIT BALLAST SYSTEM

ORBITER NEUTRAL BUOYANCY TRAINER (ONBT)

PURPOSE: PROVIDE FULL–TASK EVA TRAINING AND EMERGENCY SURVIVAL TRAINING

APPLICATION:
- HARDWARE FAMILIARIZATION, AIRLOCK OPERATION, RADIATOR CONTINGENCY OPERATIONS, DOOR CONTINGENCY OPERATIONS

ONBT DESCRIPTION:
- FULL–SCALE MOCK–UP OF ORBITER MIDDECK, AIRLOCK, PAYLOAD BAY DOORS LOCATED IN WETF

MSFC PAYLOAD CREW TRAINING COMPLEX (PCTC)

The purpose for the PCTC is to provide "hands-on" experience to Spacelab Payload Specialists (PS) and Mission Specialists (MS) which is not available from the various experiment Principle Investigators (PI). It provides high fidelity simulations of flight hardware and software.

In order to afford the payload crew the opportunity to become proficient in the operation of computer-controlled experiments and to fill the gap between decentralized investigator-provided training and participation in prelaunch integration activities, the PCTC has been included as a primary training simulator. The PCTC program familiarizes PS candidates with mission timelines, experiment procedures, and contingency operations, as well as Spacelab systems exposure. The PCTC test conductor can insert faults into the simulation, accelerate mission time, recycle, monitor simulation performance, monitor overall activities, and communicate with all PCTC elements in order to verify simulation fidelity.

It is possible to provide training for two missions (e.g., SL-1 and SL-2) simultaneously; multi-shift operation will accommodate additional missions as required.

The PCTC, located in Building 4612 includes a Spacelab Core and Experiment Module mockup with all Spacelab systems hardware. Specific hardware includes the experiment and systems racks, experiment and systems controls and displays, Scientific Airlock, Experiment Window, crew restraints, and safety and maintenance equipment. The four CDMS on-board terminals can be simultaneously and independently driven.

Other mockups include a low fidelity Spacelab 1 pallet with hardware, a Shuttle Aft Flight Deck mockup with SL-2 experiment panels, three SL-2 low fidelity pallets with hardware, and various part-task mockups.

The entire operation is controlled by a host computer system. Included is a scene generation/growth and terminal facility. Also provided is the test control room complex.

SPACELAB SIMULATOR (SLS)

The SLS provides full-task training in operation of the STS Spacelab support subsystems for pilots, mission and payload specialists. These sessions are conducted using a simulation script for both phases (Spacelab stand alone or interfaced to the SMS FBCS) or integrated (Spacelab interfaced to the SMS/MCC) training. During integrated training, the Flight Control Team and Payload Operation Control Center (POCC) participate in the training sessions. These sessions are two to four hours in duration for phase training with eight hours or longer sessions during integrated training.

The SLS facility consists of a full-scale high-fidelity Spacelab core and experiment module segment, subsystem racks, controls and displays, scientific airlock, viewport, and uses the SMS computer complex for required data processing. The SLS does not include the tunnel area or any experiments. The SLS is interfaced to the SMS FBCS to simulate Spacelab System activation/deactivation, systems operation, and data management in concert with Orbiter systems operation. Moreover, the SLS/SMS is interfaced with the MCC and POCC to enable full-up simulation of Spacelab orbital operations.

Advanced and flight specific training conducted in the SLS includes activation, operation, and deactivation of the command and data management system, caution and warning system operation, environmental system operation and malfunction analysis, HRM and recorder operation, power and thermal management, and scientific airlock/viewport operation. The SLS is located in Building 5 adjacent to the SMS FBCS at JSC.

SPACELAB SINGLE SYSTEMS TRAINER (SLSST)

The SLSST provides part-task training in operation of the Spacelab Systems interfaced to the Orbiter and the Spacelab Instrument Pointing System (IPS). The SLSST is used to train pilots, mission specialists, payload specialists, and selected ground operations support personnel on a single system basis. SLSST training follows a lesson sequence of display and control familiarization, normal operating procedures, and malfunction procedures using the Spacelab on-board checklists. Lessons are two to four hours in duration.

The SLSST facility consists of one student station with a colocated instructor station interfaced to the SST computer complex. The student station is a medium fidelity mockup of a partial Spacelab module including a CRT display, keyboard, intercom, and the control panels necessary for activation and monitoring of the Spacelab module. The Spacelab IPS is simulated using closed circuit television, image models, image displays, and the IPS control panels and keyboard.

Advanced training conducted in the SLSST includes Spacelab audio, lighting and CCTV operations, Command and Data Management System (CDMS) operation, experiment data processing equipment operation, IPS operation. caution and warning system operation, environmental and electrical power distribution system operation, and Spacelab High-Rate Multiplexer (HRM) operation.

The SLSST is located in Building 4, Room 2045B at JSC.

EL10316

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

TRAINING SIMULATION

MSFC PAYLOAD CREW TRAINING COMPLEX

PURPOSE: PROVIDE "HANDS–ON" EXPERIENCE TO SPACELAB PAYLOAD SPECIALISTS (PS) WHICH IS NOT AVAILABLE FROM THE VARIOUS EXPERIMENT PRINCIPLE INVESTIGATORS. PROVIDE HIGH FIDELITY SIMULATIONS OF FLIGHT HARDWARE & SOFTWARE

APPLICATION:

- FAMILIARIZE PS & MS CANDIDATES WITH MISSION TIMELINES, EXPERIMENT PROCEDURES, AND CONTINGENCY OPERATIONS
- PROVIDE PS CANDIDATES WITH EXPOSURE TO HIGH FIDELITY SPACELAB SYSTEMS (e.g., CDMS)
- PROVIDE TRAINING FOR MULTIPLE MISSION (e.g., SL–1 & SL–2) SIMULTANEOUSLY; MULTI–SHIFT OPERATION WILL ACCOMMODATE ADDITIONAL MISSIONS
- TEST CONDUCTOR CAN INSERT FAULTS, ACCELERATE TIME, RECYCLE, MONITOR PERFORMANCE, MONITOR OVERALL ACTIVITIES,COMMUNICATE WITH ALL PCTC ELEMENTS

PCTC DESCRIPTION:

- FOUR SIMULATED CDMS ON–BOARD TERMINALS SIMULTANEOUSLY AND INDEPENDENTLY DRIVEN
- SPACELAB CORE & EXPERIMENT MODULE MOCKUP WITH ALL SPACELAB SYSTEMS HARDWARE–RACKS, C&D, SAL, EXP. WINDOW
- SPACELAB TUNNEL
- SPACELAB–1 PALLET WITH LOW FIDELITY EXPERIMENT HARDWARE MOCKUP
- SHUTTLE AFT FLIGHT DECK MOCKUP WITH SPACELAB–2 PANELS; THREE SPACELAB–2 LOFI PALLET/ EQUIPMENT MOCKUPS
- HOST COMPUTER SYSTEM
- SCENE GENERATION/GROWTH & TERMINAL FACILITY
- TEST CONTROL ROOM COMPLEX

EL10313

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

COMPUTER–AIDED 1–G TRAINING SIMULATION

JSC SPACELAB SIMULATOR (SLS)

PURPOSE: PROVIDE FULL–TASK TRAINING IN OPERATION OF THE SPACELAB SUPPORT SUBSYSTEMS FOR PILOTS, MS'S & PS'S

APPLICATION:

- FOR STANDALONE AND/OR INTEGRATED (WITH MCC) SIMULATIONS
- INCLUDES TRAINING ON THE ELECTRICAL POWER DISTRIBUTION SYSTEM, ENVIRONMENTAL CONTROL SYSTEM, AUDIO SYSTEM, COMMAND & DATA MANAGEMENT SYSTEM, & CAUTION & WARNING SYSTEM

SLS DESCRIPTION:

- HIGH FIDELITY SPACELAB CORE & EXP. MODULE SEGMENT, RACKS, C&D, SAL, VIEWPORT
- USES SIMS COMPUTER COMPLEX; INTERFACES WITH FBCS
- DOES NOT INCLUDE EXPERIMENTS OR TUNNEL
- LOCATED IN BUILDING 5

JSC SPACELAB SINGLE SYSTEM SIMULATOR (SLSST)

PURPOSE: PROVIDE PART–TASK TRAINING FOR IPS & ORBITER–INTERFACING SPACELAB SYSTEMS TO PILOTS, MS'S, PS'S & GROUND PERSONNEL

APPLICATION:

- TRAIN PERSONNEL ON SINGLE SYSTEM BASIS
- IN CONJUNCTION WITH LESSON SEQUENCE
- INCLUDES DISPLAY & CONTROL FAMILIARIZATION, NORMAL & MALFUNCTION SPACELAB PROCEDURES

SLS DESCRIPTION:

- SINGLE STUDENT STATION WITH COLOCATED INSTRUCTOR STATION INTERFACED WITH SST COMPUTER COMPLEX
- STUDENT STATION – MEDIUM FIDELITY MOCK–UP OF PARTIAL SPACELAB MODULE
- INCLUDES CRT DISPLAY, KEYBOARD, INTERCOM, CONTROL PANELS
- IPS–SIMULATED VIA CCTV, IMAGE MODELS, IMAGE DISPLAYS, IPS CONTROL PANEL/KEYBOARD

 FILE NO.

JSC PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM (PDRS) REMOTE MANIPULATOR SYSTEM (RMS) TRAINER

The PDRS trainer provides part-task training to pilots and mission specialists in payload grappling (in the payload bay), berthing, visual operations, payload bay camera operations, and Orbiter RMS software operations. PDRS lessons are two to three hours in duration. The PDRS facility consists of an Orbiter aft crew station mockup, a payload bay mockup, mechanically operated arm, and representative retention latches.

Advanced and flight specific training conducted in the PDRS trainer includes hardware review, unloaded and loaded mechanical arm operation, payload deployment and berthing, night time operations, and contingency operations. The PDRS trainer is located in Building 9A at JSC.

SUMMARY

To summarize, there are several types and a significant number of man-in-the-loop simulators available within NASA at the present time. The use rate for these simulators, for the most part, is quite high. However, they are available to industry, academia, and other government agencies on a prioritization basis.

However, all indications are that, as space utilization increases, so will the need for simulators. The possibility exists that sufficient numbers and types of man/machine simulators will not be available for future use. Thought must be given now, as part of this workshop, as to where we go in the future. What are the simulation needs, the simulation requirements.

We wish to challenge the Workshop to:

- Define upcoming simulation requirements based on mission needs
- Likewise, the requirements for simulation facilities to meet these needs are necessary
- Lastly, we must develop innovative simulation techniques as needs and requirements become obvious.

EL 10233

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER	NAME: J. W. STOKES
CHART NO.:	HUMAN ROLE IN SPACE	DATE: AUGUST 1982

TRAINING SIMULATIONS

JSC PAYLOAD DEVELOPMENT & RETRIEVAL SYSTEM (PDRS) REMOTE MANIPULATOR SYSTEM (RMS) TRAINER

PURPOSE: PROVIDE PART–TASK TRAINING IN RMS OPERATIONS

APPLICATION:

- TRAINING IN PAYLOAD GRAPPLING (IN PAYLOAD BAY/BERTHING, VISUAL OPERATIONS, PAYLOAD BAY CAMERA OPERATIONS, & ORBITER RMS SOFTWARE OPERATIONS
- TRAINING INCLUDES HARDWARE REVIEW, UNLOADED & LOADED MECHANICAL ARM OPERATION, PAYLOAD DEPLOYMENT & BERTHING, NIGHT TIME OPERATIONS, & CONTINGENCY OPERATIONS

PDRS DESCRIPTION:

- ORBITER AFT CREW STATION MOCKUP, PAYLOAD BAY MOCKUP, MECHANICALLY OPERATED ARM, REPRESENTATIVE LATCHES
- USES NEUTRALLY BUOYANT INFLATABLES AS PAYLOAD MOCKUPS

ORGANIZATION: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES DATE: AUGUST 1982

SUMMARY

THE FOLLOWING CONCLUSIONS ARE MADE:

- VARIOUS TYPES OF MAN–IN–THE–LOOP SIMULATORS EXIST THROUGHOUT NASA
- USE RATE PRESENTLY HIGH; ANTICIPATE USE RATE HIGH; AVAILABILITY TO INDUSTRY EXISTS THROUGH PRIORITIZATION (NASA, DOD, INDUSTRY)
- WHAT ARE FUTURE SIMULATION NEEDS?
  - INDICATIONS TOWARD INCREASED REQUIREMENTS AS INDUSTRIALIZATION OF SPACE OCCURS
  - LACK CONFIDENCE TO HANDLE FUTURE SIMULATION NEEDS

CHALLENGE TO SIMULATION & TRAINING WORKING GROUP:

- DEFINE FUTURE SIMULATION REQUIREMENTS
- DEFINE SIMULATION FACILITY REQUIREMENTS
- PROVIDE INNOVATIVE SIMULATION TECHNIQUES

THE ALLOCATION OF MAN/MACHINE FUNCTIONS

Ken Fernandez
NASA-MSFC-EB44

Introduction

The problems associated with the allocation of man/machine functions on space missions are in a sense similar to those encountered in the industrial environment on Earth, and the stategies used to solve these problems are also related. In both industry and in space we are presented with goals, a job to be performed, and we must plan carefully to make optimal use of our resources. In order to make a sensible judgement the manager must be aware of the abilities and expenses associated with these resources. Making a proper choice can be thought of as a balancing act (Figure 1) in which we are comparing the advantages and disadvantages associated with using man or machine to perform a given task.

Man, Man/Machine and Machine Systems

Let us begin by first reviewing the definitions and examples of the basic alternative ways to perform a task: Man, Man/Machine and Machine (see figure 2).

Man functions are those which are performed solely by humans or, at most, by humans with hand held tools. These functions may be performed within a space vehicle (IVA) or exterior to the vehicle (EVA). A typical example of manually performed EVA activity might be the retrieval and replacement of a film cannister shown in the Neutral Buoyancy Simulator (see figure 3) or the fastening of an assembly using a power tool (see figure 4).

Man/machine systems are those in which a human manually operates or programs a machine. A distinction between this and hand tool operation is the level of performance achieved by these systems is un-attainable by the human alone. Several examples of man/machine systems include: remote manipulators originally developed to support the nuclear industry (1); exo-skeletal manipulators developed to aid in materials handling (2)(see figure 5); and interactive computer aided design systems (CADS) to name just a few. A hallmark of all these man/machine examples is the complimentary relationship between human skills and machine skills: man provides cognitive functions while the machine performs the more well defined tasks.

Machine functions are those which are performed exclusively by a computer, teleoperator, or robot under supervisory control. An example (3) of NASA's use of machines in a ground support operation is the application

WORKSHOP ON THE HUMAN ROLE IN SPACE

MAN/MACHINE FUNCTION ALLOCATION

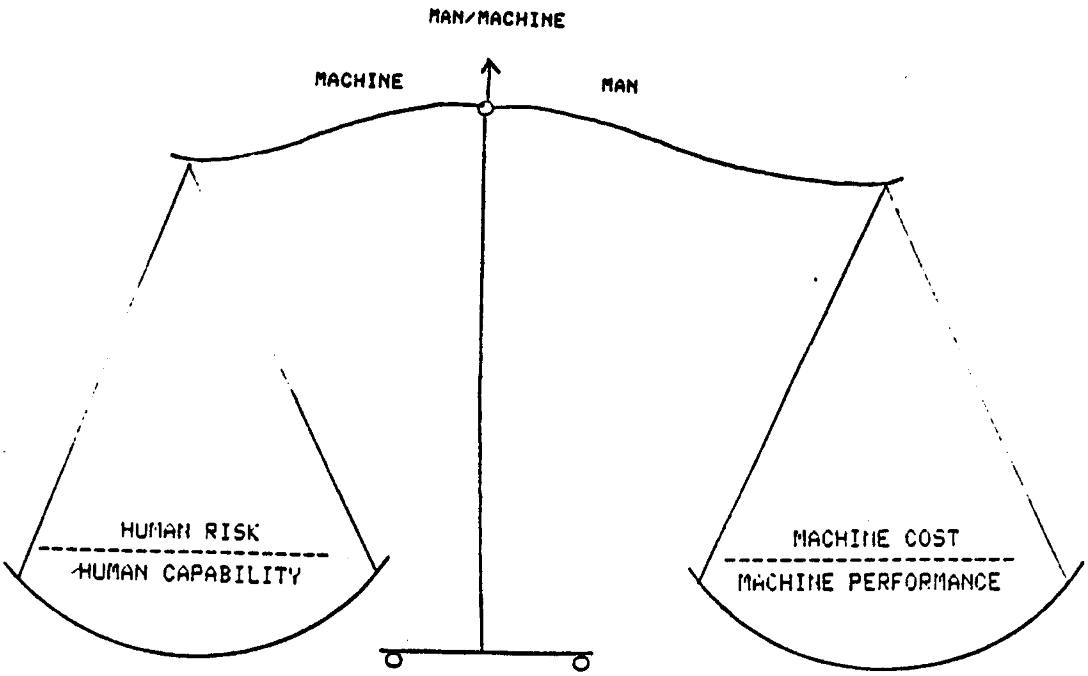


Figure 1 Man/Machine Function Allocation

DEFINITIONS

TERM	DEFINITION
HUMAN ROLE	TASK IS PERFORMED COMPLETELY BY HUMANS OR BY HUMANS WITH HAND-HELD TOOLS BETWEEN THEM AND TASK OBJECT (IVA AND EVA)
HUMAN SUPPORTED BY MACHINES	TASK IS PERFORMED BY HUMANS WITH MANUALLY OPERATED OR PROGRAMMABLE MACHINES, ONE COMPLEMENTING THE OTHER (IVA AND EVA). THIS INCLUDES RMS, INTERACTIVE COMPUTERS, ETC.
MACHINES	TASKS PERFORMED EXCLUSIVELY BY COMPUTERS, TELEOPERATORS, AUTOMATA, ROBOTS (WITH HUMAN SUPERVISION.)

Figure 2 Definitions

and repair of the thermal protection system (TPS) to the Solid Rocket Booster (SRB) and the External Tank (ET). Figure 6 depicts an SRB spray facility at KSC, while figure 7 shows the control room for a similar cell used for ET spray foam development at MSFC.--Perhaps NASA's most spectacular use of a machine system to date was the Saturn fly-by that kept us all "glued" to our TVs for each glimpse of the mysterious ringed planet.

Classification of Man, Man/Machine and Machine Tasks

A recent NASA report (4) investigating the human role in space identified those human capabilities that are extremely important to the success of a mission. These attributes include: the ability to rapidly respond to unforseen emergencies and repair, backup or improvise around failed systems; self contained operation in the absence of ground communications; to effectly perform vehicle control through rapid sensing and reaction; the ability to investigate, explore and simplify complex systems; and, most importantly, availability today.--This same report identified, by project, tasks that were suited for man, man/machines and machine systems. These results and a summary of task categories are reproduced in figures 8, 9 and 10.

In reviewing the survey of task categories in figure 10 we note without surprise that man is most versatile. We further note that a number of tasks can be performed by any of the systems. How, then, do we properly allocate these functions. To illustrate the decision process we will select a specific example: the assembly of the Geostationary Earth Orbit (GEO) Platform.

The GEO Platform is designed to be carried into Low Earth Orbit (LEO) aboard the Shuttle where it will be deployed, assembled and boosted into GEO by the Orbital Transfer Vehicle (OTV). Figure 11 shows assembly being performed by manual EVA. Several critical constraints apply to this operation: the degree-of-difficulty; the length of time required to assemble; and the amount of OTV cryogenics that can be lost without jeopardizing the mission. Failure to perform the assembly in a timely manner would require the disassembly of the GEO Platform, purging of the OTV, and return from orbit.--An alternative method is automated assembly. Designing the GEO Platform for automatic self-assembly is expensive requiring a long lead time, and this feature would have very limited utility when compared to the Platforms expected operating life.--A second alternative based on the existence of a Space Station (see figures 12 & 13) poses a less time-critical solution. With refilling of the cryogenics from supplies stored at the Space Station now possible, assembly of the GEO Platform could be performed by extended EVA. The Shuttle could even

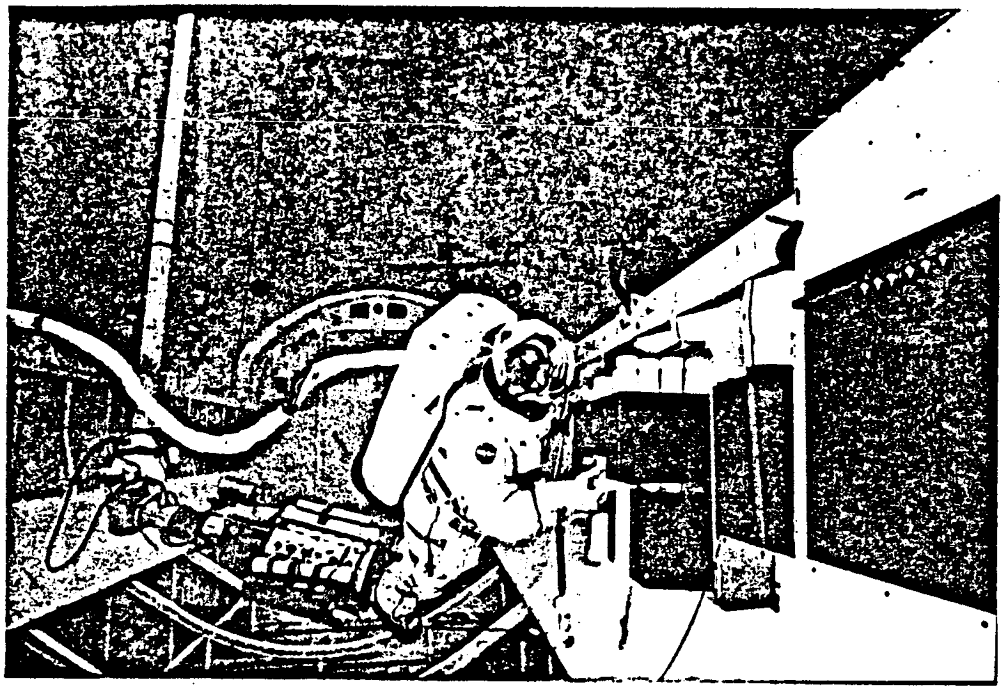


Figure 3 NBS EVA Film Pack Exchange

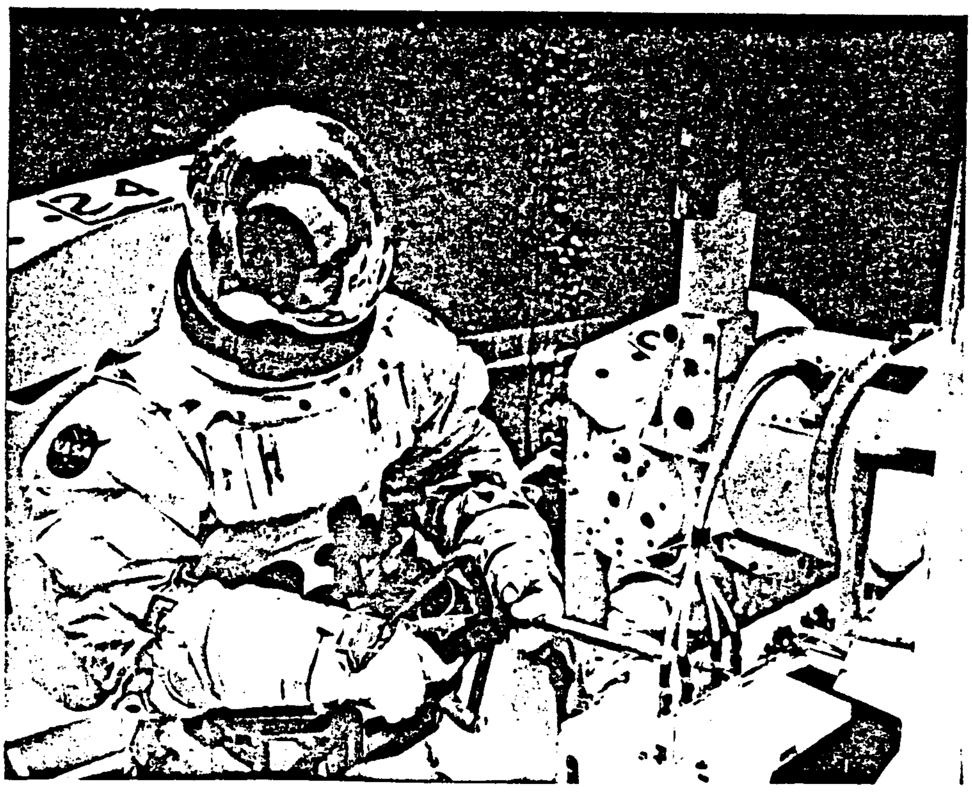


Figure 4 NBS EVA Power Wrench

depart after deployment with assembly being completed by crews from the Space Station (see figure 14). Although this example was presented to illustrate man/machine function allocation strategies, it also demonstrates the flexibility resulting from the establishment of a Space Station.

Man/Machine Allocation as a Stimulus to Research

Thus far in our discussion, we have focused upon the utilization of research from the other disciplines presented this afternoon. However the flow of information is bi-directional (figure 15). Often the questions asked can guide research down important new pathways. It is the perpetuation of this chain-reaction of information that is as important as the hardware that we develop.

Conclusions

As the Space Shuttle enters its operational phase, we will realize the valuable role that this system will play in transforming space from the cold forbodding place to which we now send only satellites and a few brave astronauts into the factory of tomorrow. The harsh environmental factors that, in the past we have viewed as obstacles to be overcome, will become precisely the resources that we seek. They will enable us to do basic research and develop materials and processes that are not possible on Earth. Today we send into space only our most physically fit, but tommorrow we may locate hospitals there.

When we achieve an advanced level of space utilization, the space worker will undoubtedly be supported by automated systems relieving him of the need to peform tasks that are either dangerous or do not make proper use of his abilities. Expert systems will manage his environment and coordinate with similar ground based systems. The level of future developments in space exploration is probably not limited by our imagination today. The most speculative science fiction writers of the past have either fallen short of today's technology or over-estimated the time frame for its development. The problem presented to us today is that we have the means to travel into space readily available to us, but we do not have the "science fiction" technology that is sure to become a reality. In this interim period we cannot afford to remain idle, but we must develop strategies to optimally assign man/machine functions based on today's technology, while providing the stimulus for future developments.

HARDIMAN: AN EARLY
EXOSKELETAL MANIPULATOR

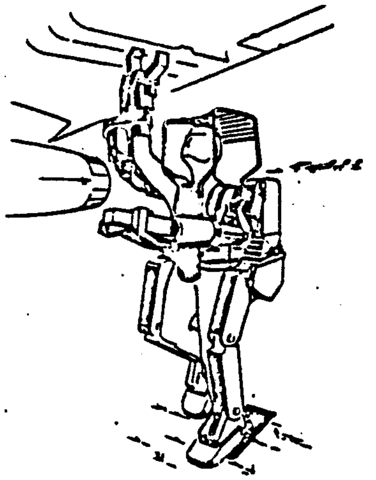


Fig. 12 - Hardiman - an exoskeletal manipulator to augment man's strength, made possible through human sensing control

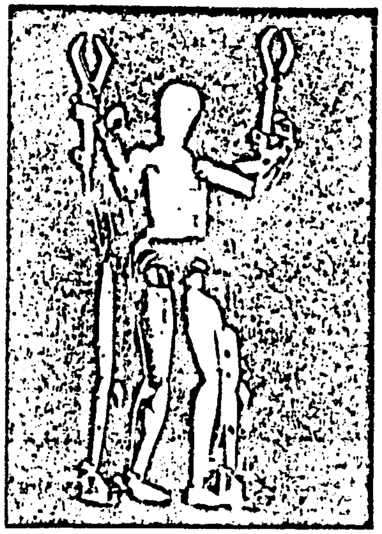


Figure 5 Mosher's Hardiman System

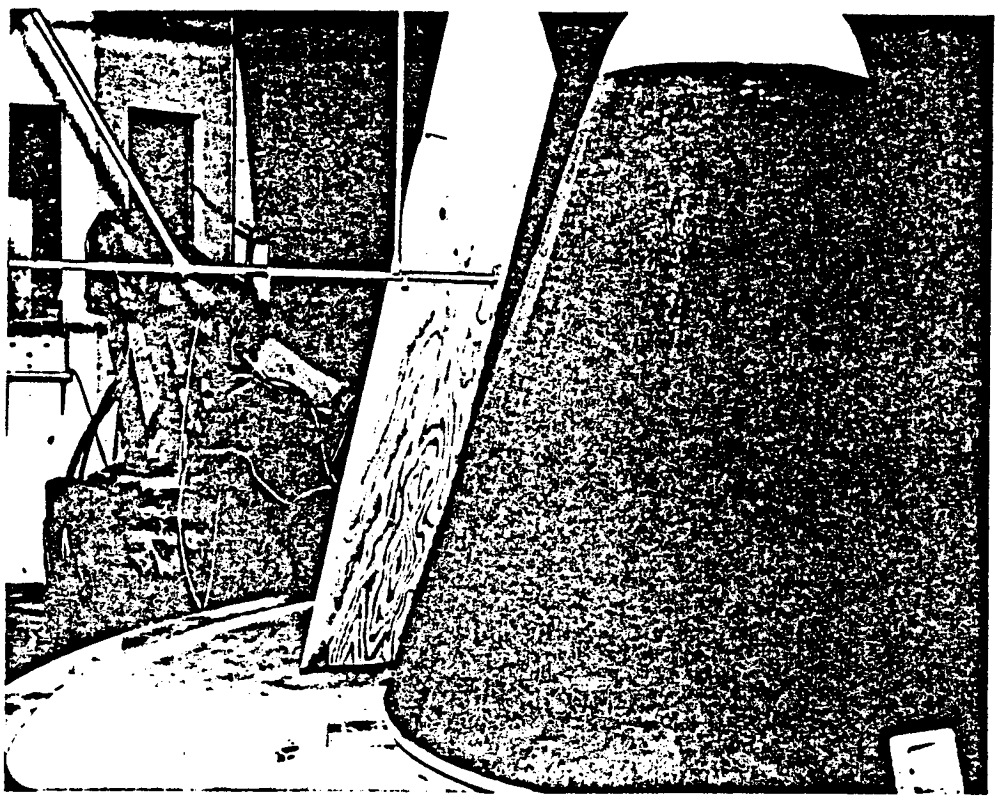


Figure 6 SRB TPS Spray Cell at KSC

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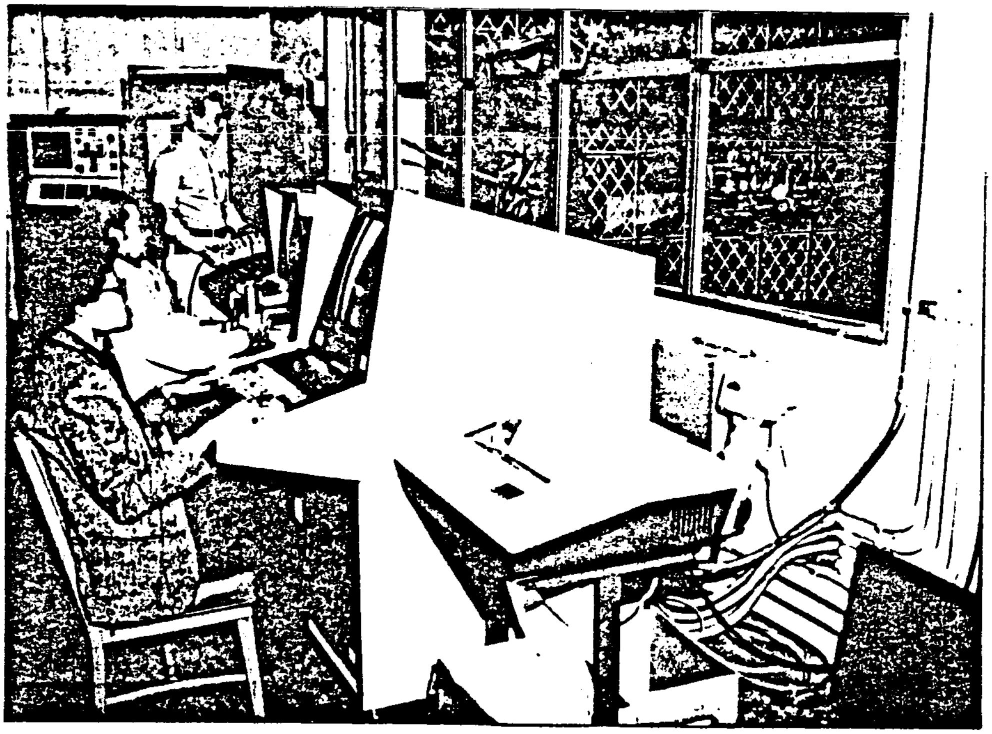

Figure 7 ET SOFI Development Cell at MSFC

TASK \ PROJECT	SASP	GEO PLATFORM	SPACE TELESCOPE	POWER SYSTEMS	LARGE SPACE STRUCT	LIFE SCIENCES	MPS
NORMAL ACTIVITIES/OPERATION							
REPLACE SPARES	✓		✓	✓	✓	✓	✓
REPLACE EXPENDABLES						✓	✓
EQT CALIBRATION						✓	✓
EXP MONITOR/SUPERVISION	✓				✓	✓	✓
ASSEMBLY	✓	✓	✓	✓	✓	✓	✓
DATA INTERPRETATION						✓	✓
SPECIMEN HANDLING						✓	✓
ROUTINE C/O, SERVICE	✓	✓	✓	✓	✓	✓	✓
CONTINGENCY ACTIVITIES							
TROUBLE SHOOT	✓	✓	✓	✓	✓	✓	✓
REPAIR	✓	✓	✓	✓	✓	✓	✓
MODIFY PROTOCOL	✓	✓		✓	✓	✓	✓
RESOURCE ALLOCATION	✓	✓		✓	✓	✓	✓
WORKAROUND SOLUTIONS	✓	✓		✓	✓	✓	✓
DEPLOY, RETRACT JETTISON APPENDAGES	✓	✓	✓	✓		✓	

Figure 8 Major Tasks Performed by Man

MAN/MACHINE

TASK \ PROJECT	SASP	GEO PLATFORM	SPACE TELESCOPE	POWER SYSTEMS	LARGE SPACE STRUCT	LIFE SCIENCES	MPS
DEPLOY PAYLOADS/SPACECRAFT	✓	✓	✓	✓	✓	✓	✓
RENDEZVOUS	✓	✓	✓	✓	✓	✓	✓
DOCKING/BERTHING	✓	✓	✓	✓	✓	✓	✓
CAPTURE W/RMS	✓		✓	✓		✓	✓
INST ORB REPL UNITS	✓	✓	✓	✓	✓	✓	✓
INSP & MAINTENANCE	✓	✓	✓	✓	✓	✓	✓
EXPENDABLE REPLENISH	✓	✓	✓	✓	✓	✓	✓
EVA REPAIR	✓	✓	✓	✓	✓	✓	✓
ASSEMBLY	✓	✓			✓		✓
CHECKOUT	✓	✓	✓	✓	✓	✓	✓

MACHINE ONLY

TASK	SASP	GEO PLATFORM	SPACE TELESCOPE	POWER SYSTEMS	LARGE SPACE STRUCT	LIFE SCIENCES	MPS
ORBIT REBOOST	✓	✓	✓		✓	✓	✓
ORBIT TRANSFER		✓			✓		
INSPECTION	✓	✓	✓	✓	✓	✓	✓
REMOTE REPAIR	✓	✓	✓	✓	✓	✓	✓
REMOTE REPLACEMENT	✓	✓	✓	✓	✓	✓	✓
HAZARDOUS OPERATIONS	✓	✓	✓	✓	✓	✓	✓
ASSEMBLY		✓			✓		

Figure 9 Major Tasks

MAN

NORMAL ACTIVITIES/OPERATION
REPLACE SPARES
REPLACE EXPENDABLES
EQT CALIBRATION
EXP MONITOR/SUPERVISION
DATA INTERPRETATION
SPECIMEN HANDLING
ROUTINE C/O, SERVICE
ASSEMBLY
CONTINGENCY ACTIVITIES
TROUBLE SHOOT
REPAIR
MODIFY PROTOCOL
RESOURCE ALLOCATION
WORK AROUND SOLUTIONS
DEPLOY, RETRACT, JETTISON APPENDAGES

MAN/MACHINE

DEPLOY PAYLOADS/SPACECRAFT
RENDEZVOUS
DOCKING/BERTHING
CAPTURE W/RMS
INST ORB REPL UNITS
INSP & MAINTENANCE
EXPENDABLE REPLENISH
EVA REPAIR
ASSEMBLY
CHECKOUT

MACHINE

ORBIT REBOOST
ORBIT TRANSFER
INSPECTION
REMOTE REPAIR
REMOTE REPLACEMENT
HAZARDOUS OPERATIONS
ASSEMBLY

Figure 10 Summary of Task Categorization

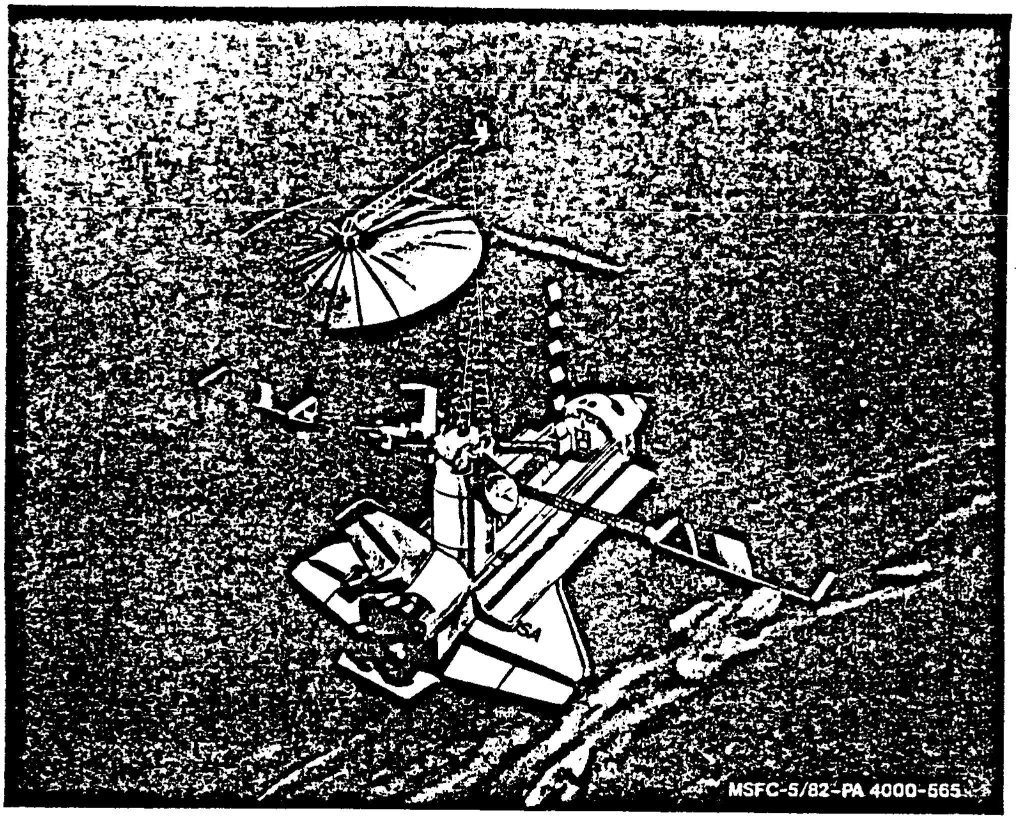

Figure 11 GEO Platform

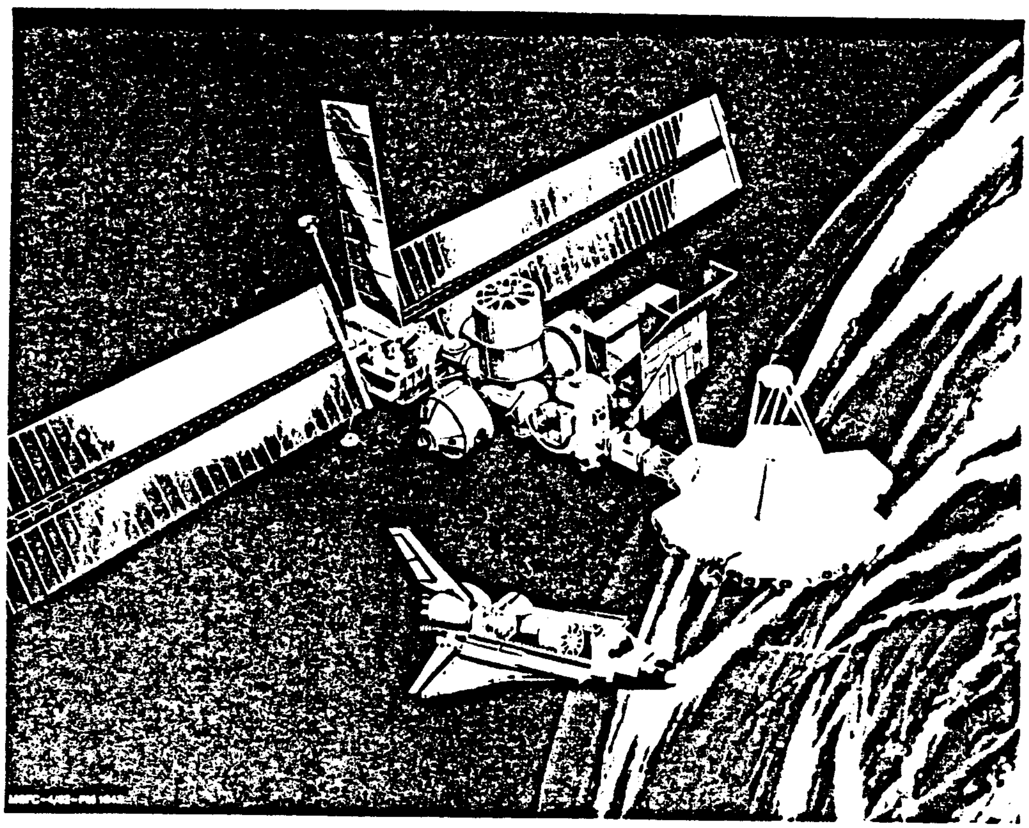

Figure 12 Space Station

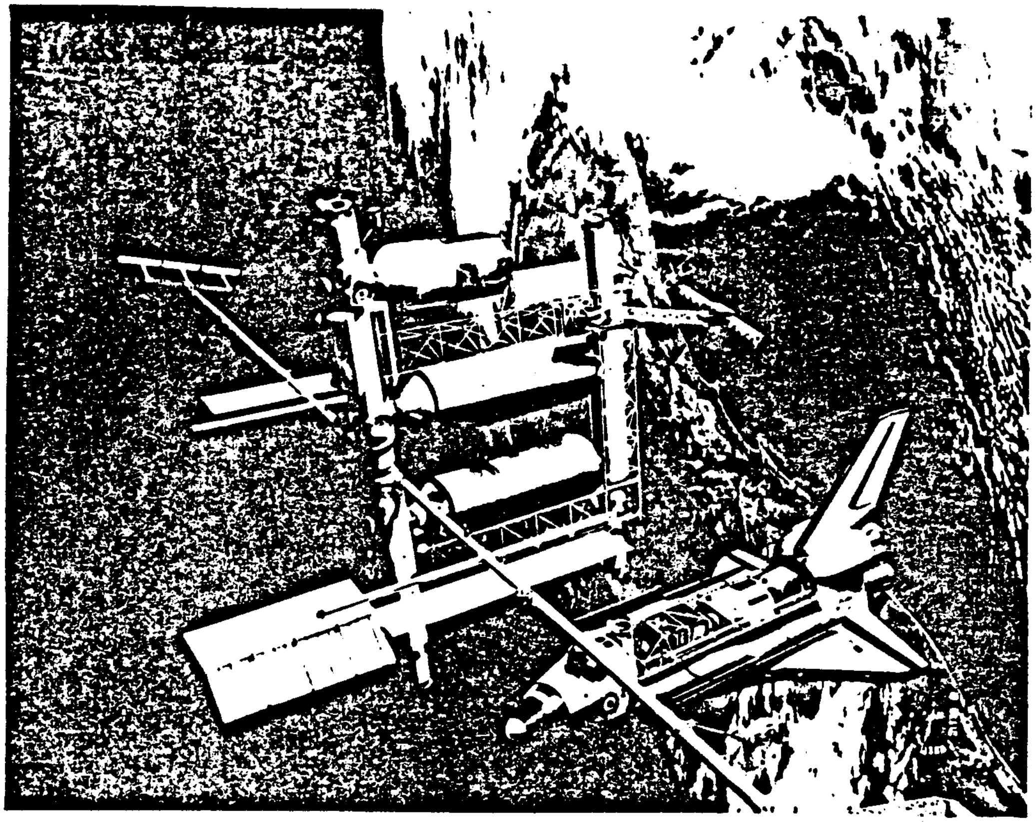

Figure 13 Alternative Space Station

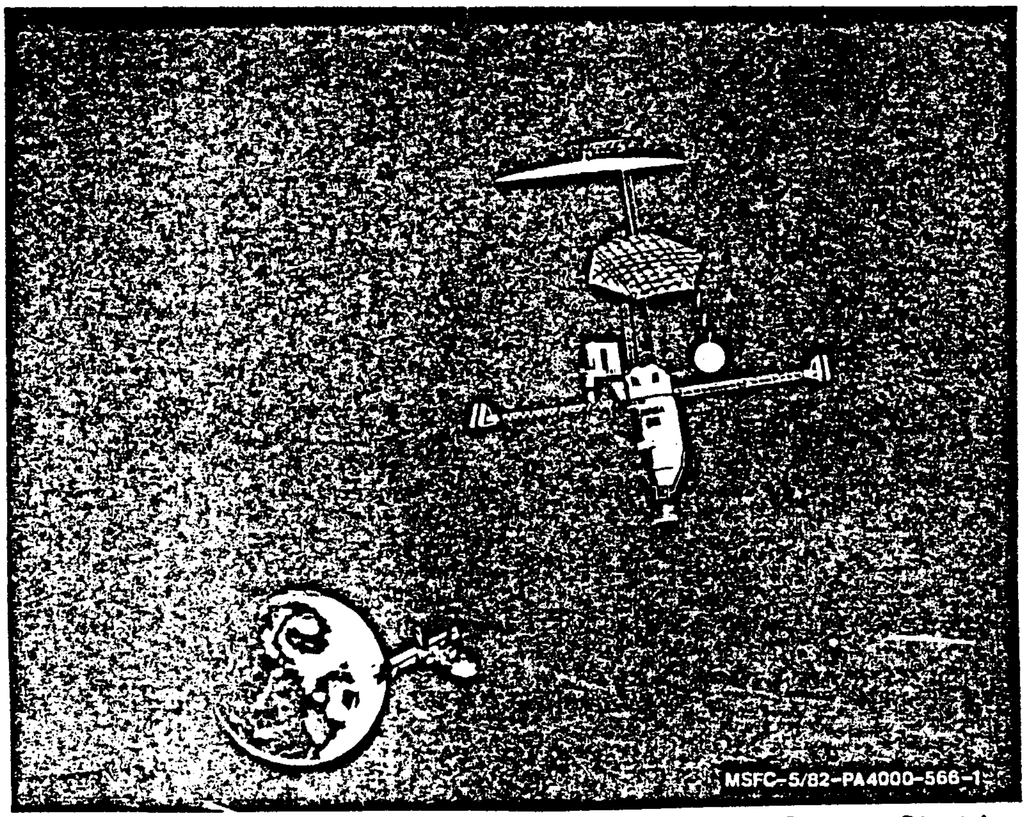

Figure 14 GEO Platform Departing Space Station

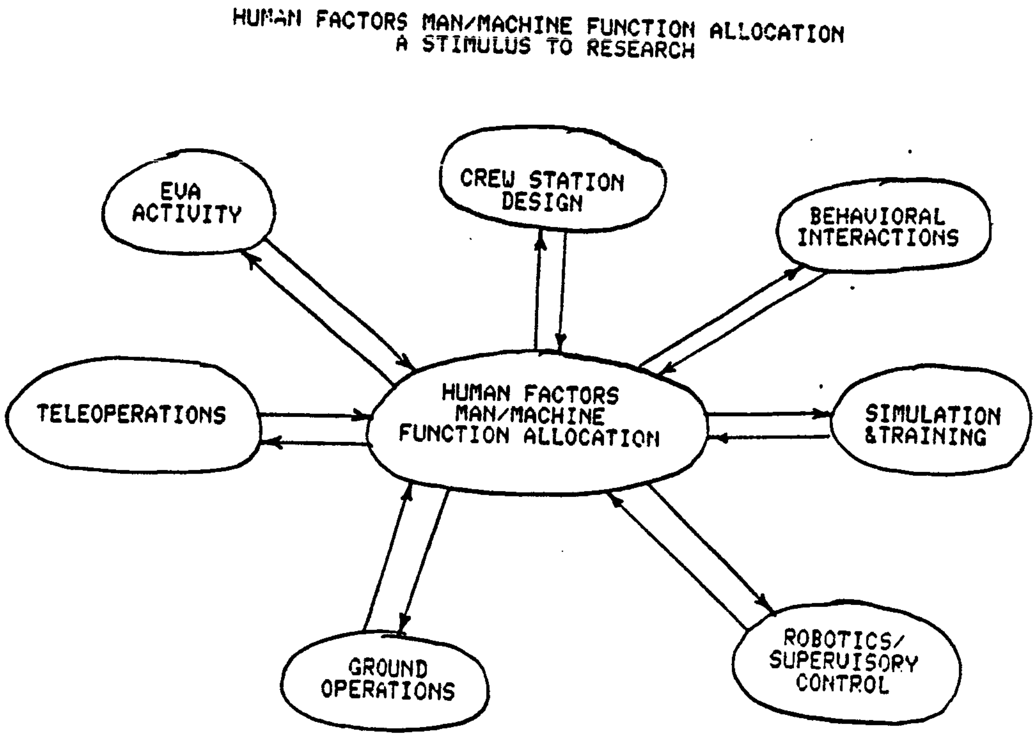

Figure 15 Man/Machine Allocation as a Stimulus to Research

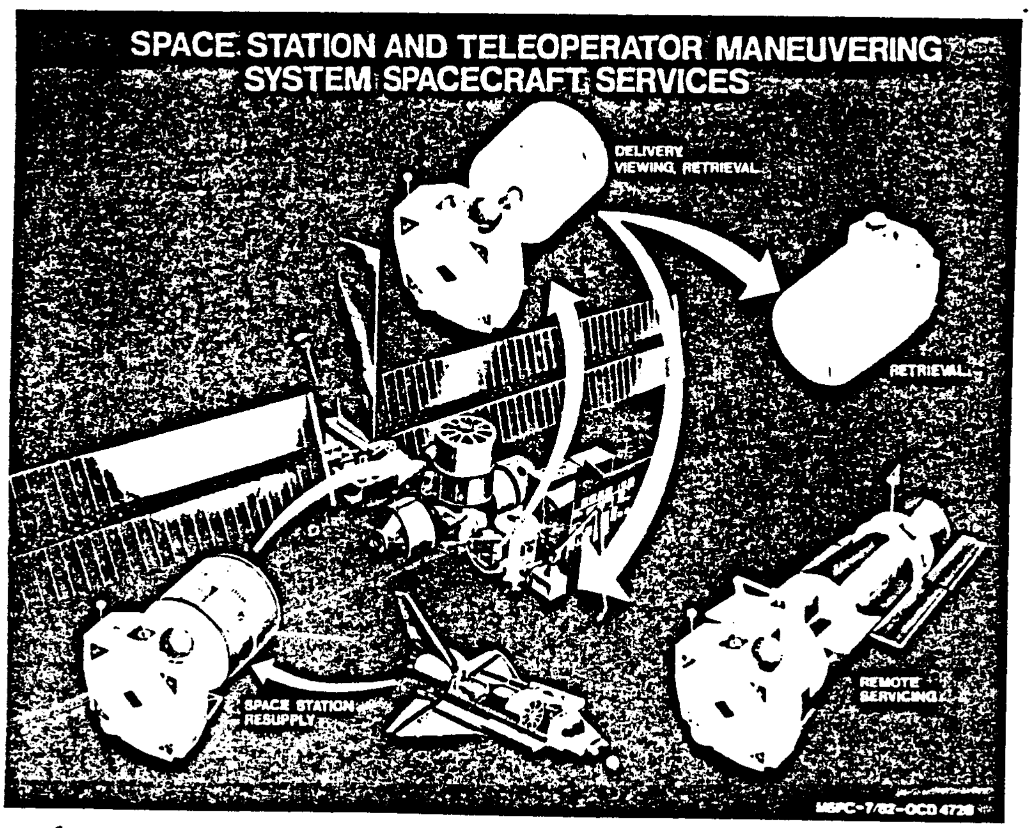

Figure 16 Space Station and Teleoperator Maneuvering System Performing Spacecraft Services