WORKSHOP PROCEEDINGS

SPACE HUMAN FACTORS

VOLUME 1 OF 2

24 - 26 August 1982
Xerox Training Facility
Leesburg, Virginia

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Sponsored by:

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Office of Aeronautics and Space Technology
Code RTH-6, Washington, D. C. 20546

Workshop Proceedings

SPACE HUMAN FACTORS

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FOREWORD

The "Human Role in Space" Workshop was held at Leesburg, Virginia, on 24-26 August, 1982. The workshop was sponsored by the Office of Aeronautics and Space Technology (OAST) of the National Aeronautics and Space Administration (NASA). The goals of the workshop were:

- To provide a focus for, and a review of, technological opportunities and requirements for the human role in space.
- To brief outstanding American human factors specialists on the nation's space program plans, and on NASA's current technology for developing effective, efficient, and safe man-machine systems.
- To delineate a data-base of human factors methods, techniques, and technologies which may prove effective in the design and development of man-machine systems for use in the space program.
- To aid in planning OAST's space human factors program by identifying technological needs and promising research topics and approaches.
- To insure that all parties involved are aware of significant programs in industry, academia, the military and the government which may be helpful in determining optimal roles, tools, procedures, training and man-machine interfaces for current and future space missions.

The workshop served to open a dialogue between the human factors community and the space program's planners, researchers and operational staff. The focus for continuing this dialogue will be the space human factors research program which has been chartered by NASA's Office of Aeronautics and Space Technology (OAST) beginning 1 October, 1982. The goal of the space human factors research program is to develop an empirical data base for determining optimal roles, tools, procedures, training and man-machine interfaces for the space program. This includes ground operations as well as on-orbit operations.

This report contains copies of all the presentations given (Sessions I-V), the reports of the working group (Session VI), and a number of reports submitted for publication that were not presented at the meeting (Appendix A). In most cases, the presentations were made with overhead transparencies, and these have been published two to a page. The author's explanatory text is presented on the facing page.

Melvin Montemerlo
Melvin D. Montemerlo
Workshop Chairman

Alfred C. Cron
Alfred C. Cron
Workshop Coordinator

November 1, 1982
Washington, D.C.

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SESSION I

INTRODUCTION

WELCOMING ADDRESS

BY

DR. RAYMOND S. COLLADAY

DEPUTY ASSOCIATE ADMINISTRATOR

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

Ladies and Gentlemen:

It is my pleasure to welcome you to the Space Human Factors Workshop.

We are now entering an exciting era in America's space program. This era will be marked by frequent and economical access to space for scientific, commercial and national security endeavors. This has been made possible, of course, by the success of the Shuttle which has just finished its developmental phase. With its next mission on November 11, the Shuttle is officially operational.

After the Columbia touched down on the fourth of July, President Reagan addressed the Nation concerning the future of the space program. He said, "...we must look aggressively to the future by demonstrating the potential of the shuttle and establishing a more permanent presence of man in space." As you will hear later this morning, the permanent presence of man in space will most likely take the initial form of a manned space station in low earth orbit.

This raises important human factors issues. For example: Which functions should be accomplished by humans and which through automation? Which functions should be performed on-site by an astronaut in space suit, and which should be performed remotely via teleoperations? How should crew stations, tools and procedures be designed to take advantage of uniquely human capabilities and to avoid human limitations?

In the years since Skylab, significant achievements have been made in the technology of automated spacecraft and in transitioning to a reusable manned space transportation system. However, the technology for dealing

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with lengthy stays of humans in space has received relatively little attention since the Apollo and Skylab programs.

In order to address this issue, we are instituting a space human factors program. I should note that we have had an aeronautical human factors program since the mid 1970s. As with our other disciplinary programs in propulsion, material and structures, aerodynamics, and controls, we expect the aeronautical and space programs to interact and to provide mutual support. This is consistent with our overall approach to disciplinary research which is fundamental and long term in nature.

Another important area for NASA coordination is with the military; with the military space program, and with the military laboratories which are involved in human factors research. As you know, the Shuttle is a joint military and civil program and a similar relationship would almost certainly hold for a space station. In this spirit of cooperation, it is good to note that the Air Force Space Division, and human factors research laboratories from the Army, Navy, and Air Force are participating in this workshop.

While we have not had a formal space human factors program, NASA does have a formidable data base on human interaction with space systems. This comes from past manned missions and from a number of research and development efforts. The new program should serve as a focus for human factors research. It must develop, advocate, coordinate and carry out a systematic long-term program.

By initiating the space human factors program we are formally recognizing the importance of what may be called "the human subsystem," and the need to develop technology for improving human capabilities in space operations--both on-orbit and on the ground.

There is a prodigious amount of human factors expertise gathered here for this workshop. We ask your help in defining and prioritizing research issues and approaches, and in elucidating the benefits that will accrue from these approaches.

In short, we are asking you to help us define how the discipline of human factors can make the greatest contribution toward making America's space plans become a reality.

Thank you for coming to this workshop and aiding in our long range planning efforts.

OPENING REMARKS: WORKSHOP GOALS

DR. MELVIN D. MONTEMERLO

Dr. Colladay, thank you for your opening remarks. You have presented the discipline of human factors with an exciting invitation, that of participating in the next phase of America's space program--the transition from frequent Shuttle missions to the permanent presence of man in space. You have also presented us with a challenge--that of defining the technology and benefits which human factors can provide to make that transition become a reality.

Invitations and challenges are exciting, but they are even more exciting when accompanied by a vote of confidence. NASA's Office of Aeronautics and Space Technology, which Dr. Colladay represents has given human factors that vote of confidence by providing us with FY 83 funding without the sequence of events which usually preceeds the funding of any new program.

That sequence usually begins with a symposium or workshop in which leading American authorities convene to develop a rationale for adding a new research area. This is followed by the formation of an intercenter steering group which spends a year developing a prioritized list of issues and approaches, and of developing support and good-will. This is followed by a further workshop in which experts from academia and industry refine the technical plan and advocacy for presentation at the next budget year's funding prioritization exercise. Even having laid this careful groundwork, there is no guarantee of success, because initial year funding for new areas is taken from on-going programs. It is in the vernacular, a zero-sum game, and the managers of existing programs tend to ask difficult questions about the potential benefits of proposed new initiatives. New initiatives which have followed this sequence of events and been successful in the last few years are: automation, computer science, and controls.

Human factors did not follow this sequence. There was neither an initial workshop to develop advocacy, nor a year-long intercenter steering group to develop technology plans. In December 1981, Dr. Jack Kerrebrock, our Associate Administrator, called a meeting to ask what NASA was doing in space human factors, and asked what NASA should be doing. As a result of that meeting, we were invited to participate in the FY 83 funding prioritization which began in January 1982. With help from NASA center personnel, a proposal was generated in the space of one month. Of necessity it was more general than the proposals of on-going programs and of other new initiatives which followed the traditional preparatory steps. However, human factors was allocated $2.4 Million for FY 83. That constitutes a clear and distinct vote of confidence for our discipline.

Upon learning of our success, I took two actions. One was to form an intercenter steering group to coordinate the center proposals (RTOPs) for FY 83. They were due in Headquarters earlier this month. Final negotiations must be completed next month.

The second action was to begin preparations for this workshop. Although an earlier date would have been more desirable in terms of NASA's annual program planning cycle, this is the earliest date the workshop could be held. It still can and will have an impact on the FY 83 program. However, the primary impact is designed to be on the long range plan (FY 84 and beyond).

NASA's annual program planning cycle is marching on. Our long range plans are due in November and the FY 84 funding prioritization exercise will take place in January. We will most certainly find the going much tougher this cycle than last. Thus the first and most time critical reason for this workshop is to enlist the aid of America's top human factors experts in defining what our discipline can do for the space program, and what the benefits will be.

The second and more important reason for this workshop is to develop a close working relationship between key NASA personnel and the human factors community. NASA has a very limited number of human factors specialists. For example, while NASA employs about 22,000 people, only 27 of them are listed in the 1982 Human Factors Society directory. The Office of Aeronautics and Space Technology has asked us to implement a disciplinary program in human factors. This can only be done with the involvement of human factors specialists. Since there is little hope of hiring many such people in the current environment, we must depend, to a large degree, on contracts and grants for human factors expertise.

Yet, there are very few human factors psychologists and engineers, outside of NASA who are knowledgeable of NASA's space programs and plans. Thus a main goal for this workshop is to brief human factors experts on this space program and to have them meet and get to know the NASA personnel who will be planning and managing the space human factors program. The Xerox training facility provides an excellent environment to facilitate that process.

The third reason for this workshop is to provide an opportunity for the military to enter this dialogue with NASA and this human factors community, right at the beginning. As you know the Shuttle is a joint civil/military venture. The Space Station is likely to foster a similar relationship. NASA and the Air Force have already begun to coordinate on human factors technology needs. I am a member of the AF/AIAA panel on "Man in Space" which is one of the number of panels contributing to the development of the "Military Space System Technology Model." It quickly became obvious that there is an overlap in the human factors technology that could impact America's civil and military space program plans. This can be seen in spite of the fact that the specific needs of neither are stated very precisely at this time. Both for example, have requirements for teleoperators, improved EVA capability and improved crew station technology. It is clear that in today's fiscal environment, there is no alternative to a sharing of the costs and responsibilities. We will be hearing from the Air Force's Space Division later this morning, and, of course, they will receive the workshop report. I believe that report will be an influential document as the Air Force refines their Military Space System

Technology Model. Thus your input to this workshop may well have a commonality to NASA and the military.

The Xerox Training Facility provides us an excellent environment to fulfill these three objectives. So, without further ado, let us proceed with the agenda.

SESSION II

THE HUMAN ROLE: MERCURY TO SHUTTLE

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EVOLUTION OF THE ASTRONAUT'S ROLE

JOSEPH P. LOFTUS, JR.
LYNDON B. JOHNSON SPACE CENTER
AUGUST 24, 1982

For additional background on this subject the reader is referred to Chapter 16 of "Foundations of Space Biology and Medicine" which is reproduced as an addendum at the end of this section.

Historically, studies of man/machine interfaces have focused on proper allocation of system operating functions between man and machine. A typical approach has been to analyze task sequences to discover task components and allocate these functions to man or machine, depending upon which would be better at the particular task. Man is able to handle a variety of information processing tasks in which input (sensory) and output (motor) aspects vary widely. He is able to store and recall great amounts of information pertinent to system operation under both normal and emergency conditions. He is able to operate as a decision-maker through his capability to evaluate information and to distinguish between useful and unusable and irrelevant information. He can solicit additional information from the system when necessary, and can estimate probabilities. The human operator can respond to the unforeseen and operate at a level of complexity exceeding any reasonable amount of premission planning and programming of on-board automatic control equipment. So far, man is the only real-time system capable of accepting and operating on asynchronous and nonsequential input data.

Man's capabilities for sensing data have been studied longer and more thoroughly than any other aspect of his performance. Much information is available concerning the basic processes of seeing, hearing, and sensing motion. Significant aspects of man's sensory capabilities are shown. Such data are in substantial agreement in US and Soviet handbook compilations.

MAN'S ROLE IN SPACE

CAPABILITIES:

- O SENSOR
- O OBSERVER
- O DATA PROCESSOR
- O REPORTER
- O ACTUATOR
- O CONTROLLER

ATTRIBUTES:

- O REPLICATION
- O INTERCHANGEABILITY
- O PROGRAMMABLE
- O LEARNING

CHARACTERISTICS OF THE SENSES

PARAMETER	VISION	AUDITION	TASTE AND SMELL	TOUCH	VESTIBULAR
INDICATIONS FOR USE	1. SPATIAL ORIENTATION REQUIRED 2. SPATIAL SCANNING OR SEARCH REQUIRED 3. SIMULTANEOUS COMPARISONS REQUIRED 4. MULTIDIMENSIONAL MATERIAL PRESENTED 5. HIGH AMBIENT NOISE LEVELS	1. NONDIRECTIONAL WARNING OR EMERGENCY SIGNALS 2. SMALL TEMPORAL RELATIONS IMPORTANT 3. POOR AMBIENT LIGHTING 4. HIGH VIBRATION OR G-FORCES PRESENT	1. PARAMETER TO BE SENSED HAS CHARACTERISTIC SMELL OR TASTE 2. CHANGES ARE ABRUPT	1. CONDITIONS UNFAVORABLE FOR BOTH VISION AND AUDITION	1. GROSS SENSING OF ACCELERATION INFORMATION

The increase in the number and scope of Apollo and Skylab mission objectives is indicated by the growth in the number of stowed items. This growth reflects increase in crew size, duration of missions, and emphasis on scientific objectives as operational maturity evolves. An analysis of the information shows that growth is caused primarily by time-dependent operational items (e.g., food and film) and by increased emphasis on scientific and applications experiment activities.

The number of items increased, also the diversity and complexity of the items. The number of stowed items increased by a factor of 4, even when the items attributable to more crewmen and a longer mission were omitted.

The relationship of crew size, pressurized volume, and usable volume of each spacecraft is shown. The usable volume is defined as that within the pressure vessel not occupied by equipment and that can be used for temporary stowage, movement by the crewmen, or other functions that enhance habitability. The volumes increased noticeably from the first to the present spacecraft configurations. For the Mercury and Apollo command module spacecraft, the relationship of the pressurized volume to effective free volume reflects that most equipment was installed within the pressure vessel. Gemini and lunar module spacecraft had only the crew instrument panels and portions of the environmental control system installed within the pressure vessel. Estimates of the volumes for Soviet spacecraft indicate similar arrangements.

NASA-S-81-2280

SPACE CRAFT STOWAGE

	COMPARTMENTS NUMBER	VOLUME (m^3)	ITEMS STOWED
MERCURY	-	-	48
GEMINI	13	.42	196
APOLLO	25	2.12	1727
SKYLAB	241	19.36	10,160
ASTP	32	2.65	1965
SHUTTLE	55	4.44	1084
SPACE STATION	300	80.0	20,000

NASA-S-81-2285

HABITABILITY CONSIDERATIONS

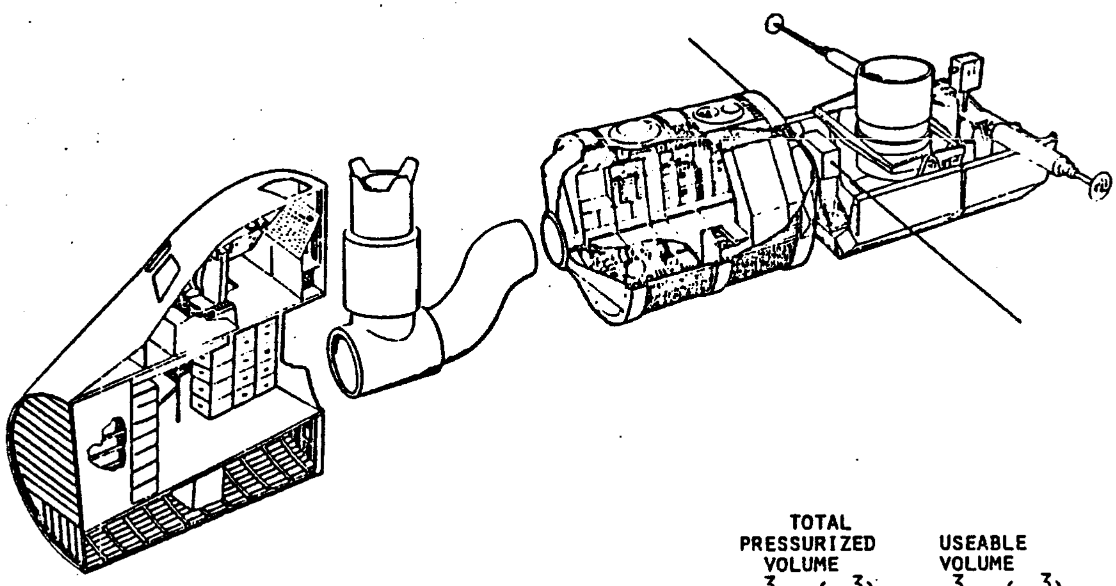
SPACECRAFT	NO. CREWMEN	PRESSURIZED VOLUME,[1] m^3	EFFECTIVE SPACECRAFT INTERIOR FREE VOLUME,[1] m^3	HABITABLE VOLUME PER CREWMAN, m^3
MERCURY	1	1.42	0.71	0.71
VOSTOK	1	2.55	2.00	2.00
GEMINI	2	2.27	1.15	0.57
VOSKHOD	2 OR 3	4.85	3.68	1.84/1.23
APOLLO				
COMMAND MODULE	3	8.95	7.27	2.41
LUNAR MODULE	2	6.63	5.25	2.62
SOYUZ				
COMMAND MODULE	1 TO 3	4.81	3.96	3.96/1.32
ORBITAL MODULE	1 TO 3	6.22	4.53	4.53/1.51
SKYLAB				
COMMAND MODULE	3	8.95	7.24	2.41
ORBITAL ASSEMBLY TOTAL	3	351.06	316.06	105.35
SHUTTLE				
CREW CABIN	3 TO 7	70.3	35.6	11.8 TO 5.1
SPACELAB	4 TO 7	81	47.6	11.9 TO 6.8
'SPACE STATION'	8 TO 12	300 TO 400	200	25 TO 15

A pictorial of Spacelab and Shuttle habitable area is shown. A comparison of available space is shown in the table.

A comparison of habitable space for Skylab, Salyut, and projected Space Operation Center and Science and Applications Manned Space Platform.

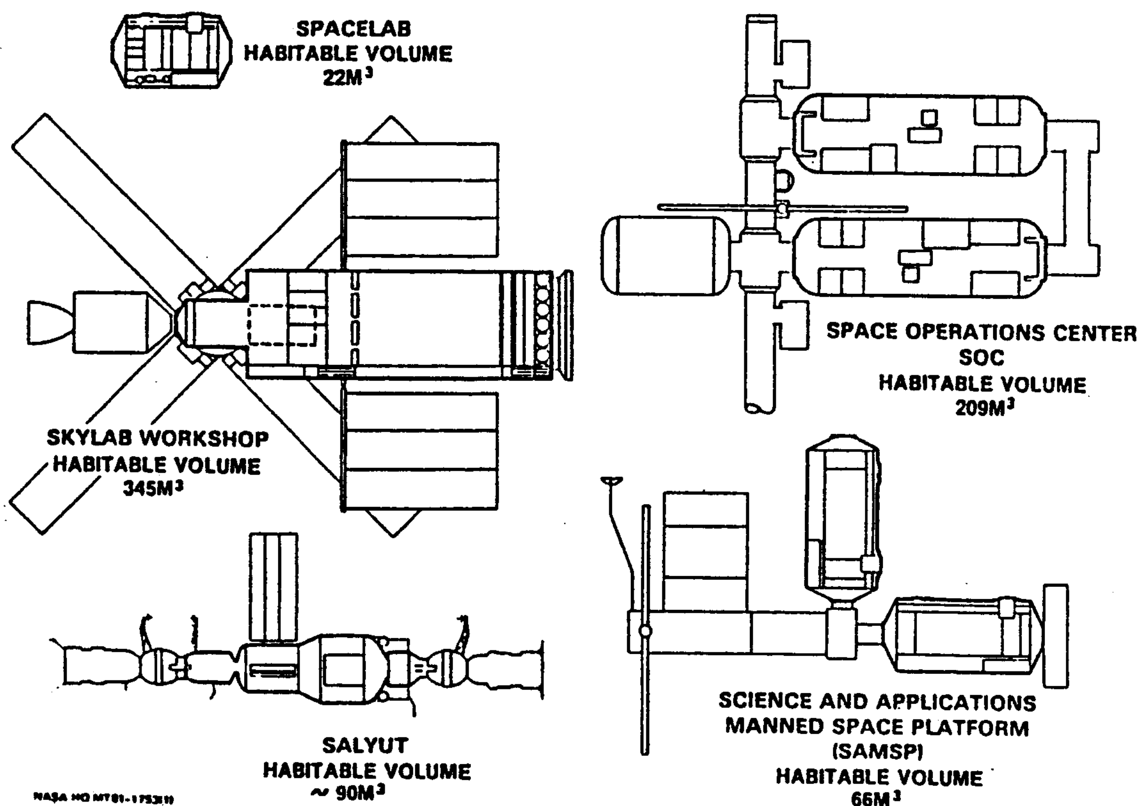
NASA-S-77-11643

SPACE SHUTTLE
HABITABILITY CONSIDERATIONS



	TOTAL PRESSURIZED VOLUME M^3	TOTAL PRESSURIZED VOLUME (FT^3)	USEABLE VOLUME M^3	USEABLE VOLUME (FT^3)
ORBITER CREW CABIN	70.3	(2475)	35.6	(1250)
TRANSFER TUNNEL	8.6	(303)	8.6	(303)
SPACELAB				
LONG	72.4	(2570)	39.0	(1448)
	151.3	(5048)	73.2	(3001)

"SPACE STATIONS" — A PERSPECTIVE

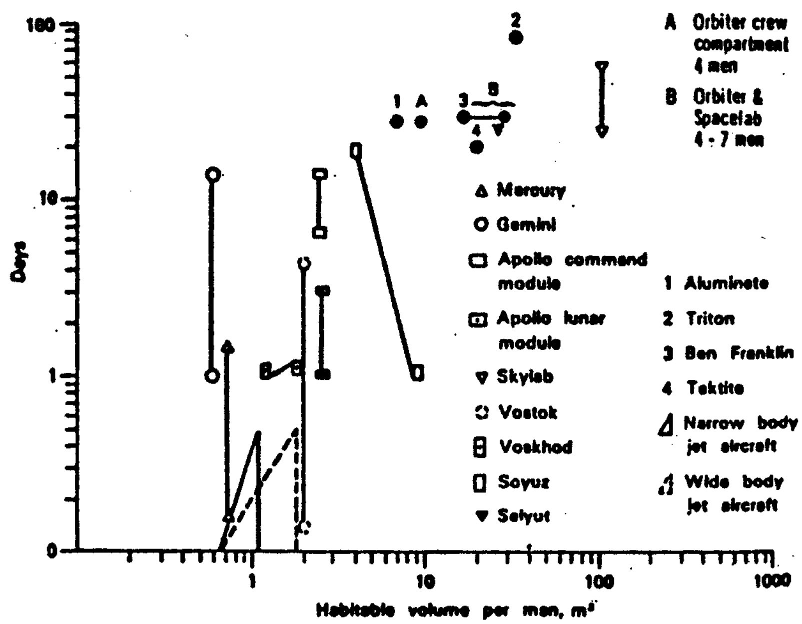


Shown are relationships of spacecraft volume, mission duration, and crew size to similar values for submersibles and aircraft. In all vehicles, the pressurized or conditioned volume of the vehicle increases as a function of both crew size and mission duration. Mission duration can be varied extensively for a given vehicle; however, for smaller vehicles, significant stresses may be placed on the crewmen.

An illustration of the weight and number of items related to on-board data management is shown.

NASA-S-77-4276

HABITABILITY CONSIDERATIONS



NASA-S-81-2283

ON BOARD DATA MANAGEMENT

	WEIGHT (kg)	NUMBER OF ITEMS
MERCURY	1.1	4
GEMINI	2.2	10
APOLLO	8.3	21
	13.0	34
SKYLAB	70.5	83
ASTP	18.6	34
SHUTTLE	28.6	37
SPACE STATION 1	50.0	75

1 ASSUMES: GROUND-TO-STATION DATAFAX.

The complexity, size, and number of display consoles in spacecraft have increased with more complicated missions and design commitment to the maximum effective use of crewmen.

The number of measurements required for each mission has grown from Mercury to Skylab. While the number has increased further from Shuttle to Space Station, the use of real-time control on-board and data base management from the ground will reduce the load on the crew and mission control substantially.

NASA-S-81-11057

STS-1 OPERATIONS

NORMAL FLIGHT

SYSTEMS CHECKOUTS/GO-NO GO's/FLIGHT TEST OBJECTIVES

ASCENT ABORTS

- RTLS
- AOA
- ATO
- ROTA
- CONT
  - 2 SSME FAIL
  - 3 SSME FAIL

- ORBIT 5 DE-ORBIT
- CONTINGENCY LANDING SITE DE-ORBIT

- DAY 2 ENTRY

SYSTEMS OPERATIONS

DDS ELEC OMS RCS ECLS APU HYD PBD MPS COMM

FAILURE CASES

ASC/ON-ORBIT/ENTRY

- LOSS OF 1 FUEL CELL/ELECT BUSSES
- LOSS OF 1 FREON LOOP
- LOSS OF TOPPING EVAP
- LOSS OF HIGH LOAD EVAP

ASC/ON-ORBIT/ENTRY

- LOSS OF CABIN PRESSURE
- LOSS OF 2 FUEL CELLS
- LOSS OF 2 FREON LOOPS
- LOSS OF 2 WATER LOOPS
- LOSS OF BOTH EVAPS
- LOSS OF BOTH CABIN FANS

ORBIT

- EVA TO CLOSE PBD's.
- EMERGENCY D/O

ASC PCL - 106 PGS
ORB PCL - 104 PGS
ENT PCL - 106 PGS

MALF PROC - 688 PGS

NASA-S-81-2284

SPACECRAFT SYSTEM INFORMATION

PROGRAM	TOTAL MEASUREMENTS		DISPLAYED TO CREW		DISPLAYED TO MISSION CONTROL	
MERCURY	100		53		85	
GEMINI	225		75		202	
APOLLO						
CM	475	948	280	494	336	615
LM	473		214		279	
SKYLAB						
CM	521	2241	289	615	365	2034
OAM	1720		326		1669	
SHUTTLE	7831		2170		3826	
'SPACE STATION' ①	10,000		4000		4000	

① ASSUMES REAL-TIME CONTROL ONBOARD, DATA BASE MANAGEMENT FROM THE GROUND

The technology of display and control components grew substantially more sophisticated from Project Mercury to the Gemini program, and this new technology was further refined for the Apollo and Skylab programs. Increased complexity of the displays and controls emphasizes the importance of crew functions on success of the mission; the emphasis is on finding the most efficient means to convey information to the crew.

Self Explanatory

NASA-S-81-2281

CREW DISPLAYS AND CONTROLS

	PANELS	WORK STATIONS	CONTROL DISPLAY ELEMENTS	COMPUTERS NUMBER/MODES
MERCURY	3	1	143	0
GEMINI	7	2	354	1
APOLLO 1	40	7	1374	4/50
SKYLAB 2	189	20	2980	4
SHUTTLE	97	9	2300	5/140
'SPACE STATION' 3	200	40	3000	8/200

1 - PRIMARY AND BACKUP IN CM AND LM

2 - CM PRIMARY AND BACKUP, TELESCOPE, WORKSHOP

3 - ASSUMES REAL TIME CONTROL ON BOARD, DATA BASE MANAGEMENT FROM THE GROUND

NASA-S-81-2282

CREW SOFTWARE INTERFACES

APOLLO

CM

PROGRAMS 43
VERBS 85
NOUNS 92

LM

PROGRAMS 31
VERBS 78
NOUNS 85

SHUTTLE

DISPLAYS 75
ITEM ENTRY 50
OPERATIONAL SEQUENCES 9
MAJOR MODES 16

- HARDWIRE MEMORY
- 3 REGISTER DISPLAY
- NAVIGATION, GUIDANCE & FLIGHT CONTROL

- READ WRITE ACCESS
  GENERAL MEMORY
  MASS MEMORY
- 3 ALPHANUMERIC & GRAPHIC DISPLAY CRT
- NAVIGATION, GUIDANCE, FLIGHT CONTROL & SYSTEMS MANAGEMENT
- REDUNDANCY MANAGEMENT

The following two charts summarize comments on various items that effected habitability and performance on the first four Shuttle flights.

Comments Continued

SUMMARY STS-1 THRU STS-4

TEMPERATURE:	CREW COMMENTS DECREASE FROM STS-1 TO STS-4 WTIH FEW COMMENTS ON STS-4
RELATIVE HUMIDITY:	CLOUDY WINDOWS (AROUND THE EDGES) AND CONDENSATION (FROM VENT DUCT) ON AFT WINDOWS ON STS-3. NO CONDENSATION ON WINDOWS, WHEN SHADES REMOVED, ON STS-4. BETTER THAN SKYLAB.
ODORS:	SOME BODY AND LAVATORY ODORS DETECTED, MOST ADDRESSABLE BY WASHING AND DEODORANT "STICK-UPS." SOME SLIGHT LAVATORY ODOR STILL DETECTABLE ON STS-4
SLEEP:	PRIMARY THRUSTERS (RCS) CAN INTERFER WITH SLEEP
WINDOWS:	EXTERNAL WHITE POWDERY SUBSTANCE ON WINDOWS 1 AND 6 ON STS-1--NONE THERE-AFTER THRU STS-4
TELEPRINTER:	USED LOTS OF PAPER ON STS-1 AND 3--NO COMMENTS ON STS-2 AND 4
COMMUNICATIONS:	WIRELESS WORKS GOOD. MOLDED EAR PIECES WORK PRETTY WELL--WITH SOME EAR SORENESS. THE CABIN FANS ARE RATHER NOISY.
DISPLAYS AND CONTROLS	SOME SWITCHES PROTRUDE PAST WICKETS AND WERE ACCIDENTALLY BUMPED ON STS-1 AND 2--NO COMMENTS ON SUCH THEREAFTER
	SOME CAUTION AND WARNING (ALARMS) DISCREPANCIES ON STS-4. PANEL LIGHTS VERY HOT

SUMMARY STS-1 THRU STS-4 CONTINUED

2

LAVATORY:	INCONVIENT AND A LITTLE DIFFICULT TO USE. WHILE SERVING ITS PURPOSE, CONSIDERABLE IMPROVEMENT IS DESIRABLE AND WARRENTED
STOWAGE:	MORE VOLUME FOR USED ARTICLES NEEDED. STS SHOULD HAVE A TRASH COMPACTOR
HYGIENE:	WASHCLOTHS AND TOWELS CREATE TRASH MANAGEMENT PROBLEM. SKYLAB HAD A WASHRAG SQUEEZER
FOOD:	GOOD. SANDWICHES AND PREPARED MEALS
WATER:	GOOD. CHILLED AND NO (OR MINIMAL) BUBBLES
TIMELINE:	QUES AND MULTIPLE ACTIVITIES SOMETIMES RESULT IN VERY BUSY PERIODS--SLACK AT OTHER TIMES. SOME TYPE OF ACTIVITIES "DISPLAY" SCOREBOARD DESIRABLE
WORKLOAD:	VERY HEAVY

The next two charts highlight comments from Shuttle flight 1 through 4 on items that could be changed to improve flight operations and habitability.

Comments Continued

"HIGHLIGHTS" STS-1 THRU STS-4

STS-1: MANY BITS OF DEBRIS (NUTS, BOLTS, AND PENCILS CAME OUT OF CRACKS AND CREVICES) FLOATED FREE IN THE SPACECRAFT UNTIL THEY ADHERED TO THE AIR CONTROL FANS' FILTERS. THE CREWS' HEADSET EARPHONES WERE FREQUENTLY JERKED OFF THEIR PROPER LOCATIONS ON THE USERS' EAR BY THE CONNECTING CABLES BECOMING TANGLED DURING ACTIVITIES. RESTOWAGE/REPACKAGING OF EQUIPMENT AND USED ARTICLES--AS COMPACTLY AS PRE-MISSION--WAS USUALLY NOT POSSIBLE. TRASH GENERATED BY THE TELEPRINTER PRINTOUT, FOOD WRAPPERS, ETC., WAS NOT EASY TO MANAGE. THE NOISE LEVEL IN THE SPACECRAFT WAS AROUND 67 DECIBELS. THE LAVATORY DID NOT WORK PROPERLY, AND IT WAS COLD THE FIRST SLEEP PERIOD.

STS-2: SOUND LEVELS ON-ORBIT WERE NOT BAD, EXCEPT FOR REACTION CONTROL SYSTEM ENGINE STARTUP--WHICH "SOUNDED LIKE A HOWITZER." SOME STOWAGE LOCKER DOORS WOULDN'T LINE UP TO ALLOW PROPER LATCHING. THE "WIRELESS" COMMUNICATION UNITS WERE VERY USEFUL. THE CABIN TEMPERATURE VARIED FROM DAY TO DAY, BUT NEITHER THE COOLEST OR WARMEST TEMPERATURES WERE UNCOMFORTABLE. AN UNPLEASANT ODOR WAS DETECTED AROUND THE LAVATORY. THE DRINKING WATER HAD GAS BUBBLES IN IT.

STS-3: THREE (3) OR FOUR (4) CAMERAS DID NOT WORK. THE LAVATORY DID NOT WORK PROPERLY. KLEENAX BECAME A LIMITED CONSUMABLE. THE TELEPRINTER SEEMS TO WASTE A LOT OF PAPER. A LOT OF MOTION (PHYSICAL ACTIVITIES) SHOULD BE MINIMIZED ON FIRST OR SECOND DAY. TOOLS MAY BE GOOD FOR CHANGING ENGINE RATHER THAN CHANGING OUT KEYBOARD. JET FIRING REVERBERATE THROUGH VEHICLE COULD AFFECT SLEEP. NO APPETITE FIRST COUPLE OF DAYS.

STS-4: CABIN "ILLUMINATION" IS NOT GOOD FOR PHOTOGRAPHIC PURPOSES. OVERHEAD LIGHTS WORTHLESS AROUND THE CENTER CONSOLE AREA AT NIGHT. ASTRONAUTS' HEAD COMES BETWEEN LIGHT AND OBJECT TO BE LOOKED AT--THE OVERHEAD LIGHTS ARE VERY HOT. THE CABIN FANS ARE THE NOISIEST--THE SILENCE WAS DEAFENING WHEN THEY WERE TURNED OFF. COMBINATION REFRIGERATOR/FREEZER VERY HELPFUL--MADE MANY ITEMS PALATABLE. THE LAVATORY IS A PROBLEM--IT WORKED THE WHOLE MISSION--JUST VERY INCONVIENT AND TIME CONSUMING.

These next two charts summarize Russian activities on Salyut 6. Particularly noteworthy is the fact that the crews contributed to six mission saving repairs.

The Russians have extensive human experience in space. Many of the capabilities of Salyut 6 require an active human involvement.

NASA-S-82-07068

RUSSIAN MANNED ACTIVITY ON SALYUT 6

- SALYUT 6 DESIGNED FOR CREW
  - ON BOARD MAINTENANCE AND MINOR REPAIRS
  - CARGO AND FUEL TRANSFER FROM MANNED AND UNMANNED SUPPLY VEHICLES
- CREWS HAVE SIGNIFICANTLY UPGRADED SALYUT 6 SINCE INITIAL OPERATION
  - NEW ITEMS INSTALLED
  - DOCKING HATCH CONFIGURATION CHANGED
  - ASSEMBLED RADIO TELESCOPE (KRT-10) AND DEPLOYED IT THROUGH REAR HATCH
- CREWS PERFORMED AT LEAST 6 MISSION SAVING REPAIRS
  - JETTISONED KRT-10 BY EVA AFTER ENTANGLEMENT WITH DOCKING TARGET
  - ISOLATED AND EMPTIED FAULTY FUEL TANK

NASA-S-82-07069

RUSSIAN MANNED ACTIVITY ON SALYUT 6

- SECOND GENERATION STATION, REPRESENTING NEW STAGE OF MANNED "COSMONAUTICS" - (REF: USSR NATIONAL PAPER, UNISPACE '82)
- EXTENDED DURATION HUMAN ACTIVITY IN SPACE
  - LYAKHOV AND RYUMIN, 175 DAYS IN ORBIT, DEVOTED
    - 1/3 TIME TO TECHNOLOGICAL WORK
    - 1/3 TIME TO EARTH OBSERVATIONS
- SALYUT 6 CAPABILITY REQUIRING MAN'S PRESENCE
  - MATERIALS PROCESSING
  - BIOSCIENCE
  - EARTH PHOTOGRAPHY
  - 1.5 METER OPTICAL TELESCOPE OBSERVATIONS
  - 10 METER RADIO TELESCOPE OPERATIONS

The lessons learned from Salyut 6 as viewed by the Russians. Besides effectively advancing space technology for the solution of scientific and economic problems, the Salyut serves in effective political roles in third world countries.

This chart provides a concise comparison between Russia and US human roles in space. Because of the difference emphasis in programs, the Russians have concentrated on the use of man in space and have more manned hours in space.

NASA-S-82-07067

RUSSIAN VIEW OF LESSONS LEARNED FROM SALYUT 6

- CONTINUOUS OPERATION OF ORBITAL COMPLEXES WITH REPLACEMENT CREWS REPRESENTS THE MOST EFFECTIVE AND PROFITABLE ADVANCE OF SPACE TECHNOLOGY FOR SOLUTION OF SCIENTIFIC AND ECONOMIC PROBLEMS
- THE EXTENDED MISSIONS PROVIDED UNIQUE EXPERIENCE OF REPAIR AND MAINTENANCE OPERATIONS UNDER SPACE FLIGHT CONDITIONS
    - DESIGN PHILOSOPHY OF MAINTAINABLE SPACE COMPONENTS WERE DEVELOPED
- JOINT INTERNATIONAL MANNED FLIGHTS IS A NEW DOMAIN OF THE SOCIALIST COUNTRIES COOPERATION
    - CURRENTLY BEING EXTENDED TO THIRD WORLD AND NATO COUNTRIES

NASA-S-82-07066

COMPARISONS BETWEEN RUSSIAN AND U.S. HUMAN ROLES IN SPACE

- RUSSIANS HAVE MANY MORE MANNED HOURS IN SPACE
    - 5 MAJOR "EXPEDITIONS" (95 TO 185 DAYS); 9 VISITING EXPEDITIONS AND 12 DELIVERY OPERATIONS AS OF MARCH 1981 FOR SALYUT 6
    - AFTER 3 SKYLAB MISSIONS (84 DAYS MAXIMUM), U.S. HAS CONCENTRATED ON SORTIES INTO SPACE
- RUSSIANS HAVE PERFORMED 3 EVA'S, PRESUMABLY ALL RELATED TO UNSCHEDULED REPAIRS
- U.S. EVA'S ON SKYLAB FOR SAME REASON. PROJECTED USE FOR SATELLITE SERVICING UNMATCHED AS YET BY RUSSIANS

Design implication for future manned operation in space should consider the listed items and their impact on productivity.

DESIGN IMPLICATIONS

O PRODUCTIVITY VS. MINIMAL REQUIREMENTS

EXAMPLES:

O CABIN NOISE LEVELS

O PERSPECTIVE DISPLAYS--ORBITAL GROUND TRACK

O ANCILLARY EQUIPMENTS

- MOTION PICTURE CAMERA
- HAND CALCULATORS

O HYGIENE

O STOWAGE

ADDENDUM

omit

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Chapter 16

ASTRONAUT ACTIVITY

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Manned space flight evolved from the confluence of two adjacent lines of technology. One line was developed from experience with high-performance and experimental aircraft; the other evolved from experience with rocket-propelled vehicles. The characteristics of manned spacecraft have been derived almost completely from the traditions of aircraft. At the time rocket technology was progressing at a rate that would make manned space flight feasible, high-performance aircraft already were operating at altitudes functionally equivalent to space flight. Control stability over a wide range of dynamic conditions had been studied, and substantial empirical and experimental data about optimum methods of integrating man into the vehicle, both as a control element and as a system and mission manager, had been developed. Major modifications to crew accommodations in the progression from aircraft to spacecraft were: geometric accommodations to the acceleration environments of launch and entry, and to the weightless conditions of orbital flight [6, 42]. Other modifications were induced by the *shiplike* characteristics required for long-duration missions, which imposed system servicing requirements and long-term habitability management on the spectrum of crew duties.

The effects of the space environment on man's sensory and motor performance and on higher order mental functioning could not be predicted with certainty. Therefore, man's role at the beginning of manned spaceflight programs was that of a semipassive passenger whose capability had to be demonstrated and who could act as a backup system if a primary system failed. With continued successful task accomplishment, man's role in spacecraft has evolved to that of mission manager where crewmen supervise highly automated systems and manually execute critical operations. In this capacity, the crewman provides the capabilities to select the systems configuration and modes most suitable for characteristics of the particular mission phase and to reconfigure the systems to influence system performance during off-nominal conditions.

Optimization of the crew-to-spacecraft interface is not a specific objective of any manned spaceflight program. This is important to note in any review pertaining to spacecraft design details influenced by the interface between crew and spacecraft. The design objective is to optimize the achievement of program objectives, not the configuration of the crew compartment, the displays and controls, or the other interfaces through which the crew affects spacecraft activities. In this group of interfaces, as in all other systems, compromises are made to each of the interfacing elements to achieve overall program effectiveness.

The sections that follow describe the characteristics of man pertinent to the design and operation of spacecraft, geometric characteristics of spacecraft that define the degree and type of confinement imposed on the crew, and character of equipment management and housekeeping necessary for hygiene, comfort, and safety. The controls and displays of each spacecraft are described to indicate the degree to which crew functions become integral to functions of the total spacecraft. The last section summarizes the contribution of the crew to system reliability and performance and notes the increasing significance of the crew's role in scientific observation and experiment.[1]

MAN/MACHINE FUNCTIONAL CAPABILITIES

Historically, studies of man/machine interfaces have focused on proper allocation of system operating functions between man and machine [1, 3, 6, 8, 9, 13, 16, 24, 27, 28, 30, 35, 43]. A typical approach has been to analyze task sequences to discover task components and allocate these functions to man or machine, depending upon which would be better at the particular task. Man is able to handle a variety of information processing tasks in which input (sensory) and output (motor) aspects vary widely. He is able to store and recall great amounts of information pertinent to system operation under both normal and emergency conditions. He is able to operate as a decision-maker through his capability to evaluate information and to distinguish between useful and unusable and irrelevant information. He can solicit additional information from the system when necessary, and can estimate probabilities. The human operator can respond to the unforeseen and operate at a level of complexity exceeding any reasonable amount of premission planning and programing of on-board automatic control equipment. So far, man is the only real-time system capable of accepting and operating on asynchronous and nonsequential input data. However, certain functions have been identified where man could be expected to perform more poorly than the machine. His limitations include a relatively low information-handling rate, limited short-term memory, and poor performance in detecting infrequent signals for which the time of occurrence is unpredictable (vigilance tasks).

Recent design practices emphasize a trend toward viewing the human operator as a system component recognizing that optimal use of man may involve a task that a machine could do better, but in which operator performance expected would be adequate to perform the function. In such circumstances, his availability should be exploited when cost effective.

Senses as Information Collectors

In operating a spacecraft, the crewman is required to perform a variety of tasks beginning with gaining information through his sensory apparatus. Vision, hearing, and proprioception are the most important senses for information collection during space flight. The information is processed in various ways, and appropriate control adjustments are made to obtain and maintain the desired state of system operation, correct out-of-tolerance conditions, and achieve new modes of operation when necessary. Research in these processes as they occur in man has been conducted for many years. The information obtained from research is valuable in defining the proper role of man in the operation of manned space vehicles.

Man's capabilities for sensing data have been studied longer and more thoroughly than any other aspect of his performance. Much information is available concerning the basic processes of seeing, hearing, and sensing motion. Significant aspects of man's sensory capabilities are shown in Table 1. Such data are in substantial agreement in US and Soviet handbook compilations.

The most significant sense, vision, has been

[1] The data presented were prepared from material compiled by N. D. Zavalova and V. A. Ponomarenko of the USSR [50], and J. P. Loftus, Jr., R. L. Bond, and R. M. Patton of the US, who prepared reviews and abstracts of the literature in their respective nations and languages.

TABLE 1. —*Characteristics of the Senses*

Parameter	Vision	Audition	Taste and smell	Touch	Vestibular
Sufficient stimulus	Light-radiated electromagnetic energy in the visible spectrum Heavy particles	Sound-vibratory energy, airborne or structural paths	Particles of matter in solution (liquid or aerosol)	Tissue displacement by physical means	Accelerative forces
Spectral range	Wavelengths from 400 to 700 μm (violet to red)	20 to 20 000 Hz	Taste: salt, sweet, sour, bitter Smell: fragrant, acid, burnt, and caprylic	> 0 to < pulses/s	Linear and rotational accelerations
Spectral resolution	120 to 160 steps in wavelength (hue) varying from 1 to 20 μm	~ 3 Hz (20 to 1000 Hz) 0.3 percent (above 1000 Hz)	--	$\frac{\Delta pps}{pps} \approx 0.10$	--
Dynamic range	~90 dB (useful range) for 3×10^{-9} cd/cm^2 (0.00001 mL) to 32 cd/cm^2 (10 000 mL)	~ 140 dB 0 dB = 0.0002 dyn/cm^2	Taste: ≈ 50 dB 3×10^{-5} to 3% concentration quinine sulphate Smell: 100 dB	~ 30 dB 0.01 to 10 mm	Absolute threshold ≈ 0.2°/s
Amplitude resolution $\frac{\Delta I}{I}$	Contrast = $\frac{\Delta I}{I}$ ≈ 0.015	0.5 dB (1000 Hz at 20 dB or above)	Taste: ≈ 0.20 Smell: 0.10 to 50	$\frac{\Delta I}{I}$ nonlinear and large at low force levels ~ 0.15	~ 0.10 change in acceleration
Acuity	1° of visual angle	Temporal acuity (clicks) ≈ 0.001 s	--	Two-point acuity ≈0.1 mm (tongue) to 50 mm (back)	--
Response rate for successive stimuli	~ 0.1 s	0.01 s (tone bursts)	Taste: ~ 30 s Smell: ~ 20 to 60 s	Touches sensed as discreet to 20/s	~ 1 to 2 s nystagmus may persist to 2 min after rapid changes in rotation
Reaction time for simple muscular movement	~ 0.22 s	~ 0.[illegible]9 s	--	~ 0.15 s (for finger motion, if finger is the one stimulated)	--
Best operating range	500 to 600 μm (green-yellow) 107.6 lm/m^2 (10 ft-ca) to 2152 lm/m^2 (200 ft-ca)	300 to 6000 Hz 40 to 80 dB	Taste: 0.1 to 10 % concentration	--	~ 1-g acceleration directed head to foot

TABLE 1.—*Characteristics of the Senses*—Continued

Parameter	Vision	Audition	Taste and smell	Touch	Vestibular
Indications for use	1. Spatial orientation required 2. Spatial scanning or search required 3. Simultaneous comparisons required 4. Multidimensional material presented 5. High ambient noise levels	1. Nondirectional warning or emergency signals 2. Small temporal relations important 3. Poor ambient lighting 4. High vibration or g-forces present	1. Parameter to be sensed has characteristic smell or taste 2. Changes are abrupt	1. Conditions unfavorable for both vision and audition 2. Visual and auditory senses	1. Gross sensing of acceleration information

studied extensively. The basic operation of visual receptors is reasonably well understood, as are certain mechanisms of color vision, characteristics of depth and distance perception, and conditions under which various visual illusions are produced. In addition to viewing displays inside the spacecraft, other significant tasks involve viewing features outside the spacecraft.

1. Visual reference to the horizon or other external reference criteria for spacecraft heading and spacecraft orientation in pitch, roll, and yaw;
2. Visual observations of a ground plane for reconnaissance or determining spacecraft location;
3. Visual observations in surrounding space for reconnaissance or maintenance of relative position of one spacecraft to another;
4. Stellar navigation and astronomical observation;
5. Observation of external indications of the function or malfunction of components of the spacecraft.

In a spacecraft where the astronaut could assume a variety of orientations during weightlessness, there was concern for possible difficulty in reading instruments designated for viewing from a particular orientation which might increase errors and reading time. It was thought that, either the spacecraft should be designed to provide a consistent visual *up*, or displays be designed for ready interpretation by an observer in any position. Such difficulty has not occurred so far, perhaps because spacecraft built in a gravity field have an inherent *up*, and, although work stations may be at substantially different orientations to each other, each has its own axis of action.

Man's ability to perceive change in either sound level or composition has been widely studied. The sensitivity of the ear to changes in frequency or intensity is quite high; however, ability to assign absolute values to either frequency or intensity is poor. The most useful operational auditory cues are the abrupt, or those with dramatic change in character. Even with such restrictions, there are many uses of auditory cues because they do not require directional focus by the crewman. Mechanical, pneumatic, and pyrotechnic systems are monitored for function or malfunction and alarm signals are used to waken crewmen or direct their attention to appropriate displays when conditions are abnormal.

Interaction between vestibular organs of balance and the vagal nervous system has been studied to find effective palliatives for motion sickness. Great concern had been expressed that such malaise would impact crewmen who were being abruptly placed in the weightless condition after launch acceleration. Discomfort has been reported on several flights but has never precluded successful continuation of the mission. The widely known illusions and disorientation caused by moving the head during acceleration have been experienced by most pilots, but none of the incidents has been forceful enough to interfere with normal operations.

No explicit use was planned for man's ability to detect the condition of systems through taste and smell, although the sensitivity of this capability, recognized as aiding in detection of anomalous conditions, has been used on several occasions.

The greatest value of the astronaut as a system operator is in complex information processing. In performing any operational task, the astronaut must first gather information from a variety of sources, including instrumentation, data transmitted by voice from the ground, and directly observable features of his environment—both internal and external to the spacecraft. He must delete useless or obviously inaccurate information but retrieve necessary information from long-term or short-term memory storage to supplement present information and evaluate its meaning. He must call for more or better information if that which he has is inadequate. Finally, he must decide on appropriate control action.

Information and Decisionmaking Models

The question of how decisions are derived continues to be investigated. Two early models of information processing and decisionmaking (decision theory and information theory) have been used to define man's role in spacecraft operations. Significantly, each model of man is an analog or variation of models used in communication systems or computer design theory. Developments in this field have proved at least partly applicable to the description of human decision processes, and demonstrate the utility of viewing man as a system or system element with operating characteristics analogous to hardware systems. The models also aid in assessing the value of crew intervention.

Decision Theory

Decision theory, developed by Edwards and others [10, 11, 47], concentrates on the risks in reaching a decision. The theory begins by assuming that the individual will always optimize benefits and is never completely informed in advance about the outcome of his choice. In situations of concern, at least two or more alternatives exist, and each has two or more possible outcomes. Two questions arise: the first concerns the probabilities attached to possible outcomes; the second, the utility of each outcome, that is, where each stands on a scale ranging from highly desirable to highly undesirable (+1 to −1). Decision theorists speak of a payoff matrix that specifies attendant gains and losses for each possible choice, both when that choice is right and when it is wrong. Multiplication of utility by probability results in *expected utility* and forms a basis for the choice of one possible course of action over another.

In principle, a fully automated decision system could be computer-implemented. However, this is possible only if all contingencies can be foreseen and all probabilities and utilities stated explicitly. Even if this could be done, there is no adequate strategy that will at all times establish rules to minimize losses and maximize gains to the system for every decision point.

In practice, decision situations are often ambiguous in structural and temporal values, and the information on which the decision must be based may be incomplete, contradictory, or unreliable. The human decisionmaker can often make appropriate choices under such circumstances by assigning what are termed *subjective expected utilities* to the alternatives. Obviously, experience and training enhance judgment in decision situations. Astronaut and cosmonaut selection and training are strongly influenced by these considerations as is the selection of control and display design strategy.

Information Theory

The information theory model was originally developed to study transmission characteristics of communication systems, and has been used to study the rate and accuracy of human information processing [4, 12, 14, 26, 32, 36, 41, 44]. Information has been defined as the aspect of a message that reduces uncertainty; the unit of measurement is the *bit*. One bit of information is defined as the amount that reduces uncertainty by one-half. Thus, in a situation where two alternatives are equiprobable as far as the information receiver knows, one bit of information permits selection of one or the other. The amount of information (usually denoted by the symbol H) is given by the formula $H=\log_2 n$, where n is the number of equally probable alternatives. This formula is used where many alternatives are possible requiring only that they be equally probable.

Where events are not equiprobable, the usual case, information content declines but can be calculated by a somewhat more complex procedure. A formula commonly used is $RT=0.17+0.14\ \log_2 n$, where n is the number of alternatives, and reaction time is used as the measure of uncertainty.

Developments in information theory have enabled measurement of the quantity of information conveyed by one or more stimuli dimensions and the maximum rates for human information processing. In operation, subjects could accurately identify as many as 15 pointer positions on a scale, thus transmitting 3.9 bits. This is an unusually high figure for a single-stimulus dimension; multiple dimensions give improved performance.

Another consideration is the rate at which information can be processed (i.e., human channel capacity). Test results of channel capacity in sequential dial reading and air traffic control tasks indicate that approximately 8 bits/s may be realistic maximum value.

Both theories endeavor to characterize complex human activities in simple mechanistic terms. A man does, on occasion, act in such a simple mechanical manner, but, when simple modes of action are inadequate, he resorts to more complex strategies or processes for which no adequate model exists. Numerous authors have discussed the inadequacy of these theories and models as descriptive of man's decision formulation and information acquisition processes [23, 26, 33, 45]. Others have challenged the relevance of the model variables to design criteria [7, 23, 33]. Although there are real and significant shortcomings to these theories and models, they are of some use in formulating a *figure of merit* which may be used to assess design alternatives in engineering trade studies.

Displays and Controls

In the operation of any complex system, numerous displays and controls are available to the operator for monitoring system status and maintaining or altering that status. A closed-loop tracking system is used to control the attitude and flight path of spacecraft. Given a set of desired vehicle motion characteristics, a system must be developed in accordance with the expected inputs and control characteristics with the characteristic transfer function of the operator linking the two. This human transfer function must account for man's sensory and perceptual processes, reaction and decision times, and accuracy in force and direction of control movements. All these affect his characteristic as a link between display and control.

Closed-loop tracking systems incorporate a means for sensing the system output and presenting a form of error information to the astronaut through a feedback loop, permitting him to adjust controls to minimize error. This process is continuous in tracking tasks.

The control order of a system is determined by the order of the mathematical equation necessary to define the human transfer function. Zero order, or position control, means the operator's control output directly determines the system output: the only concern is the necessary amplification or gain (equivalent to arithmetic multiplication). First order, or rate control, means the operator must perform an operation equivalent to differentiation to perform the task. Second order, or acceleration control, in effect, requires double differentiation.

In general, tasks involving second-order or higher order functions are not suitable for manual systems. There is evidence that humans perform integration better than differentiation, but performance deteriorates if too much such activity is required. These requirements often can be eliminated by designing the machine to perform integrating and differentiating functions and to display the results of these computations to the operator. Such "aiding" of the operator makes integrated flight control displays more effective than the sum of the input data.

Servosystems. In the type of system under discussion, man operates in a manner analogous to a closed-loop servosystem. A basic assumption of linearity—that the observed response of a system to multiple inputs equals the sum of the response to the separate inputs—is made in servosystem theory. However, humans are not linear. In practice, functions are developed for particular cases that consist of a linear component and a remnant. The latter includes both systematic nonlinear elements and noise elements that are random and unpredictable.

The ability of pilots to operate manual control systems successfully in response to various forcing functions has been studied extensively. Specification of successful tracking limits of complex functions, such as those that occur in turbulent air, is of particular importance to aircraft designers. Human bandwidth characteristics preclude successful operation at frequencies higher than approximately 3 Hz. Because the operational regimes of manned spacecraft have not encountered extensive regions of such random phenomenon as turbulence, system design has been somewhat simpler.

The inclusion of man in the control system rather than use of a servosystem is desirable because the crewman is inherently adaptive. The pilot is not only adaptive in a gain-varying sense, but also he is adaptive in the sense of imposing purpose. He can operate to varying criteria of precision and time to complete a given maneuver. This is particularly important in spacecraft energy conservation.

The application of knowledge about man's capability to definition of his role in a new system has been assessed in many ways. Walker [48] endeavored to evaluate the benefit of the pilot to the X–15 experimental rocket aircraft program. He concluded that system redundancy in a piloted vehicle gave the greatest potential for mission success, and that elimination of either redundancy or the pilot had comparable impact (an estimated 40% reduction in successful missions, based on an analysis of 44 flights).

In another line of reasoning to define man's role in space flight, the endeavor was to assess his contribution to time-dependent system reliability [19, 20, 31, 38]. With the use of performance data characteristic of systems operational between 1950 and 1960, various studies led to the conclusions that man's contribution to mission success lay in the maintenance of redundant systems, and that for long-term missions, he was cost-effective in this role. Such arguments are highly sensitive to the state of the art in electronic piece parts, and the effect of integrated circuits was not foreseen. Although these study results continue to have force for some electromechanical and mechanical systems, the argument is substantially modified from the early conception of primary electronic system maintenance.

Stress. In contrast to those considerations that argued for the inclusion of man in space systems, there have been concerns about man's response to the physiologic and psychologic stresses of space flight. Isolation, confinement, and disruption of the diurnal cycle have been studied as significant forms of stress [25, 37, 49, 51, 52]. In general, experimental studies identify performance degradations, such as longer periods required to complete tasks, higher error rates in the execution of tasks, and reduced ability to concentrate.

In the limited number of space flights so far, such performance losses have not been observed. Failure to observe such degradation is attributed to substantial overtraining of flight crews for the tasks they must perform, diverse and interesting stimuli present in the real environment contrasted with minimum stimulation environment in simulations, and stronger motivation in flight crews compared with test subjects. The selection of cosmonauts and astronauts is strongly biased to identify men of superior psychologic stability and stress tolerance. The relevance of sensory deprivation studies to current spaceflight operations seems marginal. Confinement is not frustrating to the crewman's purpose or desire; the flight activities required of him are varied and demanding, not minimal and monotonous. Finally, the crewman is in frequent or continuous voice communication involving both work and social topics. Normal operations of space flight contrast significantly with the conditions that induce isolation symptoms.

Work-rest cycles. The variation of work-rest cycles has been studied intensively because of its significance to productivity and safety. Operator efficiency is highest when a stable 24-h period of work and rest is maintained. The most important benchmark is a consistent time for sleep. Other cycles, such as 4 h work followed by 4 or 2 h sleep, have been studied and are less satisfactory, both physiologically and psychologically, than the customary 24-h day, with an uninterrupted 8 h sleep.

Although the orbital period of the spacecraft may be only 90 min and the track over the ground varies continuously, generally it has been possible to design spacecraft systems and plan flights so crews can sleep their accustomed cycle.

A common argument for the inclusion of man in a system is the use of human judgment; that is, the ability of man to perceive the relevant in novel situations and to improvise and react intelligently to the unanticipated. This argument, although hard to quantify, is applied equally to man's role as a system operator or as a scientific observer and is consistent with historical experience (e.g., Darwin's insight as a function of his voyage on the Beagle).

The role of the crew in manned spacecraft, as it has reflected these theories, considerations, and studies, is discussed in subsequent sections of this chapter.

GEOMETRIC CONSIDERATIONS

The most prominent characteristic of manned spacecraft is orientation of seating so that launch and entry loads are imposed on the crewman transversely, that is, from front to back rather than from head to foot. This orientation maximizes physiologic tolerance to acceleration. Orientation of interior work stations is fixed by this consideration in Mercury, Gemini, Vostok, and Voskhod spacecraft. In the Apollo command module, a second array of interior work stations is oriented at 90° to the launch- and entry-oriented main display console. These stations are used for operation of the navigation optics, food preparation, and other functions. The Apollo lunar module was configured so as to provide maximum visibility with the smallest possible window. Because flight acceleration loads are less than 1 g and the worst-case landing impact loads are small, the crewmen can attenuate such loads with their legs and be positioned upright close to the front of the spacecraft with the window oriented so that they can see down, ahead, and to the sides.

The Soviet Soyuz spacecraft has two habitable modules: the command module, with primary controls arranged in panels accessible from the launch and entry couch; and an orbital module, with stowage compartments and work stations arranged around the periphery of the spacecraft. The Salyut configuration establishes a conventional gravity-oriented architectural arrangement relative to a floor on one side of the spacecraft. This spacecraft has three discrete, though not isolated, volumes: transfer tunnel, console area, and (in the region of maximum diameter) a large working area. Instruments and viewing ports are provided at locations throughout the spacecraft.

The Skylab configuration is controlled by the need to maintain a central-axis transit passage and by the endeavor to achieve a conventional architectural arrangement normal to the major axis of the spacecraft. By all previous standards, the Skylab orbital workshop module is a spacious spacecraft. This configuration is attributable, in part, to its derivation from an existing structure, the Saturn IVB (S–IVB) stage, and in part to the need for assessing the value of greater volume to the operational effectiveness of longer missions. Volume use rate also will be low, reflecting the restrictions of the initial launch weight and the limited payload to and from Skylab that can be accommodated by the Apollo command module. Distribution of volume among so many modules and levels has some disadvantages in the loading and transportation of equipment through the assembly.

The general configurations for each American spacecraft and current Soviet manned spacecraft are shown in Figures 1 to 5.

The relationship of crew size, pressurized volume, and usable volume of each spacecraft is shown in Table 2. The usable volume is defined as that within the pressure vessel not occupied by equipment and that can be used for temporary stowage, movement by the crewmen, or other functions that enhance habitability. The

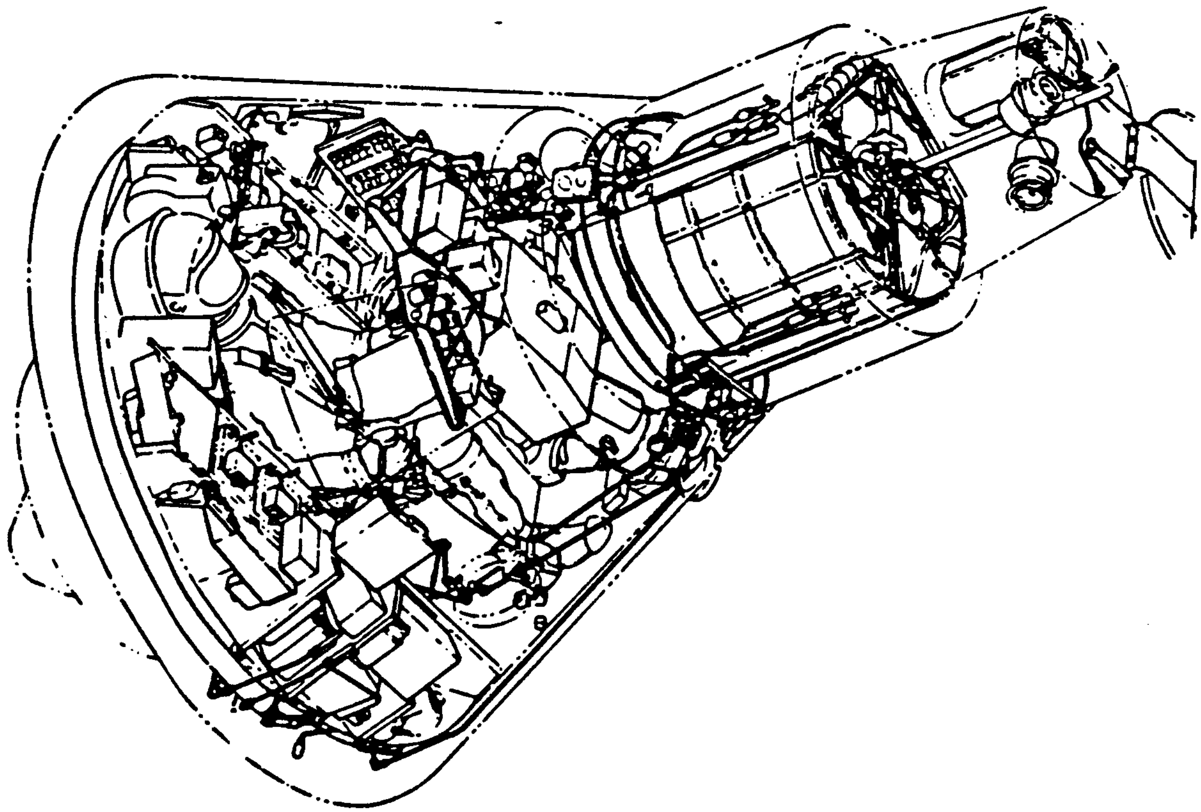


FIGURE 1.—Mercury capsule internal arrangement.

volumes increase noticeably from the first to the present spacecraft configurations. For the Mercury and Apollo command module spacecraft, the relationship of the pressurized volume to effective free volume reflects that most equipment was installed within the pressure vessel. Gemini and lunar module spacecraft had only the crew instrument panels and portions of the environmental control system installed within the pressure vessel. Estimates of the volumes for Soviet spacecraft indicate similar arrangements.

There are relationships of spacecraft volume, mission duration, and crew size to similar values for submersibles and aircraft (Fig. 6). In all vehicles, the pressurized or conditioned volume of the vehicle increases as a function of both crew size and mission duration. Mission duration can be varied extensively for a given vehicle; however, for smaller vehicles, significant stresses may be placed on the crewmen.

Fraser [15], in 1965, reviewed extensively the literature compiled on the effects of confinement. He indicates that motivated and experienced personnel, occupied with meaningful tasks and informed as to the status and duration of the mission, need a volume of 0.7 to 3.5 m^3/man for missions of 7–10 d and that 4.24 m^3/man appears to be adequate for missions as long as 30 d. Present spacecraft are adequate by such standards, which flight experience substantiates. However, more general experience indicates that such cramped quarters are not efficient for larger populations or for small crews subjected to high workloads.

Stresses placed on the crew by limited volume are: lack of movement and exercise that leads to physiological deconditioning; loss of efficiency as two or more crewmen endeavor to pursue their duties without interfering with each other: and sleep disturbance when one crewman's motion disturbs others.

Spacecraft dimensional characteristics become

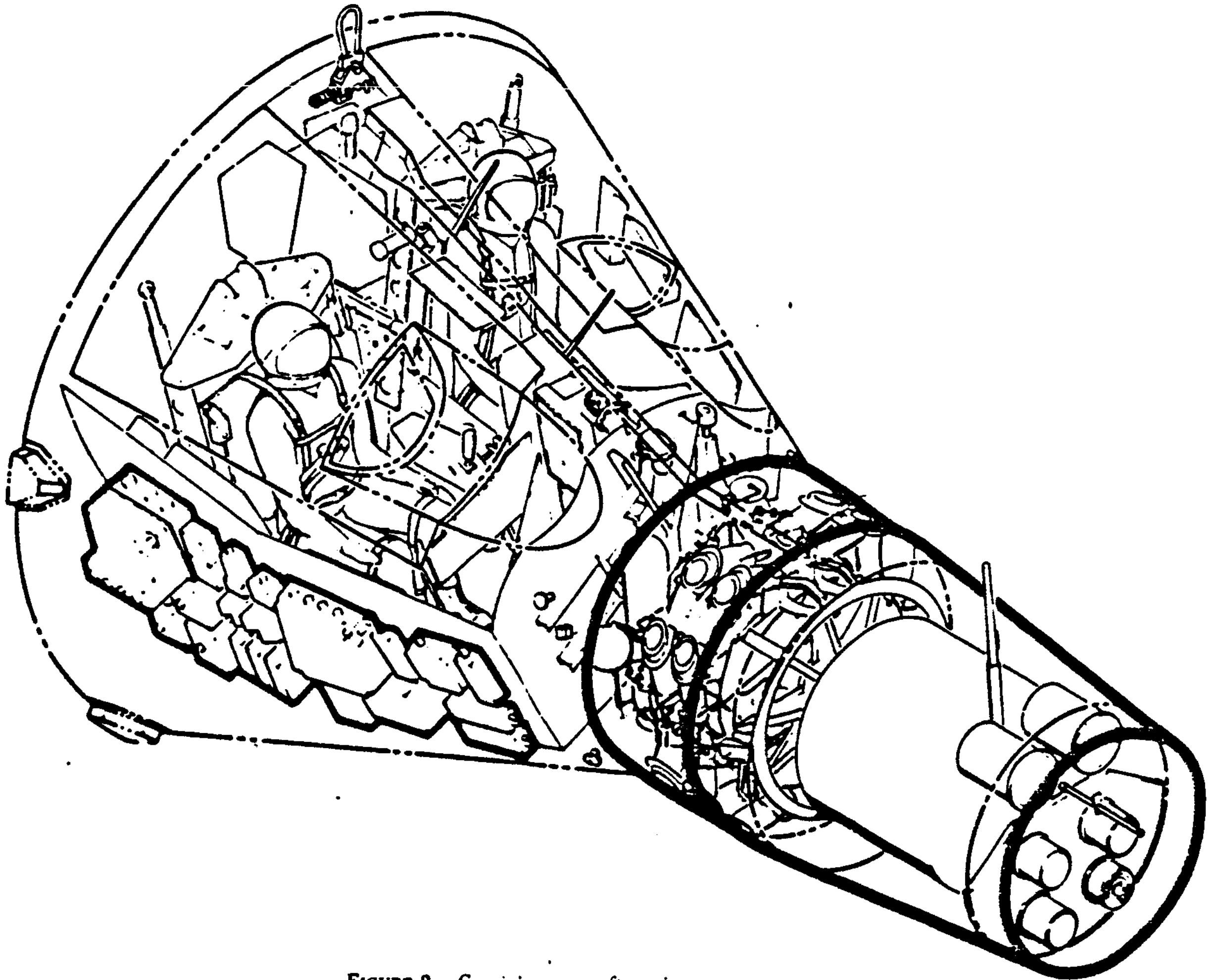


FIGURE 2.—Gemini spacecraft equipment arrangement.

significant as total spacecraft size and volume increase. Movement of crewmen and equipment can disturb the spacecraft and experiments. Such movements also can induce crew hazards from too-rapid free flight, tumbling, and impact on protuberances. Crewmen must also exercise caution in movement to avoid inducing vestibular disturbances.

Crew and medical reports indicate that increased volume of the Apollo spacecraft and opportunity for movement have removed many of the discomforts and debilitating effects of the close confinement characteristics of Mercury and Gemini spacecraft. For future space vehicles with increased performance, more volume for each occupant will enhance both efficiency of operation and habitability.

STOWAGE, HOUSEKEEPING, AND EXTRAVEHICULAR ACTIVITIES

The weightless environment, confined volume, and considerations of safety and efficiency make stowage accommodations and housekeeping procedures a significant part of the crewman's total activity. During extravehicular activity (EVA), safety precautions become even more significant. The dynamics of object movement in orbit are such that items not secured to the spacecraft or to the crewman will separate rapidly; consequently, efficient operation requires orderly procedures and careful stowage and handling of all items. Because of inherent interdependency of extravehicular activities with stowage and housekeeping, these tasks are discussed collectively.

The Mercury spacecraft pilot was restrained by his couch harness assembly and by the spacecraft's interior confines. The spacecraft was designed as a one-man vehicle, with all items necessary for either vehicle control or personal use within reach from the crewman's restrained position in the couch. Only one stowage compartment was available, which was used for flight checklists and other documents. Other equipment items were stowed in bags, pouches, or on specific attachments to the interior structure.

The Gemini Program introduced a spacecraft with a two-place, side-by-side seating configuration (Fig. 2). Quarters were still cramped, and essential cockpit activities again were confined to the approximate reach envelope of the seated crew. However, increasing activity by the crewman in more complex mission operations is evidenced by the increased number of stowed items compared with that of the Mercury spacecraft (Table 3). The advent of several compartments within the cockpit for stowage of specific items generated the need for disciplined management of loose items to make efficient use of space, avoid time lost searching for stowage space for items in use, or recover from stowage items required for anticipated activities.

The increase in the number and scope of Apollo and Skylab mission objectives is indicated by the growth in the number of stowed items. This growth reflects increase in crew size, duration of missions, and emphasis on scientific objectives as operational maturity evolves. An analysis of the information in Table 3 shows that growth is caused primarily by time-dependent operational items (e.g., food and film) and by increased emphasis on scientific and applications experiment activities.

The number of items increased, also the di-

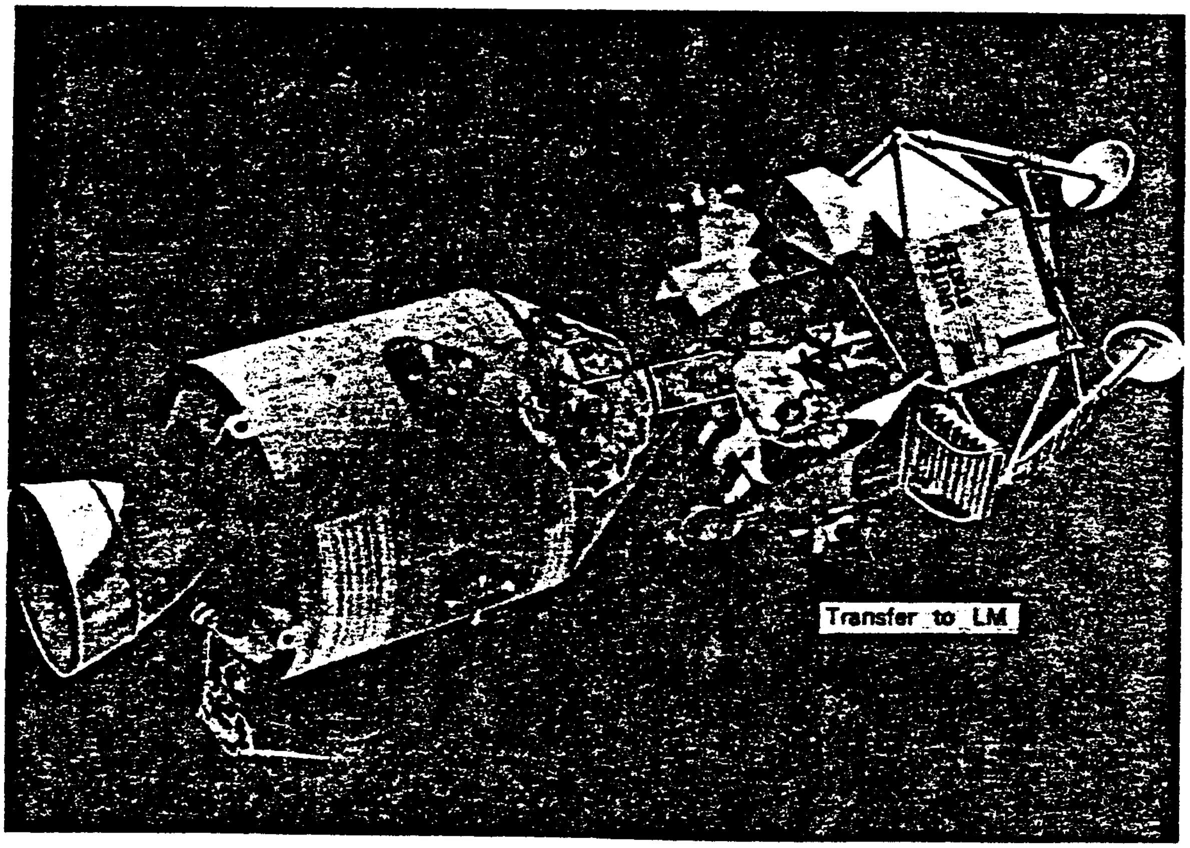


FIGURE 3. — Apollo command and lunar module configuration.

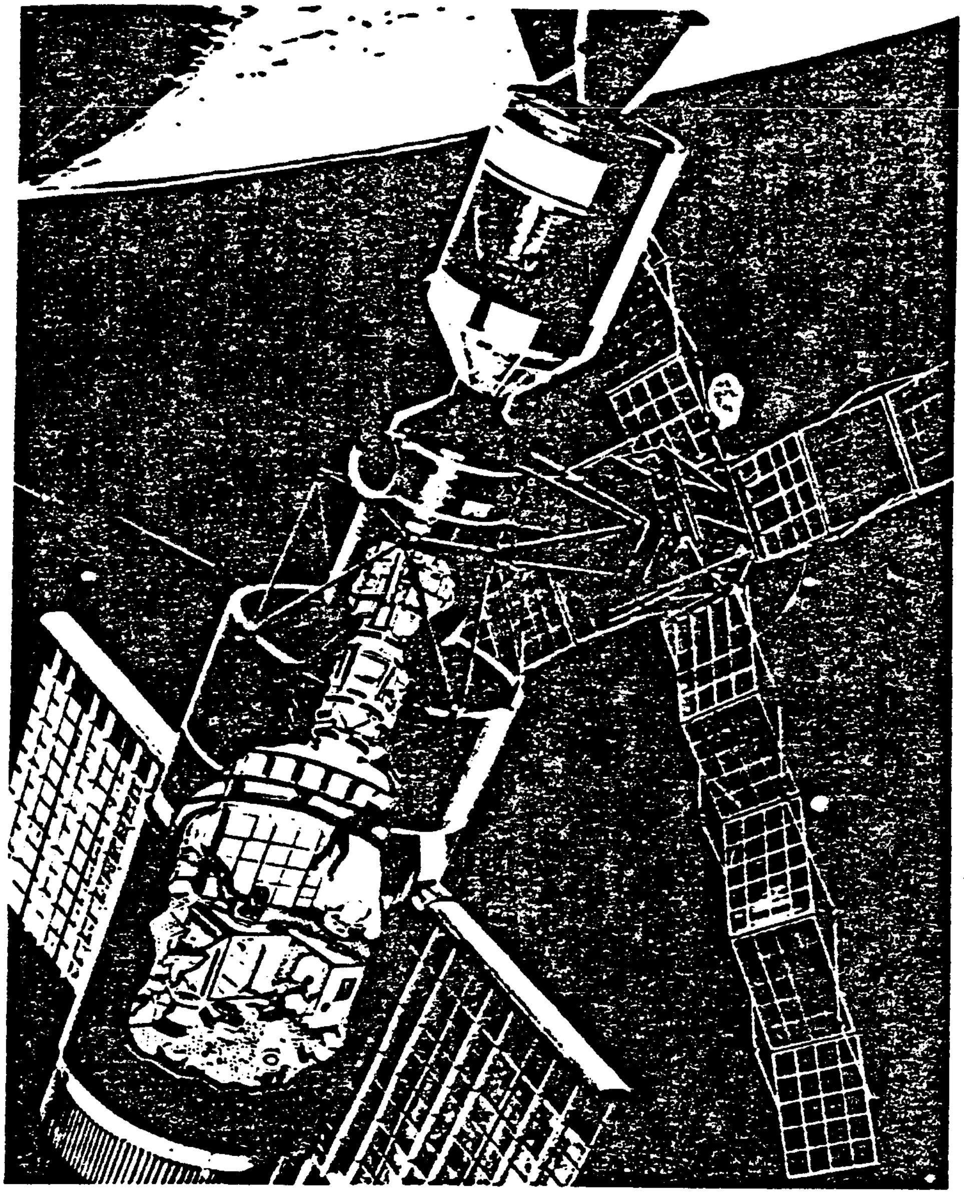


FIGURE 4.—Skylab spacecraft configuration.

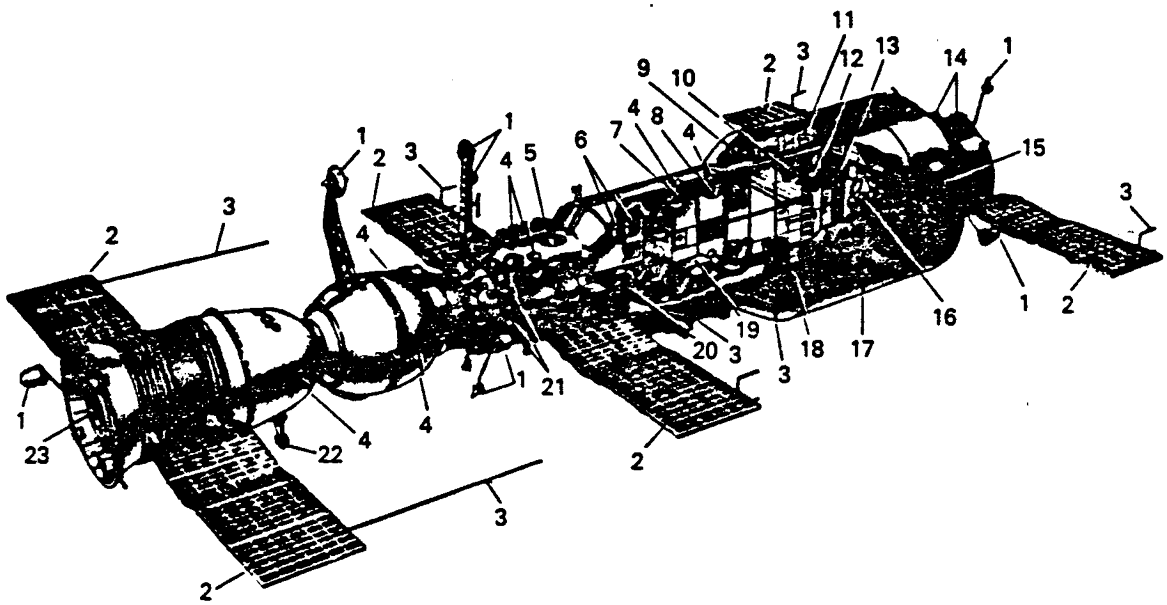
versity and complexity of the items. Table 3 indicates that the number of stowed items increased by a factor of 4, even when the items attributable to more crewmen and a longer mission were omitted.

A problem not apparent in the tabulation of this experience is the demand placed on the crew to become familiar with all equipment manipulations. Each unit is simple in its operation and stowage, but the proliferation of such items places great demands on the crew. To contend with these factors, extensive use of decals and placards with appropriate instructions is required which helps to minimize training requirements and save time during mission operations.

EVA Considerations

Preparation for EVA is one of the most demanding activities for space crews. The cabin to be depressurized must be properly organized, the equipment donned, and its operation tested. In the limited volume of the spacecraft, this requires well-planned procedures, teamwork, and extensive training. The need for such careful simulation and training was established during some of the early Gemini extravehicular activities, when astronauts were not able to complete planned tasks. The simulation of weightlessness by water immersion has been an effective method for developing procedures and training astronauts. The water immersion simulation is augmented by short periods of zero g produced in aircraft.

Both astronauts and cosmonauts report that EVA is pleasant, with no difficulties in orientation [18, 21]. The crewman appears to use his body or the spacecraft as a frame of reference and is not disturbed by his relative location to the Earth and spacecraft. Because vision is the only sense stimulated and because it provides adequate reference, there are apparently none of the illusions



Design outline of the "Salyut" orbiting scientific station

1. Antennas for the rendezvous radiotechnical system
2. Solar battery panels
3. Antennas for the radio telemetric systems
4. Beacons
5. *Orion* stellar telescope
6. Air-conditioning unit
7. Motion picture camera
8. Photographic equipment
9. Equipment for biological experiments
10. Refrigerator for food supply
11. Sleeping berth
12. Water supply tanks
13. Water collectors
14. Motors of orientation system
15. Fuel tanks
16. Sanitary and hygiene unit
17. Micrometeroid registration sensor
18. Treadmill
19. Work table
20. Central control post
21. Tanks for pressure charging system
22. Cosmonauts' sighting device
23. Engine assembly of the Soyuz spacecraft

FIGURE 5. – Soyuz-Salyut spacecraft configuration.

TABLE 2.—*Relationship of Crew Size and Spacecraft Volume*

Spacecraft	No. crewmen	Pressurized volume,[1] m^3	Effective spacecraft interior free volume,[1] m^3	Habitable volume per crewman, m^3
Mercury	1	1.42	0.71	0.71
Vostok	1	2.55	2.00	2.00
Gemini	2	2.27	1.15	.57
Voskhod	2 or 3	4.85	3.68	1.84/1.23
Apollo				
Command module	3	8.95	7.27	2.41
Lunar module	2	6.63	5.25	2.62
Soyuz				
Command module	1 to 3	4.81	3.96	3.96/1.32
Orbital module	1 to 3	6.22	4.53	4.53/1.51
Salyut	3	90.00	81.00	27.00
Skylab				
Command module	3	8.95	7.24	2.41
Orbital assembly total	3	351.17[3]	316.06	– –
Multiple docking assembly		32.57	28.30	105.35
Airlock module	– –	16.99	12.74	– –
Orbital workshop	– –	301.61	279.71	– –

[1] Pressurized volumes are derived from design data for US spacecraft and from reports in literature for USSR spacecraft.
[2] All effective free-volume estimates are based on geometric analyses.
[3] Total volume of all modules of the orbital assembly.

customary when sensory cues conflict. Certain visual illusions are present to a greater degree than when the crewman is inside the spacecraft; bright stars seem closer, and dim stars seem farther away. This illusion appears to some degree in all orbital and in many high-altitude aircraft flights.

The $\frac{1}{6}$-g environment of the lunar surface proved to be both a help and hindrance to crewmen during EVA. Loads heavy and cumbersome in 1 g become quite manageable in $\frac{1}{6}$ g. However, lightweight items reacting readily to Earth gravity tend to respond quite slowly in reduced gravity and can become critical in the development of a proper time line. Lightweight items, such as thermal blankets, have inherent stiffness and must be placed in the specific location desired in the $\frac{1}{6}$-g environment; in a 1-g environment, the mass overcomes the stiffness and items fall into place.

To develop the lunar surface time line properly for a given mission, the crew begins exercises without suits to gain familiarity with all items and progresses through a set of activities wherein each step approximates more closely the actual lunar surface activity in terms of procedural details and time planned. Final practice runs are made in pressurized suits using working models of actual hardware and adhering strictly to time allocations and procedural details.

Adaptation to the $\frac{1}{6}$-g environment has proved reasonably rapid. Movement across the surface averages 0.38 m/s during the first excursion and increases to an average of 0.61 m/s for later excursions.

Despite the extensive training, the activities take almost 30% longer during flight than during training. This additional time is caused, in part, by the extra time required for each movement when moments of inertia are high and control capability dependent upon gravity forces low, and in part by the time required to assess characteristics of the real-time situation.

The EVA experience so far is shown in Table 4. An increasing demand has been placed on lunar mission crews in terms of time allocated to actual surface EVA excursions. As the Apollo program matured, greater confidence was gained in hardware performance, and crew capability was better understood, there was a larger commitment to surface EVA as a function of total surface stay time. The initial Apollo mission committed only 10% of surface stay time to EVA, while subsequent missions committed as much as 30% of total lunar stay time. Most of this additional exploration capability was a function of systematically maturing hardware and procedures.

Orbital EVA proved more predictable as soon as proper techniques were designed. Efficient methods provided for the return of primary image materials to Earth, adding significantly to the lunar science experiments. In Skylab, there were provisions for EVA to recover the film canisters from the Apollo telescope mount. The techniques for this operation included the use of handrails, tethers, and supports similar to those used on Gemini 12, Soyuz, and Apollo spacecraft for extravehicular transfer, and for film recovery from the Apollo scientific instrument module.

Structural failure of the meteoroid shield during launch and subsequent failure during the mission of other equipment led to a great number of excursions and tasks not considered in the original plans. The crew successfully executed repairs and adjustments for which no preflight design

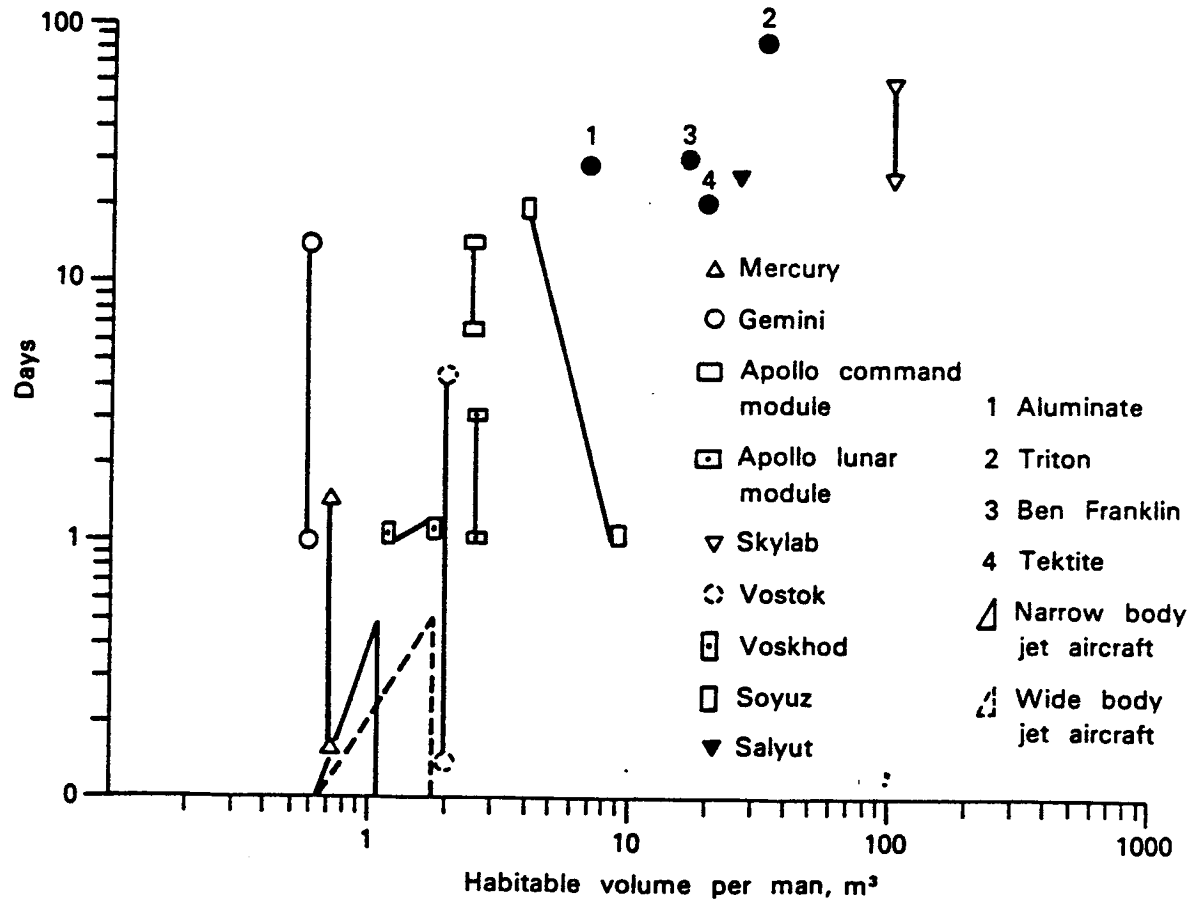


FIGURE 6.—Confinement effect of mission duration and spacecraft size.

TABLE 3.—*Spacecraft Stowage Characteristics*
(All numbers are typical and vary for specific missions)

Class of equipment	Spacecraft								
	Mercury	Gemini	Apollo			Skylab[1]			
			Command module	Lunar module		Command module[2]	Orbital assembly module		
				Ascent stage	Descent stage		Multiple docking adapter	Airlock module	Orbital workshop
Food and hygiene,[3] no. items	10	46	200	40	0	45	0	0	743
Experiment equipment, no. items	16	7	12	4	33	22	192	6	330
Television and photographic equipment, no. items	7	52	40	18	7	35	0	0	254
Extravehicular activity equipment, no. items	0	21	30	62	5	35	1	2	14
Operational equipment, no. items	15	70	230	89	8	285	44	417	455
Total no. of items	48	196	512	213	53	422	237	425	1796
No. stowage compartments	0	13	32	22	8	32	14	8	186
Nominal mission duration, d	⅓–1½	3–14	8–14	1–3		5	– –	140	– –
No. crewmen	1	2	3	2		3		3	

[1] Planned.
[2] For each of three spacecraft.
[3] One unit of food is three meals for one man.

provisions had been made. The success of these endeavors confirms the adequacy of the basic design provisions and the training regimen. Orbital EVA offers no significant difficulty if the crewman has adequate cooling in his life-support system and mounting provisions which allow him to react to forces appropriately.

Increased duration and complexity of missions; increased number, duration, and complexity of extravehicular activities; and forces during launch, spacecraft maneuver, and entry all demand orderly progression of equipment from stowed positions to use positions and to disposition locations. Many hours are spent by crews during preflight training to become thoroughly familiar with stowage provisions for each item and with the sequence in which the item is unstowed, used, and restowed or jettisoned. The precision with which these actions are performed has significant influence on the time allotments provided within the operational time line. Realistic values must be determined during preflight training for the times to be allocated to these activities in the mission flight plan. All astronauts and cosmonauts, during and after their missions, have remarked on the importance of order and discipline in these activities to efficient conduct of the mission. The consistency with which this aspect of each mission is discussed by astronauts and cosmonauts indicates that this aspect of accommodating to the weightless environment is a source of significant stress, where new design approaches might be beneficial. It is noteworthy that only in these housekeeping

TABLE 4.—*Extravehicular Activity Summary*

Mission	Type of EVA	Objective	Remarks	Standup EVA time, h:min	Umbilical EVA time, h:min	Free EVA time, h:min
Voskhod 2	Earth-orbital	Demonstrate feasibility of EVA	First EVA: all objectives satisfied	0	00:12	0
Gemini 4	Earth-orbital	Demonstrate feasibility of EVA Demonstrate maneuvering capability with hand-held maneuvering unit (HHMU)	All objectives were satisfied	0	00:36	0
Gemini 9	Earth-orbital	Retrieve experiment package Demonstrate astronaut maneuvering unit (AMU) Perform experimental star photography	Successfully retrieved experiment package Difficulty in AMU donning and visor fogging led to early termination of EVA	0	02:07	0
Gemini 10	Earth-orbital	Retrieve experiment package Evaluate HHMU Perform star photography	All objectives were satisfied First transfer of tethered crewman between undocked, orbiting vehicles	00:50	00:39	0
Gemini 11	Earth-orbital	Perform simple work tests Evaluate HHMU Perform star photography	Experiment package retrieved EVA terminated early because of metabolic overload of crewman	02:10	00:33	0
Gemini 12	Earth-orbital	Evaluate matrix of simple tasks Evaluate translation and restraint aids Perform experimental photography	All objectives were satisfied	03:24	02:06	0
Soyuz 4	Earth-orbital	Transfer crewman between spacecraft	Transfer successful	0	0	00:15
Soyuz 5	Earth-orbital	Transfer crewman between spacecraft	Transfer successful	0	0	00:15
Apollo 9	Earth-orbital	Demonstrate lunar module to command module transfer capability Demonstrate adequacy of Apollo EVA equipment and procedures	All objectives were satisfied This was first two-man EVA	00:47	0	00:47
Apollo 11	Lunar-surface	Demonstrate lunar-surface EVA capability Gather samples Emplace experiment station	All objectives were satisfied This was first lunar-surface EVA	0	0	02:48 per astronaut
Apollo 12	Lunar-surface	Emplace experiment station	All objectives were satisfied	0	0	07:56 per astronaut

TABLE 4.—*Extravehicular Activity Summary*—Continued

Mission	Type of EVA	Objective	Remarks	Standup EVA time, h:min	Umbilical EVA time, h:min	Free EVA time, h:min
Apollo 12—Con.		Conduct geological traverse and sampling Inspect and recover parts of Surveyor 3 spacecraft				
Apollo 14	Lunar-surface	Perform scientific experiments Emplace an experiment station Conduct geological traverse	All objectives were satisfied	0	0	09:20 per astronaut
Apollo 15	Lunar-surface	Perform scientific experiments Emplace an experiment station Conduct extended traverse using lunar roving vehicle	All objectives were satisfied	00:38	0	18:35 per astronaut
	Trans-Earth	Recover film from service module instrument bay		0	00:39	
Apollo 16	Lunar-surface	Perform scientific experiments Emplace an experiment station Conduct extended traverse using lunar roving vehicle	All objectives were satisfied	0	0	20:15 per astronaut
	Trans-Earth	Recover film from service module instrument bay		0	01:24	
Apollo 17	Lunar-surface	Perform scientific experiments Emplace an experiment station Conduct extended traverse using lunar roving vehicle	All objectives were satisfied	0	0	22:04 per astronaut
	Trans-Earth	Recover film from service module instrument bay		0	01:07	
Skylab [1] 1st visit	Earth-orbital	Deploy failed solar array	Attempt failed	00:35		
		Deploy failed solar array Retrieved and installed film packs Retrieved and installed film pack Deployed samples Repaired equipment	All objectives were satisfied		4:59 per astronaut	

See footnote at end of table.

TABLE 4.—*Extravehicular Activity Summary*—Continued

Mission	Type of EVA	Objective	Remarks	Standup EVA time, h:min	Umbilical EVA time, h:min	Free EVA time, h:min
Skylab [1]—Con.						
2nd visit		Retrieved and installed film packs and samples	All objectives were satisfied			
		Mounted experiment				
		Deployed sunshade				
		Repaired gyros and experiment covers				
		Cleaned occulting disk			13:42 per astronaut	
3rd visit		Installed and retrieved film pack	All objectives were satisfied			
		Mounted samples and experiment and experiment apparatus				
		Repaired experiment apparatus				
		Observed Comet Kohoutek				
		Documented spacecraft exterior systems			22:15 per astronaut	
		Made atmospheric and contamination observations				

[1] Preplanned mission objectives contained 18 discrete tasks and required 14:30 hours of EVA for each of the crewmen. Contingency and mission objective opportunity tasks numbered 51 and extended actual total EVA time to 40:56 for each of two crewmen and an additional 35 minutes of standup EVA.

activities and in the related extravehicular activities does flight performance require significantly longer amounts of time than performance in training simulators.

CONTROLS AND DISPLAYS

The complexity, size, and number of display consoles in spacecraft have increased with more complicated missions and design commitment to the maximum effective use of crewmen. Panel layouts from each US spacecraft are shown in Figures 7–11 and for Soyuz spacecraft in Figure 12. This growth, in terms of types and number of components for US spacecraft, is shown in Table 5. The technology of display and control components grew substantially more sophisticated from Project Mercury to the Gemini program, and this new technology was further refined for the Apollo and Skylab programs. Increased complexity of the displays and controls emphasizes the importance of crew functions on success of the mission; the emphasis is on finding the most efficient means to convey information to the crew.

The Mercury display and control panel is noteworthy for relative simplicity of displays, large number of sequential backup controls, and prominence of sequence and time displays. The instrument panel illustrated in Figure 7, for the last flight (Mercury-Atlas 9), reflects the most complex configuration of the series. The major factors in the derivation of this configuration

TABLE 5.—*Crew Control and Display Characteristics*

Device characteristic	Spacecraft							
	Mercury	Gemini	Apollo		Skylab			
						Orbital assembly module		
			Command module	Lunar module	Command module	Multiple docking adapter	Airlock	Orbital workshop
Panels	3	7	28	12	26	31	58	74
Work stations	1	2	5	2	5	3	4	8
Control elements (total)[1]	98	286	721	378	760	350	694	363
Circuit breakers	(20)[2]	107	264	160	256	19	307	214
Toggle switches	56	123	326	144	372	239	326	88
Pushbutton switches	8	20	13	7	15	12	0	0
Multiposition rotary switches	6	19	21	16	19	50	22	32
Continuous rotary switches	3	0	35	21	36	17	3	9
Mechanical devices	3	13	57	26	57	7	35	18
Unique devices[3]	2	4	5	4	5	6	1	2
Display elements (total)[1]	45	68	131	144	152	222	323	116
Circular meters	16	7	24	6	23	1	0	2
Linear meters	0	25	33	25	33	14	64	42
Digital readouts	3	14	18	13	19	20	1	18
Event indicators	19	16	47	96	68	182	258	50
Unique displays[4]	7	6	9	4	9	5	0	4
Inflight measurement points[1]	100	225	475	473	521	918	521	281
Telemetered	85	202	336	279	365	918	521	230
Displayed on board	53	75	280	214	289	167	129	30
Caution and warning	9	10	64	145	61	97	91	8
Input								
Analog signal	9	10	42	45	33	2	87	2
Discrete signal	0	0	22	100	28	95	4	6
Output	9	10	35	34	35	13	38	8

[1] Numbers for each program vary, depending on particular spacecraft.
[2] Fuses, not circuit breakers, used in Mercury.
[3] Three-axis hand controllers, computer keyboards, etc.
[4] Flight director attitude indicator, computer displays, entry monitor, cross points.

were:

- the principle that there would be redundant means available to accomplish all critical functions;
- the need to have available both on-board and ground data concerning the status of consumables;
- the need, with intermittent communications, to maintain a common time reference with the ground control system to control mission sequences and the retrofire maneuver, which initiates ballistic entry.

To save weight and power, attitude was displayed on a meter with three movements: a horizontal needle moving in the vertical plane for pitch and two vertical needles (one at the top and one at the bottom) moving horizontally to display yaw and roll. Attitude rates were displayed on separate movements arranged around the attitude indicator.

With ground command, the automatic stabilization and control system could perform all the critical flight maneuver sequences; in fact, the system had been used for unmanned flights. On manned flights, as a rule, the crewmen used a rate-command mode to conserve propellants. The simplicity of the system reflects minimal demands on the crewman and simplicity of the mission.

The Vostok and Voskhod spacecraft also had relatively simple controls and displays. Both portholes and a periscope were used for viewing outside the spacecraft. Systems displays were simple, circular meter movements. The most prominent display element was an Earth sphere that provided reference to groundtrack.

The Gemini panel (Fig. 8) was notably more complex than that of the Mercury. The Gemini panel introduced the computer keyboard and digital readout; the integrated display of attitude, attitude error, and rates on the flight director attitude indicator; the comparative display of redundant system conditions; vertical-scale meters; and the extensive use of circuit breakers, not only to protect circuits but also to disarm selected systems during certain mission phases. The panel arrangement was similar to that of aircraft, in that flight-control displays were furnished for each crewman (command pilot and pilot), supporting systems were centrally located and shared, propulsion systems were primarily accessible to the command pilot, and navigational systems were primarily accessible to the pilot.

Increased complexity of the spacecraft and mission objectives resulted in additional subsystems (e.g. the inertial reference unit, the radar system, and the computer) and in greater complexity and redundancy in other systems (e.g. the attitude maneuvering system and electrical power systems). These complexities were reflected in the larger number of display and control

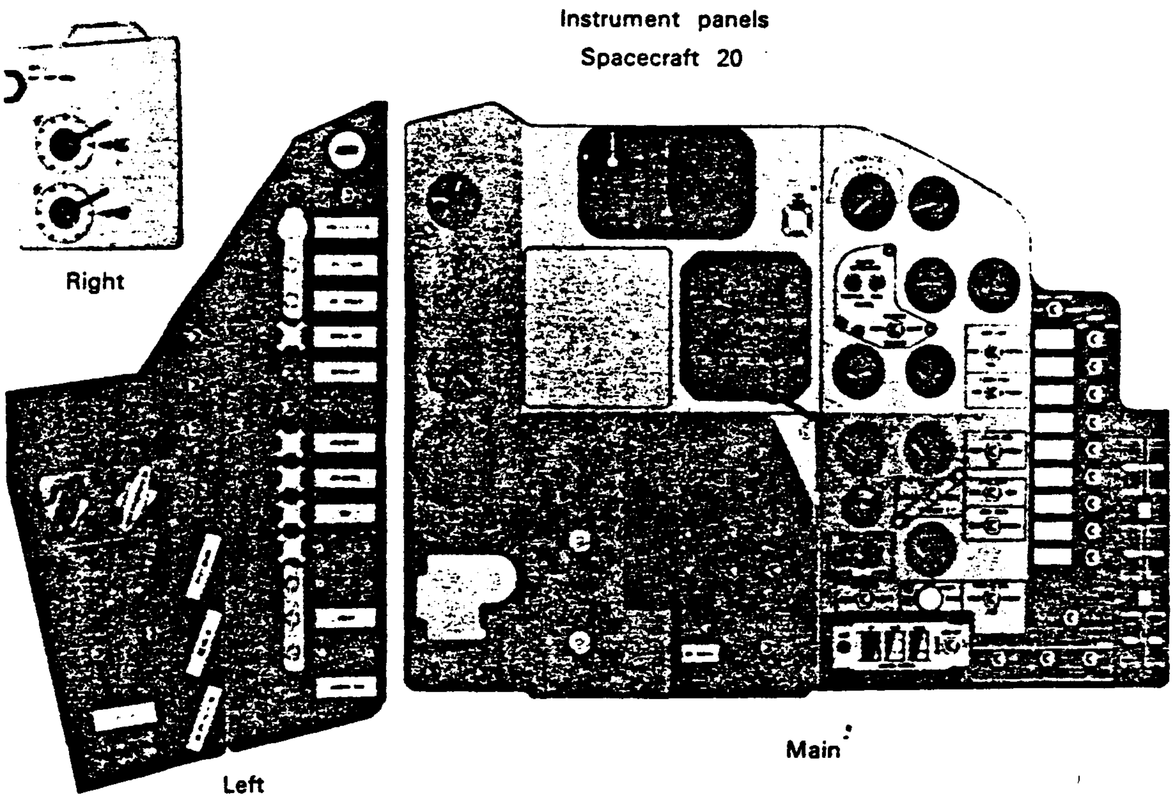


FIGURE 7.—Mercury spacecraft instrument panel.

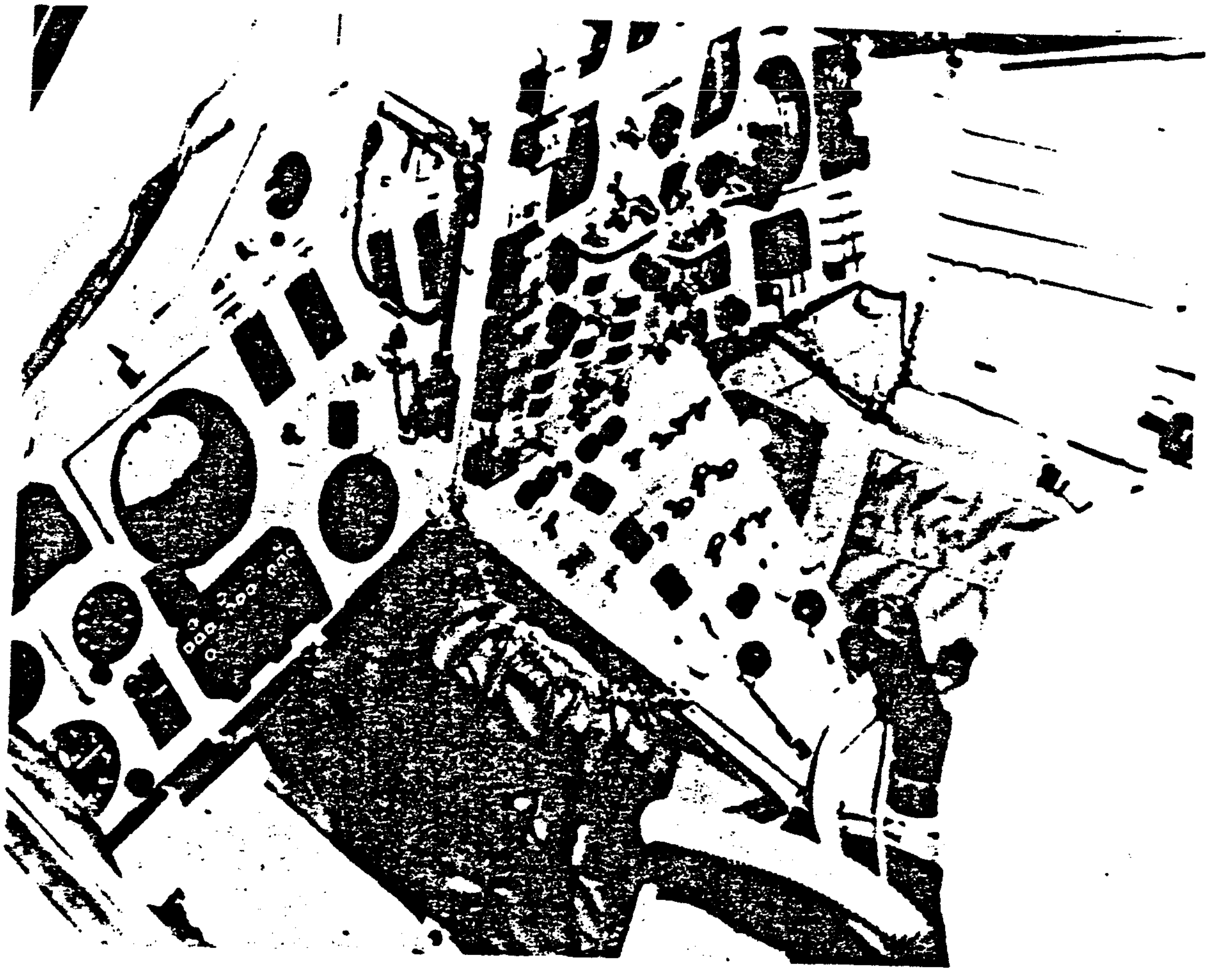


FIGURE 8.—Gemini spacecraft displays and controls.

elements and increased telemetry of data to the ground. To accommodate display requirements, many of the meters were time-shared among several parameters for a subsystem or among redundant systems for a single parameter.

Experience with the display and control system indicated that the integrated display of attitude and rate information on the flight director attitude indicator was superior to the Mercury display. For most flight modes, a local vertical reference was useful; for rendezvous, however, maneuvers were more effectively visualized in a target-centered inertial frame.

The use of vertical-scale meters conserved panel space and provided a more effective cross-check than had been attainable on the Mercury spacecraft with circular meters that were in line only at the 9 and 3 o'clock positions. Similarity of the cockpit to that of high-performance aircraft illustrates the degree to which the crew had been allocated a similar role. With ground assistance in navigation and flight planning, the mission could be conducted from on-board the spacecraft.

The Apollo command module and lunar module display and control panels (Figs. 9, 10) are three to four times more complex than the Gemini panel. The increase in complexity results from additional mission phases and level of system redundancy provided. The Apollo Program includes all the elements of planetary exploration. No previous spacecraft has had more than a fraction of this capability; at least a second generation of spacecraft must be developed before another program will require such capability.

The left side of the main panel of the command module (Fig. 9) is arranged for the commander and has the displays and controls for launch, entry, and all propulsive maneuvers. The center section provides access to guidance, navigation, and propulsion functions; the right center and right panels contain primary displays and controls for the sustaining systems (environmental control, communications, and electrical power). In addition to the main panel array accessible from the couch, 17 to 20 other panels are located elsewhere in the command module. The most significant are the guidance and navigation station in the lower equipment bay, where navigational optics are located, and the environmental control system management panel in the lower left equipment bay, where a large number of mechanical controls are located. The other panels have controls and displays for special system functions.

In Figure 9 and in Table 5, several trends are evident in the Apollo console arrangement. Circular meters are used in only a few cases and only for parameters with a limited range of excursion; vertical meters are predominant and are time-shared by switching to display a parameter for several redundant systems; prominence in access and visibility is provided for the flight director attitude indicator, the display and keyboard, and the caution and warning matrix; discrete elements (such as circuit breakers, toggle switches, and event indicators) are used extensively. Discrete controls and displays are used

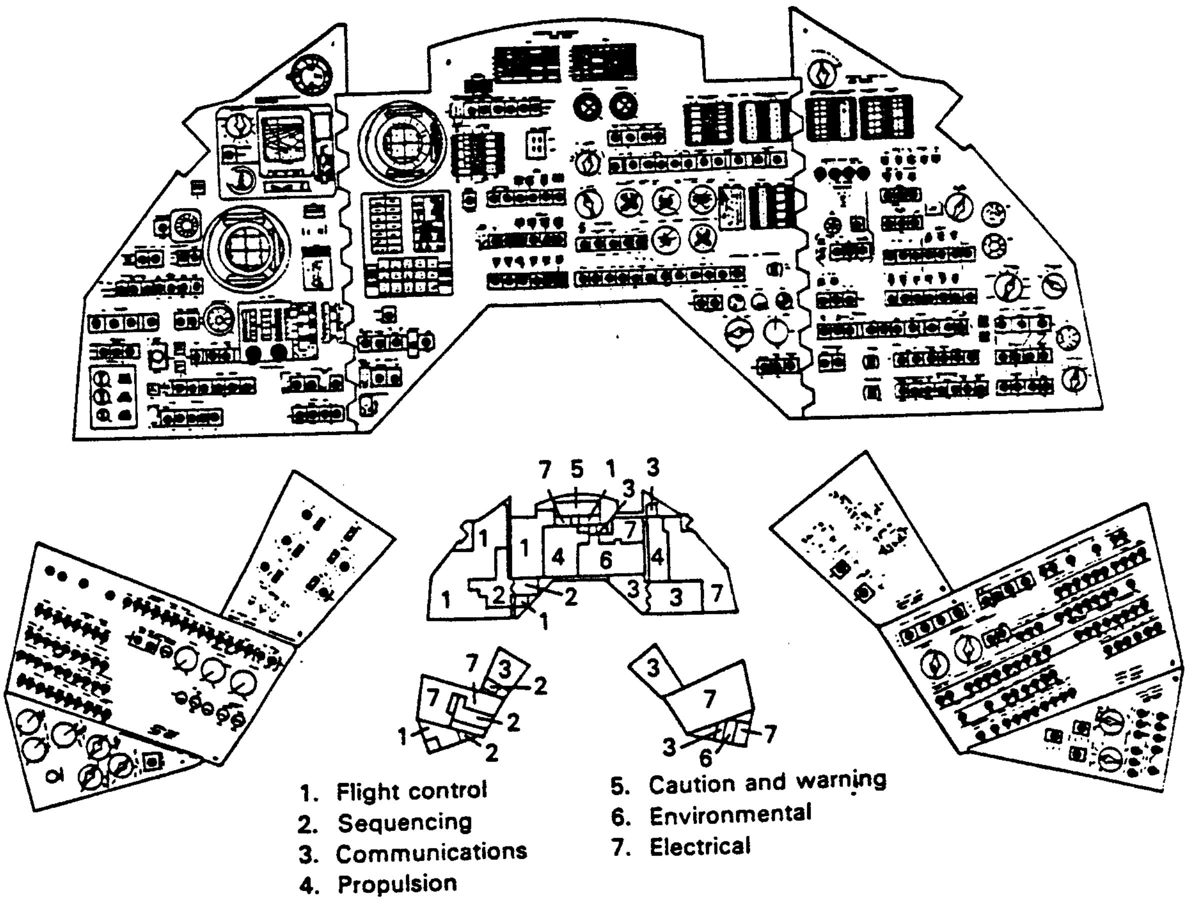


FIGURE 9. – Apollo command module display and control panel.

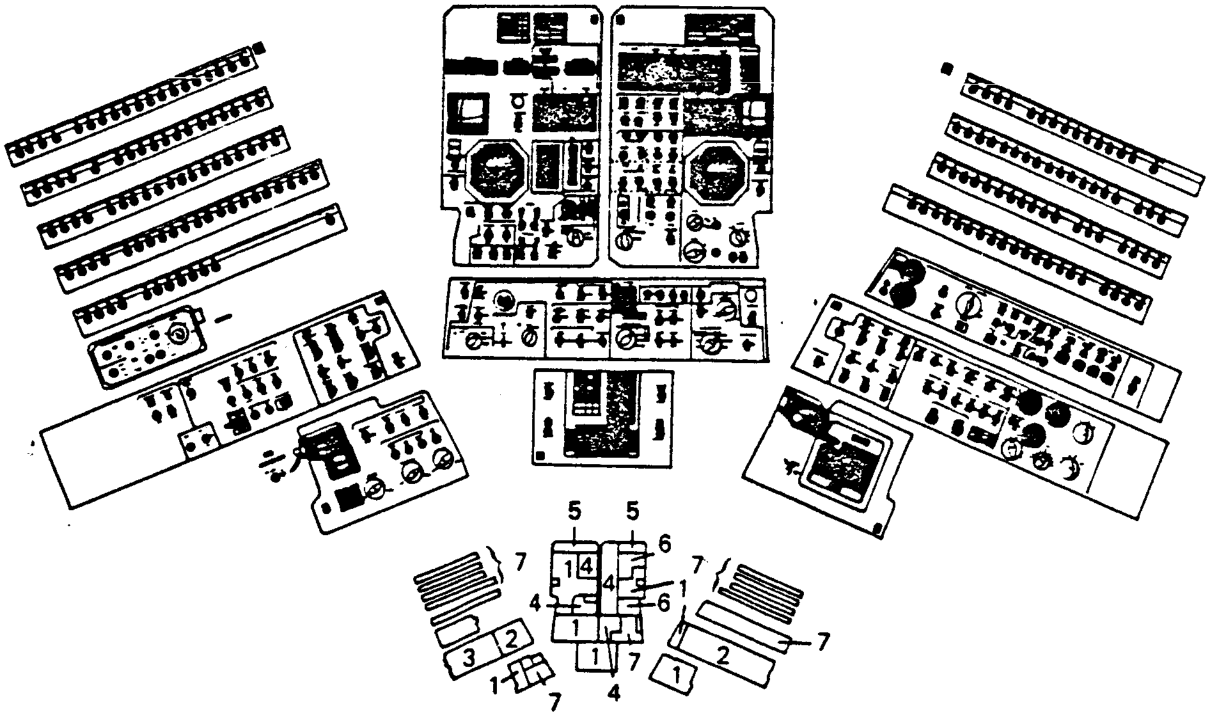


FIGURE 10.—Apollo lunar module display and control panel.

more extensively in diagnostic procedures than in nominal system reconfiguration.

The lunar module panel (Fig. 10) indicates many of the same points noted for the command module panels. Circular displays are used only for secondary parameters; unique devices, such as the flight director attitude indicator, the display and keyboard, and data entry and display assembly are most prominent. The large number of discrete control elements is related to the several configurations of the lunar module after launch; that is, to the parallelism of ascent- and descent-stage subsystems for electrical power, environmental control, and propulsion. The panel arrangement is typical for two-man, side-by-side flight vehicles. Each astronaut has the primary flight instruments located in the same visual scan area with a window. The commander on the left has access to the flight-control and propulsion systems; the lunar module pilot on the right has access to the alternate flight-control system, the abort guidance assembly, and the sustaining systems.

One of the most significant aspects of the lunar module displays is the importance of the caution and warning system. This system is substantially more complex than that in any other spacecraft because the lunar module is either in powered flight (landing, ascent, and rendezvous) or in a dormant state (while the crew sleeps or is absent on the lunar surface) during its active life. Because these mission characteristics allow the lunar module crew little time to monitor many subsystem functions, the caution and warning system and the Mission Control Center via telemetry act as a third crew member to perform this status monitoring function.

The Skylab command module displays represent only minor modifications from the Apollo configuration, but the controls and displays in the remainder of the modules are a significant departure from previous spacecraft. For example, Figure 11 shows the controls and displays for the Apollo telescope mount. This panel, located in the multiple docking adapter, provides for control of the solar telescopes and instruments located on the mount. While this panel is of the same order of complexity as the Gemini controls and displays, its purpose is to acquire scientific data, not to conduct flight operations.

Notable characteristics of the panel are: use of cathode-ray tubes to display telescope views and amplitude-time plot of x-ray activity; extensive use of digital displays; and relatively low proportion of data displayed to those telemetered. Again, the types of displays reflect advances in spacecraft technology, such as cathode-ray tubes being conditioned to endure launch vibration and acceleration environments. Digital displays are required to provide adequate scale resolution for the parameters of interest.

The fraction of data displayed to ensure proper data acquisition is a small proportion of those data required for eventual analysis. This reflects the program and flight planning emphasis on using flightcrew time to acquire data, with data reduction and analysis to be performed on the ground. A certain amount of data analysis will be made during the mission to allow evaluation of achievement and to replan further data acquisition. The design logic of this console is the same as that for the flight controls and displays. The objective is to provide a capability for autonomous spacecraft operation, which, in this case, is supplemented by ground-based data analysis

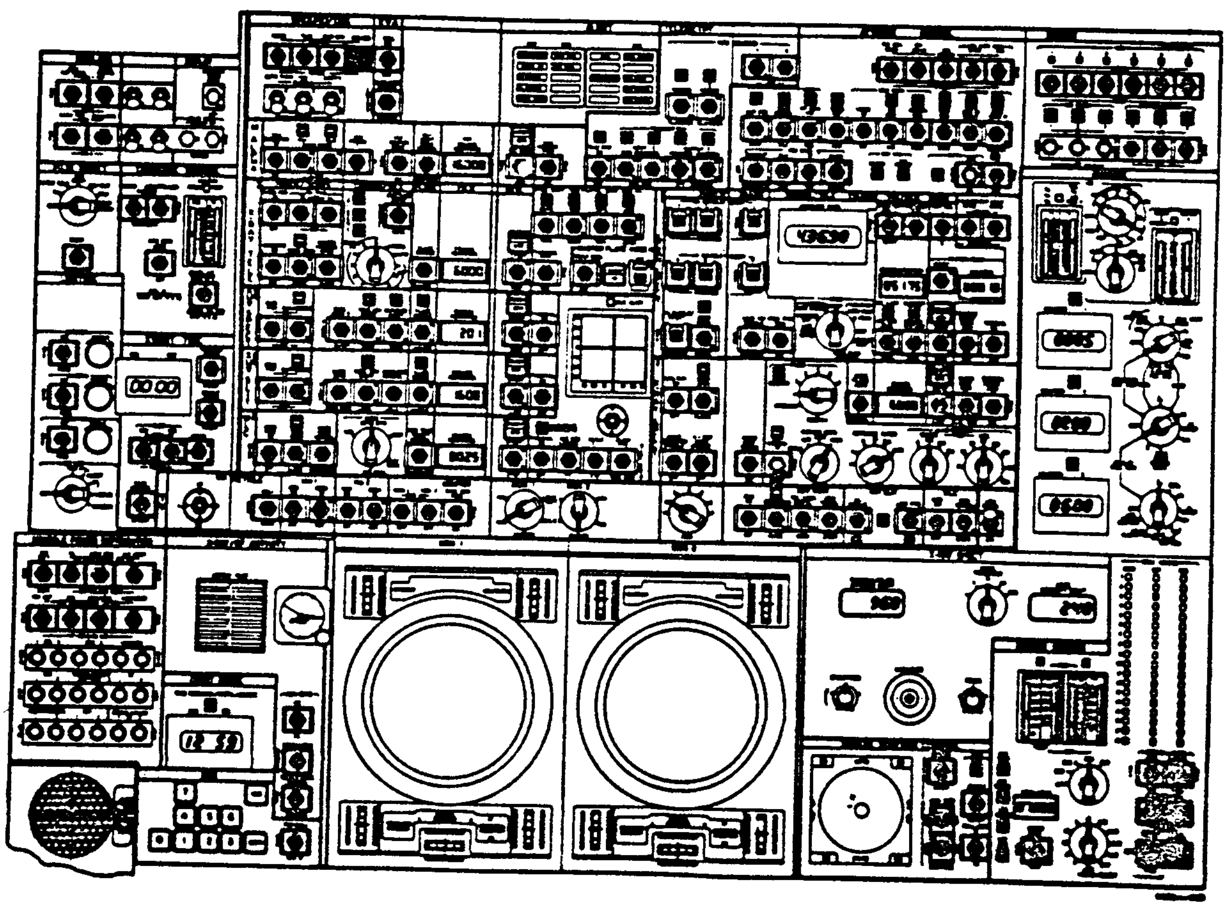


FIGURE 11.—Skylab Apollo telescope mount displays and controls.

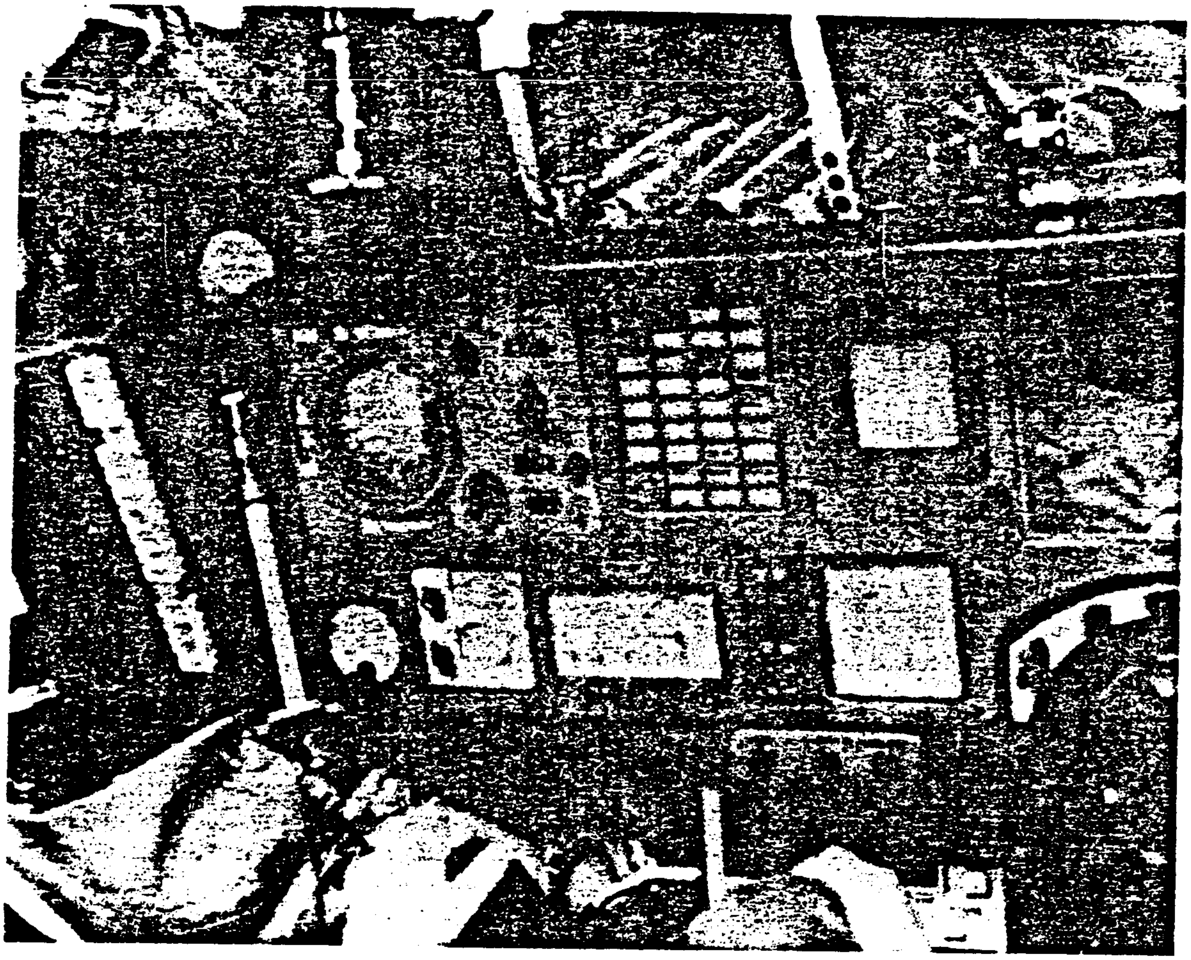


FIGURE 12. — Soyuz display and control panels.

and up-link command to enhance effectiveness and reliability.

The bulk of controls and displays in the orbital assembly is used for experiment operation and control, which is shown in Table 5. The operational instruments are used primarily for housekeeping; that is, maintenance of thermal and habitable environments and control of consumables such as water, oxygen, nitrogen, and electrical power.

The magnitude of this trend to increase scientific operations relative to flight systems is evident from the number of work stations and panels in the orbital assembly modules. The large number of panels reflects the number of experiment installations in each of the various modules. The numbers in Table 5 indicate that each panel is small and devoted to operational controls for the experiment. Data for experiments other than the Apollo telescope mount are returned to the ground primarily by voice link during the mission, and by written forms, film, and magnetic tape at the end of each crew visit.

For all spacecraft, the degree to which the flightcrew can be assisted by the ground in system monitoring is indicated by comparing the number of available measurements displayed with those telemetered. The crew and the ground share a common set of parameters; that is, those parameters critical to crew safety and the correct execution of powered flight maneuvers. The ground also has access to a large number of sensors not displayed to the crew, as well as access to data on a continuous basis that is accessible to the crew only as a discrete event. The ground-based flight control team can maintain continuous time histories of parameters, never needs to time share parameters on a display, and has independent trajectory data available from ground-based tracking that are not directly available to the crew. Also, ground-based personnel can size their team to the task at hand and afford to assign controllers to particular functions without the need for time sharing their attention among several functions. Because of these advantages, both analog and discrete data not furnished the crew are telemetered to the ground, and data that are time-sampled by the crew are monitored continuously. The ground has primary responsibility for detecting all gradual degradation failure modes, for example, gyro drift. Sampling rates are selected as a function of the dynamic variability of the parameter and the resolution required for flight control decisions.

Through the spacecraft and experiment status information conveyed by this telemetry, the Mission Control Center monitors the spacecraft for the crew while they sleep or address themselves to scientific observations and experiments. The telemetry data allow both the flightcrew and Mission Control Center to confirm the conditions of all spacecraft systems and assure that proper procedures are being followed. These data are also used to aid the crew in replanning the flight to take advantage of unexpected opportunities or recover from the failure of a particular instrument or previously planned experiment.

The unique control devices and displays are primarily associated with flight control of the spacecraft. They are the most complex of the control and display elements and can be typified by a description of the primary guidance and navigation system display and keyboard.

The Apollo primary guidance and navigation system's display and keyboard is the most complex and powerful of the unique crew interface elements (Fig. 13) [3, 22, 40]. It displays the status of the computer, inertial systems, and program within the computer. With this device, the crew can monitor program status and activity, and sequence and initialize the systems as desired. Communication between crew and system is conducted in terms of a set of program blocks identifying specific functions such as preflight operations (0X), monitoring launch (1X), and lunar module rendezvous (7X). The second digit identifies specific program activities within each major set. Within each program block, a set of two-digit verbs and nouns specifies actions to be performed and the object of the action, including the data to be entered into the calculation or to be displayed during the calculation. The computer can also drive the flight director attitude indicator sphere and error needles to provide analog displays. Figure 14 illustrates characteristics of a typical program element: in this case, the program for executing a command module maneuver to change orbital parameters by using targeting information furnished by the ground-based navigation system.

When the computer program requires a crew management decision about the acceptability of results or the need for new input data, the crewman is queried by flashing the verb and noun displays. This two-way communication between crew and computer is quite complex, requiring approximately 10 000 key strokes to complete all elements of a lunar landing mission. Approximately 40% of all crew training for a lunar landing mission is required to master the system. In this system, as in the others described, much of the complexity derives from providing crew access to a very low level of function. To guard against procedural errors, on-board data are provided to reinitialize erasable memory if an error occurs, and the probability of error is reduced by training each crewman to a high level of proficiency and assigning to each specific mission phase operations.

Another class of crew activity, related to control and display, is effected by crew observation of exterior objects through either the windows or the optical systems used to aline the inertial reference systems. In these activities, the crew has the task of recognizing complex patterns and providing either direct steering commands or input data to the automatic systems. The crew performs such functions in docking, rendezvous targeting, erecting and alining the inertial plat-

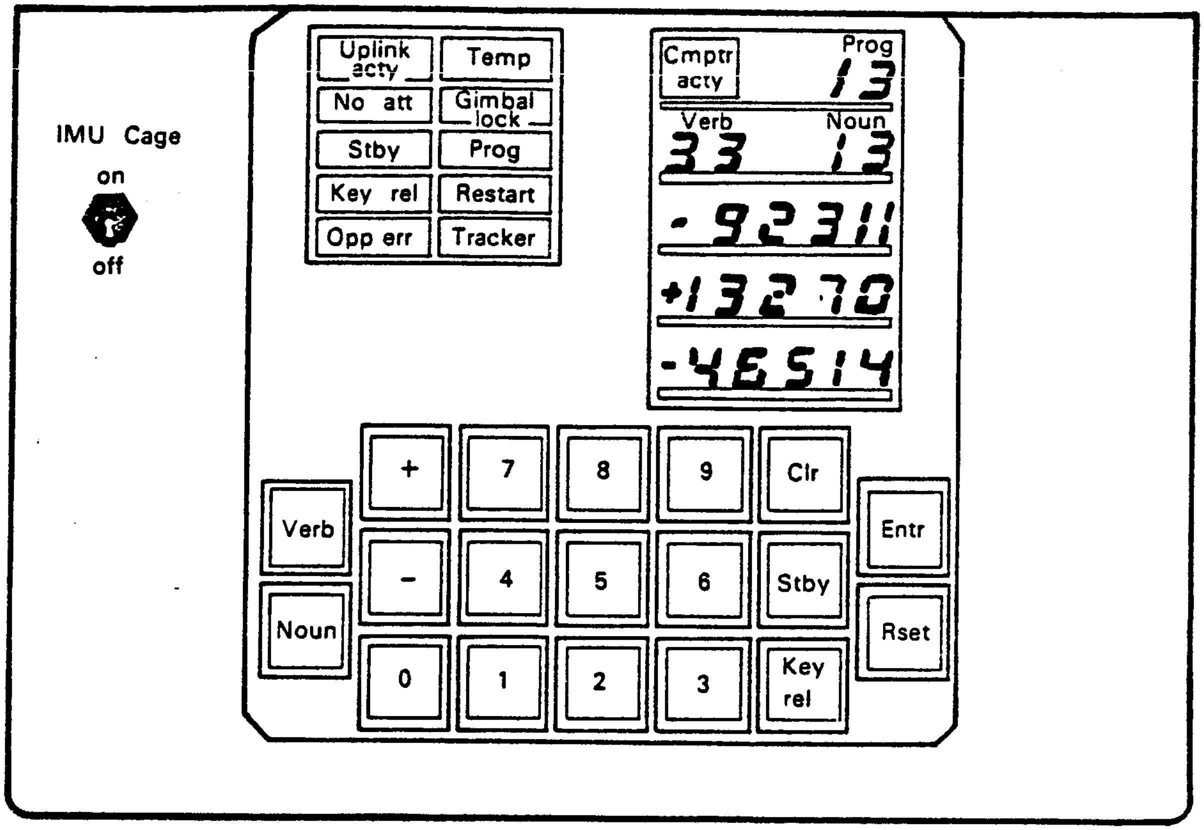


FIGURE 13.—Guidance and control system display and keyboard.

forms, aiming scientific instruments, and landing the lunar module.

The view from the lunar module as it approaches lunar landing and the system used during this maneuver are shown in Figure 15. The display and keyboard of the primary guidance and navigation system displays the elevation and lateral angle of the target point. If the target is not a suitable landing point, in the pilot's judgment, he can redirect the system to a more acceptable target by input of the coordinates of the desired site. The computer will then retarget. Alternatively, the crewman can take over and perform the complete maneuver manually. In this and other uses of the crew's primary senses as part of spacecraft information acquisition, there is no way to perform the function without the crewmen.

The Soyuz control panels (Fig. 12) illustrate several notable differences from US spacecraft. The main console consists of a central panel and two identical side panels. The side panels, one accessible to each crewman, are the master sequence controls and present a vertical column of switches and annunciators activated in accordance with the mission phase and system configuration desired.

The central console contains displays shared by the two crewmen. The navigation indicator, an Earth globe, displays latitude and longitude, period of rotation, daylight and dark periods, and nominal landing point. The caution and status panel indicates subsystem status. The cathode-ray tube is used to display systems performance data and as a monitor for a television camera located on the longitudinal axis. The television scene is used for Earth viewing, rendezvous, and docking. System status values also can be displayed on this tube. A rear screen projection panel displays procedural data; when each function is completed, that inscription becomes dim. A digital data entry device allows the crew-

P30-External Delta V Program

Purpose:

1. To accept targeting parameters obtained from a source(s) external to the CMC and compute therefrom the required velocity and other initial conditions required by the CMC for execution of the desired maneuver. The targeting parameters inserted into the CMC are the time of ignition (TIG) and the impulsive ΔV along CSM local vertical axes at TIG.
2. To display to the astronaut and the ground certain specific dependent variables associated with the desired maneuver for approval by the astronaut/ground.

Assumptions:

1. Target parameters (TIG and ΔV(LV)) may have been loaded from the ground during a prior execution of P27.
2. External Delta V flag is set during the program to designate to the thrusting program that external Delta V steering is to be used.
3. ISS need not be on to complete this program.
4. Program is selected by DSKY entry.

Selected Displays:

1. V06 N33	
Time of ignition for external ΔV burn	OOXXX. h
	OOOXX. min
	OXX.XX s
2. V06 N81	
Components of ΔV(LV)	XXXX.X ft/s
3. V06 N42	
Apocenter altitude	XXXX.X nmi
Pericenter altitude	XXXX.X nmi
ΔV	XXXX.X ft/s
4. V16 N45	
Marks (VHF/optics)	XXbXX marks
Time from external ΔV ignition	XXbXX min/s
Middle gimbal angle	XXX.XX deg

CMC=command module computer
Delta V=thrust applied to change orbital ephemeris
ISS=inertial subsystem
DSKY=display and keyboard
CSM= command and service module

FIGURE 14.—Typical guidance program.

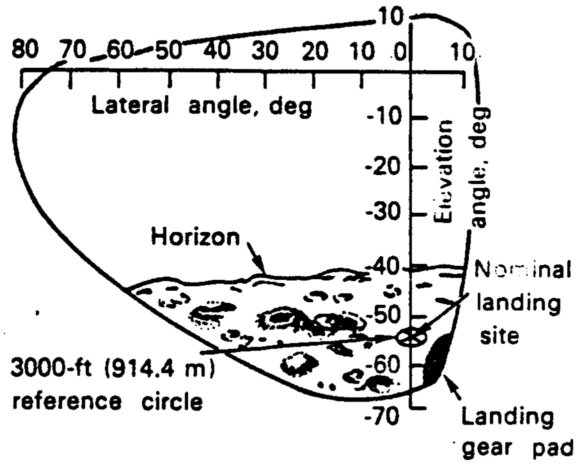


FIGURE 15.—Landing area perspective as seen by the lunar module pilot during final approach.

man to program the automatic system for the orientation and magnitude of maneuvers. Electrical power system performance, event timers, and radar range and range rate indicators are arrayed to the left of the periscope viewing screen. The periscope optics can be rotated to view the Earth beneath the spacecraft, the Sun, or a target vehicle: the peripheral field of view includes the visible horizon.

These displays and controls reflect the same reliance on ground-based navigation and flight planning assistance as US spacecraft and are adequate for all Earth-orbital operations of maneuvering, rendezvous, and docking. The most notable differences from US spacecraft are reliance on programed sequences in the management of subsystems, and absence of large numbers of discrete controls for malfunction isolation. The lesser volume occupied by the displays and controls contributes to the greater habitable volume in Soviet spacecraft.

MISSION EXPERIENCE

The crew's role has become increasingly complex and diversified as flight experience has increased. The early Mercury, Vostok, and Voskhod flights tested man's ability to endure in space and matured to demonstrate the potential value of Earth observation systems,

Maneuver	Reference	Time maneuver initiated h: min, G.c.t.	Control mode	Auto fuel, lb	kg	Gyro switch position
—— 1	Window	01:41	FBW-low	0.39	.18	Normal
– – 2	Periscope	01:50	FBW-low	0.32	.15	Free

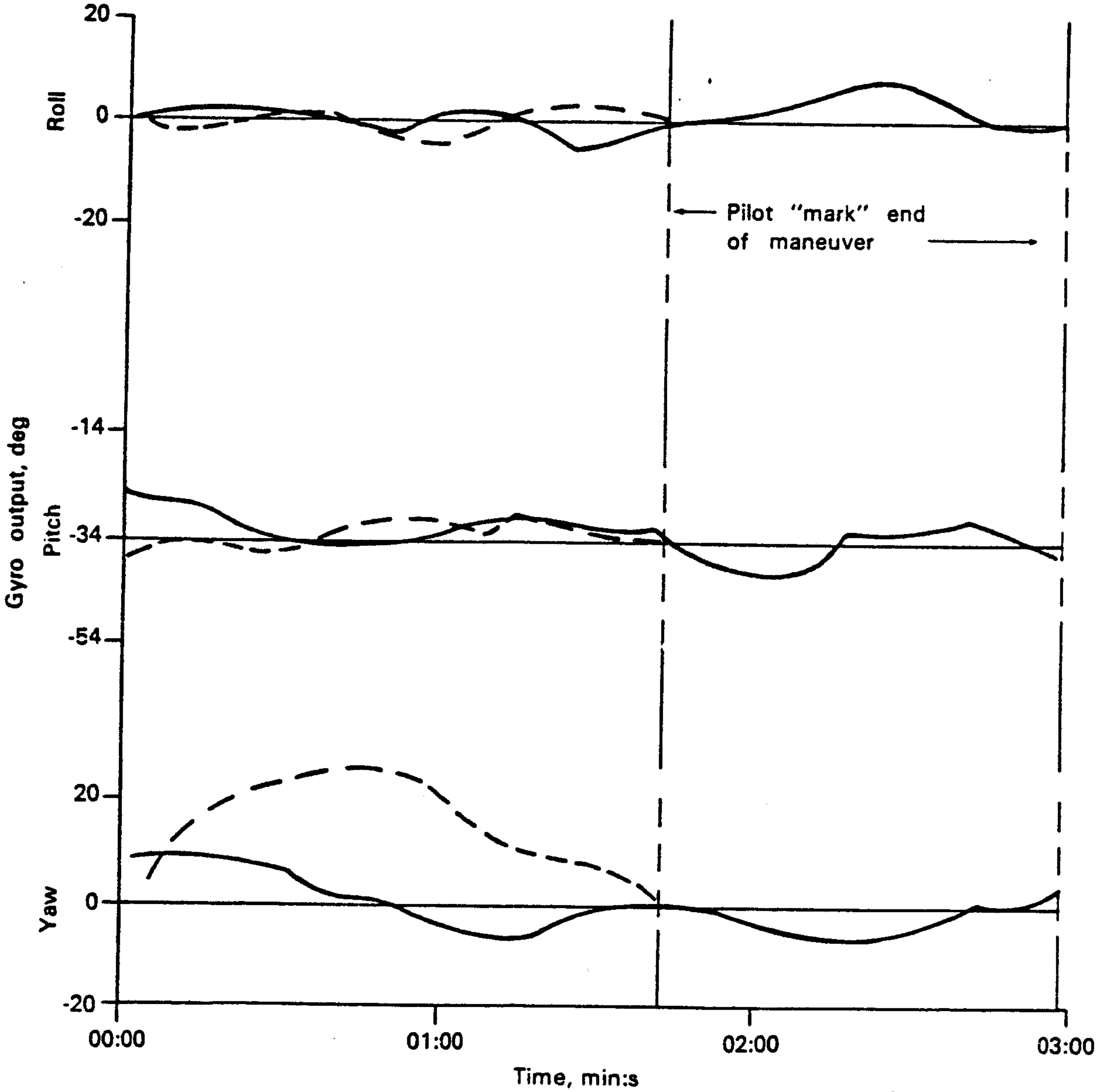


FIGURE 16. — Mercury attitude maneuver.

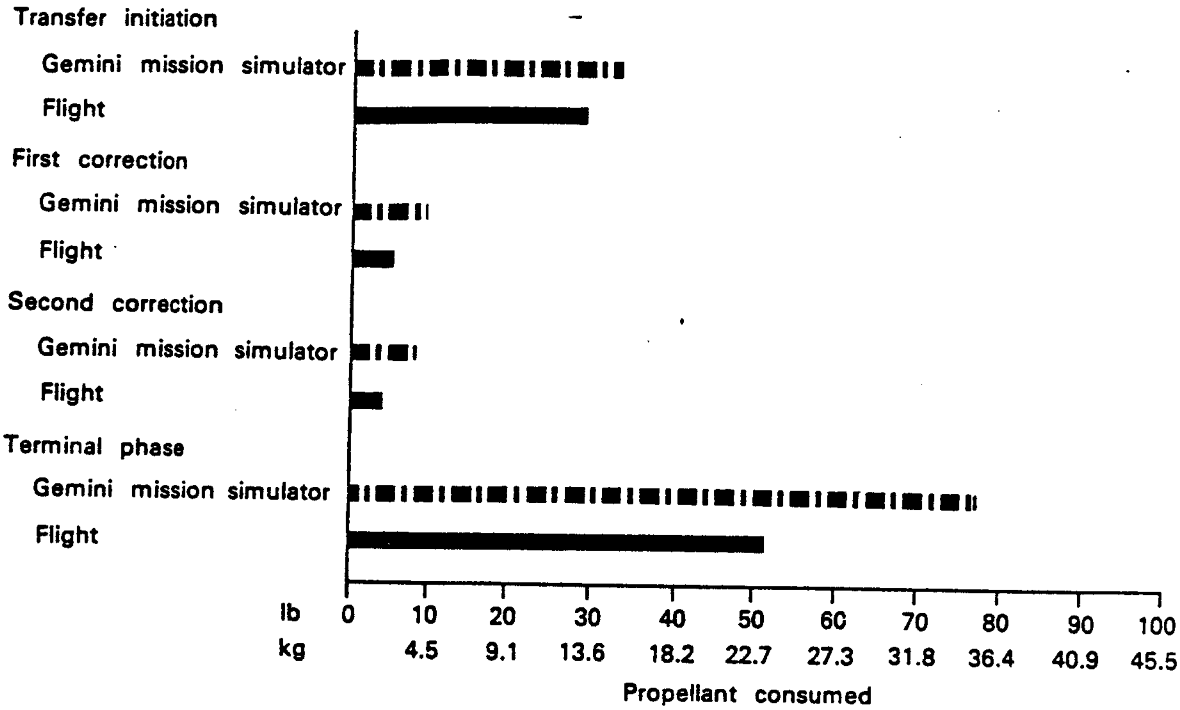


FIGURE 17.—Gemini spacecraft maneuver.

man's ability as a scientific observer, and the capacity of the crew to overcome substantial system failures and return the spacecraft to Earth. The Gemini Program demonstrated not only several rendezvous techniques, but also the ability to conduct simple and meaningful experiments. On the Gemini 8 mission, the crew successfully handled an unexpected and potentially catastrophic failure in the attitude control system. Each Apollo mission has been substantially more complex in both operational and scientific objectives. In this program, again, the Apollo 13 crew proved the capability to return to Earth safely even after a major system failure. The Skylab crew repair of equipment extended the life of the spacecraft and restored to operation several scientific instruments. In the Soviet space program, Soyuz and Salyut missions similarly demonstrated that the crew can perform critical operational duties in maneuvering spacecraft and operating complex scientific instruments. Such a record indicates that man contributes substantially to space systems.

Performance of the crew in the flight environment reflects the effect of extensive training in preparation for the mission. Figure 16 illustrates a typical comparison of Mercury crew performance in flight and during training. The maneuver is smooth, end conditions are precise, and control fuel cost is near optimum with less than 10% of the automatic system requirement [39]. The fuel saving is possible because in some cases the crew can select lower maneuver rates and more efficient sequences than the automatic system. Similar data for rendezvous maneuvers of the Gemini 9 flight are illustrated in Figure 17. Again, the consistency of performance is noteworthy. The propellant consumption in flight was less than that during simulation because the mission differential altitude was only 22.4 km (12.1 nmi) while the simulation data were gathered at a differential altitude of 26.8 km (15 nmi) [46]. The crew relies on the computer to calculate magnitude and direction of major maneuvers but controls final station keeping and docking directly.

Docking and Lunar Landing

Crew performance in the Apollo missions is illustrated by the execution of two critical maneuvers: docking and lunar landing. The docking maneuver normally is performed with the control system configured so that spacecraft attitude is held within a band of $\pm 0.5°$ in all axes; while the pilot controls closure velocity and lateral and vertical displacement manually. Table 6 shows the relationship of several significant parameters as reflected in the system specification, measured during piloted simulation tests, and estimated from telemetered data and crew reports for 10 Apollo missions. Clearly, flight performance is quite precise. The system capability is dictated by contingency modes not yet experienced in any flight. Simulation data include degraded system modes of operation and show increased variability in execution of the maneuver. The greatest variance in performance for degraded modes of control does not appear to be in the docking performance parameters, but in the time required and the propellant used to execute the maneuver. Both these values vary significantly as a function of the degree of control system degradation. Ample contingency propellant is available for critical lunar docking; neither the lunar nor the transposition docking are time critical.

The lunar landing also illustrates the combination of manual and automatic system control modes. During descent, the crew can select a manual descent mode by which they can control vertical and horizontal velocity while the autopilot provides an attitude hold. Figure 18 shows specification performance limits of the vehicle structure in terms of the velocity at touchdown that the landing gear can attenuate; that is, 3.05 m/s vertically at 0 m/s horizontally and 2.13 m/s vertically at 1.22 m/s horizontally. The ellipsoids centered at 1.83 m/s vertically represent the probability region of touchdown conditions. These probabilities are based on simulation of many landings with system performance varying within specification limits, and manual control based on instrument displays.

The flight points in Figure 18 represent Apollo lunar landings. The point plotted for the lunar landing training vehicle shows the average landing condition for a set of training flights. That landings executed on the Moon are softer than those simulated is not surprising. Even with blowing dust obscuring the surface near the time of touchdown, the pilot obtains significant information not available in simulations. Flight provides real proprioceptive and visual cues that are absent or incomplete in simulations. Finally, and perhaps most importantly, the flight maneuver is *scored* by the crewman on how gently he can execute the landing when he has arrived at a suitable touchdown location. In the simulation, the most readily obtainable performance measurements are the time and the propellant remaining as soon as acceptable conditions are attained. The margin reflected in these values becomes the index of success. The difference in the simulation and real flight situations appears to bias the results in different directions. Consequently, simulations are characterized by a positive rate of descent at landing probe contact, while flight landings are characterized by a near-zero rate of descent at probe contact and by a short delay in cutting off the descent engine after probe contact is established.

Crew Reliability

Demonstration of a high degree of predictability of crew reliability has been another facet of mission experience. A major simulation of the Apollo mission was conducted to assess potential reliability of crew performance [17, 34]. This simulation reflected the configuration of the spacecraft as nearly as possible, illustrated routine and most demanding procedures, and used as test crews personnel who met many criteria for astronaut selection. Several were, in fact, later selected for the astronaut group.

Study results indicated that crew performance could be expected to be very good. Procedural reliability varied from 0.94 to 0.98 as a function of mission phase or of the particular crew considered. Two of the crews were not given feedback about their performance during training, and their error rate was higher than that of the three crews who were given such information. Astronaut crews have always been furnished

TABLE 6.—*Spacecraft Docking Maneuver Characteristics*

Characteristic	Design envelope	Average of simulation results	Average of mission results
Closure rate, cm/s	0.3–30.5	10.4	6.89
Lateral displacement, cm	30.48	6.10	3.94
Lateral displacement rate, cm/s	0–15.0	.91	--
Rotational rate (any axis), deg/s	1	.06	--
Rotational misalinement, deg	±10	.9	1.12

feedback on performance during training. Conclusions from the study were:

1. Mission time-dependent performance in simulation increased variability rather than effecting any absolute change in performance.
2. Variations in constancy of workload appeared to be more important than peak workload as a factor in crew performance against the criteria that were used.
3. The criticality of "error" gave indication of no significant deviations in the performance of discrete task elements but could become significant in such integrated error tasks as manual nulling of steering errors in trajectory guidance.

The conduct of such studies is very difficult. Selection, and especially training, of test crews is necessarily much less rigorous than it is for flightcrews. Flightcrew training includes participation in many systems definition and development activities and in information acquisition opportunities of their roles in the management structure. It is even more significant that such simulations cannot make predictions, but can only mimic the influence of real-time purposive behavior.

A substantial artifact in all simulations is that they must establish readily accessible criterion measurements to produce quantitative and repeatable performance data so that design, procedure, or training decisions may be made. When properly selected, the character of these measurements is such that they bear direct relationship to a real optimum solution; however, by virtue of the simulation mechanization, the relationship is often a secondary measure of successful "real world" performance. It is not intended to find fault with such endeavors, but merely to note an inherent limitation that is particularly significant as the human "purpose-dominated" element is introduced.

This factor is most conspicuous in discrete element performance, as it is measured to establish a "reliability" number in the study noted. For a criterion, the checklist must be the standard. The difficulty with such a standard is indicated by noting that 17% of the switching errors by crews is attributed to lack of clarity in the checklist. Even after correction for clarity errors, the standard must remain because it is readily counted. Such a measure, although neatly quantitative, is hard to weigh in terms of significance because many such errors are of no consequence or are recognized and reversed by the crew. To note such deficiencies is to note that few laboratory tests are as complex as the real event.

Analysis of selected samples of flight telemetry for several missions has furnished data comparable to those from simulation studies. The switching error rate was very low; reliability, as measured by compliance to the checklist, was 0.996. All errors noted were promptly detected and corrected by the crew without ground comment. The bulk of errors occurred during keying operations of the display and keyboard of the primary guidance and navigation system.

In another analysis of these data to establish crew workload, the information processing rate during the lunar landing was estimated at 3.90 bits/s with most of the data flow being the lunar module pilot's callouts of descent rate and altitude to the commander. Because this is the period of highest crew activity during the mis-

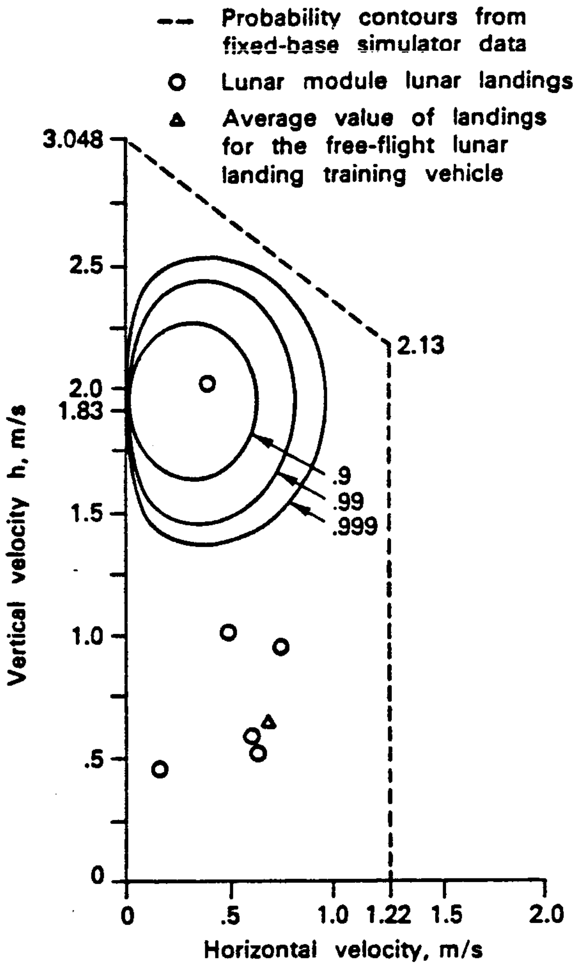


FIGURE 18. – Lunar landing performance.

sion, this information processing rate represents a maximum to be expected. Less demanding maneuvers are characterized by rates between 1 and 2 bits/s.

These data substantiate the observation that crew performance is very reliable. All errors observed were indifferent in consequence and detected and corrected promptly by the crew. Perhaps the error correction effectiveness is more noteworthy than the exceptionally low rate of error incidence.

Scientific Observations

Man's unique contribution to the scientific objectives of space missions is less readily quantified but not less significant. Both cosmonauts and astronauts have made significant scientific observations since the very first flight, and this facet of their activity has increased markedly as basic operational systems and procedures have developed during the decade 1960–1970.

The simplicity of early spacecraft and test character of the missions limited early scientific activity to observations on the crew's performance, and observation, and photography by the crews. Crew activity indicated that the human could and did effectively adapt to space environment, not encounter any significant sensory disturbances, and perform effectively under the stresses of the missions as psychologically stable individuals.

Phenomena observed during early flights included weather patterns, refractive distortion of the Sun at sunrise and sunset, presence and altitude of the night airglow, layered structures in the Earth atmosphere, and geologic and geographic structures. These crew observations were supported by photographs that permitted later, more extended analyses.

During all orbital flights, synoptic terrain photography has provided useful products for both geologic and topographic mapping. Photographs of the oceans under various angles of solar illumination indicated sea states as a function of glitter. Both the observed resolution and that apparent in photographs was greater than many anticipated.

Star sightings made during both day and night viewing conditions included identifications down to 5.95 magnitude at night and 4.00 magnitude at day. Meteors, auroras, and other satellites also have been observed.

In addition to these observations, experiments were conducted on biologic specimens (sea urchins, frog eggs, and white blood cells); effect of spacecraft passage on ion flow; and effects of micrometeorite impact on prepared samples [5, 29].

The major manned scientific missions have been the Apollo lunar surface explorations, Apollo lunar orbit observations, Skylab solar, medical and earth resources observations, and Salyut astronautical and electromagnetic fields experiments. The eight Apollo missions to lunar orbit and the six lunar surface explorations have been notably successful. Crew observations provided the basis for selection of photography, instrument observations, and geological samples. The productivity of subsequent analyses has been markedly improved by supplementary notes and priority selection provided by the crew. Among significant observations made by crews are the degree to which color variations in the lunar surface are most pronounced at low sun elevation, prevalence of breccia formation, detection of light flashes from several regions (even though these could not be located to specific coordinates), and similarity of the near and far sides of the Moon in the detailed characteristics of geological units.

On the Soyuz 11-Salyut mission, cosmonauts operated an astronautical telescope and performed an electromagnetic fields experiment. Success in demonstrating high-frequency secondary electron resonance in space and acquisition of spectrograms of Beta Centauri and Lyra were attributable to the same crew efficiency in operating space experiments as in operating the spacecraft. The ability to control experiments and react to the character of the data being acquired significantly improved the final data and experimental results [3].

The Skylab experience embodied two unique new elements: extended operations on orbit of a complex man-operated scientific facility for medical, solar, astronomical and terrestrial observations; and the capability to revisit this facility modifying the crew skill complement and instrument complex. Crew intervention not only sustained the facility, but also sustained the operations and modified the original character and purpose of the observing instruments. The three visits added new instruments and new observing protocols. The science skills of the crewmembers augmented by ground-based facilities and teams of scientists fostered new methods of operations. The timing of Comet Kohoutek was fortuitous in that it provided a unique opportunity to test this capability.

While it is too early in the assessment of data collected on this mission to characterize its scientific value, it is clear that properly selected and trained crews can contribute to the reliability and productivity of scientific facilities, as they have to flight systems.

Clearly, the techniques of exploiting man's capability in the operation of flight systems, mechanisms for the exploration of space, are well understood. It is not equally clear that there is a body of information or theory adequate to expolit his capability in confronting the challenging problem of how to productively explore this new space domain or exploit its unique opportunities to assess man and his environment effectively. The problems before us are not how to use man effectively in managing systems to predetermined ends, but in how to supplement his unique intellectual functions in exploring these new frontiers of man's inquiry into his own nature and that of the universe of which he is a part.

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SESSION III

PROGRAM PLANS AND REQUIREMENTS

D2

HUMAN FACTORS AND FUTURE SPACE TRANSPORTATION SYSTEMS

EDWARD A. GABRIS
AUGUST, 24, 1982

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I am responsible for technology activities which relate to current and advanced space transportation systems.

These objectives are accomplished by system-level studies aimed at identifying and quantifying the value of technology advances by close contacts with centers of excellence both within and external to the agency including DoD and industry, and by the formulation of working groups to address specific issues.

D2

- NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

- OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

- TRANSPORTATION SYSTEMS OFFICE - EDWARD A. GABRIS, MANAGER

TRANSPORTATION SYSTEMS OFFICE

- PROVIDE SCOPE AND DIRECTION TO OAST'S SPACE TRANSPORTATION R&T PROGRAMS
  - -- IDENTIFY HIGH PAY-OFF AND ENABLING TECHNOLOGY CATEGORIES
  - -- PLAN AND ADVOCATE TECHNOLOGY DEVELOPMENT PROGRAMS

- PRINCIPLE INTERFACE BETWEEN RESEARCH AND TECHNOLOGY OFFICE AND SPACE TRANSPORTATION DEVELOPMENT OFFICE

The existence of the Shuttle and IUS, and to a lesser extent, the existence of the "standard" expendable launch vehicles has restructured the planning of missions such that most transportation needs will be within the capabilities of these systems. However, we are confident that the uses of space are sure to expand with attendant needs for new transportation vehicles, and these are likely to be principally justified on their economic impact. To accommodate this official picture of complacency with our more optimistic outlook, my office has created a vehicle model which plans a number of advanced vehicles in a time frame we feel is probable. This model allows us to identify the need for technology programs and to advocate and justify the allocation of resources to support them.

This vehicle model suggests that the Shuttle will be the standard transportation vehicle through the end of the century and that a replacement vehicle is unlikely to have an IOC prior to the 2005 time frame. This advanced vehicle will have lower payload costs, some growth in delivery capability, and will be totally reusable. Although not clearly indicated, the model does recognize the highly probable Shuttle improvement programs which will accommodate some performance growth, but which will more likely principally provide improvements in system reliability, turn-around time, and launch charges. The Shuttle-derived vehicle is a larger cargo vehicle capable of delivering 125 to 200 K lbs to LEO and is now viewed as less probable. Further this vehicle is not a significant technology driver. The priority vehicle is pursued as principally a military vehicle providing rapidness to space for military missions.

Upper stage requirements will initially be satisfied by the IUS and perhaps a Centaur. However, a true OTV will be required by the mid-1990s. This vehicle will be a high performance vehicle capable of delivering 15 to 20 K lbs to GEO and returning to LEO. It will have a high performance, cryogenic propulsion system, be recoverable and reusable utilizing aero-assist to return to a low-Earth orbit, and be space durable. The vehicle design will be sensitive to in-space maintenance and servicing needs. This vehicle will grow to support manned sortie missions to GEO in the late 1990s. An advanced OTV will occur when a breakthrough in propulsion occurs. This breakthrough system will require significantly less propellants, thereby reducing the principal cost of upper stage operation, the transportation of propellants from Earth to LEO.

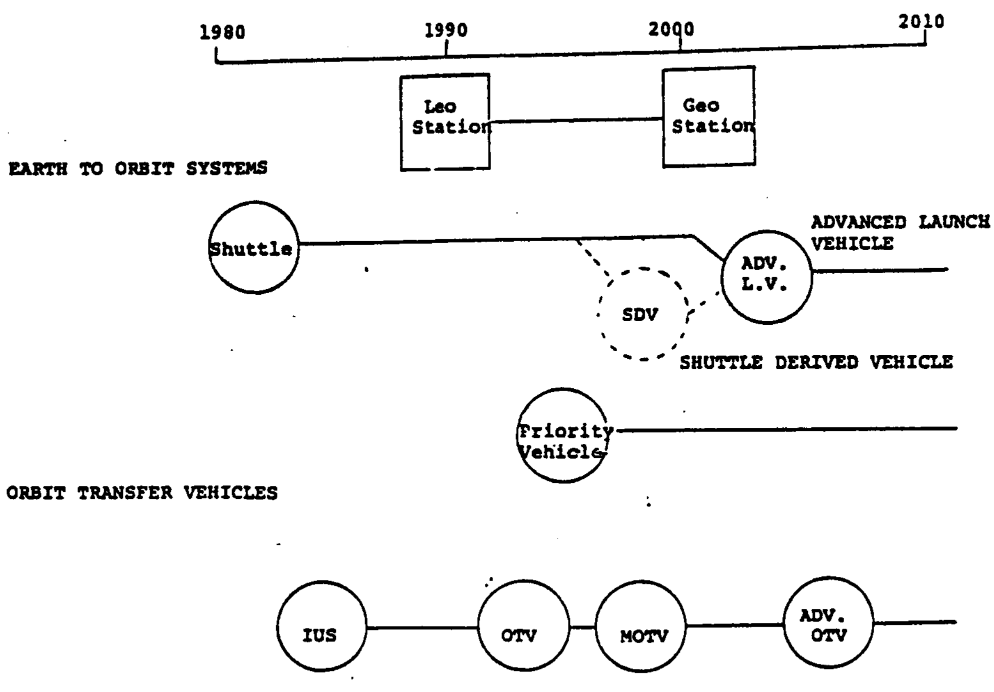
WHAT IS THE FRAME OF REFERENCE?

- DEFINED MISSION REQUIREMENTS ARE COMPATIBLE WITH SHUTTLE/IUS CAPABILITIES

- HOWEVER, WE EXPECT AN EXPANDING AND VIGOROUS SPACE PROGRAM TO OCCUR
  - -- NATIONAL REQUIREMENTS WILL EXPAND
  - -- CURRENT VEHICLE SYSTEMS WILL REQUIRE REPLACEMENT
  - -- FOREIGN COMPETITION WILL BECOME KEENER
  - -- MAN WILL ASSUME "PERMANENCE" IN SPACE
  - -- ECONOMICS WILL BECOME THE KEY "FIGURE-OF-MERIT"

- THEREFORE, A VEHICLE MODEL HAS BEEN DEVELOPED TO PROJECT A FLEET CAPABILITY TO MEET THESE CHALLENGES - THIS IS THE FRAME OF REFERENCE WE USE TO GUIDE THE TRANSPORTATION TECHNOLOGY PROGRAM

SPACE TRANSPORTATION SYSTEMS SCENARIO



Man will play a critical role in the operation of these transportation systems: as a pilot, as a planner, as a servicer of missions, as an integrator of payloads, and as a critical element in the accomplishment of mission objectives. The allocation of technology resources to increase the effectivity of man's role will compete with other technology needs. Thus it is imperative that the important issues and the attendant technology deficiencies be identified.

Just considering in-space operations--there needs to be a systematic understanding of man's relationship to automation and robotic capability. Some would argue that man is not needed and that we can automate everything that <u>needs</u> to be accomplished and that automation is more cost-effective. I do not believe this. Man will play an important role in mission objective attainment.

TRANSPORTATION TECHNOLOGY FOCUS

- THE PROGRAM MUST FOCUS ON CRITICAL TRANSPORTATION SYSTEMS NEEDS
- ENHANCED SPACE TRANSPORTATION CAPABILITY (ETO, OTV, ON-ORBIT, PLANETARY)
- ENHANCED OPERATIONS IN SPACE
  - -- PAYLOAD DEPLOYMENT AND RETRIEVAL
  - -- SPACE STATION CONSTRUCTION, SERVICING, AND SUPPLY
  - -- OTV BASING (DEPLOYMENT, FUELING, RECOVERY, MAINTENANCE AND REPAIR)
- ENHANCED GROUND OPERATIONS
  - -- MISSION PLANNING
  - -- GROUND FLOW/LOGISTICS
- -- MAN'S ROLE WILL BE MORE THAN JUST A PILOT

MAN'S ROLE IN SPACE OPERATIONS

- THERE NEEDS TO BE A SYSTEMATIC, WIDELY-APPLIED TEHCNOLOGY BASE FOR ALLOCATING FUNCTIONS BETWEEN THE SPACE CREW AND CURRENT AUTOMATION AND ROBOTICS CAPABILITY
  - -- CREW STATION DEVELOPMENT
  - -- CREW TRAINING
  - -- MATCHING SYSTEM DESIGN TO HUMAN PERFORMANCE/RESPONSE
  - -- ON-ORBIT OPERATIONS
- THE OBJECTIVE IS TO ENHANCE MISSION CAPABILITY
- A METHODOLOGY IS NEEDED TO EVALUATE OPERATIONAL TASKS
  - -- TO DETERMINE MAN'S REQUIRED INVOLVEMENT VIS-A-VIS AUTOMATED, ROBOTIC, TELEOPERATOR OPPORTUNITIES
  - -- TO DETERMINE THE OPTIMUM MAN/HARDWARE MIX

This then is the opportunity--the promise of effective use of man is significant. Recognizing that the environment is hostile, much work needs to be done to understand the issues, the needs, and the opportunities. We need to understand the implication of man to define technology programs which will exploit these advantages.

OPPORTUNITY

- THE SPACE HUMAN FACTORS RESEARCH AND TECHNOLOGY PROGRAM HAS THE POTENTIAL
  - -- TO ENHANCE MAN'S EFFECTIVENESS IN SPACE
  - -- TO ENABLE BROADER AND MORE EXCITING MISSION SETS (SPACE BASE LABORATORIES, FACTORIES, REFURB GARAGES, ETC.)
  - -- TO HELP MAKE FUTURE SPACE SYSTEMS MORE AFFORDABLE

- TO EXPLOIT MAN'S CAPABILITIES TO PERFORM IN AN ALIEN ENVIRONMENT
  - -- ENVIRONMENTAL OBSTACLES MUST BE NEUTRALIZED
  - -- SYSTEMS DESIGNS MUST BE "HUMAN FACTOR CONFIGURED"

- HOWEVER, THE PROGRAM MUST BE SENSITIVE TO THE TECHNOLOGY TRANSFER ISSUES FOR APPLICATION TO FUTURE SYSTEMS
  - -- KNOW AND UNDERSTAND THE USERS NEEDS
  - -- PROMOTE CAPABILITIES - DEMONSTRATE UTILITY
  - -- PROCEED TO A POSITION OF OPERATIONS READINESS

SPACE STATION

RICHARD CARLISLE

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This chart offers a rationale for the Space Station Technology Steering Committee.

- Keyword is the <u>desired</u> level of technology for a Space Station. Skylab was a Space Station, although not designed for permanent presence in space. Space Shuttle is available for transportation.

- The task of the SSTSC, through the ten working groups, is to determine what the level of technology readiness is now and should be within the next few years to support a Space Station launch by the late 1980s.

- A half dozen year-long mission definition studies expected to get underway in the next month or two will provide configuration and mission concepts for a Space Station.

- Merging the technology evaluations of the SSTSC, the mission definitions and perspectives from outside advisory groups will permit NASA to formulate a program that would establish manned permanent occupancy of space.

INTRODUCTION

- SPACE STATION STEERING COMMITTEE (SSTSC) WAS FORMED TO PROVIDE GUIDANCE TO NASA IN DETERMINING THE READINESS OF TECHNOLOGIES NEEDED FOR A SPACE STATION.
- SSTSC INITIALLY FORMED NINE TECHNOLOGY WORKING GROUPS. A TENTH WORKING GROUP, DEALING WITH HUMAN CAPABILITY, HAS RECENTLY BEEN ADDED.
- HUMAN CAPABILITY INTERFACES WITH LIFE SCIENCES, LIFE SUPPORT AND SYSTEMS OPERATIONS: IT INCLUDES TRADITIONAL HUMAN FACTORS CONSIDERATIONS.
- THE OBJECTIVES OF HUMAN CAPABILITY "TECHNOLOGY" ARE TO KEEP THE CREW HEALTHY AND PRODUCTIVE, BOTH MENTALLY AND PHYSICALLY.

SPACE STATION TECHNOLOGY STEERING COMMITTEE
GOALS AND OBJECTIVES

GOALS:

PROVIDE BROAD AGENCY GUIDANCE IN THE INITIATION AND IMPLEMENTATION OF TECHNOLOGY DEVELOPMENT PROGRAMS TO SUPPORT AN AGENCY THRUST TO ESTABLISH MANNED PERMANENT OCCUPANCY OF SPACE.

OBJECTIVES:

1. ESTABLISH THE DESIRED LEVEL OF TECHNOLOGY TO BE USED IN THE INITIAL DESIGN AND OPERATION OF AN EVOLUTIONARY LONG LIFE SPACE STATION AND THE LONGER TERM TECHNOLOGY TO BE USED FOR LATER APPLICATION FOR IMPROVED CAPABILITIES. INITIAL TECHNOLOGY SHOULD BE AVAILABLE BY APPROXIMATELY 1986 TO SUPPORT A SPACE STATION LAUNCH AS EARLY AS 1990.
2. ASSESS THE LEVEL OF TECHNOLOGY FORECAST TO BE AVAILABLE FROM THAT PORTION OF THE CURRENT BASE R&T PROGRAM WHICH WILL BE APPLICABLE TO A SPACE STATION.
3. PLAN, RECOMMEND, AND MONITOR A PROGRAM TO MOVE THE CURRENT TECHNOLOGY PROGRAM TO THE LEVEL STATED IN NUMBER ONE ABOVE.
4. IDENTIFY, EVALUATE, AND RECOMMEND OPPORTUNITIES TO UTILIZE THE SPACE STATION AS AN R&T FACILITY.

- We do not yet have a specific mission defined or specific technology requirements identified. However, there are many functions and tasks which any Space Station must carry out.

- These ground rules have been carefully thought out and from them much guidance can be obtained as to broad technology requirements.

- Rather than go into interpreting each ground rule. I shall identify some key words and phrases that have important implications for human capability. Your expertise is needed to fully recognize and examine those implications.

- Second Bullet: 90 day Shuttle support cycle

- Third Bullet: Indefinite life; on-orbit maintenance

- Fourth Bullet: Evolutionary growth

- Fifth Bullet: Life cycle cost

- Interwoven with all technology needs and human capability considerations is a critical technology driver--the degree of on-board automation. What should be the role of the crew in a highly autonomous, complex station?

- The challenge to our human capability working group and to your members of the space human factors community is to begin to identify the full implications of these ground rules to build perspective on human function in relation to highly automated, even autonomous, systems; and to clarify what human roles could and should be in a permanent Space Station.

SPACE STATION TECHNOLOGY WORKING GROUP

GROUND RULES

REVISION A, APRIL 1982

- o SPACE STATION WILL BE IN LEO
- * o SPACE STATION WILL BE SUPPORTED BY THE SHUTTLE INITIALLY ON 90 DAY CYCLES
- * o SPACE STATION SHALL HAVE A DESIGN GOAL FOR INDEFINITE LIFE THROUGH ON- ORBIT MAINTENANCE
- o MODULAR-EVOLUTIONARY DESIGN THAT PERMITS GROWTH AND ACCEPTS NEW TECHNOLOGY
- o LIFE CYCLE COST (DEVELOPMENT, OPERATION, MAINTENANCE UTILIZATION) IS A TECHNOLOGY DRIVER
- o INITIAL PLANNING ASSUMES A PHASE C/D START BY OR BEFORE FY 1986 TO SUPPORT A FLIGHT AS EARLY AS 1990
- o INCLUDE TECHNOLOGY TO SUPPORT SPACE STATION MISSION OBJECTIVES BUT NOT THE TECHNOLOGY TO DEVELOP PAYLOADS
- o INCLUDE TECHNOLOGY TO INTERFACE WITH SPACE TRANSPORTATION SYSTEMS BUT NOT TECHNOLOGY TO DEVELOP NEW TRANSPORTATION VEHICLES
- o COMMUNICATIONS TO BE COMPATIBLE WITH TDRSS/TDAS, FREE-FLYERS, OTV'S AND SHUTTLE
- o PROVISION FOR NON-HAZARDOUS, PLANNED REENTRY
- o SYSTEM WILL BE A MANNED SYSTEM, THOUGH NOT NECESSARILY IN THE FIRST PHASE

* CHANGE BY REVISION A, APRIL 1982

FUTURE SPACE OPTIONS

WILLIAM L. SMITH
ADVANCED DEVELOPMENT
OFFICE OF SPACE FLIGHT
NASA HEADQUARTERS

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The first vugraph deals with the overall goal of the Office of Space Flight of establishing a permanent presence in space. In regards to that goal, we are dealing with the infrastructure of the elements that might be representative of a permanent presence in space which includes both manned and unmanned components. Unmanned low earth orbit operations are expected by 1990 with a goal of man in GEO operations by the year 2000.

This chart lists the required functions to support our goal. Although it is not an exclusive list, it includes the aggregation of payloads, maneuvering of satellites, low cost transfer to geostationary orbit including reusable orbital transfer vehicles, remote satellite servicing and upgrading propellant storage in orbit, and on-orbit assembly and checkout. In all of these areas, we see significant roles for man.

OVERALL GOAL

"ESTABLISH PERMANENT PRESENCE IN SPACE"

- INFRASTRUCTURE OF ELEMENTS
- MANNED AND UNMANNED COMPONENTS
  - IN LOW ORBIT BY 1990
  - MANNED IN GEO BY 2000

REQUIRED FUNCTIONS

- AGGREGATION OF PAYLOADS
- MANEUVERING OF SATELLITES
- LOW-COST TRANSFER TO GEO
- REMOTE SATELLITE SERVICING/UPGRADING
- PROPELLANT STORAGE IN ORBIT
- ON-ORBIT ASSEMBLY/CHECKOUT

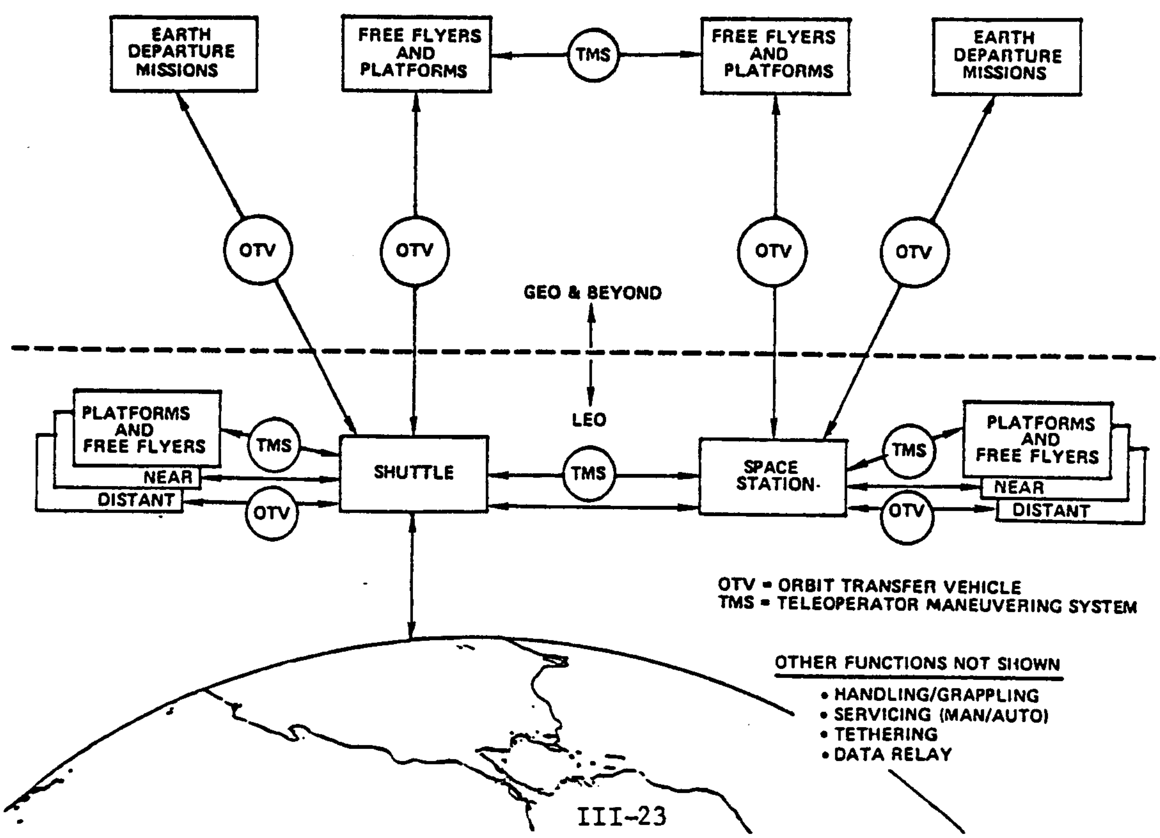
The major elements which are required to support our goal are listed on this third vugraph and include transportation, orbital services, unmanned platforms, and manned facilities. We see significant roles for man in operations of orbital transfer vehicles, in local maneuver of vehicles, and in refueling and servicing of those systems. Man's role in orbital services includes docking, grappling, handling, and module change mechanisms. This role includes both manned EVA, as well as man in the loop either directly or automated with man supervising. On free-flyers and tethered satellites where we are looking at "man in the loop" supervision, we see significant roles for: manned facilities for LEO Space Stations, GEO sortie hangers, and eventually crew capsules with OTVs that would imply geostationary operations.

The elements of the space infrastructure are shown in this vugraph. Indicated are both Shuttle-based operations and Space Station based operations serving a wide variety of potential systems such as platform free-flyers, geostationary operations, and earth departure missions out of earth orbit. Implication of man's role in operations are prevalent throughout all of these infrastructures.

REQUIRED ELEMENTS

TRANSPORTATION	ORBITAL TRANSFER VEHICLES "LOCAL" MANEUVERING VEHICLES
ORBITAL SERVICES	DOCKING/GRAPPLING/HANDLING MODULE CHANGEOUT MECHANISMS
UNMANNED PLATFORMS	FREE-FLYERS AND TETHERED LEO AND GEO
MANNED FACILITIES	LEO SPACE STATION GEO SORTIE HANGAR CREW CAPSULE FOR OTV

ELEMENTS OF SPACE INFRASTRUCTURE



The four major thrusts of the STS evolution plan are illustrated in the chart. From the Office of Space Flight standpoint, we see man's involvement in all of these systems including everything from manned EVAs to man in the supervisory mode where there are automation or robotics capabilities applied to our space systems. There are vital roles for man in all of these thrusts.

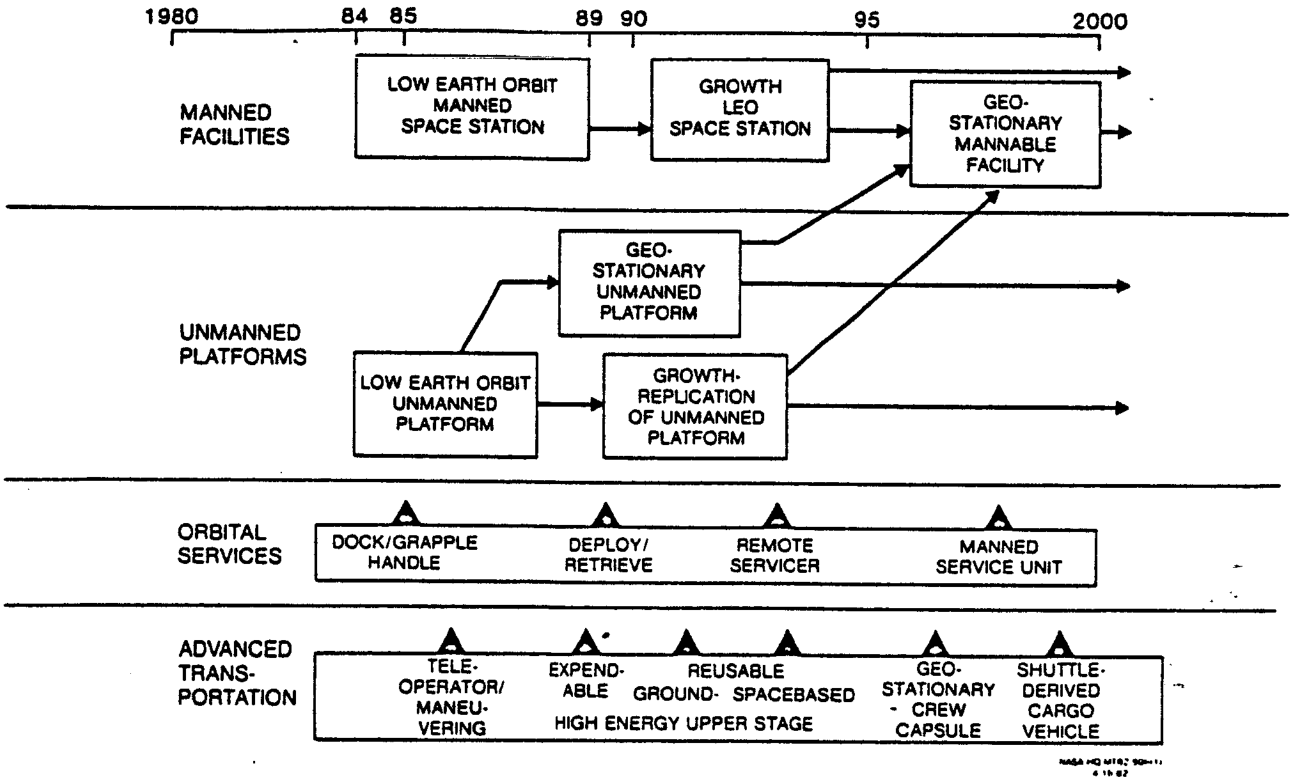
Manned facilities require both manned EVA involvement, as well as remote manned systems such as highly dexterous manipulator systems.

Unmanned platforms require man for Shuttle servicing and eventually station servicing.

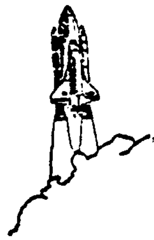
Orbital services includes both manned and unmanned activities for a docking and grappling capability to deploy and retrieve an advanced and remote servicer that is either a teleoperator system or a man in a supervisory mode system. A direct man in the loop type involvement includes the manned servicing unit which is shown in between the year 1995 and 2000.

Advanced transportation requires teleoperator maneuvering vehicles first with man directly in the loop and eventually in a manned supervisory role. We see the high energy upper stages requiring support of man initially to provide refurbishment for orbitally based upper stages. The geostationary crew capsule obviously needs man involvement and man will also play a role in the Shuttle derived cargo vehicle.

STS EVOLUTION PLAN



NEEDS FOR MAN IN SPACE



Jesco von Puttkamer
Advanced Planning
Office of Space Flight
NASA Headquarters

After the successful conclusion of its orbital flight test program, the Space Shuttle is in the process of establishing operational capability of routine flights to and from low Earth orbits. As the next logical step in America's space program, NASA is now turning to the development of our permanent presence in space.

This program will have to include a manned space station with an evolutionary capability that allows us to go from a modest-to-moderate initial step to more ambitious phases lateron as man's growing permanent presence in space increasingly provides all elements necessary for safe, productive, comfortable human living conditions.

Manned space programs of the past, especially Skylab, have yielded a great amount of new information on the utility of man in space. In many cases, what were rather speculative guesses about man's potential contributions have been supported and corroborated by real flight experience. In other areas, the actual performance and capabilities of the crews have far exceeded preflight expectations. It is the purpose of this study to present some summary conclusions on the human role in space in light of past experience, and to examine man's future needs as we move toward permanent presence in space which will impose requirements on man/machine function allocations, crew systems, human factors, habitation comforts and manned/teleoperated/automated operations an order of magnitude beyond the state-of-the-art of past and present programs such as Skylab and Shuttle/Spacelab.

In order to accomplish this purpose and to suggest some important issues that remain for future study, the presentation addresses a number of questions which are listed on the chart.

The human role in space seems to fall naturally into two categories: (1) the utilization of man in space with his unique attributes and capabilities, but also relative frailties and survival needs, in order to serve practical national and global interests; and (2) the existence ("being there") of man in space for humanistic reasons.

As shown on the facing chart, man's purpose in space, in a very direct, materialistic sense, comprises primarily utilitarian roles aimed at (a) understanding man himself through a variety of empirical investigations, and (b) utilizing man in scientific, military and economic/industrial operations. In the latter aspect, automation or remote control also have a distinct potential role. The division of manned and automated operations is a function of the technology at the time and its economy. While the relative emphasis between the two has naturally shifted with time, there has always been a balance. This will continue to be so: such balance will also establish itself in space, driven by technological "can do" on one side and the desire for economy in doing it on the other side.

QUESTIONS ADDRESSED

- What is the rationale for Man in Space?
- What is the evolution of Man in Space?
- What have we learned from past manned missions?
- What are the pertinent general human qualities / capabilities?
- What manned systems are we presently planning for the future?
- What are the major human factors issues of future manned systems?
- How can future space systems be optimized for man?
- What unknowns / issues / questions remain for study?

(#1 of 2)

REASONS FOR MAN IN SPACE

- UTILITARIAN
    - UNDERSTANDING MAN (for potential utilization)
        - Behavior of man in space
        - Applied science experiments
        - Advanced Technology experiments
        - Demonstration - Proof of concept
    - UTILIZATION OF MAN
        - Scientific
        - Military
        - Economic/Industrial

(cont'd)

There is also a humanistic role of man in space which derives basically from his idealistic needs, desires and aspirations. This is because humans are intellectual, social and ethical beings. Some of these needs may be less tangible than his utilitarian functions and may be open to ideological argument regarding their relative merits and priorities, but they are nevertheless real and important attributes of man's well-being and quality of life.

With the establishment of permanent presence in space, political factors, particularly at the international level, are of major import. This is demonstrated by the USSR Salyut space station program which by now has logged twice as many total manhours in space as the entire US manned space program. While social factors of the space program may be assumed a primary influence in the world, it is probably more realistic to recognize the political estimate of this social influence as the chief factor.

With permanent presence in space, the concept of international participation - always a key element of NASA's charter - will be expanded to include physical participation by foreign personnel. The image of probing exploration by man, strong technological development and peaceful applications elicits great prestige value while at the same time carrying an awareness that such technology is on hand to apply to national security.

Human ethics include intellectual, moral, spiritual and other factors. Curiosity, love of adventure, search for truth, goodness, justice, wisdom and beauty, belief in higher goals, etc., are recognized manifestations of human ethics. Some sociological/ethical needs of man which his presence in space may help to fulfill are listed.

In a long-range view, man's increasing capability in space can be seen to advance in three major phases: (1) Easy access to and return from space; (2) permanent presence in low Earth orbit; and (3) limited self-sufficiency of man in space.

The development of the Space Shuttle for transportation and of an initial space station for orbital habitation are the main elements of the infrastructure of Phase I, to be accomplished by the end of this decade. But permanent manned presence requires more than this: an orbital operations capability of a scale large enough to respond adequately to the projected socio-economic needs of the 90s. In particular, Phase II will add the capability of manned access to geostationary orbit and the operational deployment of large space structures.

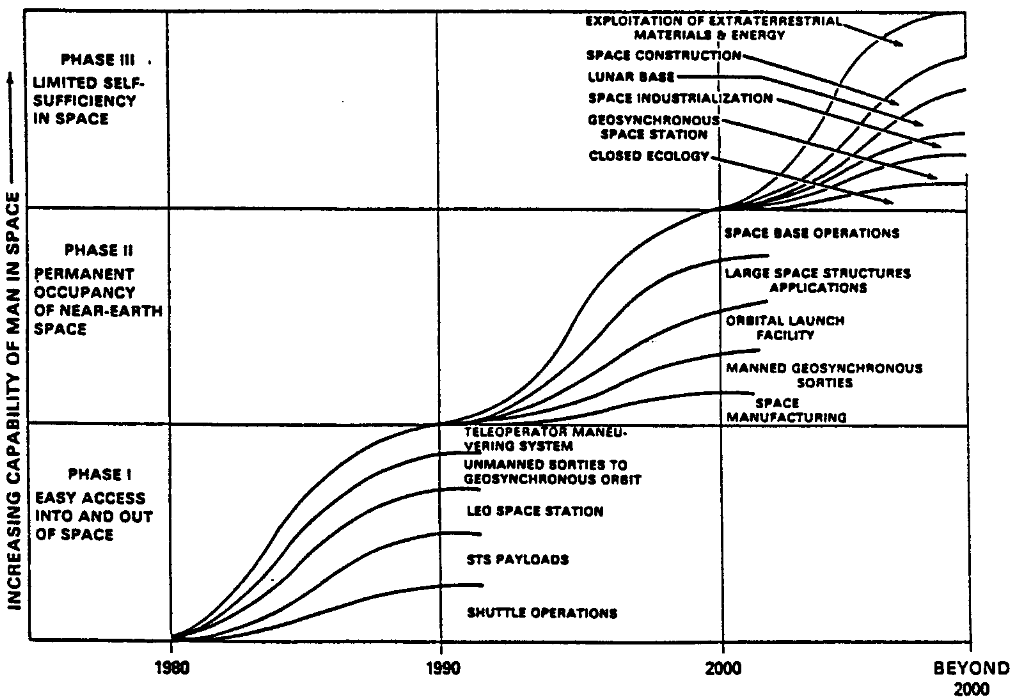
To become more autonomous in space, man will continue to develop closed-cycle life support systems and larger-scale industrial applications in space which, in Phase III, should lead to closed ecological systems (including space-grown food), space construction, space industrialization, and access to extra-terrestrial materials.

REASONS FOR MAN IN SPACE (cont'd) (#2 of 2)

- **HUMANISTIC**

  - POLITICAL
    - -- Means for political pressure (diplomatic tool)
    - -- Propaganda
    - -- International prestige
    - -- War surrogate
  - SOCIOLOGICAL/ETHICAL
    - -- Presence: National identity
      Inspiration and morale
        - social-economic value
        - vicariousness (sense of participation)
        - new information ("gee whizz")
        - dollar value
    - -- Exploration: Education
      Curiosity and love of adventure
      Search for truth
      Belief in higher goals
    - -- Settlement: Physical and mental growth
      New future options

MAN'S PROGRESS IN SPACE



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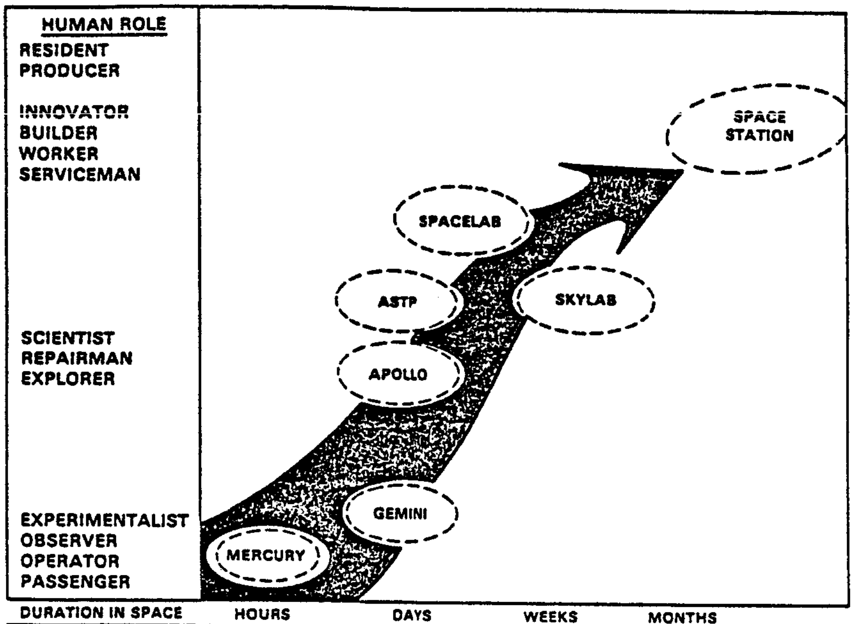
The progress of the human function in orbital programs leading to permanent presence in space is shown. Also listed are the total manhours in space accumulated by astronaut crews in each of the five major US programs of the past, as well as the times spent on extravehicular activities (EVA). With permanent presence in space, the manhour count for STS/Space Station becomes indefinite.

The objectives of the Apollo missions would have been impossible or inordinately expensive and time-consuming to achieve with an unmanned vehicle.

An examination of manned flights during the Apollo Program yields a number of unique capabilities and attributes exhibited by man which are relevant to future developments. These are listed.

Not listed are other benefits of Apollo because of manned involvement which, although very real, are difficult to measure. There is no question that landing man on the moon demonstrated to the world our national strength, unity, and technical competence. In these respects, Apollo was strongly motivated by humanistic objectives.

EVOLUTION OF MAN'S ROLE IN SPACE



	MERCURY	GEMINI	APOLLO	SKYLAB	ASTP	SPACE STATION
TOTAL MANHOURS	54	1940	7560	12,351	652	INDEFINITE
EVA MANHOURS		12	168	82		INDEFINITE

NASA HQ MT82-16781(1)
8-17-82

MAN's CAPABILITIES IN SPACE
THE APOLLO EXPERIENCE

- RAPID RESPONSE TO EMERGENCIES
  - e.g., Lunar touchdown, Apollo 11
    Lightning strike, Apollo 12
- SELF-CONTAINED OPERATION IN ABSENCE OF COMMUNICATION WITH GROUND
  - e.g., Major maneuvers behind Moon
- RAPID SENSING, REACTION, AND VEHICLE CONTROL
  - e.g., Lunar Orbit Rendezvous (LOR) decision
- ENHANCEMENT OF INSTRUMENT FLEXIBILITY
  - e.g., In-flight EVA for film retrieval
- REDUCTION OF AUTOMATION COMPLEXITY IN MULTI-PURPOSE MISSIONS
  - e.g., Lunar surface sampling
- EQUIPMENT REPAIR AND IMPROVISATION
  - e.g., Lunar Rover fender repair
    Air filter, Apollo 13
- INVESTIGATION AND EXPLORATION
  - e.g., 33 km in 3 days, Apollo 17 (vs. 10.25 km in 10½ months, Lunokhod-1

After the conclusion of the Apollo Program, a number of questions regarding man's capabilities in space remained open which the Apollo missions, due to their limitations in duration, scope and equipment, as well as relative inflexibility, could not answer. These questions, listed on Chart 8, before Skylab could only be answered tentatively by studies, analyses and extrapolations of data available from previous manned space programs.

The three Skylab missions, accumulating a total of 171 manned days, answered these questions in the affirmative, as shown on the next three charts. Thus, they provided building blocks for future space programs.

Skylab was the first manned space program where man's functions were manifold and the spacecraft more than a vehicle for transporting him to his work.

The chart lists experiential examples of man's capabilities as (a) Scientific Observer where his observations and judgment made it possible to obtain data that could not otherwise have been recorded (e.g., descriptions of Comet Kohoutek); (b) Operator with the ability to make real-time changes in planning, objectives, film and data management; and (c) Engineer/Technician performing planned and unplanned repairs and maintenance on both the spacecraft and the experiments.

MAN'S CAPABILITIES IN SPACE

QUESTIONS ASKED BEFORE SKYLAB

- Can man function effectively in space over long periods of time?

- Are there worthwhile experiments, tasks, and services which can only be accomplished through manned operations?

- Will the worthwhile services man can perform in space compensate for the added complexity required to put him there?

MAN'S CAPABILITIES IN SPACE

THE SKYLAB EXPERIENCE

- SCIENTIFIC OBSERVER
  - Apollo Telescope Mount
  - Comet Kohoutek
  - Earth Observations
  - Zero-Gravity Flammability
  - Materials Processing in Space
  - Barium Plasma Observations
  - Earth Laser Beacon
  - Student Experiments
  - Science Demonstrations (TV)
- OPERATOR
  - Real-Time Planning
  - Film Management
  - Experiment Pointing
  - Data Management
  - Scientific Airlock Operations
  - Extravehicular Activities
- ENGINEER/TECHNICIAN
  - Unplanned Repairs and Maintenance (in-flight supply of parts and development of procedures)
  - Planned Repairs and Maintenance (use of spares, trained procedures)

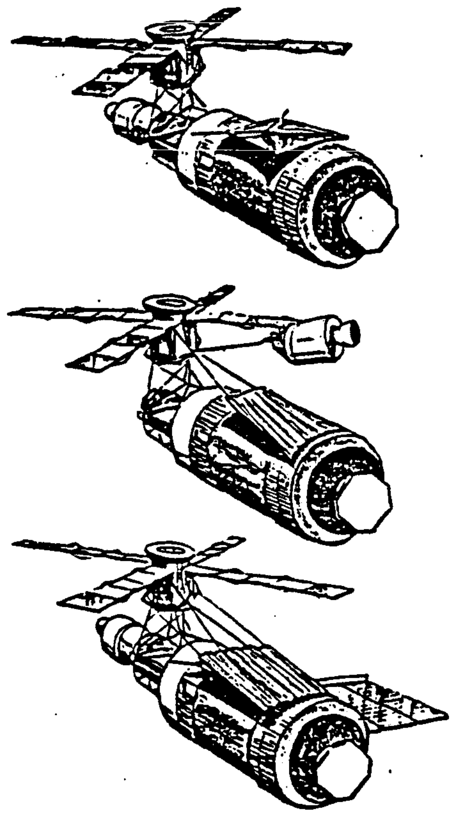
An example for major unplanned repair on Skylab is given.

During the Skylab SL-1 launch, the micrometeorite shield was lost, one of the Solar Array System wings was ripped off, and the second SAS wing was jammed shut. The micrometeorite shield not only provided protection against micrometeorites but also provided thermal protection for the Orbital Workshop (OWS) to maintain habitable temperatures.

Three "thermal fixes" were developed within 10 days from the mishap, shown on the chart. All three were flown into space; the JSC-developed Parasol was deployed during SL-2, the MSFC-developed Twin-Pole Sail during SL-3. A third device, the JSC "Stand-up EVA (SEVA)" Sail, remained in reserve and was not deployed. The presence of man made the deployment of these fixes and of the jammed SAS wing possible and thus led to the successful recovery of Skylab, a $2½ billion program.

The Skylab Program proved that man does add extra dimensions to the overall success of certain types of space missions.

Listed on Chart 11 are some of the more important answers furnished by Skylab and its crews to the understanding of the human role in space.



SKYLAB OWS SUNSHADE SCHEMES

JSC PARASOL

JSC SEVA SAIL

MSFC TWIN-POLE AWNING

MAN'S CAPABILITIES IN SPACE

ANSWERS FURNISHED BY SKYLAB

- Man can live and do useful work over extended periods in space (less than 12 man-hours were lost due to motion sensitivity out of 200 man-hours of work);
- A single man can perform many tasks in space originally planned for two;
- Man can move large and massive objects with precision;
- Interchange of information between crew and ground-based scientists enhances experiments, specifically during solar events;
- Crew judgment and knowledge of hardware and experiment objective aid the success of materials processing and other experiments;
- Crew's ability to restore experiments to their original data gathering capability and to operate experiments in degraded mode to gather useful data contributes significantly to mission success.

The next three charts attempt to extract some general observations on man's qualities and capabilities from the experience of past manned space programs.

There is no adequate substitute for man as a general sensor, manipulator, evaluator and investigator now or in the foreseeable future. Man is essential to research, development, initial operations, assembly and troubleshooting of large and complex systems, or a combination of these.

These functions, for which he is uniquely suited, increase considerably our options to explore and use space. Conversely, if man is eliminated from space missions, these options will be reduced significantly.

Man's characteristics as a sensor of visual, auditory, olfactory and tactile information, and as a computer capable of conceptual thinking, interpretive thinking, memory and adaptive and inductive reasoning combine to provide him with powerful abilities which set him apart from (current) machines. Some of these are discussed on Chart 13.

HUMAN FUNCTIONS IN SPACE

- SENSOR
  - more flexible than instruments
  - can select data, systematize and recognize patterns
- MANIPULATOR
  - performs similar to technician or laboratory assistant on ground
  - can overcome or bypass equipment failures in preplanned activities
  - could be done by robotics but would be difficult and would introduce possibility of equipment malfunction
- EVALUATOR
  - controlls what he perceives as sensor and how he reacts as manipulator
- INVESTIGATOR
  - responds creatively to unexpected situations
  - acts as scientist, research, etc.

(#1 of 2)

HUMAN CAPABILITIES

In general, man —

- is able to recognize and use information redundance (patterns) in the real world to simplify complex situations;
- has a high tolerance, i.e., can "live with" ambiguity, uncertainty and vagueness;
- can interprete an input signal accurately even when subject to distraction, high noise level or message gaps;
- has very low absolute thresholds and difference thresholds for vision, audition, and the tactile sense;
- has an excellent long-term memory for related events;
- is a selecting mechanism.

(cont'd)

As an evaluator, investigator and manipulator, man moves from the passive role of sensor to active involvement with his environment.

His characteristics as a communicator with the abilities of command execution and interpretive translation, as an adaptive servomechanism and as a physical manipulator with high dexterity in translational and rotational degrees of freedom combine with sensory and mental processes to provide man with the capacity to function with a high degree of self-reliance.

Some examples are discussed on the chart.

What will be required of future orbital systems, subsystems and operations to support man's permanent presence in space can be reduced to three simple statements.

The achievement of these requirements, however, will be anything but simple. In many instances, it requires considerable advances and quantum leaps in the state of the art of orbital habitation technology, crew comfort and safety, operational effectiveness and reliability, and man/machine interactions.

HUMAN CAPABILITIES (cont'd)

In general, man —

- can develop high flexibility for task performance;
- has the ability to improvise and exercise judgment based on long-term memory and recall;
- performs well under transient stress and overload;
- can make inductive decisions in novel situations and has the ability to generalize;
- can modify his performance as a function of experience and can "learn" as well as "learn to learn";
- can override his own actions if needed;
- is reasonable reliable and can add overall reliability to systems performance.

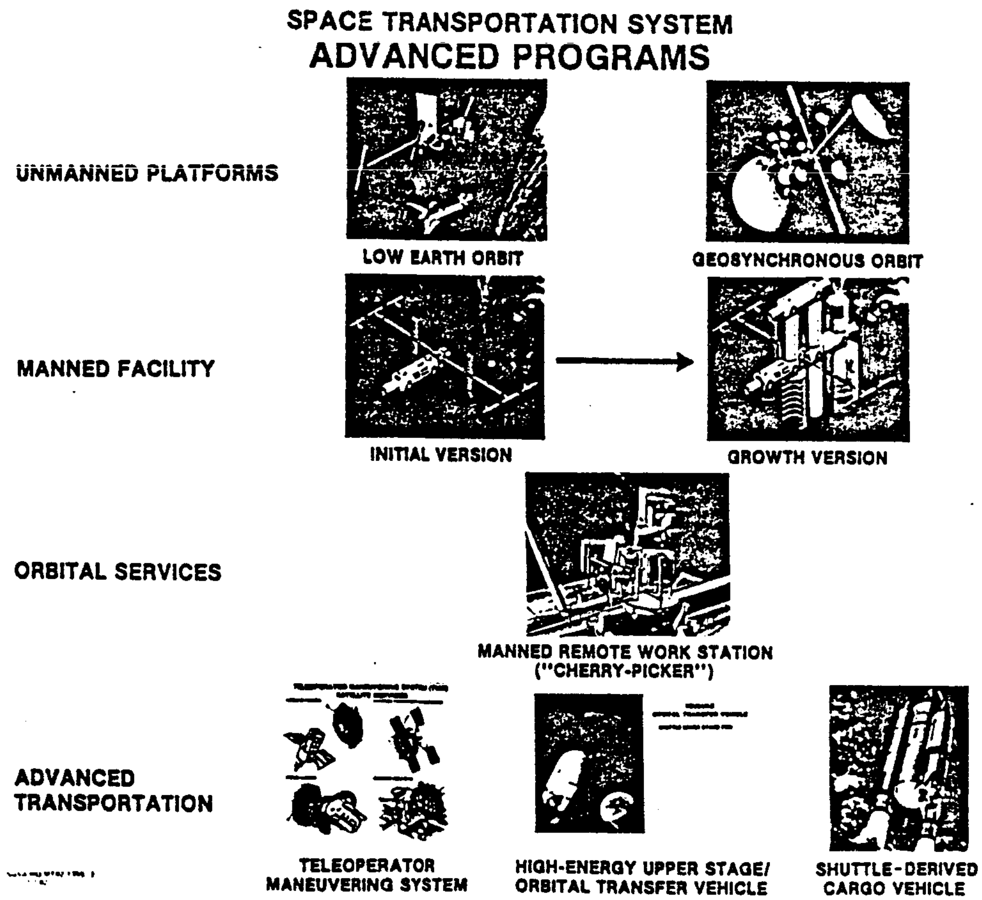
BASIC REQUIREMENTS FOR FUTURE MANNED PRESENCE IN SPACE

- GO INTO SPACE AND RETURN AT WILL WITH FULL SAFETY AND ADEQUATE SUPPORT EQUIPMENT
- STAY IN SPACE IN ROUTINE MANNER FOR LONG PERIOD
- PERFORM COMPLEX TASKS IN SPACE JUST AS ON GROUND.

Depicted are key future systems required to achieve permanent presence in space that are currently in the conceptual stage under study.

They involve unmanned space platforms in low and geostationary Earth orbit, manned space station, satellite services equipment, and advanced transportation including a Teleoperator Maneuvering System (TMS) for operations remote from Shuttle and Space Station, and a reusable Orbital Transfer Vehicle (OTV) for sorties to geostationary orbit, initially unmanned and later manned.

Future systems shown on the preceding chart will involve the human in a number of definable aspects, summarized on the chart and discussed in more detail on the following three charts.



MAJOR ASPECTS OF MAN'S ROLE IN FUTURE SYSTEMS

- CREW SYSTEMS
- HABITABILITY
- SATELLITE/SPACECRAFT SERVICING AND REPAIR
- SPACE ASSEMBLY AND CONSTRUCTION
- OBSERVATIONS, EXPERIMENTS, AND EVALUATIONS
- BIOMEDICAL REQUIREMENTS

The chart lists major issues and technologies that future systems will encompass in the areas of Crew Systems and Habitability. Particularly in the latter area, there is need for considerable advancement in the state of the art beyond current technologies. To sustain permanent presence in space, current Orbiter-era habitability is inadequate.

Man's roles in future space systems are listed in the areas of Satellite/Spacecraft Servicing and Repair and Space Assembly and Construction.

Here, too, new developments will pace the gradual achievement of permanent manned presence in its true meaning.

(1 of 3)

MAJOR ASPECTS OF MAN'S ROLE IN FUTURE SYSTEMS

- CREW SYSTEMS
  - CREW STATION DESIGN (IVA)
  - EVA PRESSURE SUIT
  - EVA WORK STATION DESIGN
    - Cherrypicker (open/closed cab)
    - Positioning, Mobility, and Handling Aids
    - Standardized and Specialized Tools
  - MANNED MANEUVERING UNIT (MMU)
  - TELEOPERATOR MANEUVERING SYSTEM (TMS)
  - MANEUVERABLE TELEVISION (MTV)
- HABITABILITY
  - SPACE SHUTTLE ORBITER
  - SPACE STATION
  - CREW SIZE vs. FLIGHT DURATION
  - CREW SIZE vs. CREW EFFICIENCY vs. VOLUME PER PERSON

(2 of 3)

MAJOR ASPECTS OF MAN'S ROLE IN FUTURE SYSTEMS

(cont'd)

- SATELLITE/SPACECRAFT SERVICING AND REPAIR
  - PROPELLANT TRANSFER
  - MODULE EXCHANGE
  - MODULAR UPGRADE
  - CHECKOUT AND CONTROL
  - SPACECRAFT DESIGN
    - Modularity
    - Accessibility
    - Standardized Hardware (connectors, fasteners, etc.)
  - ORBITAL LAUNCH OPERATIONS
- SPACE ASSEMBLY AND CONSTRUCTION
  - ASSEMBLY AIDS
  - CONSTRUCTION FIXTURES
  - ALIGNMENT VERIFICATION
  - "LOCAL" TRANSPORTATION

The chart shows where man's roles will be in future space systems in the areas of Observations, Experiments, and Evaluations, and Biomedics.

To achieve permanent manned presence in space it is not sufficient to consider man merely as another subsystem, added to a spacecraft that has largely been designed on the basis of specifications derived from original program "requirements". Future systems need to be increasingly optimized for man.

In considering man's capabilities and needs from past manned programs, we can already identify a number of "hard" musts that routine operations by man in space in future years will impose. This chart lists some of these requirements for man-tending where man performs orbital servicing, repair, maintenance and upgrading on unmanned orbital systems in the course of intermittent Shuttle visits.

MAJOR ASPECTS OF MAN'S ROLE IN FUTURE SYSTEMS
(cont'd)

- OBSERVATIONS, EXPERIMENTS, AND EVALUATIONS
  - MANNED FACILITY vs. UNMANNED PLATFORM
    - Visual Perception and Cognition
    - Knowledge and Intellect
    - Physical Dexterity and Mobility
  - ENGINEERING RECORD/PHOTO DOCUMENTATION
  - METEOROLOGY
  - OCEANOGRAPHY
  - GEOLOGY
  - PHYSIOLOGY
  - PSYCHOLOGY, etc.

- BIOMEDICAL REQUIREMENTS
  - ANTHROPOMETRICS/ERGONOMICS
  - PSYCHOMETRICS
  - MOTION SENSITIVITY
  - CARDIOVASCULAR DECONDITIONING
  - OSTEOPORESIS (BONE DEMINERALIZATION)
  - RADIATION EXPOSURE

FUTURE SYSTEMS NEED TO BE OPTIMIZED FOR MANNED OPERATIONS (#1 of 2)

MAN-TENDING (ORBITAL SERVICING, REPAIR, MAINTENANCE, AND UPGRADING)

- Consider EVA a normal means of man-tending and a "natural" way of life
- Provide proper procedures, tools, equipment, mobility & positioning aids for crew usage
- Design systems to facilitate in-flight man-tending –
  --- provide adequate accessibility, work space, and work clearance,
  --- provide worksite, repair bench or equivalent (IVA & EVA) equipped with adequate restraints for crewman, tools, and equipment,
  --- provide effective containment of hardware components (nuts, bolts, washers, etc. by means of boxes, bungee cords, etc.
- Promote standardization of mobility & positioning aids, tools, fasteners, joints, connectors couplings, etc., and limit their number and variety
- Provide high-fidelity man-tending training simulator and adequate crew training.

(cont'd)

Some basic requirements for the development of permanently manned orbital systems in the future are listed on Chart 22.

In the increasing optimization of orbital habitation systems, the need for human comfort, well-being and quality of life must become a firm requirement as real as the more traditional requirements of cost effectiveness and performance. Adequate human engineering standards, not existing now, must be developed before final design. It thus may become desirable, even necessary increasingly to include the thinking of skilled architects in the design approaches.

Numerous questions still remain to be answered. New questions have joined old ones as we have penetrated deeper into the area of the human role in space.

More in-depth studies and analyses are necessary to answer these questions, supported by ground-based laboratory and simulator experiments and Shuttle-based technology R&D in human factors.

Some of the major questions are listed on Chart 23. They will be the subject of a specific study activity being planned by the Office of Space Flight and Marshall Space Flight Center at present.

FUTURE SYSTEMS NEED TO BE OPTIMIZED FOR MANNED OPERATIONS (#2 of 2)

PERMANENTLY MANNED (ORBITAL HABITATION)

- Develop improved human engineering standards before final design
- Use Skylab experience wherever applicable
- Fundamental habitability should be built-in, not added on
- Separate on-board functions - work, eating, sleeping - so as to avoid noise, light, physical interference
- Provide for off-duty activities including exercise and looking out the window
- Provide for personal privacy
- With increasing flight duration provide increasing personal comfort.

MAN'S ROLE IN SPACE

QUESTIONS REMAINING

- What are man's basic, unique capabilities for future space activities, and what are his limitations?
- Which of the activities within presently planned space projects and missions should preferrably be carried out by humans, and what are the required skills to be developed?
- What impacts has human presence in space on the requirements for spacecraft design, equipment, power, logistics, and habitation?
- What are the economics of human space activities?
- What technology advancements will enhance human productivity in space?
- How can the available data and information on human potentials in space be made available to project managers in a manageable and practical form?
- What new data and information is needed for efficient future planning for man's role in space?

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

MAJOR LARRY J. GLASS
MAJOR RUDY R. FEDERMAN

Self Explanatory

Self Explanatory

PURPOSE

PROVIDE AN OVERVIEW OF THE AF MANNED SPACE-FLIGHT ENGINEER (MSE) PROGRAM

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

OBJECTIVE

- CHARTER / MISSION
- PROGRAM DESCRIPTION
- MSE ACTIVITIES
- FUTURE ACTIVITIES

Comments:

What can the Space Shuttle do relative to supporting the military role in space?

The Manned Spaceflight Engineer has many duties while assigned to a Program Office. However, his knowledge of the orbiter, mission requirements, etc., will ensure that the utility of the Shuttle is:

- Understood
- Enhanced when required
- Exploited
- Supported.

Self Explanatory

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

CHARTER

- INSURE THAT THE MILITARY UTILITY OF THE SHUTTLE, AND ITS CREW, IS:
  - UNDERSTOOD
  - ENHANCED WHERE REQUIRED
  - EXPLOITED
  - SUPPORTED

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

MISSION

- CONDUCT MSE PROGRAM
  - SELECT MSES
  - TRAIN MSES
  - PROVIDE MSES TO WORK IN PROGRAM OFFICES
  - SUPPORT MSES AND THEIR PROGRAMS
- EXPLOIT THE MILITARY UTILITY OF THE SHUTTLE
  - DEVELOP CAPABILITIES
  - DISSEMINATE INFORMATION

Self Explanatory

Self Explanatory

AF MSE PROGRAM CONCEPT

- DEVELOP AND USE DOD EXPERTISE
  - SHUTTLE
    - — INTERFACES
    - — IMPLICATIONS
  - MAN / PAYLOAD INTERACTIONS
    - — MAXIMUM SYSTEM EFFECTIVENESS
- RECOGNIZE AND USE NASA EXPERTISE AND SERVICES
  - SHUTTLE VEHICLE
  - SHUTTLE CREW (CMDR, PILOT, MS)
  - PAST MANNED SPACEFLIGHT EXPERIENCE
- OPERATIONAL SECURITY PHILOSOPHY

AIR FORCE MANNED SPACEFLIGHT ENGINEER PROGRAM

OPERATIONAL APPROACH

- MANAGEMENT ORGANIZATION UNDER SPACE DIVISION. DEPUTY COMMANDER FOR SPACE OPERATIONS (SD/YOM)
  - — JOINT SD / SAFSP PROGRAM
- USE TEST PROGRAM EXPERIENCE
- SELECT HIGHLY QUALIFIED TECHNICAL OFFICERS
  - — TRAIN TO UNDERSTAND INHERENT CAPABILITIES OF SHUTTLE AND ITS CREW
  - — USE AS <u>DEVELOPMENT</u> <u>ENGINEERS</u> IN PROGRAM OFFICES
  - — PROVIDE POOL FOR MISSION SPECIFIC SUPPORT
- MISSION SPECIFIC ACTIVITIES FUNDED BY USERS

Self Explanatory

The MSE training/utilization flow can be divided into three basic phases.

I - MSE selected and given basic qualification training while being assigned to a Program Office.

II - MSE(s) selected and designated as Flight MSE(s) are given flight specific training and begin integrated training with NASA astronauts.

III - MSE supports actual flight. Note that MSE(s) will have ground responsibilities as well as space flight responsibilities. Therefore, MSEs not selected to support a mission as a flight MSE can be utilized as ground specialists.

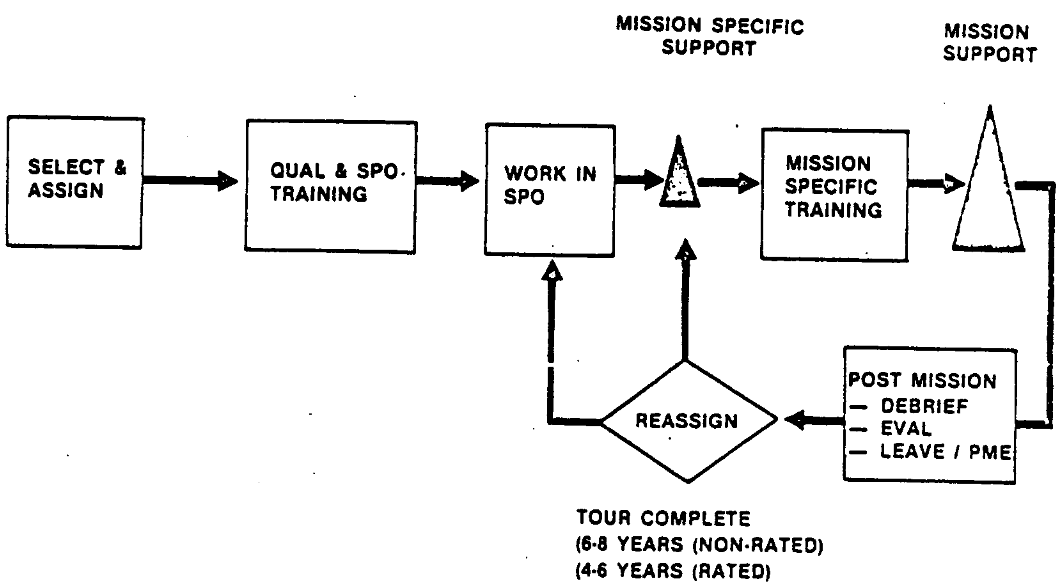
AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

PROGRAM DESCRIPTION

- FOUR PHASES
  - SELECTION
  - TRAINING
  - PROGRAM OFFICE DUTIES
  - POTENTIAL FLIGHT ACTIVITIES

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

MSE UTILIZATION PLAN



Self Explanatory

It is our (Space Division) hope to have this training program as an official Air Force school. Work is ongoing currently to get this accomplished.

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

FY 83 MSE CADRE

- NUMBER TO BE SELECTED
  - FOURTEEN MSES
- SCHEDULE MILESTONES

— MAY 82	— CALL FOR VOLUNTEERS BY AFMPC
— MAY - JUL 82	— APPLICATION PERIOD
— AUG - SEP 82	— SELECTION BOARD
— OCT 82	— BOARD RESULTS
— JAN 83	— SELECTEES REPORT TO SPACE DIVISION

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

TRAINING

- QUALIFICATION PROGRAM
  - INITIAL TRAINING ON SHUTTLE CAPABILITIES AND HUMAN FACTORS
- CONTINUING EDUCATION

Self Explanatory

Specific Program Office responsibilities are numerous for the MSE(s).

AF MSE PROGRAM QUALIFICATION PROGRAM

- OBJECTIVE
  - UNDERSTAND
    - SHUTTLE DESIGN AND CAPABILITIES
    - MANNED SPACEFLIGHT DESIGN AND CAPABILITIES
    - SHUTTLE PAYLOAD INTERFACE
    - MANNED SPACEFLIGHT ACTIVITIES
    - PAYLOAD DESIGN
    - PAYLOAD INTEGRATION

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

PROGRAM OFFICE DUTIES

- WORK AS DEVELOPMENT ENGINEERS
- IDENTIFY BENEFICIAL USES OF CREWS
- SUPPORT LAUNCH SYSTEM INTEGRATION AND OPERATIONS TEAM
- MANAGE MANNED SPACEFLIGHT ACTIVITIES
  - PREPARE TIMELINES
  - IDENTIFY CREW MEMBER ACTIVITIES
  - PREPARE PLANS FOR
    - PROCEDURE DEVELOPMENT AND VALIDATION
    - CREW TRAINING
    - FACILITY & EQUIPMENT REQUIREMENTS

Self Explanatory

Self Explanatory

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

POTENTIAL FLIGHT ACTIVITIES

REPORT AND ADVISE IN GO / NO-GO DECISION

PERFORM PAYLOAD CHECKOUT

CONDUCT EXPERIMENTS

ACT AS FLIGHT SECURITY ADVISOR

INSPECTION (CLOSEOUT PHOTOS, DAMAGE ASSESSMENT, GO / NO-GO INPUT)

MINOR REPAIR AND CONTINGENCY FUNCTIONS

REMOVE COVERS

IN-BAY CONTAMINATION EVALUATION AND CLEAN SURFACES

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

FUTURE ACTIVITIES

- SELECTION OF MSES
  - BOARD CONVENES-30 AUG 82
  - SELECTIONS ANNOUNCED MID-OCT 82
- ALLOCATION OF MSES
  - BASED ON MISSION MODEL
- TRAINING OF MSES
  - BEGINS 17 JAN 83

Self Explanatory

These are items considered to be a small shopping list of items which concern us (the military) relative to man's role in space.

We must stress here that in order to properly address these items of concern, we must establish and maintain with NASA and other payload communities a cooperative learning effort.

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

SUMMARY

- PROGRAM UNDERWAY
- MSES ON-SITE MID JAN 83

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

KEY ISSUES

- EXTENSION OF MAN TO THE JOB
- SPACECRAFT DESIGN
- SERVICING, REPAIR, ASSEMBLY OF SPACECRAFT
- EXPERIMENTS / EVALUATIONS
- BIOTECHNOLOGY

- We must fully integrate man into the space environment. We must make it easy for the payload community to integrate into the Shuttle. One way to do this is through the Orbital Payload Work Station.

- We must explore all requirements and constraints for an EVA Work Station. Also, EVA must be a nominal mission event, not just contingency. EVA can be profitable!

- Further work must be done in space suit technology. The effort given to the 8 psi suit is good.

- Teleoperator/Robotics requires us to blend man and machine in any given mission.
  (Same discussion relative to the remaining items.)

Efficient spacecraft design requires us to consider many areas where improvement is required.

(1) We must get standardized. A helpful tool would be a very definitive payload/Shuttle handbook.

(2) The MSE can help from program inception to design the payload with the Shuttle vehicle requirements considered. The payload can be designed modularly and such that it can be accessible. Again, EVA or teleoperator robotics is being considered during development.

(3) Engineering design has to consider fuel (consumable) servicing requirements/methodology.

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

EXTENSION OF MAN TO THE JOB

- ORBITAL PAYLOAD WORK STATION (OPWS)
  - DIGITIZED TV
- EVA WORKSTATION
  - STANDARDIZED TOOLS / INTERFACES
  - TORQUE COMPENSATING TOOL
- SPACESUIT
- TELEOPERATOR / ROBOTICS
- MANNED MANEUVERING UNIT (MMU)
- REMOTE SERVICER / MANEUVERABLE TV
- HANDLING POSITIONING AID (HPA)

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

SPACECRAFT DESIGN

- DESIGN HANDBOOK
- DESIGN PHILOSOPHY
  - MODULARITY
  - ACCESSABILITY
- IMPLEMENTING TECHNOLOGY
  - STANDARDIZED
    - CONNECTORS
    - FASTENERS
    - JOINTS / COUPLINGS
- FUEL TRANSFER EQUIPMENT

Self Explanatory

In order to perform the mission right the first time, we must consider the characterization of man and the platform.

- Platform: Quantify the orbit
  Contaminants problems
  Thermal considerations, etc.

- Man: Quantify the individual
  Select crew for mission based on known data relative to the man and his ability to do the task
  -- Visual perception/cognition
  -- Knowledge intellect
  -- Physical dexterity and mobility.

Engineering record keeping and photo documentation to date has been relatively immature and not suitable engineering data. (Good data is important in the remaining items on the slide.)

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

SERVICING, REPAIR, ASSEMBLY OF SPACECRAFT

- FUEL TRANSFER
- MODULAR UPGRADE
- ACCESSABILITY
  - TO SPACECRAFT
  - TO MODULES / COMPONENTS
  - FOR CHECKOUT

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

EXPERIMENTS / EVALUATIONS

- CHARACTERIZATION OF PLATFORM
- CHARACTERIZATION OF MAN
  - VISUAL PERCEPTION & COGNITION
  - KNOWLEDGE & INTELLECT
  - PHYSICAL DEXTERITY & MOBILITY
- ENGINEERING RECORD / PHOTO DOCUMENTATION
- METEOROLOGICAL
- OCEANOGRAPHIC
- GEOLOGICAL
- PHYSIOLOGICAL
- PSYCHOLOGICAL

Much work needs to be done in quantifying man.

- Ergonomics--how much work can a human do while under certain mission constraints. Body efficiency ratings.
- Psycometrics
  - Impact on crew on long missions
  - Crew member compatibility
  - How do we pick the right crew to insure mission success?
- Space sickness--do not understand
  - Impact on mission success
- Problems associated with
  - Cardiovascular deconditioning (related to space sickness?)
  - Bone demineralization
  - Radiation exposure, etc.

The Air Force is seeking help from the Brooks Air Force Base Aeromedical Center to assist in quantifying man in each of these areas and others.

AIR FORCE MANNED SPACEFLIGHT ENGINEER (MSE) PROGRAM

BIOTECHNOLOGY

- ERGONOMICS
- PSYCHOMETRICS
- SPACE SICKNESS
- CARDIOVASCULAR DECONDITIONING
- BONE DEMINERALIZATION
- RADIATION EXPOSURE

SESSION IV

SPACE HUMAN FACTORS TECHNOLOGY: CURRENT CAPABILITIES AND NEEDS

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

- PRECLUDED IN EARLY DESIGN STAGES
  - CAMERA MOUNTS
  - TELEPRINTER
  - TEXT/GRAPHICS SYSTEM
  - CREW COMPARTMENT EXPERIMENTS
  - CREW SIZE
  - INFLIGHT MAINTENANCE
- DEFERRALS
  - SLEEP COMPARTMENTS
  - GALLEY
  - PERSONAL HYGIENE STATION
  - PRIVACY CURTAIN
  - STOWAGE COMPARTMENTS
  - WET TRASH STOWAGE
  - OPERATIONAL SEATS
- LATE DISCOVERIES
  - DFI
  - EJECTION SEATS
  - FLASH EVAPORATOR WATER TANKS
  - HUD
- GROWTH
  - 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

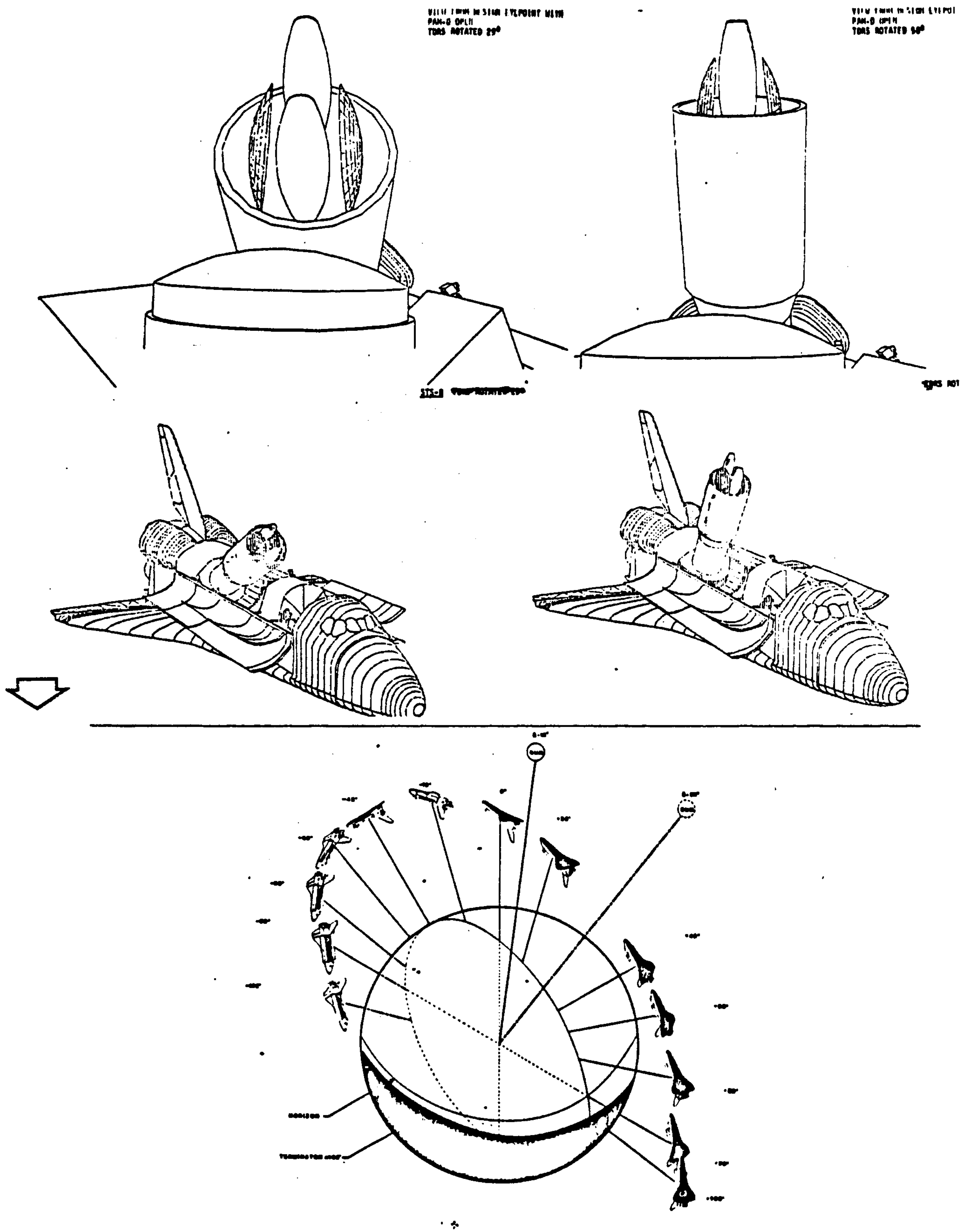
SYSTEMS OPTIMIZATION

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

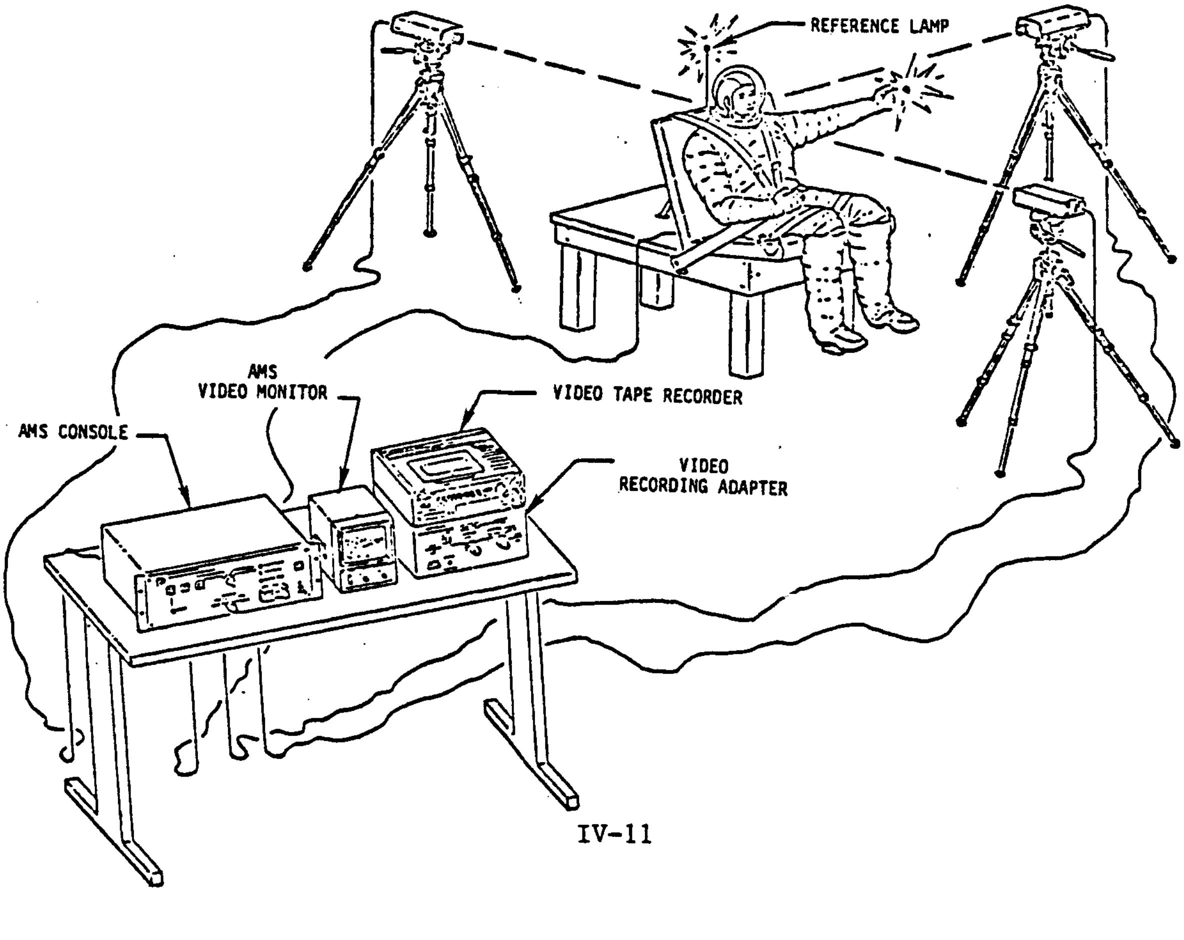


RMS OPERATIONS- SUN ANGLE FOR STS 2-3

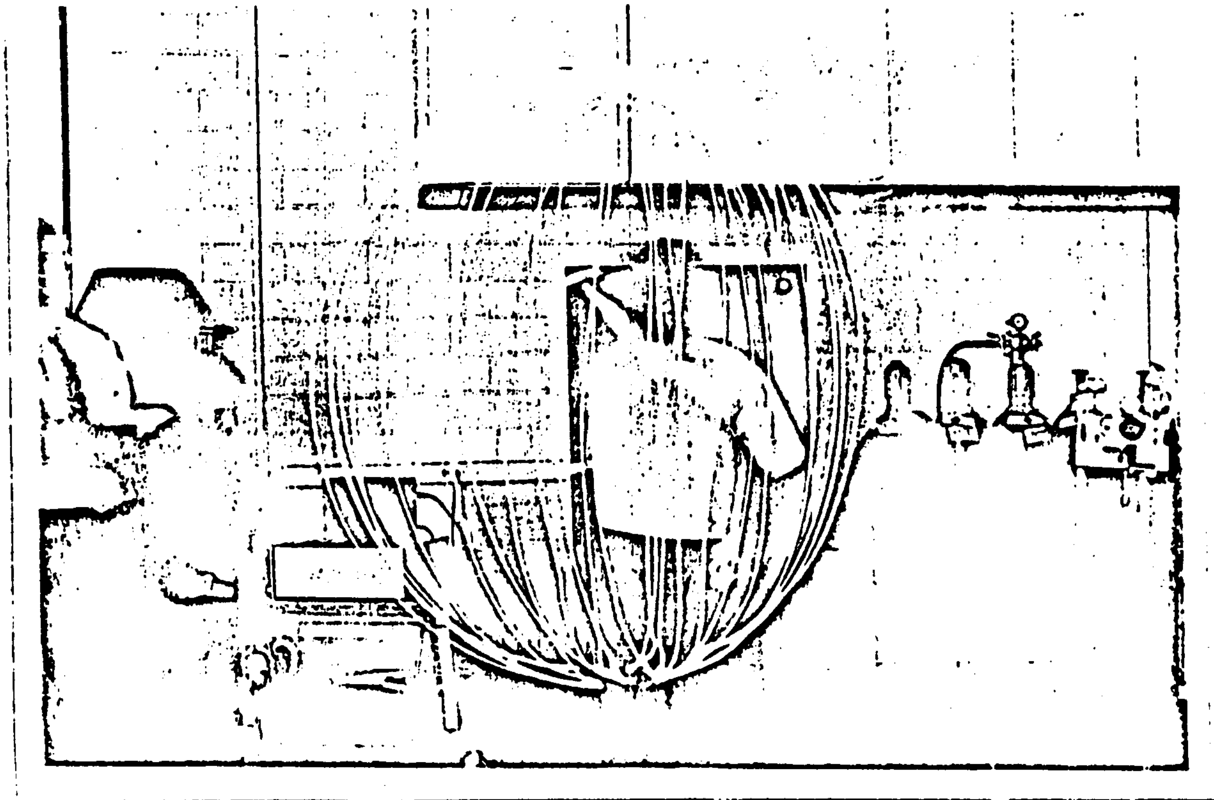
ANTHROPOMETRIC MEASUREMENT LABORATORY

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

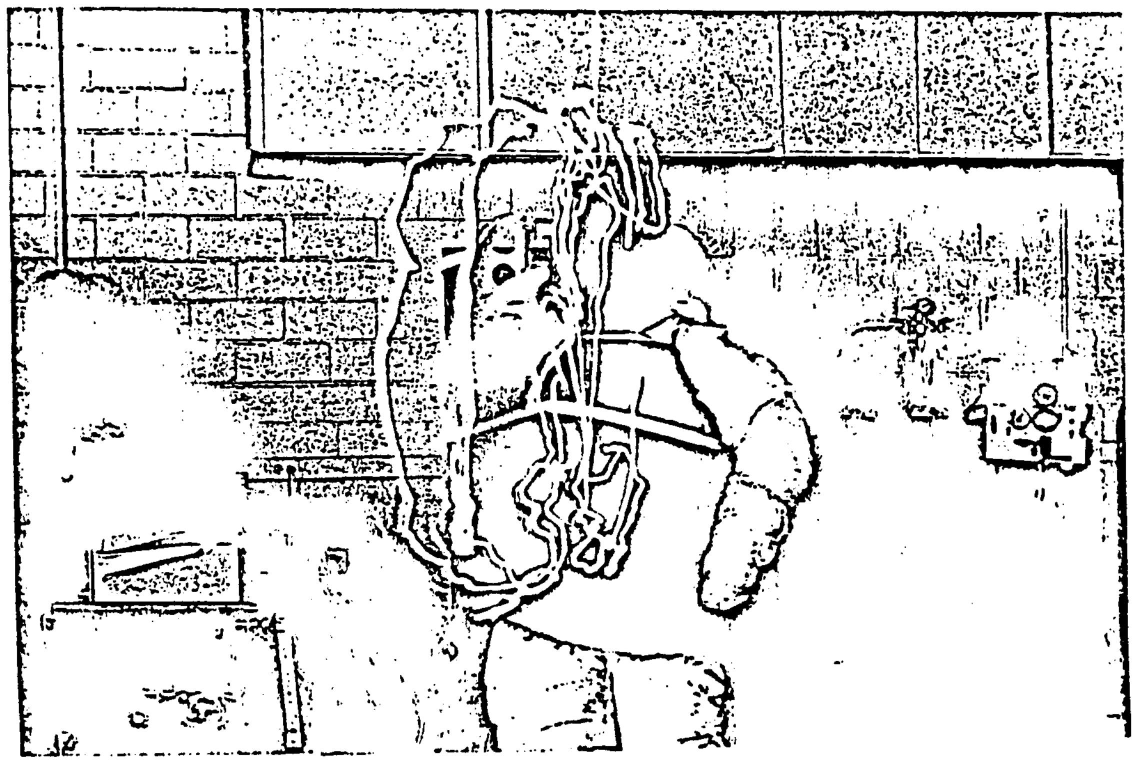
MODIFIED VIDEO RECORDING AMS SYSTEM



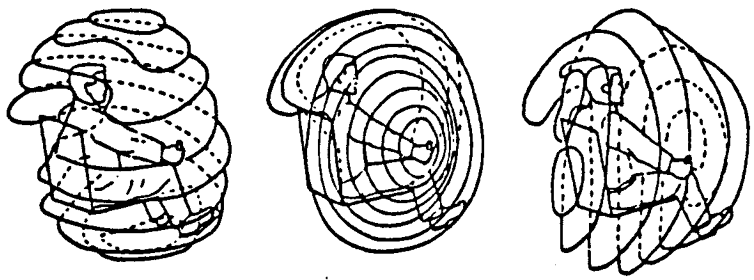
MAXIMUM SHIRTSLEEVE
RIGHT HANDED RESEARCH VOLUME

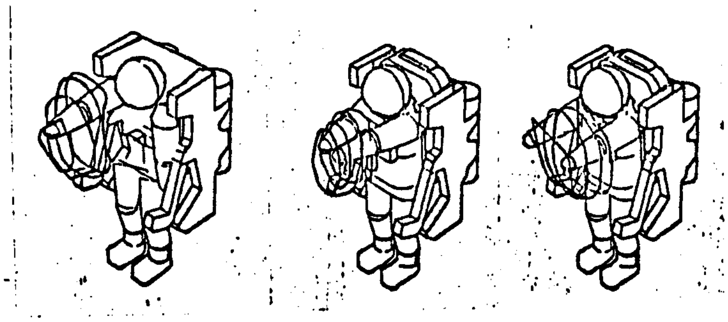


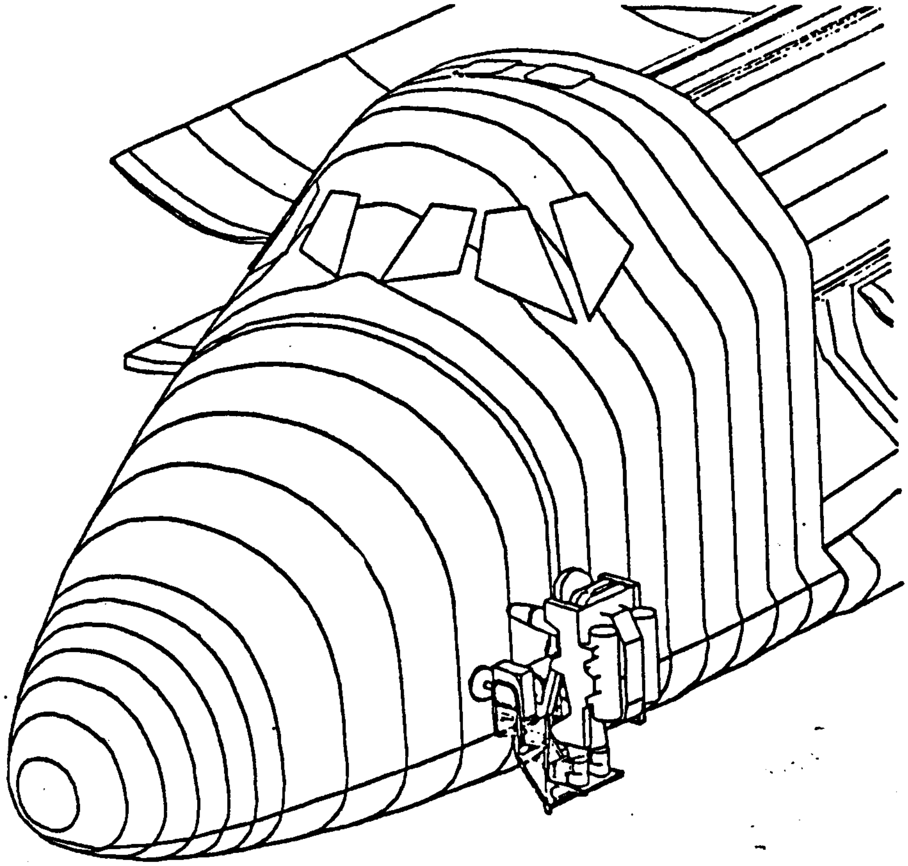
MAXIMUM PRESSURIZED
RIGHT HANDED REACH VOLUME
3.8 PSID

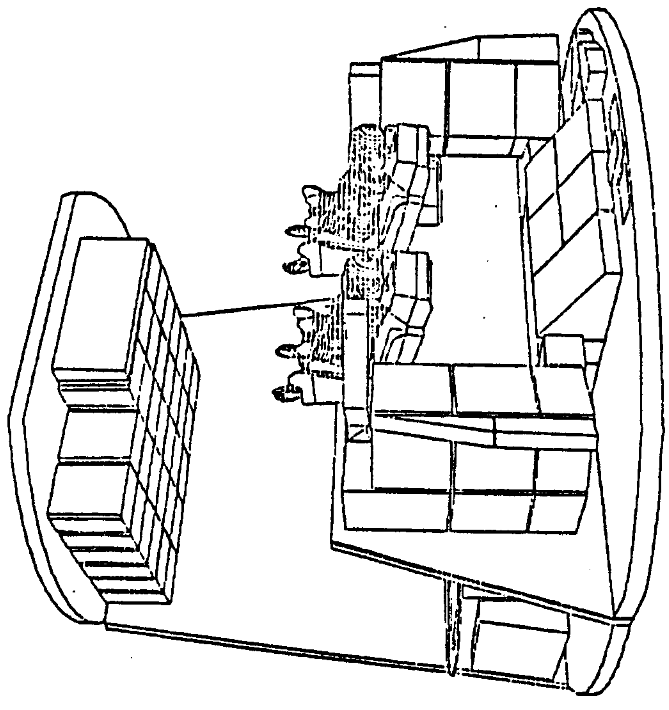


ANTHROPOMETRIC MEASUREMENT SYSTEM
ORTHOGONAL REACH PLANES









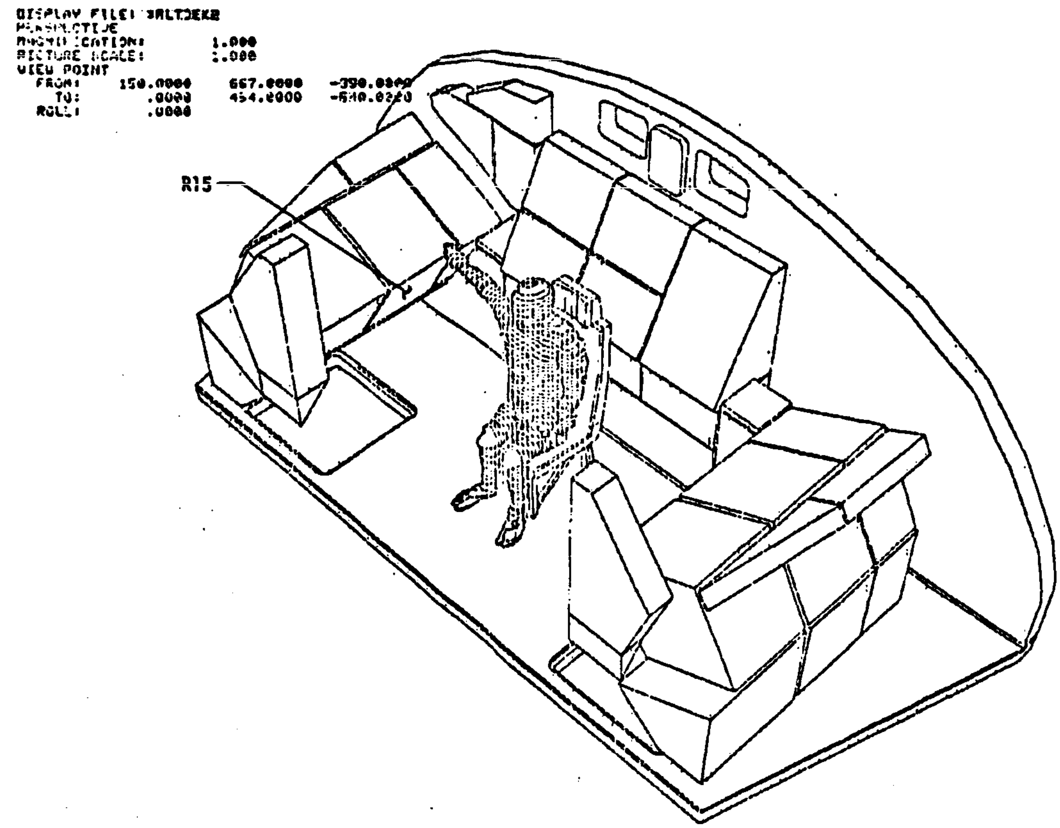


FIGURE 5: HIDDEN LINE VIEW OF TEST CONFIGURATION

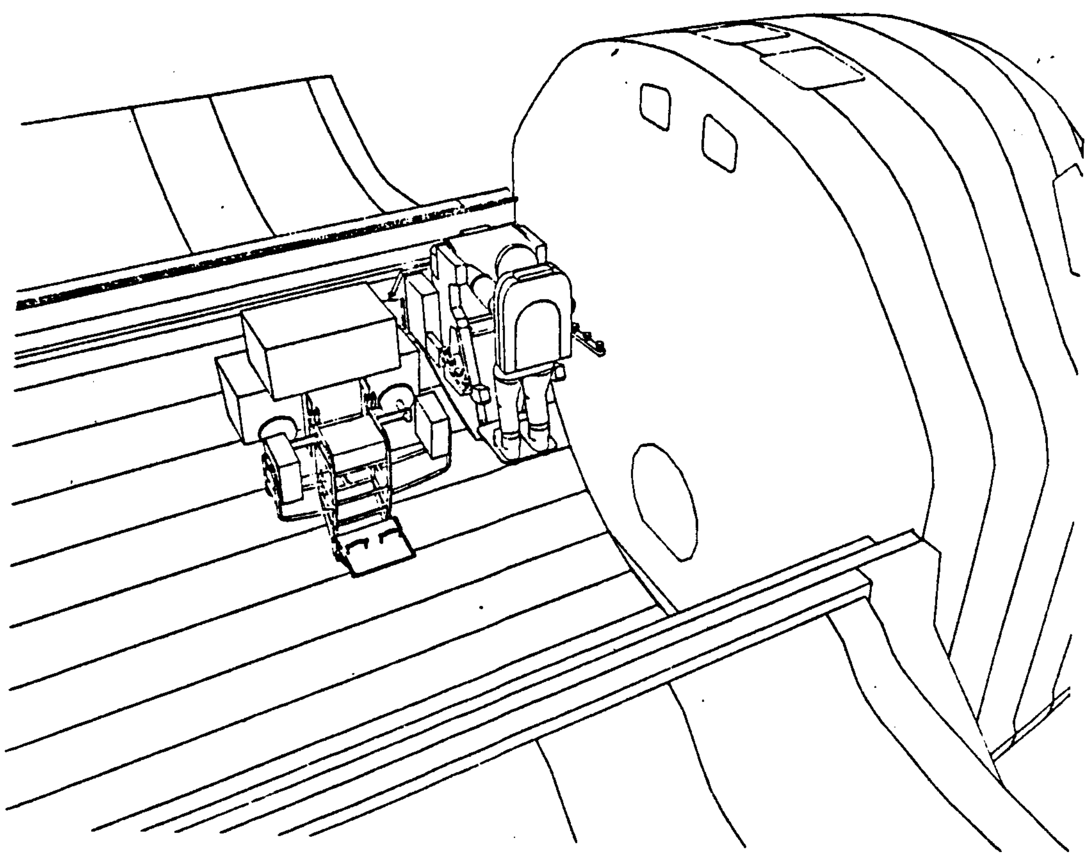


FIGURE 7.

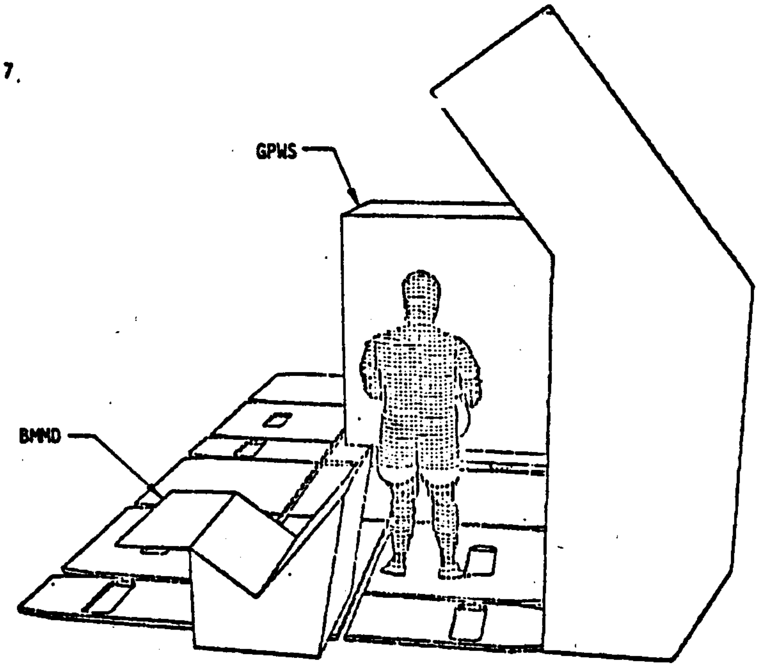
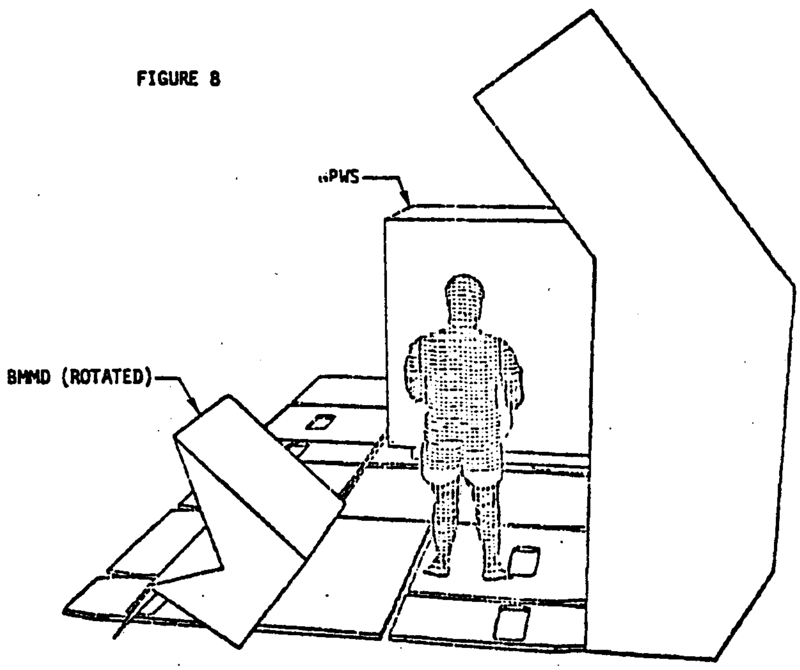
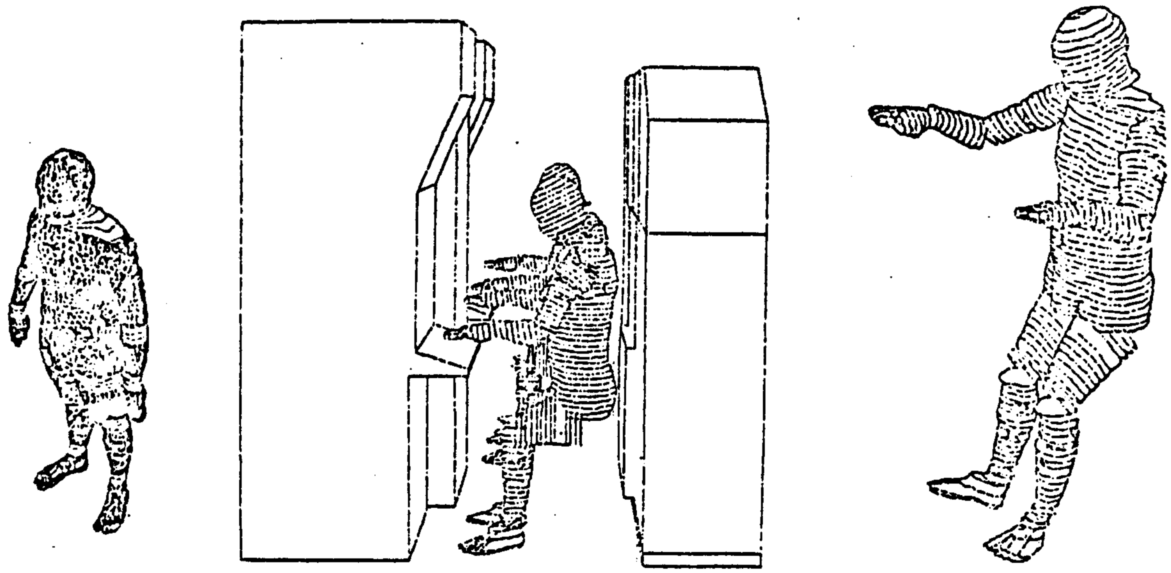


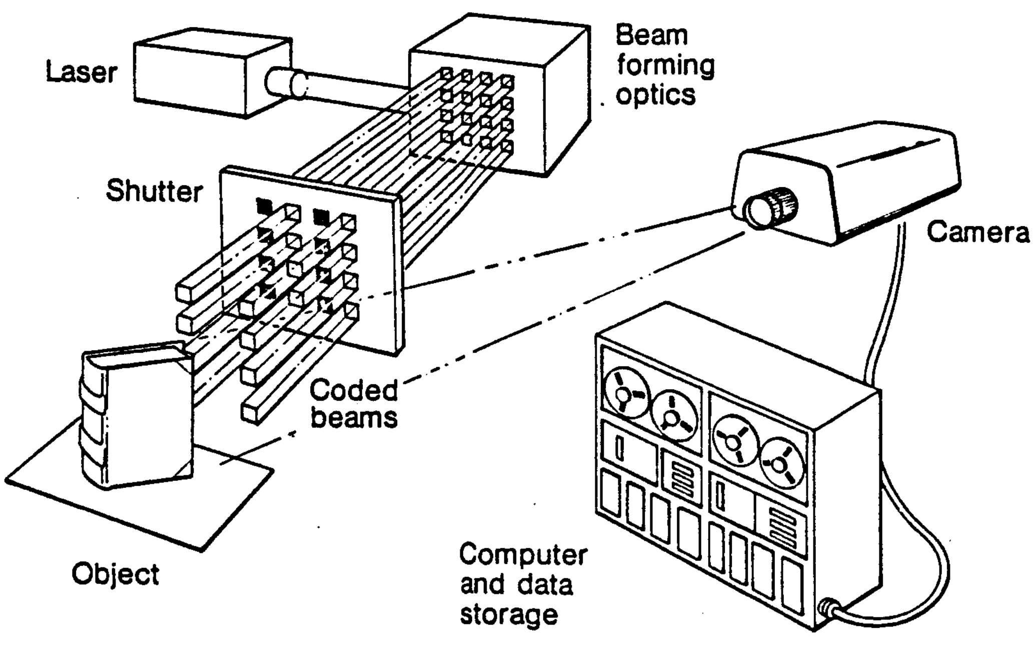
FIGURE 8





NASA
S-81-10781

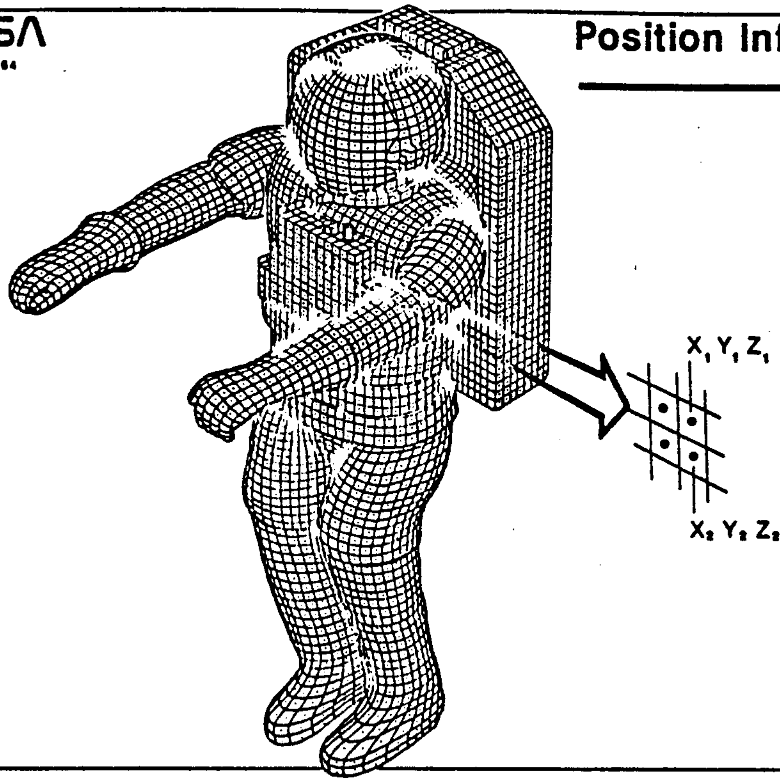
Topographic Mapping Data Aquisition



NASA

S-81-10764

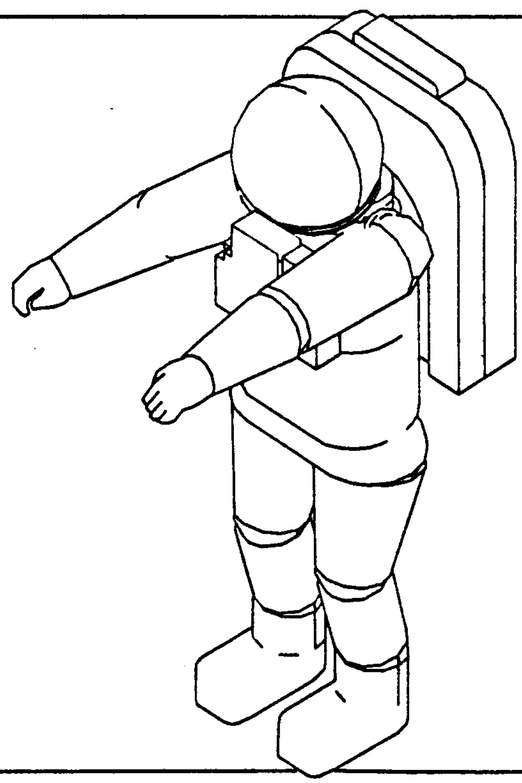
Position Information

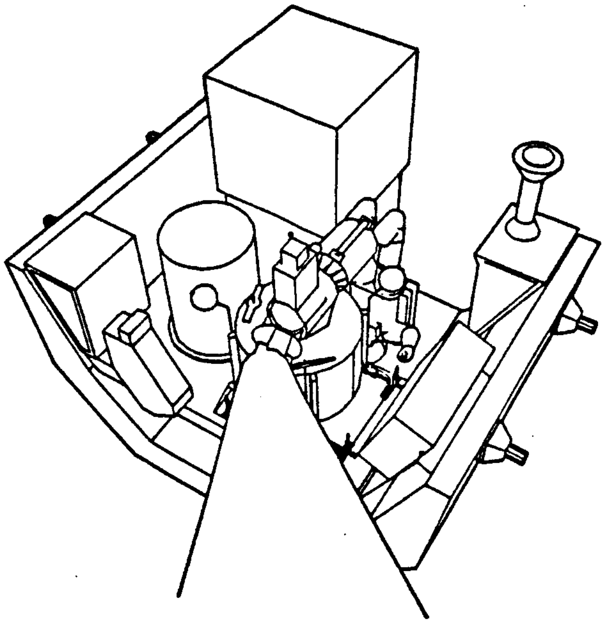


NASA

S-81-10760

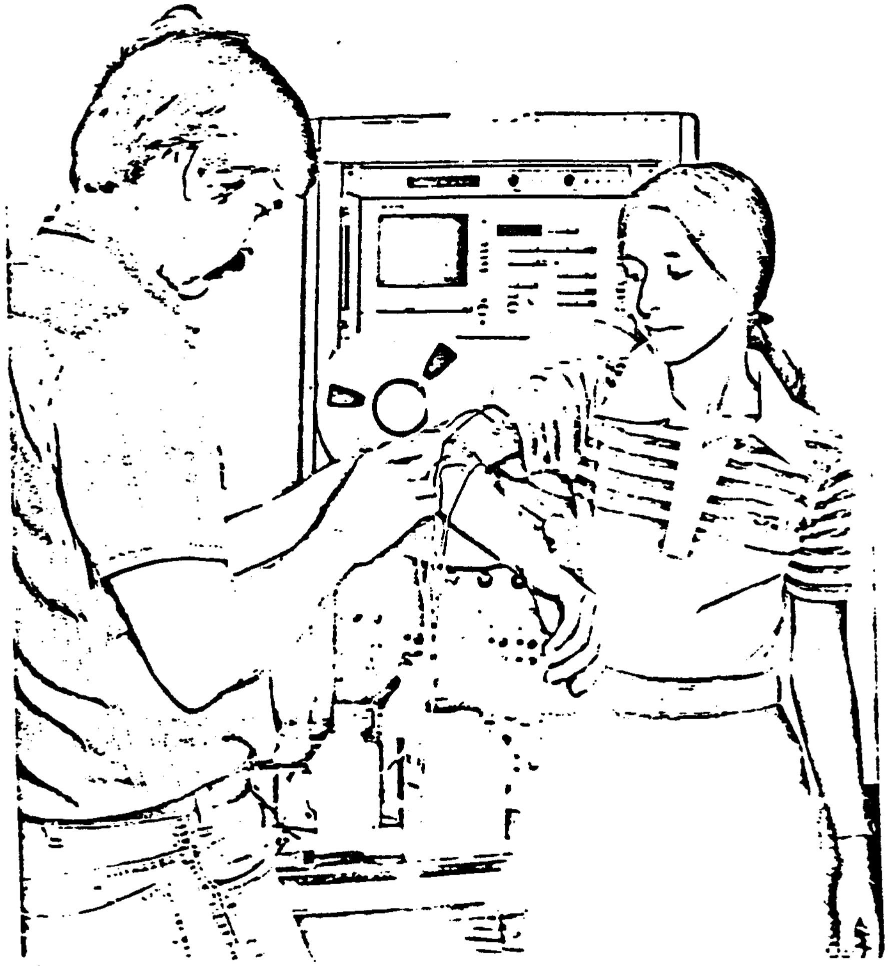
Computer Graphics Reconstruction

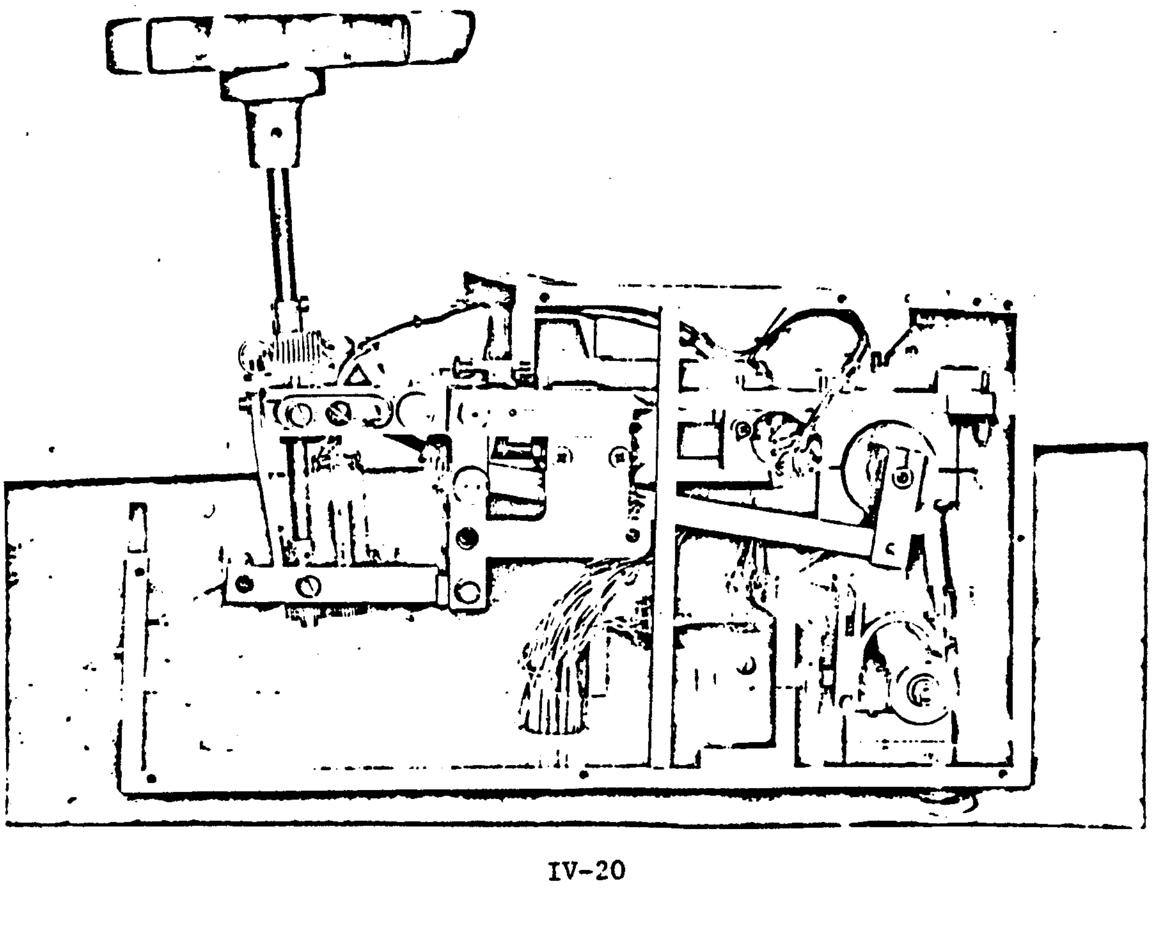




CONTROLLER DESIGN REQUIREMENTS SYSTEM

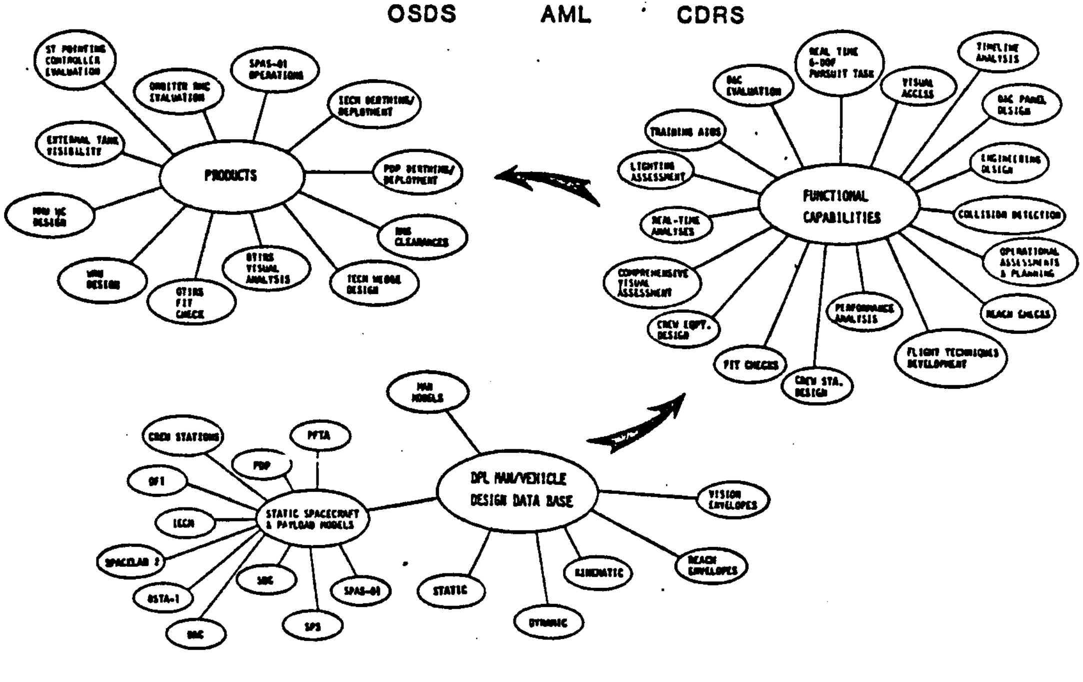
- MAN-IN-THE LOOP SIMULATOR
- TWO VEHICLE TRACKING/PURSUIT TASK
- CONFIGURABLE VEHICLE CONTROL SYSTEM
- UNIVERSAL CONTROLLER INTERFACES
- FLEXIBLE D&C INTERFACES





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

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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 FVA becoming a baseline activity for the Space Shuttle Program.

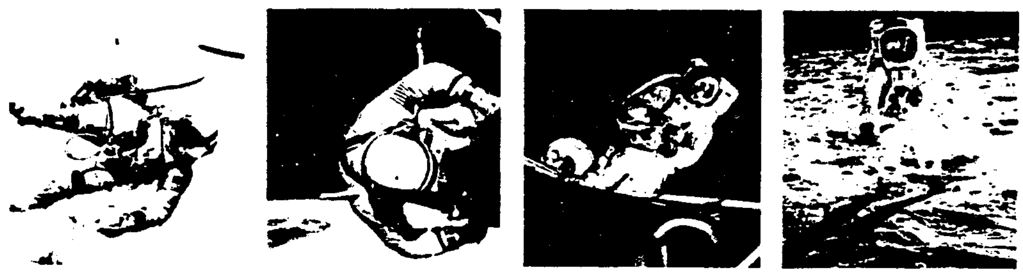
National Aeronautics and Space Administration

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)

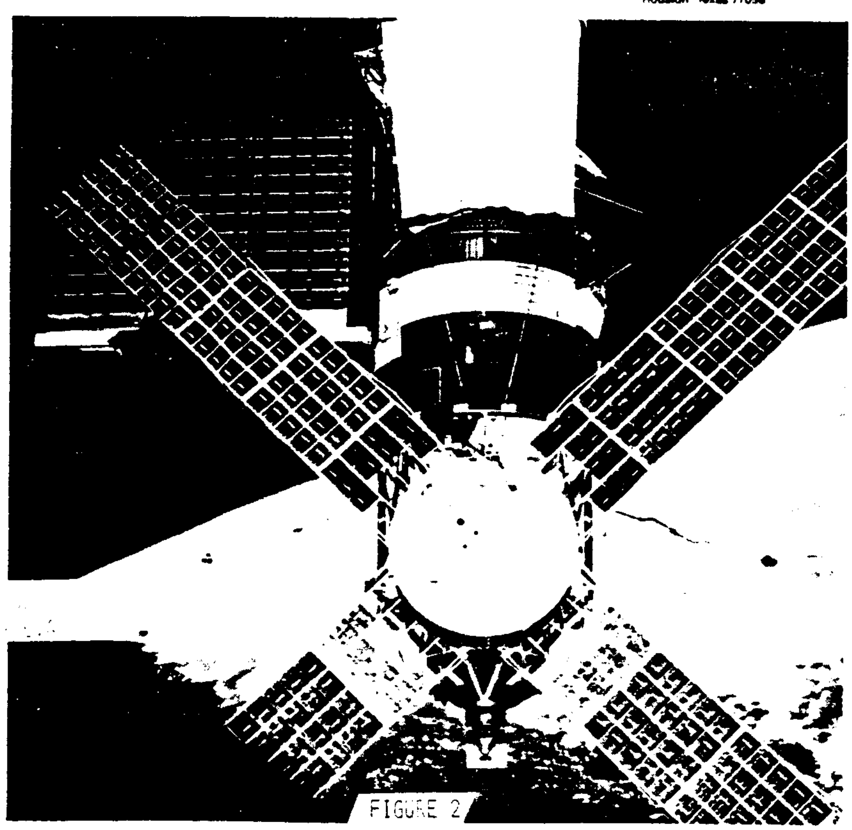


FIGURE 2

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.

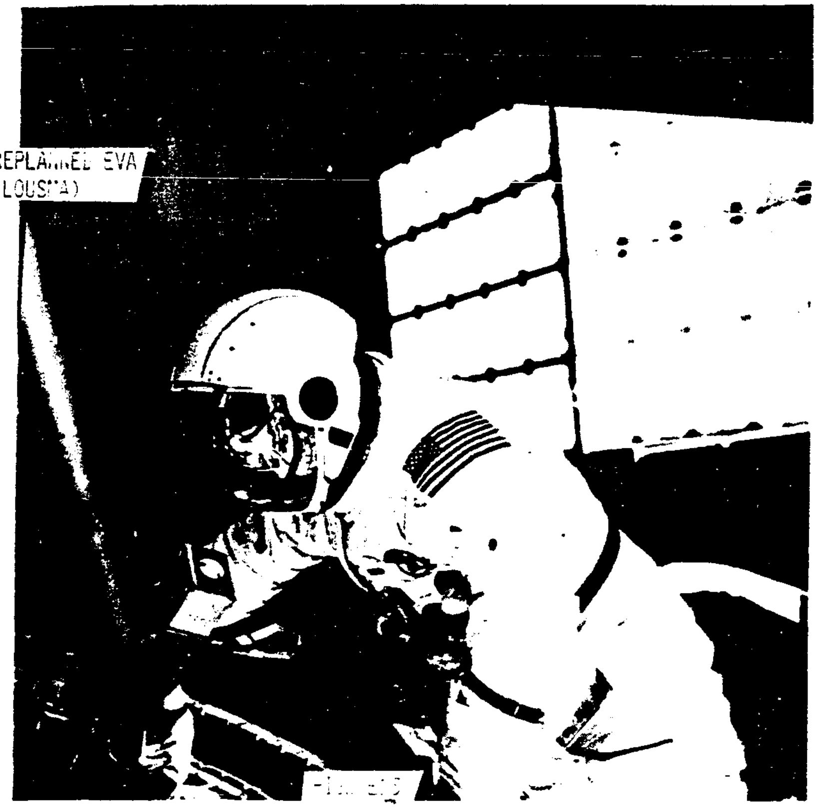
Contingency EVA - All EVA activities required to effect a safe return of the Orbiter and crew.

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 PREPLANNED EVA
(JACK LOUSMA)

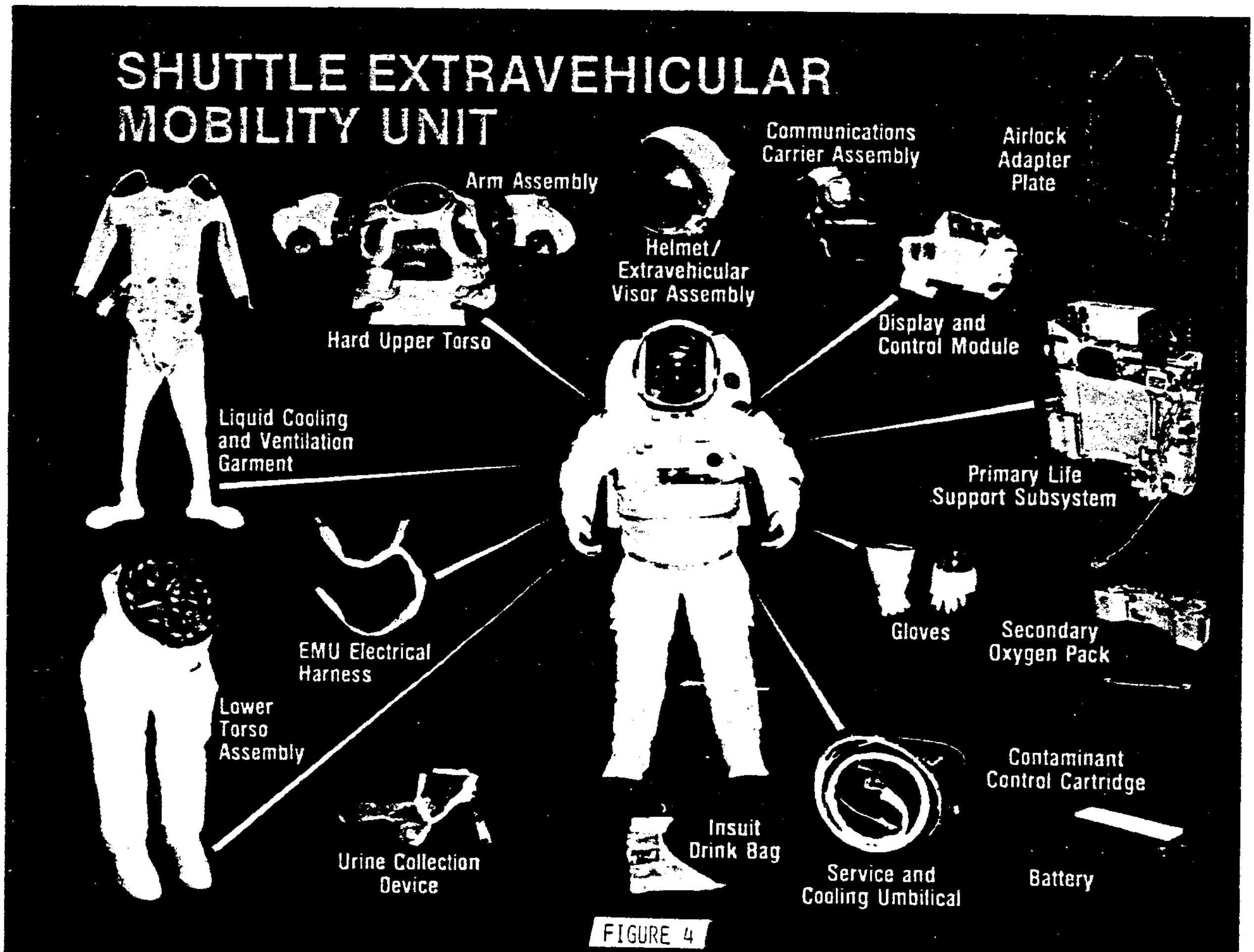

SHUTTLE EXTRAVEHICULAR
MOBILITY UNIT
Arm Assembly
Communications
Carrier Assembly
Airlock
Adapter
Plate
Helmet/
Extravehicular
Visor Assembly
Hard Upper Torso
Display and
Control Module
Liquid Cooling
and Ventilation
Garment
Primary Life
Support Subsystem
EMU Electrical
Harness
Gloves
Secondary
Oxygen Pack
Lower
Torso
Assembly
Contaminant
Control Cartridge
Insuit
Drink Bag
Urine Collection
Device
Service and
Cooling Umbilical
Battery

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

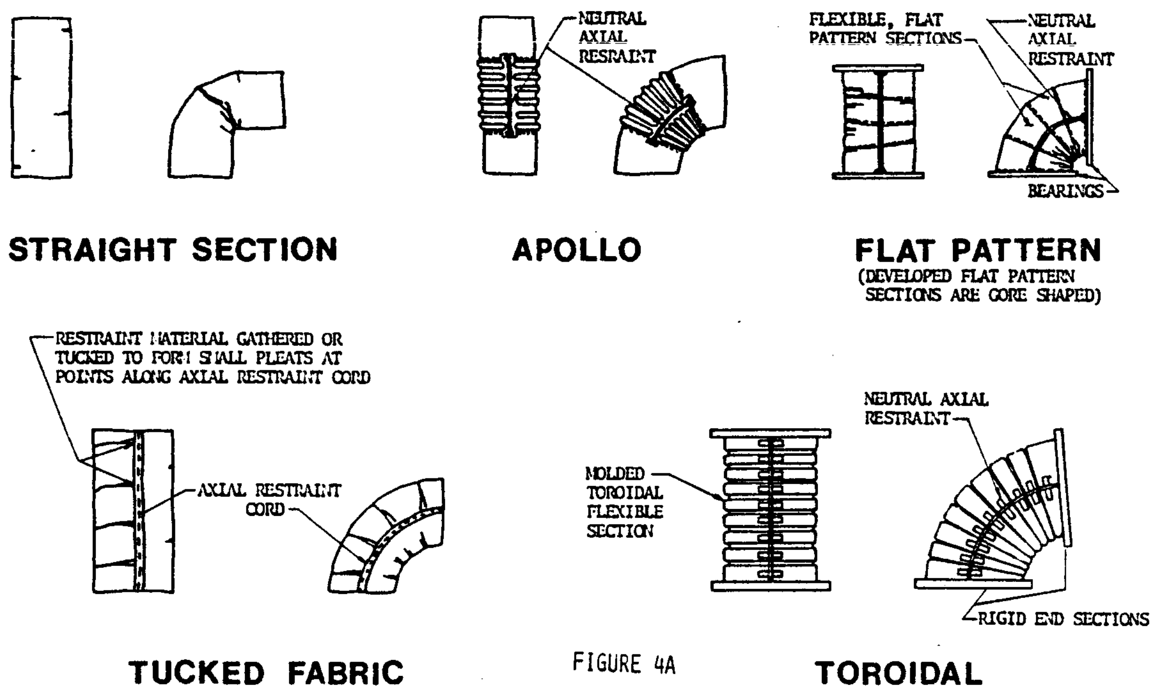


FIGURE 4A

NASA-S-71-2028-S

SUIT DEVELOPMENT IN CREW SYSTEMS DIVISION

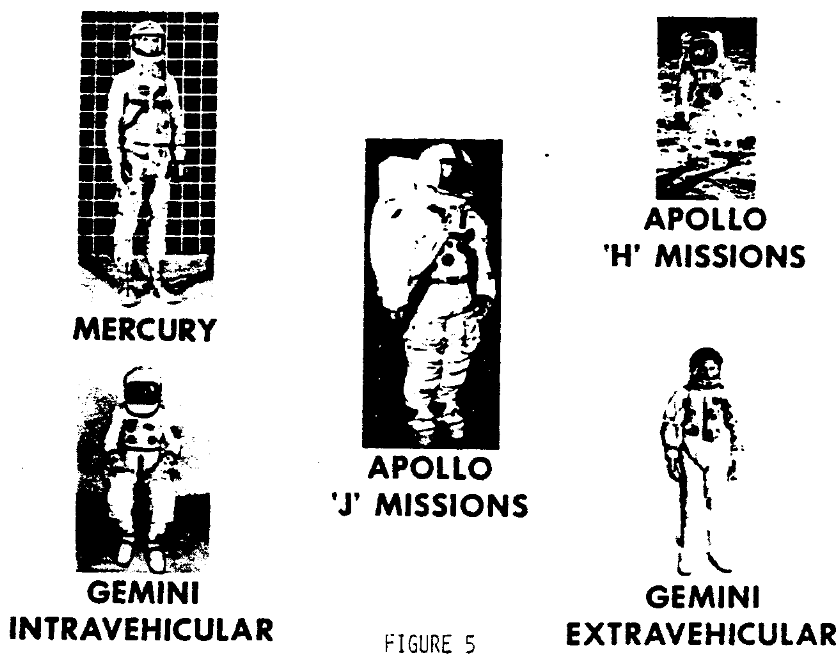


FIGURE 5

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

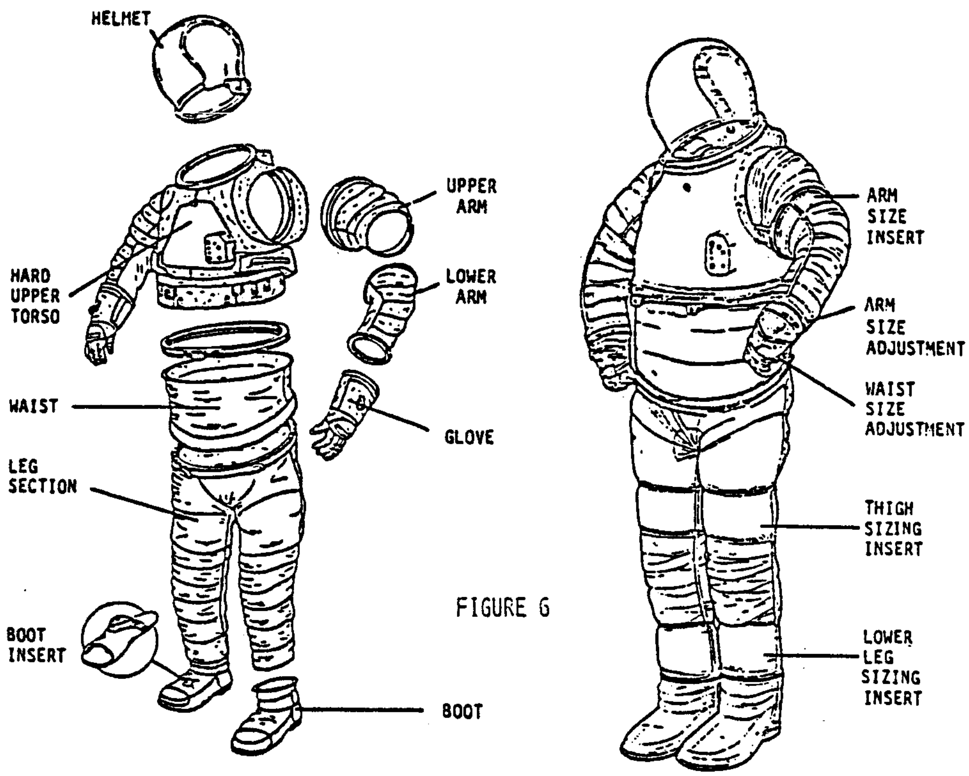
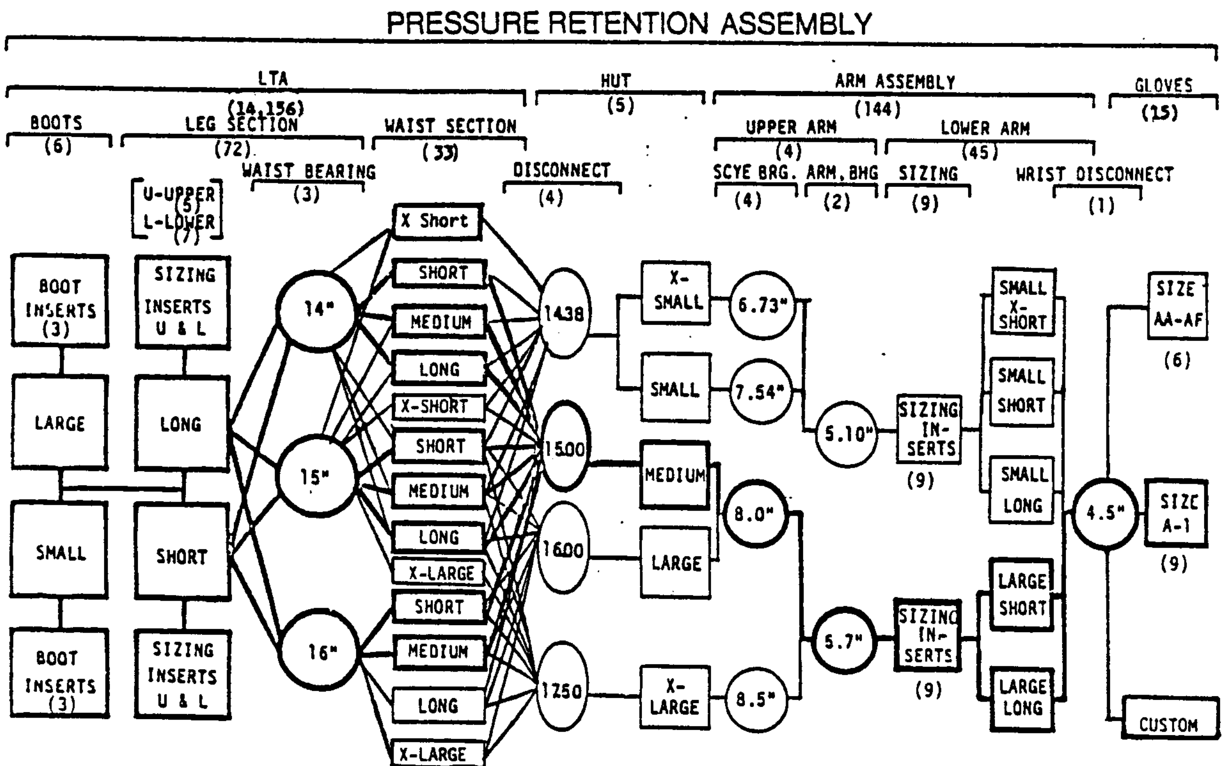


FIGURE 6

SPACE SUIT SIZING SYSTEM

8/82



( ) Qty Possible Sizes

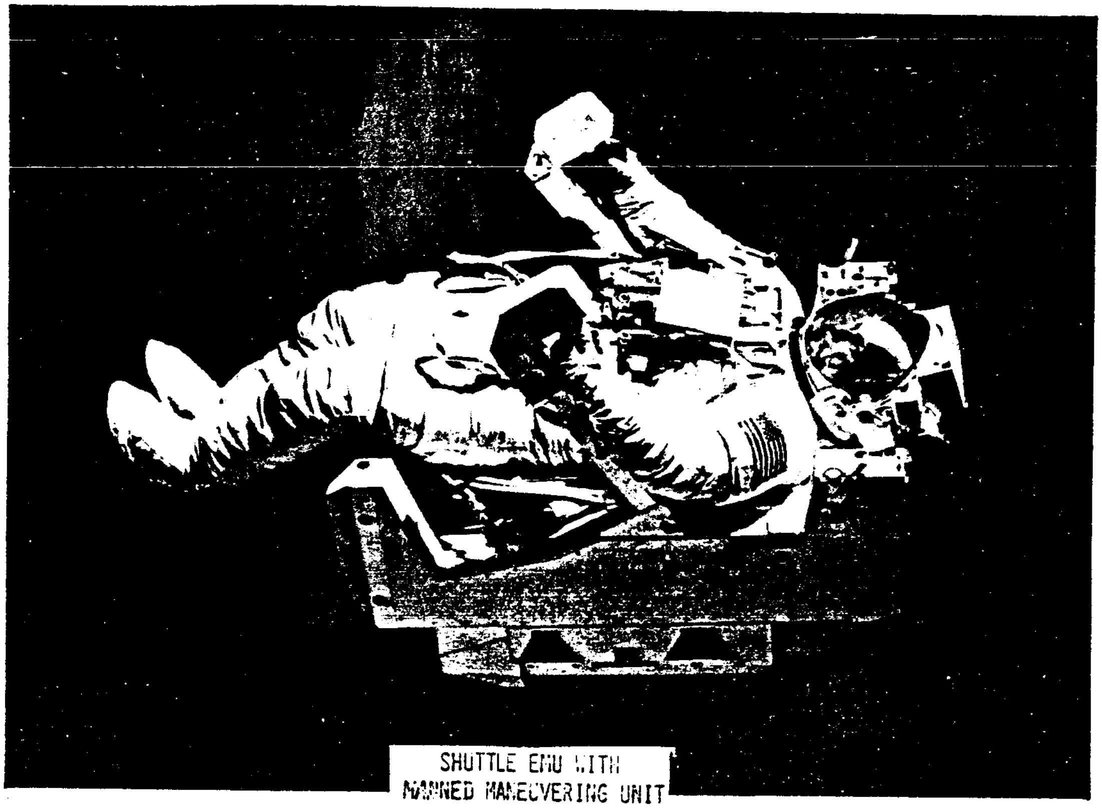
FIGURE 7

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

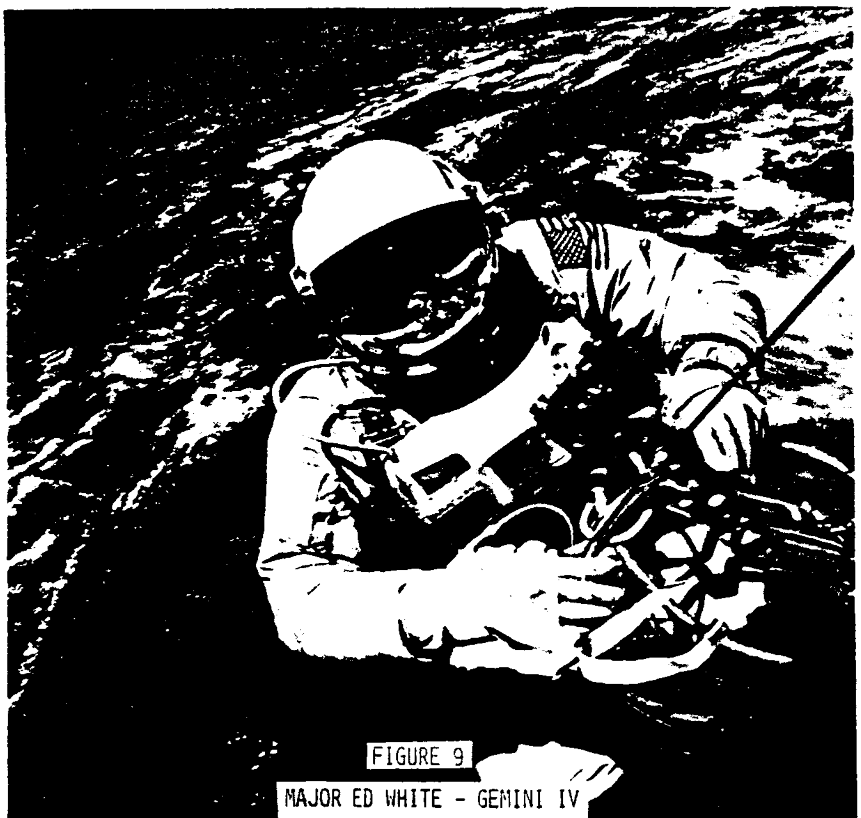


FIGURE 9
MAJOR ED WHITE - GEMINI IV
EVA EQUIPMENT

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 EMU manned activity is conducted at one-G.

Other comforts provided for in the Shuttle EMU 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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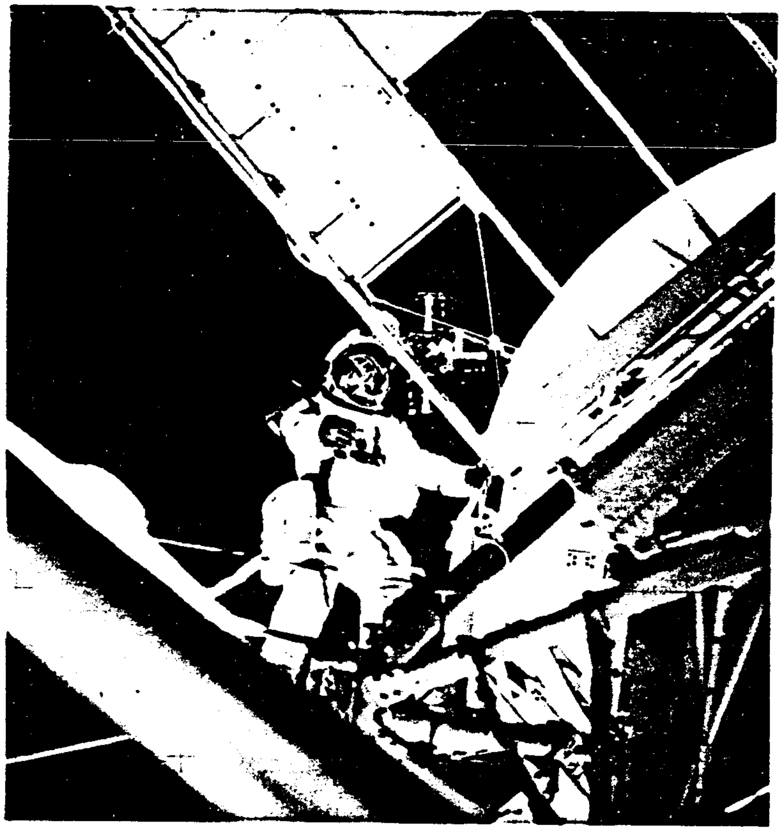
Houston, Texas 77058

NASA-S-74-4649



EXPERIMENT INSTALLATION

FIGURE 10

SKYLAB EVA EQUIPMENT
JACK LOUSMA

NASA National Aeronautics and Space Administration

NASA
AS12-47-6919

Lyndon B. Johnson Space Center

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

CDR KEN MATTINGLY
APOLLO EVA EQUIPMENT DONNING

FIGURE 12

NASA-S-78-12051

OPEN LOOP SYSTEM

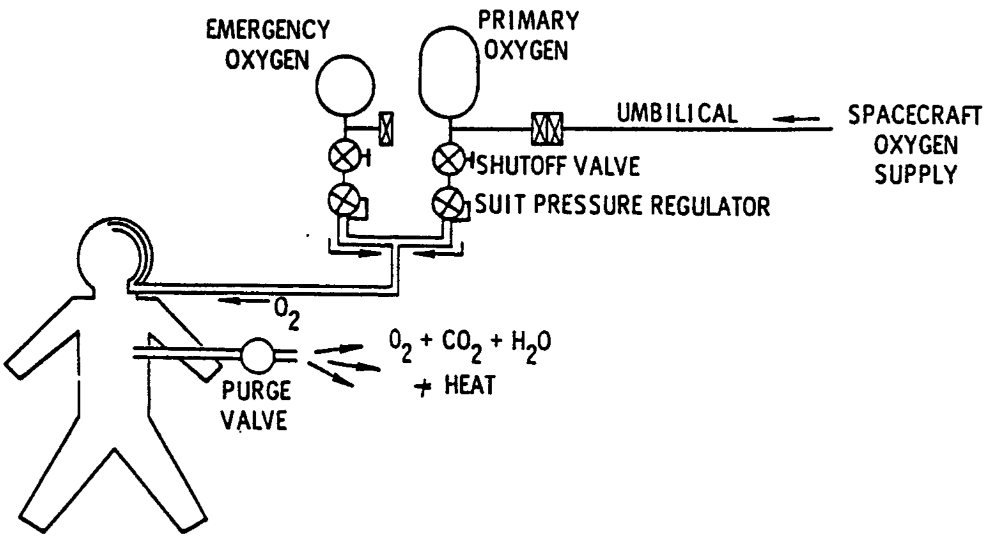


FIGURE 13

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CLOSED LOOP SYSTEM

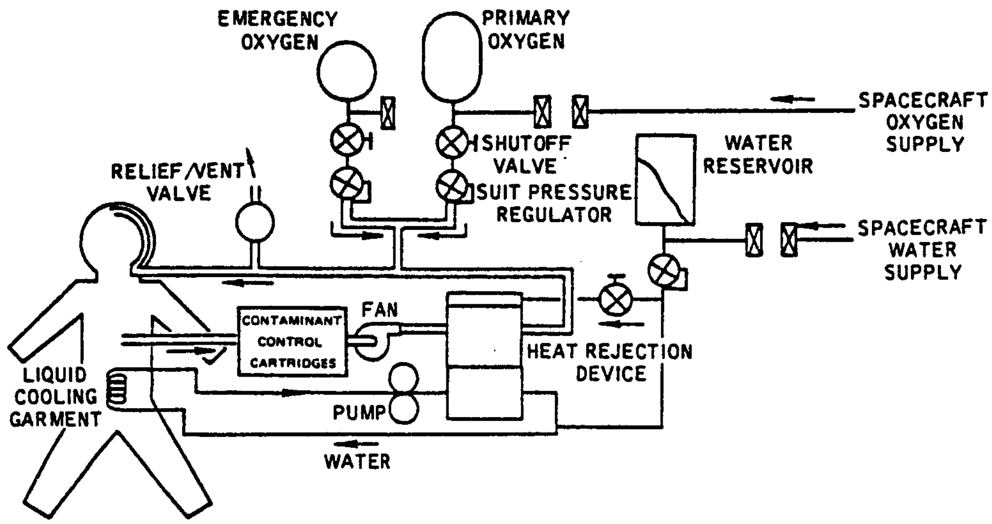


FIGURE 14

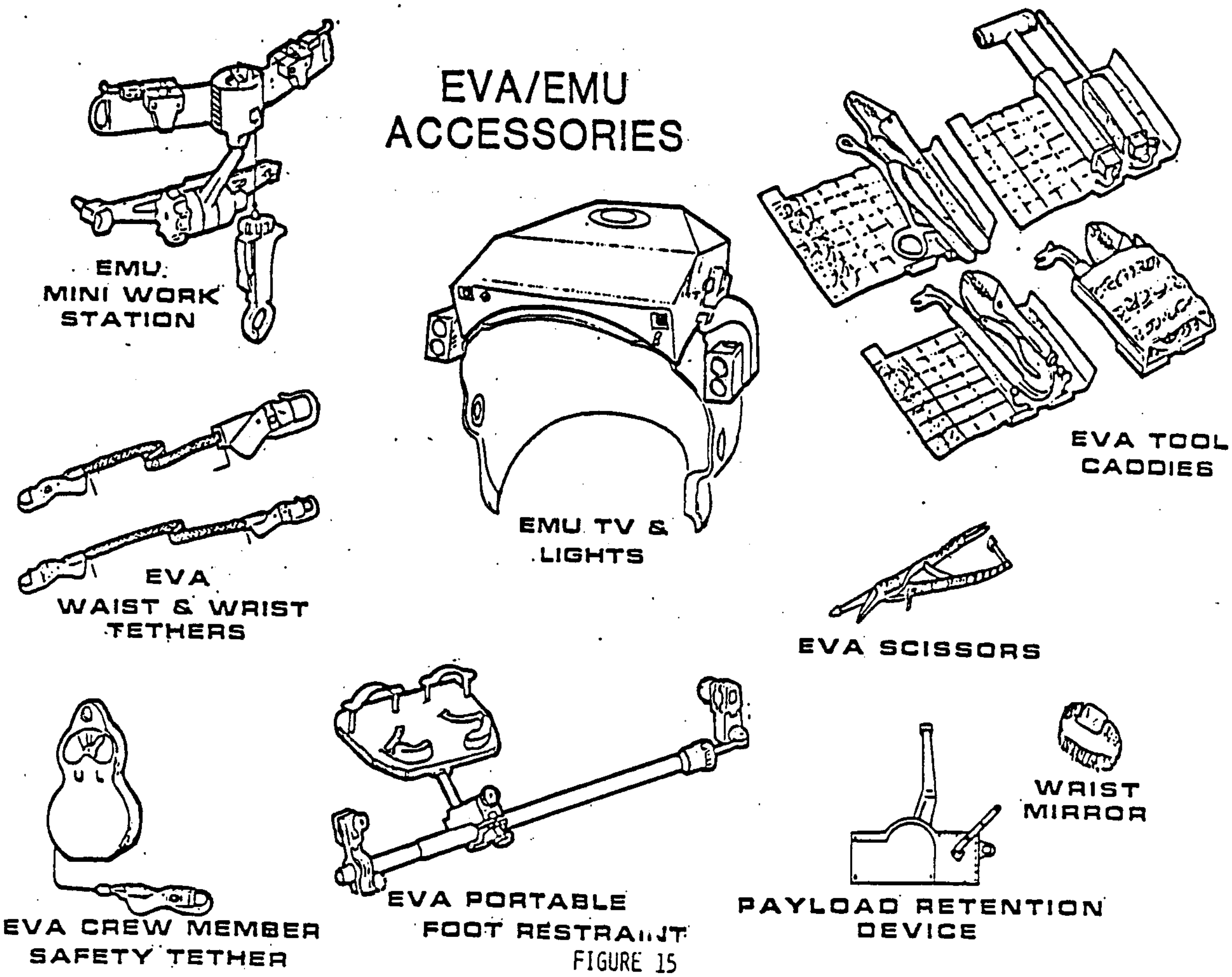


FIGURE 15

Appendix

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.

NASA Lyndon B. Johnson Space Center — Engineering and Development Directorate

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.

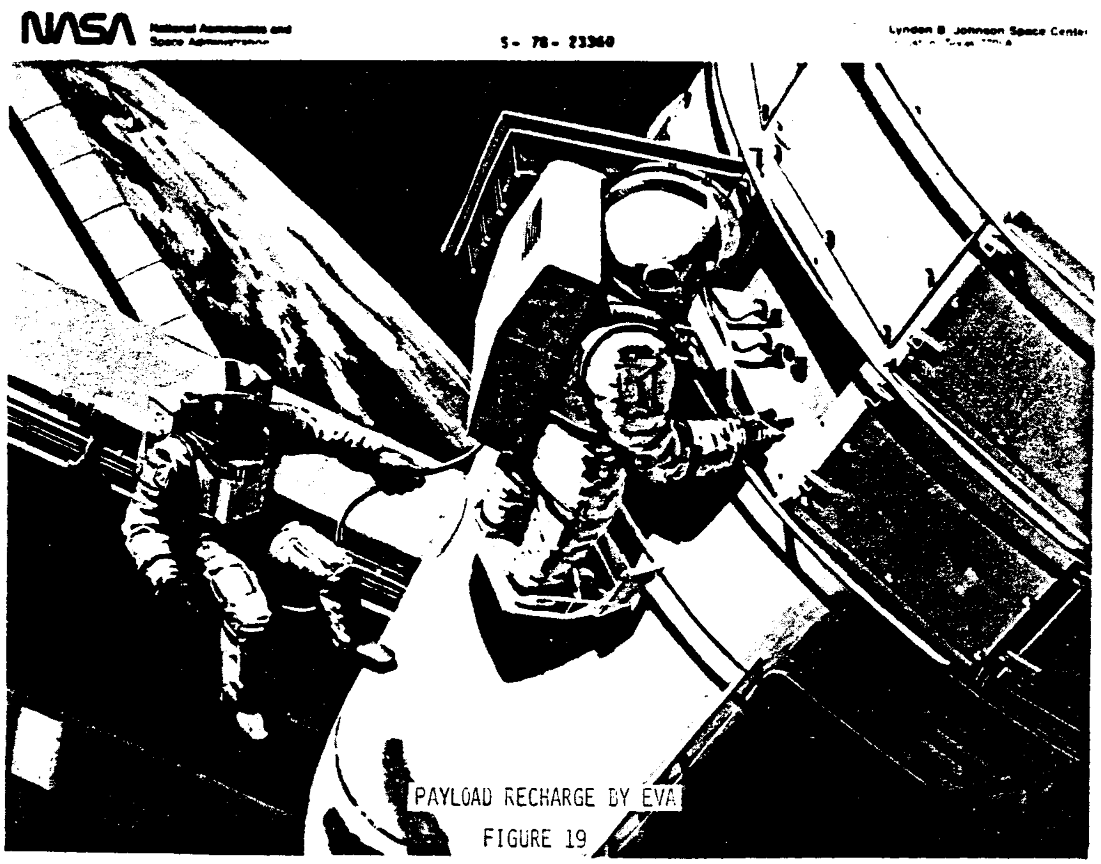
3. The Display and Controls Module (DCM) is a chest-mounted pack which provides controls for EMU operation, a 12-character LED status display, and a purge valve for emergency mode operation.

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.

FIGURE 18 PAYLOAD MODULE REPLACEMENT BY EVA



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.

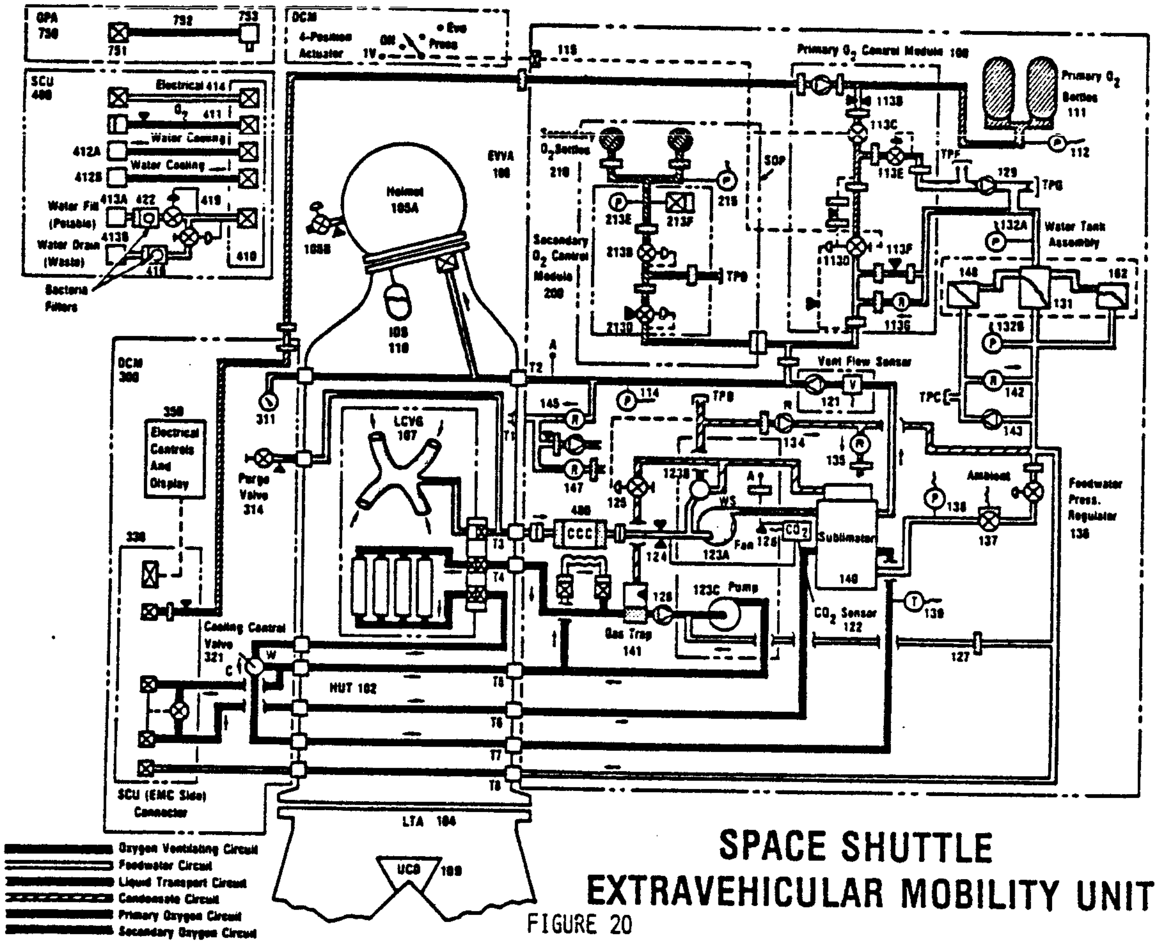
9. The Airlock Adapter Plate (AAP) is a frame, mounted to the airlock wall, in which the EMU is retained when not in use.

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

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OVERVIEW

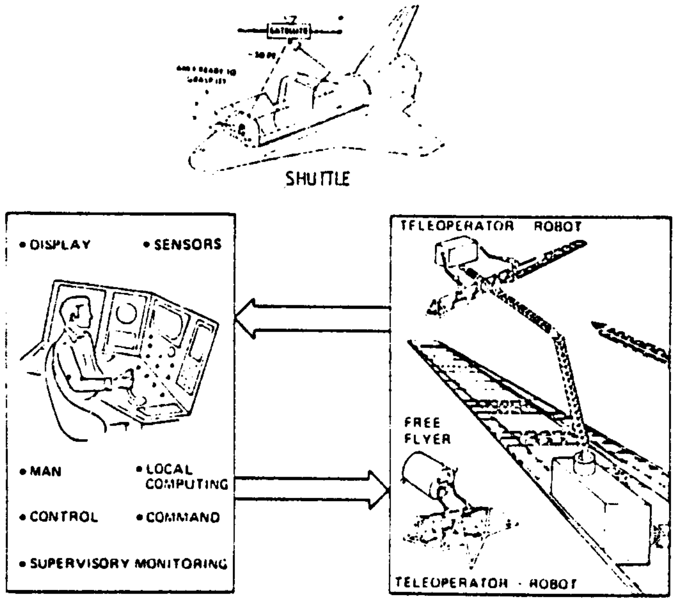
- TELEOPERATOR HUMAN INTERFACE TECHNOLOGY
- GENERIC HUMAN FACTORS ISSUES AND R&D TOPICS
- ONGOING ADVANCED R&D WORK

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.

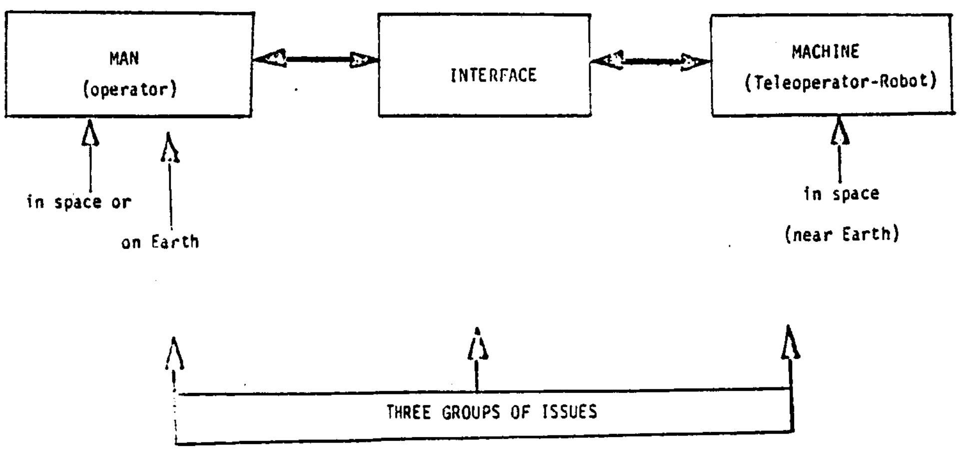
TELEOPERATION IN SPACE

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

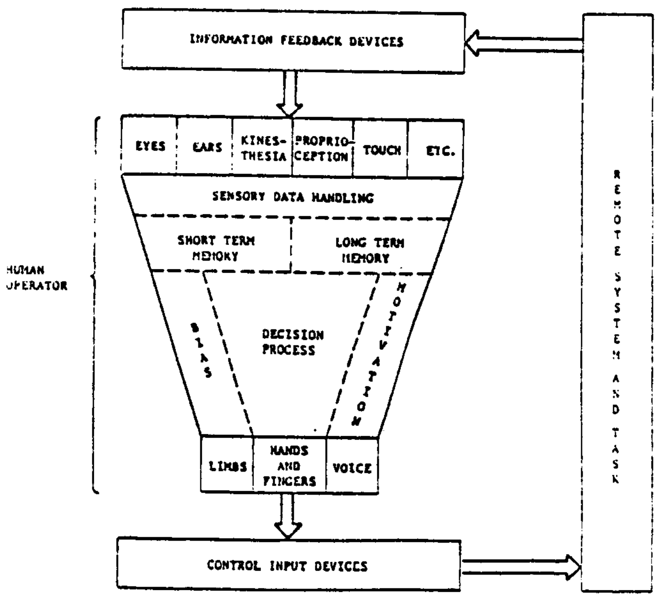
WHAT
- A RELATIVELY NEW TECHNOLOGY INVOLVING DIFFERENT DISCIPLINES: SENSOR INSTRUMENTATION, COMPUTER SYSTEMS, DISPLAY ENGINEERING KINEMATICS & DYNAMICS ANALYSIS, CONTROL SYSTEMS, HUMAN ENGINEERING, PSYCHOMETRICS, KINESIOLOGY, ANTHROPOMETRICS, ETC.

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:

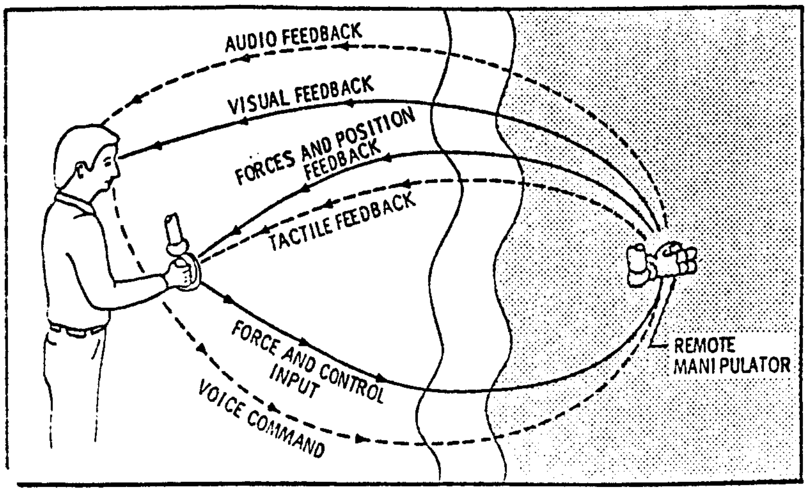
- HUMAN IS ESSENTIAL
- HUMAN PRESENCE IS BIDIRENCTIONAL
- HUMAN IS LIMITED AND ASSYMETRIC IN I/O HANDLING
- HUMAN NEEDS AIDS
- HUMAN PRESENCE SHOULD BE OPTIMIZED

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

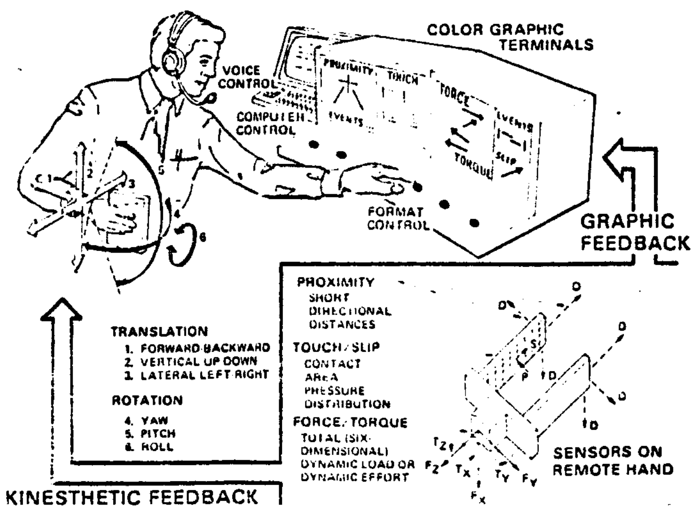
A HUMAN I/O CHANNEL VIEW



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)

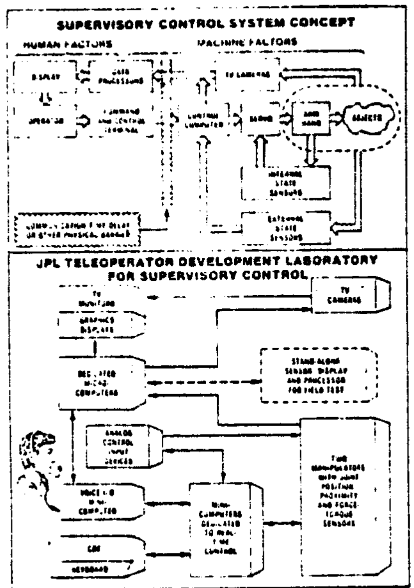
PERFORMANCE STUDIES OF PARTICULAR INTEREST

- 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

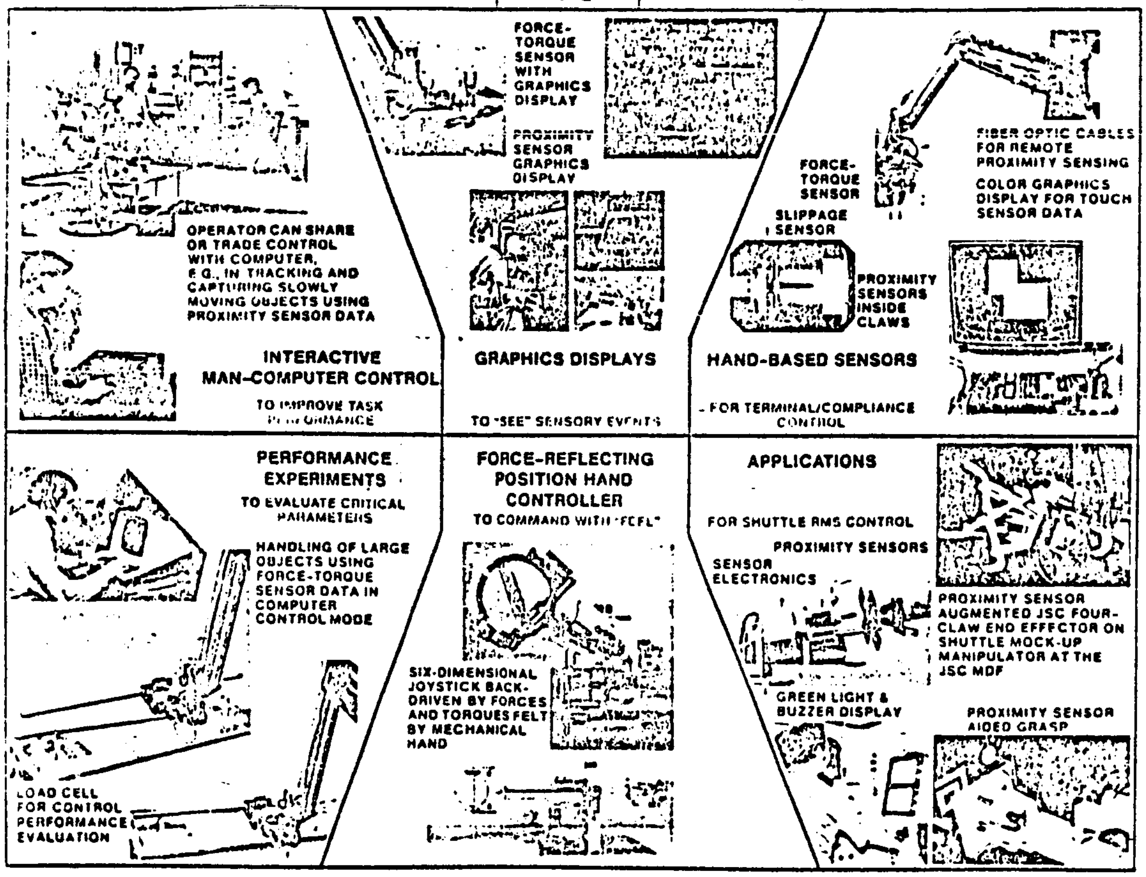
ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT AT JPL

- CONTROL CAPABILITY ENHANCEMENT
  - NON-VISUAL SENSORS
  - COMPUTER-AIDED CONTROL
    - KINEMATICS
    - DYNAMICS
- MAN-MACHINE INTERFACE ENHANCEMENT
  - INFORMATION FEEDBACK ENHANCEMENT
    - VISUAL DISPLAYS
      - MONO
      - STEREO
    - GRAPHIC DISPLAYS
    - INTEGRATED & "SMART" DISPLAYS
    - AUDIO FEEDBACK
      - ANALOG
      - COMPUTER
  - INTEGRATED CONTROL STATION
    - SYSTEM ARCHITECTURE
  - COMMAND/CONTROL INPUT ENHANCEMENT
    - MULTIFUNCTIONAL CONTROL BOARDS
      - ANALOG
      - DIGITAL
    - FORCE-REFLECTING HAND CONTROLLER
    - VOICE COMMAND (COMPUTER-DISCRETE WORDS)
- PERFORMANCE EVALUATION
  - GENERIC TASK BOARDS
  - PERFORMANCE EXPERIMENTS
  - DATA EVALUATION & REDUCTION

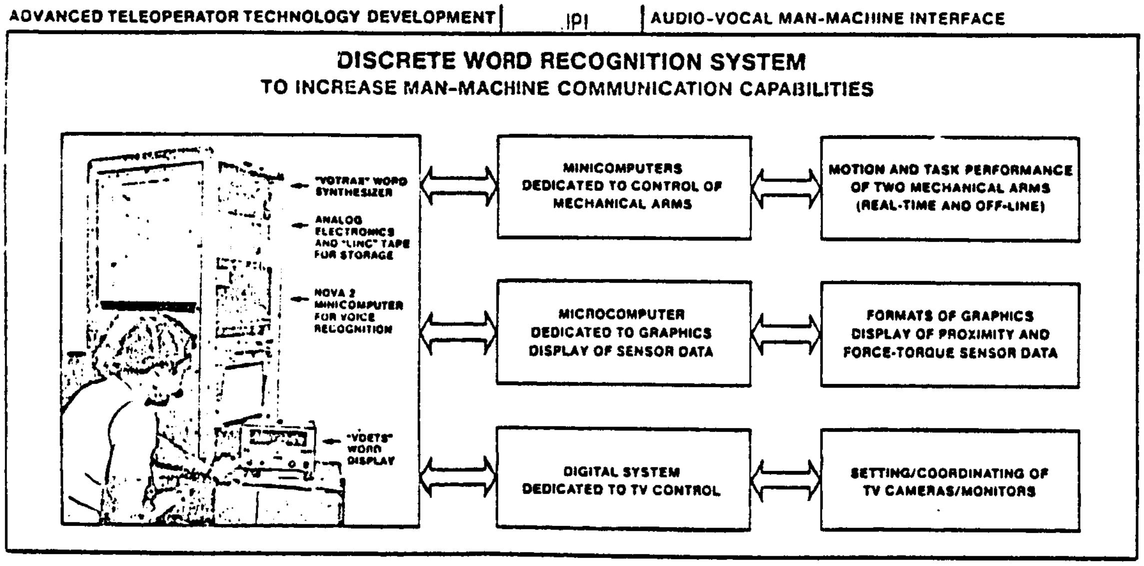
This viewgraph presents a graphic summary overview of the JPL activities in advanced teleoperator technology development.

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

ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT | JPL | REMOTE MANIPULATOR SYSTEMS CONTROL



ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT | JPL | AUDIO-VOCAL MAN-MACHINE INTERFACE



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

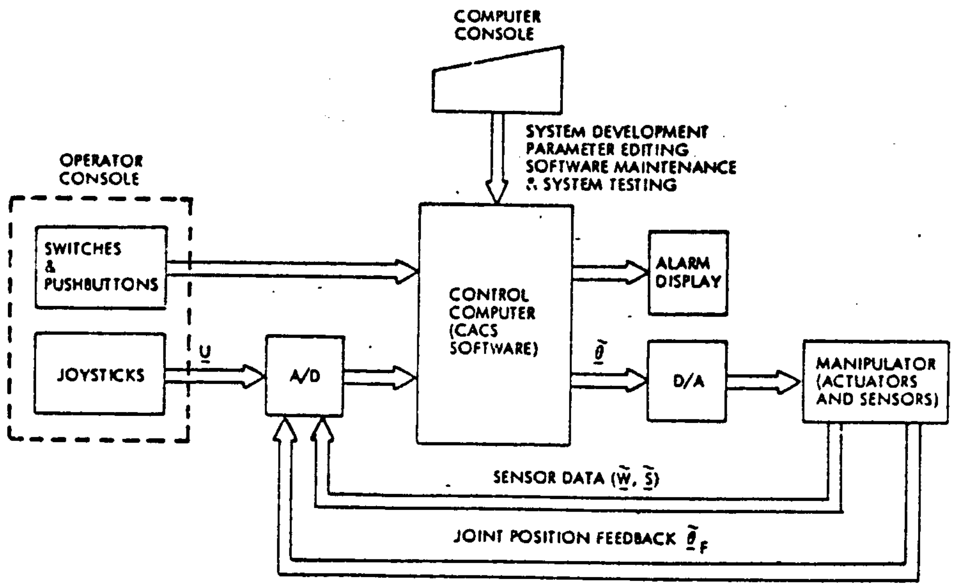
EXAMPLES

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.

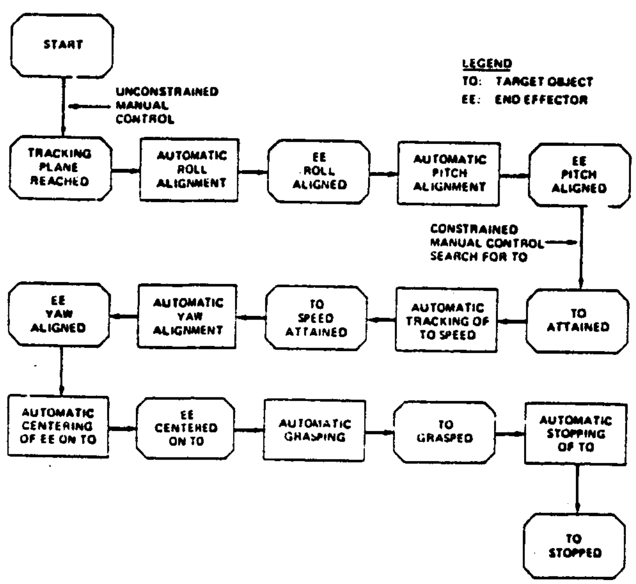
TECHNICAL GOALS AND ACTIVITIES EXAMPLE

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.

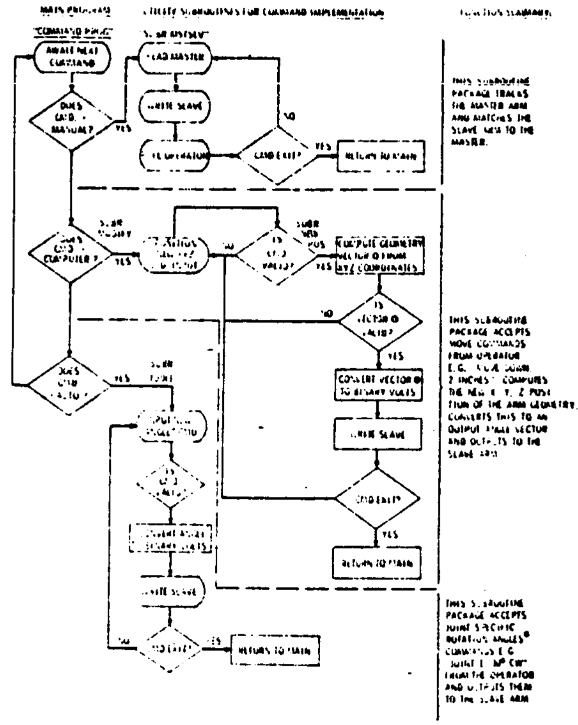
The force-reflecting position hand controller is a general purpose six-dimensional control input device which can be back-driven by forces and torques sensed at the base of the end effector of a remotely controlled mechanical arm. The device is general purpose in the sense that it does not have any geometric/kinematic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

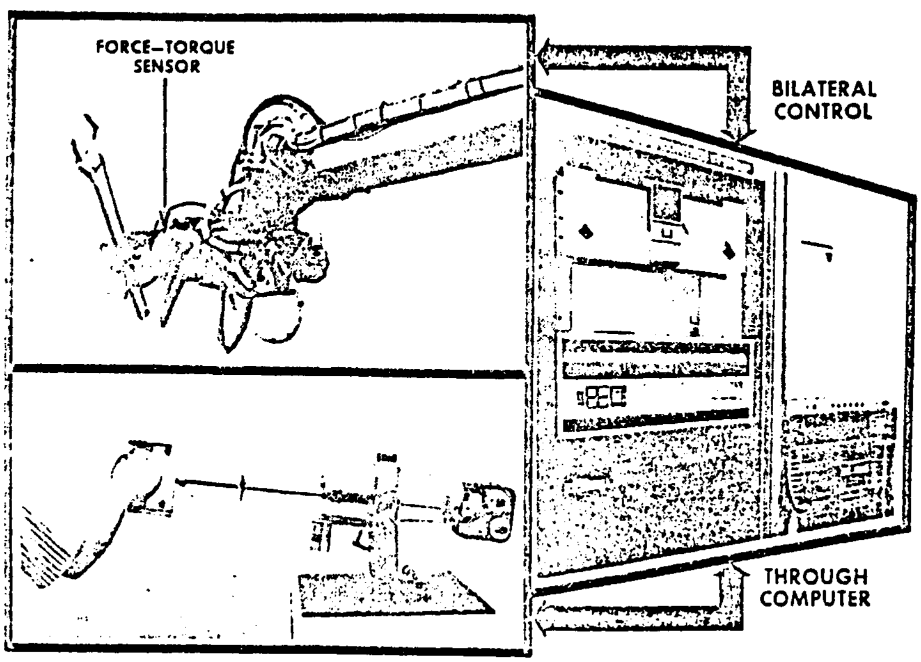
TECHNICAL GOALS AND ACTIVITIES EXAMPLE

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.

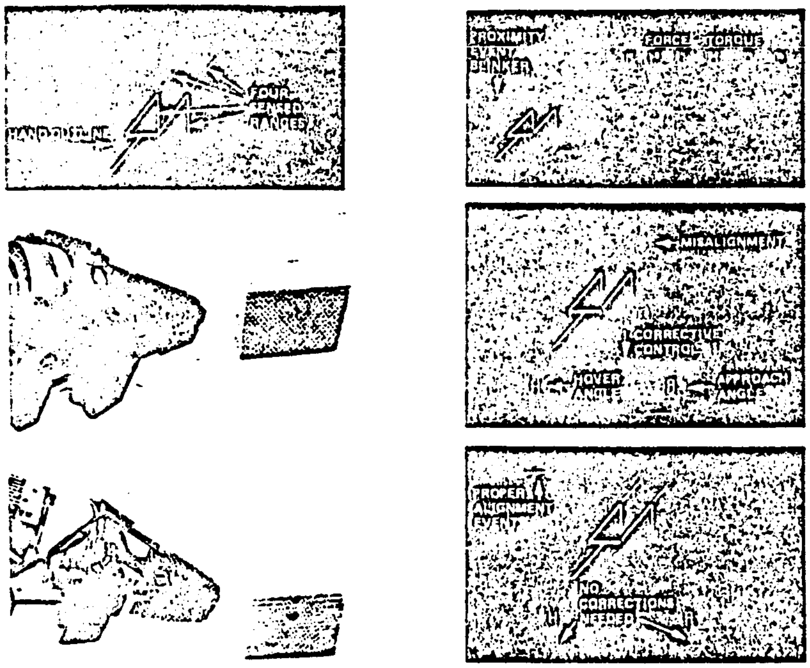
The upper right picture shows a combined ("dual") display of both proximity and force-torque sensor data, together with the "proximity event" blinker. This display is related to a task scenario which requires the simultaneous monitoring of both proximity and force-torque sensor information.

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

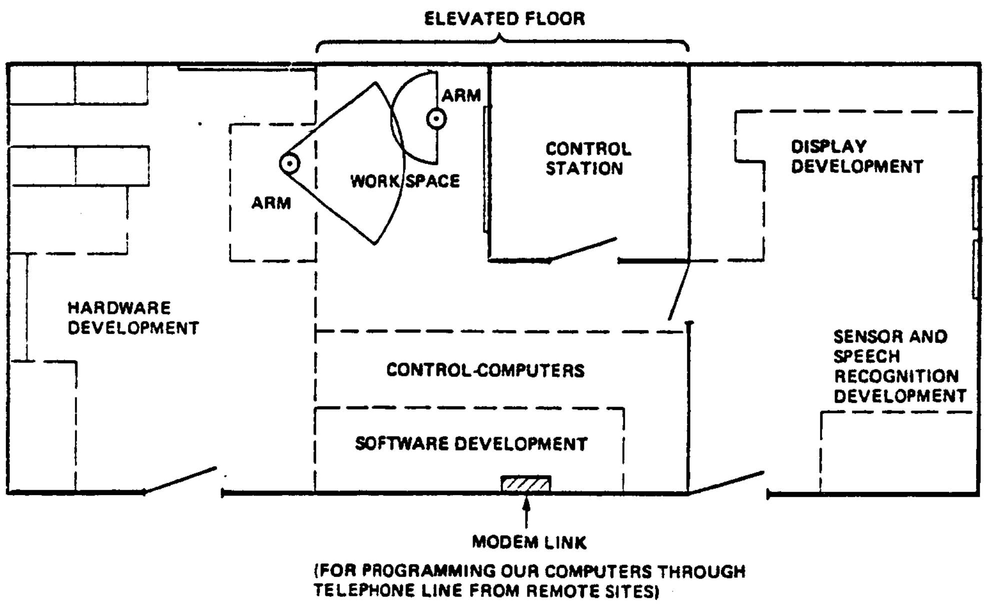
EVENT-DRIVEN DISPLAYS FOR PROXIMITY SENSOR DATA



TECHNICAL GOALS AND ACTIVITIES EXAMPLE

TELEOPERATOR LABORATORY

(52' by 22' AREA)



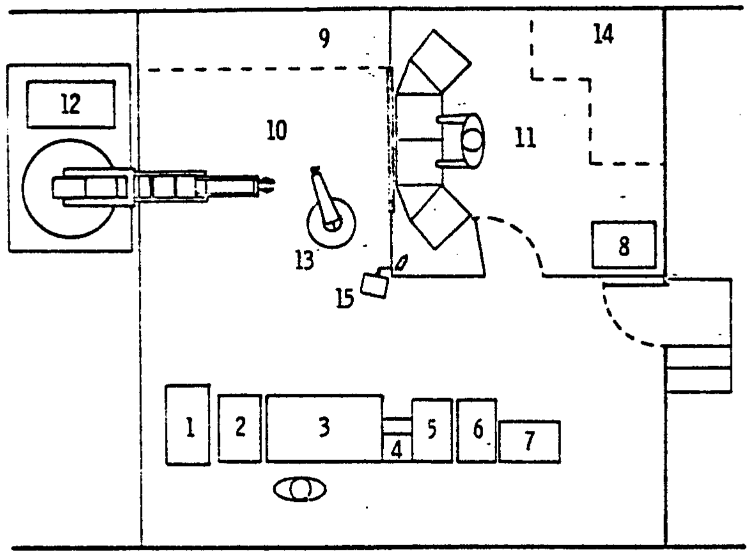
The teleoperator laboratory can be divided into four major areas: (1) the control station, (2) the manipulator workspace, (3) the test director's stand, and (4) the processing section. This figure shows the relationships of these areas and their associated equipment.

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

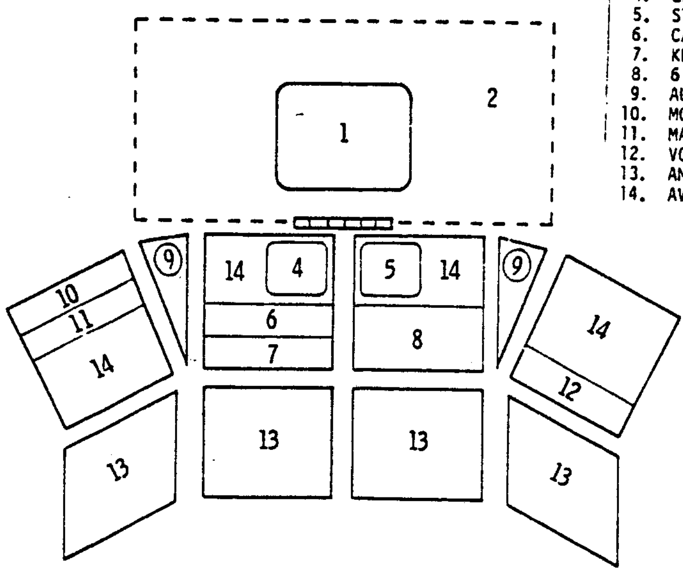


1. AMES SERVO CONSOLE
2. CURV CONTROL CONSOLE
3. TEST DIRECTOR'S STATION
4. TELETYPE
5. INTERDATA M70
6. INTERDATA 8/16E
7. HIGHSPEED PRINTER
8. VOICE COMMAND COMPUTER
9. TASK STORAGE AREA
10. MANIPULATOR WORKSPACE
11. CONTROL STATION
12. CURV VEHICLE AND ARM
13. AMES ARM
14. INTERFACE STORAGE AREA
15.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



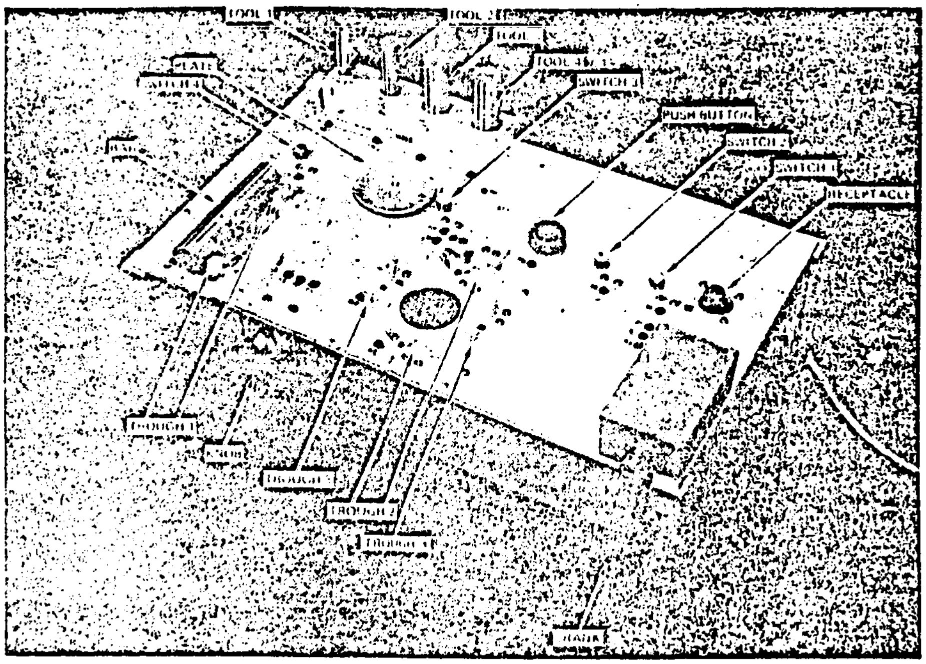
The task board has been designed and built at SRI International under a JPL contract. It is instrumented for seven different tasks, some with a variety of tolerance tools and movement distances. Each contact point is equipped with microswitches to detect the raising of a tool or the touching at contact. 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

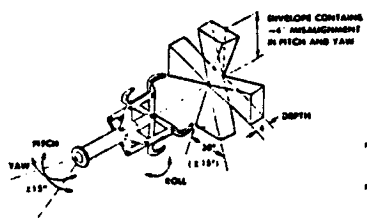
TASK BOARD FOR CONTROL EXPERIMENTS WITH/WITHOUT FORCE FEEDBACK



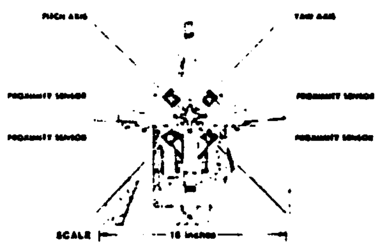
ACCOMPLISHMENTS EXAMPLE

PROXIMITY SENSOR SYSTEM FOR SHUTTLE RMS EXPERIMENTS AT JSC MDF

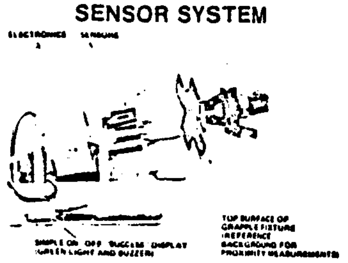
JSC FOUR-CLAW END EFFECTOR GRAPPLING ENVELOPE



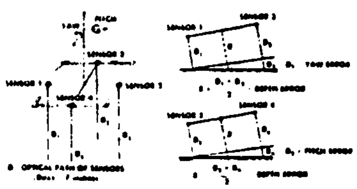
SQUARE MATRIX CONFIGURATION OF PROXIMITY SENSORS ON FOUR-CLAW END EFFECTOR



OVERALL PROXIMITY SENSOR SYSTEM



FOUR-SENSOR OPERATION CONCEPT FOR SIMULTANEOUS MEASUREMENT OF DEPTH, PITCH AND YAW ERRORS



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.

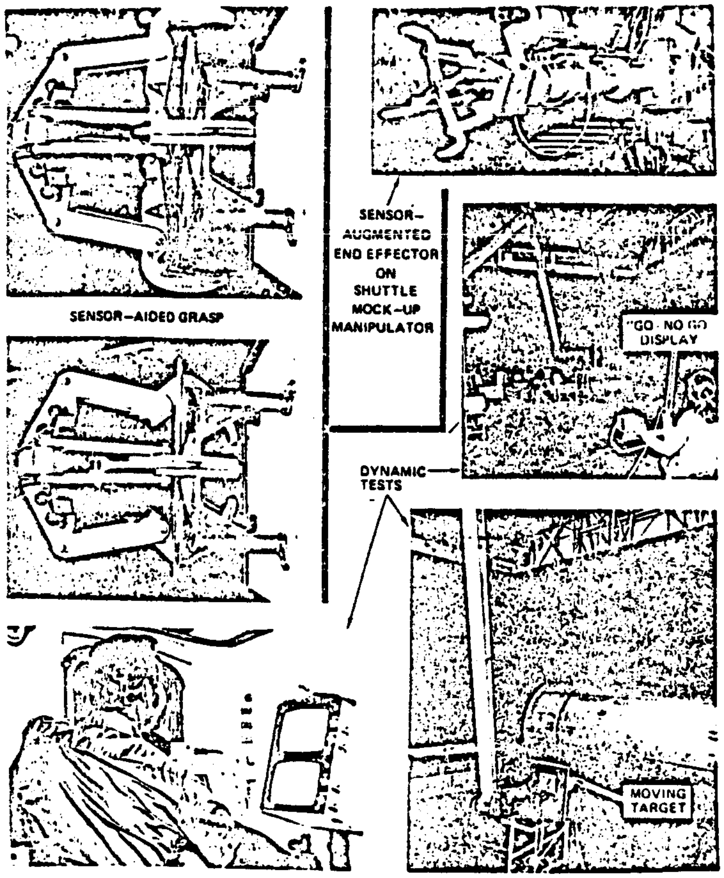
The graphic display resolution is 0.5 cm per display element in depth, and 1 degree per display element in pitch and yaw errors. The quantitative value of each error bar is increasing away from the center green lamp. Hence, zero error for each bar is at the center of the display. This focuses the operator's 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.

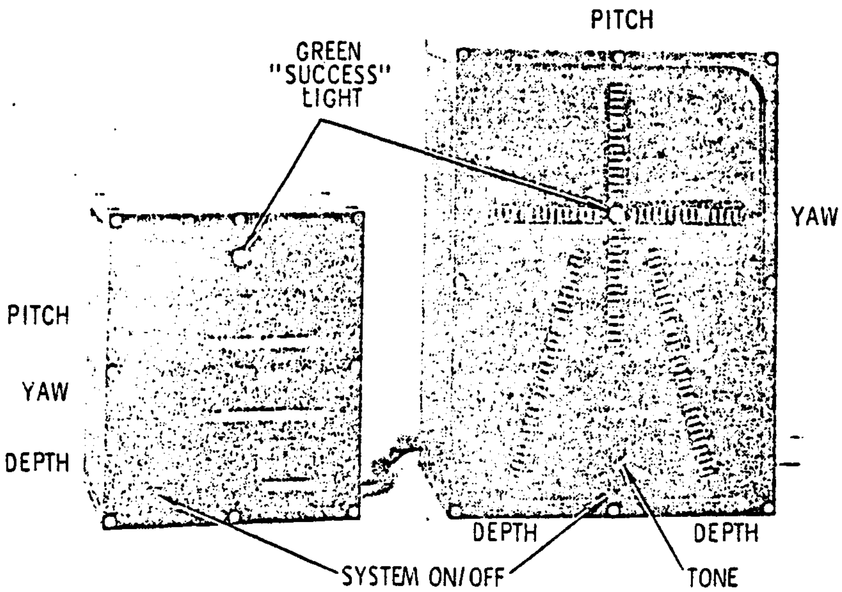
ACCOMPLISHMENTS
EXAMPLE

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

PROXIMITY SENSOR AIDED CONTROL OF SHUTTLE RMS AT JSC MDF

SUMMARY OF DYNAMIC TEST DATA

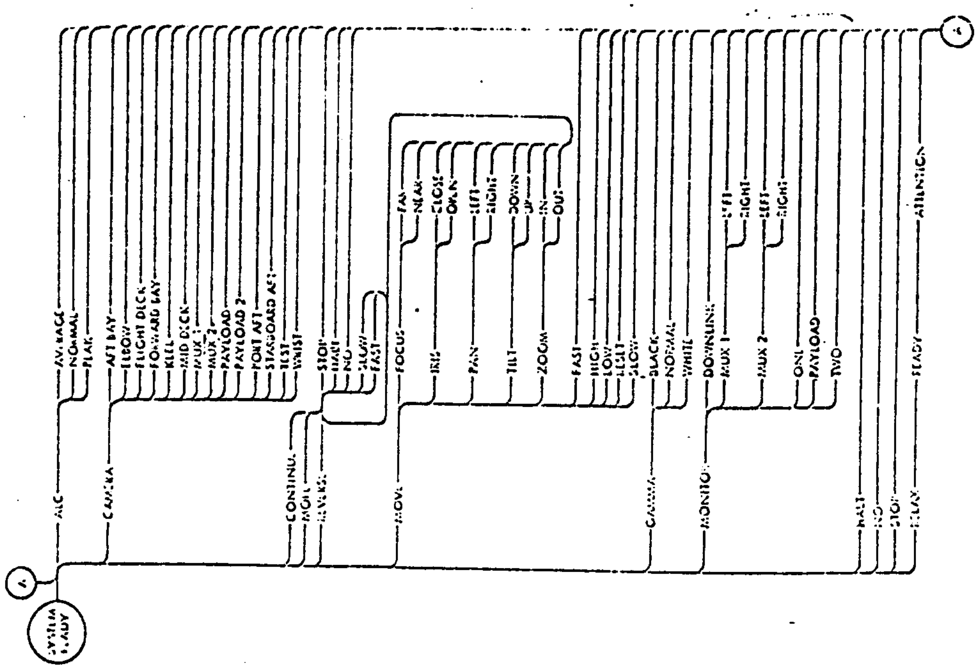
	USING GRAPHIC AND NUMERIC SENSOR DISPLAYS	USING ONLY "GREEN LAMP" SENSOR DISPLAY	WITHOUT SENSOR DISPLAYS
OPERATOR	AVERAGE RANGE ERROR (IN.)	AVERAGE RANGE ERROR (IN.)	AVERAGE RANGE ERROR (IN.)
NO. 1, 6 RUNS EACH	0.4	1.3	1.4
NO. 2, 6 RUNS EACH	0.5	0.8	1.1
NO. 3, 6 RUNS EACH	0.9	0.5	1.0
TOTAL OF 18 RUNS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

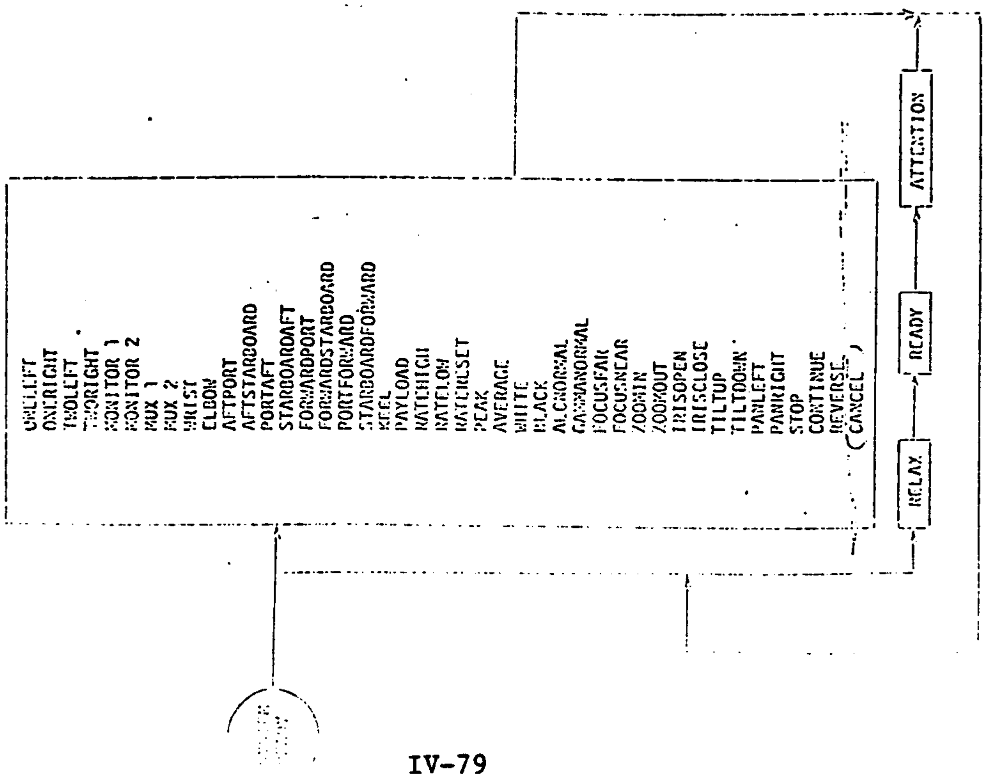
ACCOMPLISHMENTS EXAMPLE

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:

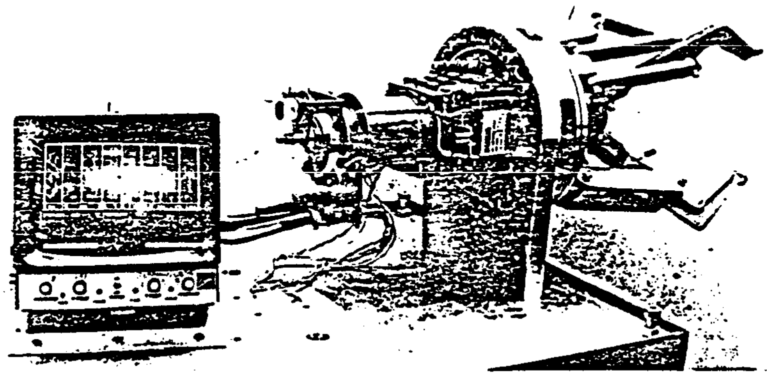
a) Two force-torque sensors; one is operating in the 0 to 100 lb (0 to 445 N) range, the other is the 0 to 200 lb (0 to 890 N) range.
b) A servo-controlled end effector drive system using a brushless DC torque motor in position or rate control mode; the rate control can be proportional or preselected 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.

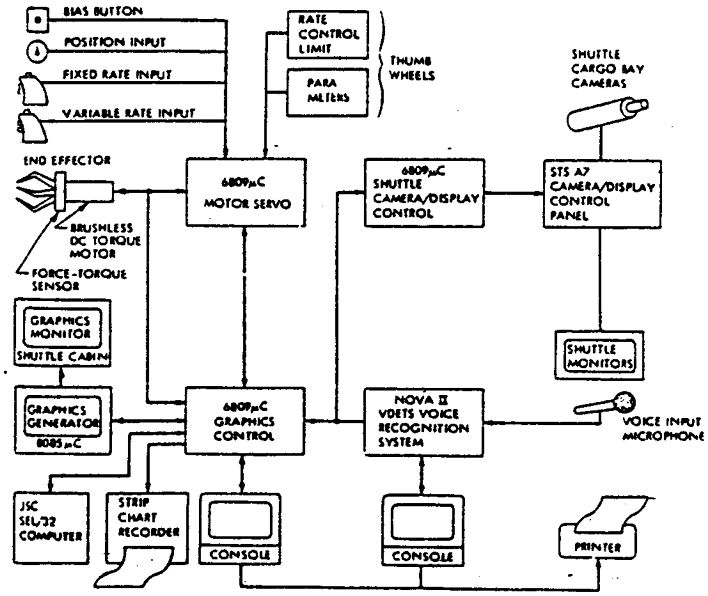
The forces and torques measured by the sensor at the base of the claws were displayed to the operator on a 9-inch B/W monitor in graphics format. This monitor was mounted to the right of the TV monitors as shown in the pictures. The graphics display generator used in the present experimental system has 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.

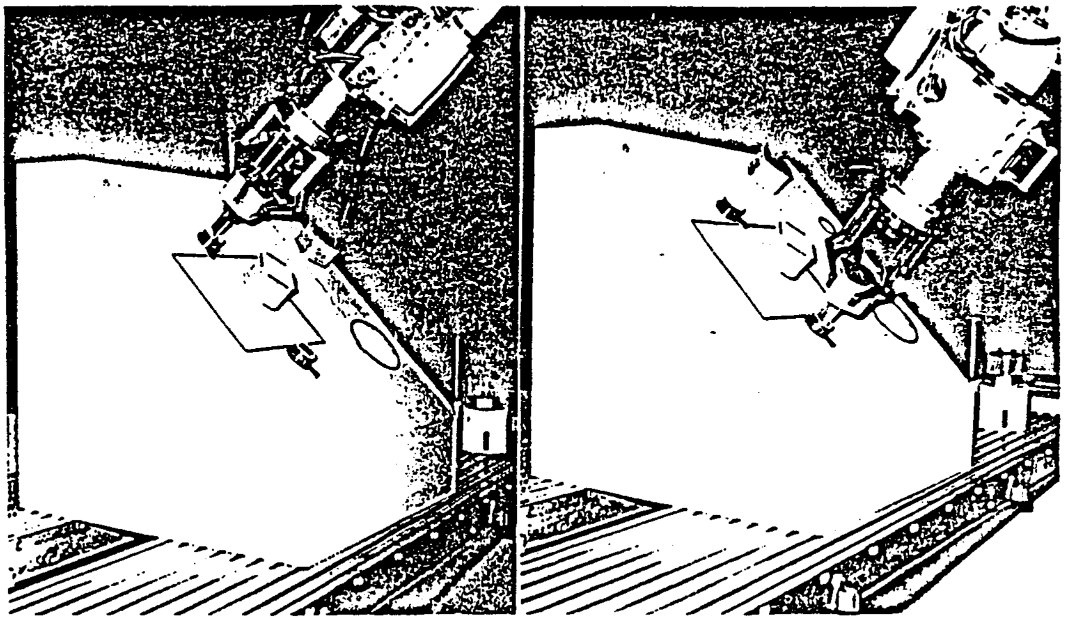
The "tool" and "module" handling task board was placed in the bay of the Shuttle mock-up, about 8 meters (25 feet) from the Shuttle cockpit. The task board contained (a) a box, (b) a keyed cylinder, (c) a screwdriver, and (d) a square-base wrench. The operator's task was to remove the "modules" from 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

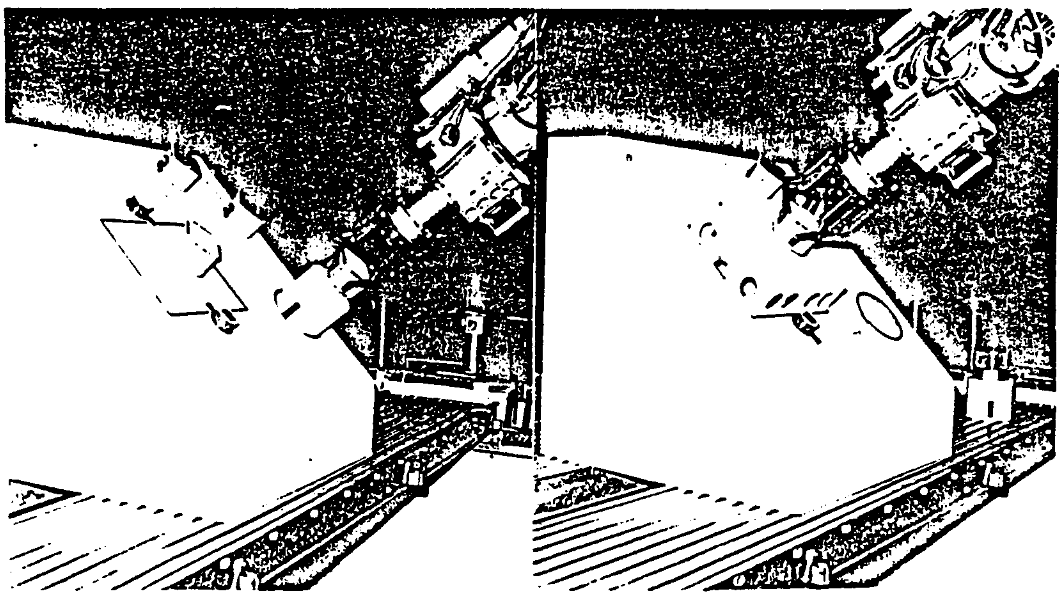
-TOOL HANDLING-



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.

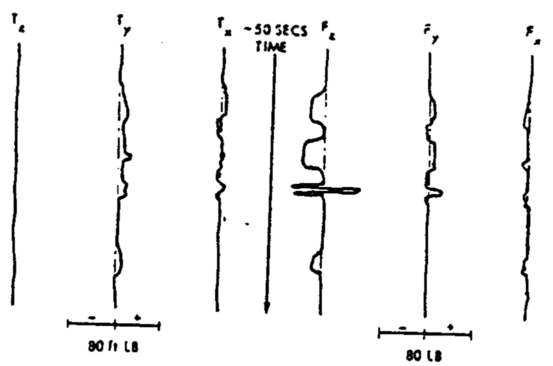
ACCOMPLISHMENTS
EXAMPLE

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

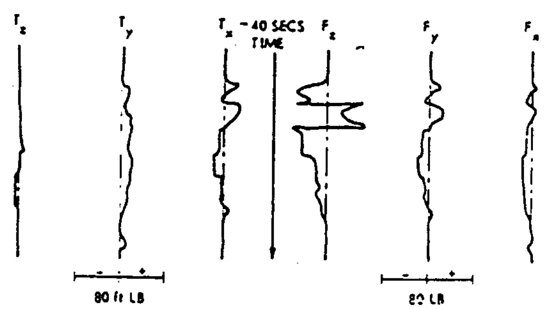
	mean Δt [min:sec]	max. Δt [min:sec]	min. Δt [min:sec]
START RUN			
BOX GRAPPLED	1:19	2:12	:26
BOX MANEUVERED	3:00	5:23	1:43
BOX INSERTED	4:26	21:20	:21
RED TOOL GRAPPLED	2:03	5:03	:01
RED TOOL EXTRACTED	0:30	2:18	:07
RED TOOL MANEUVERED	2:25	4:43	:20
RED TOOL INSERTED	1:19	4:23	:01
RED LATCH CLOSED	:38	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

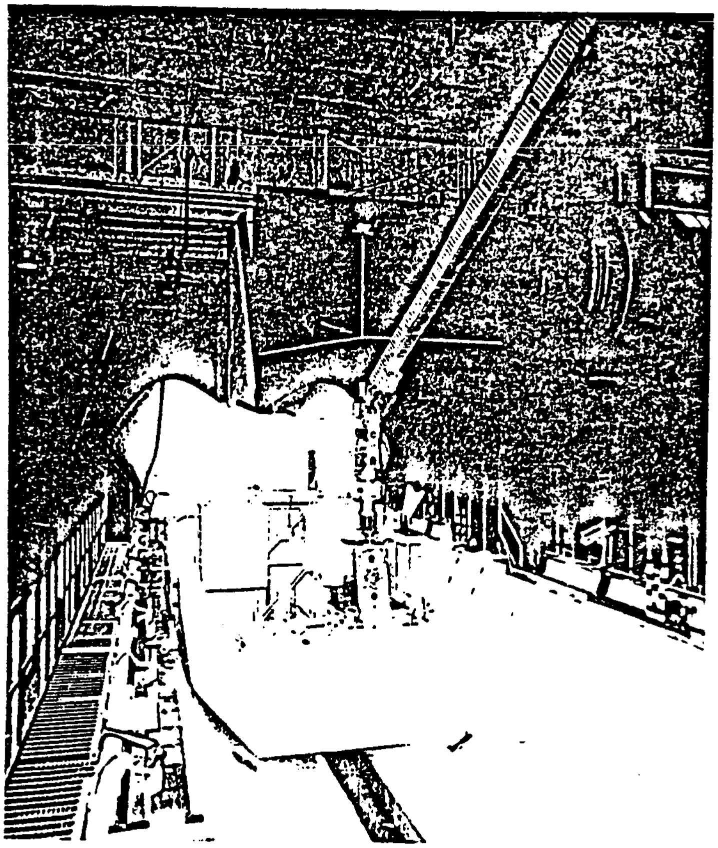
The objective of the payload berthing test was to maneuver the simulated PDP payload into a retention or latching mechanism shown in the figure. The latch assembly was placed in the bay of the Shuttle mock-up about 10 meters (30 feet) from the Shuttle cockpit. The berthing tests were performed so that 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.

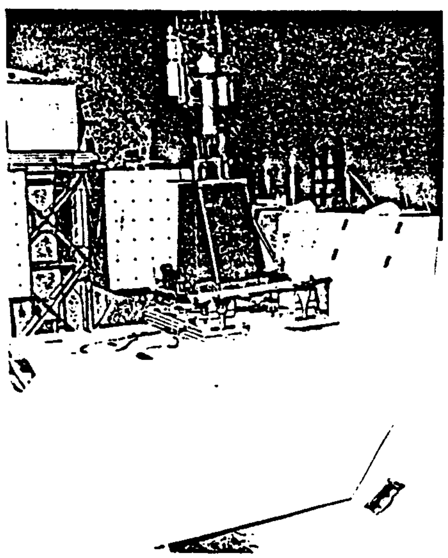
ACCOMPLISHMENTS
EXAMPLE

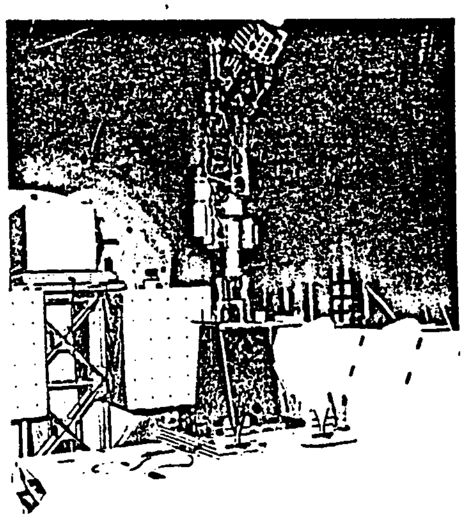
FORCE-TORQUE
CONTROL EXPERIMENTS
AT JSC MDF

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 <u>without</u> 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

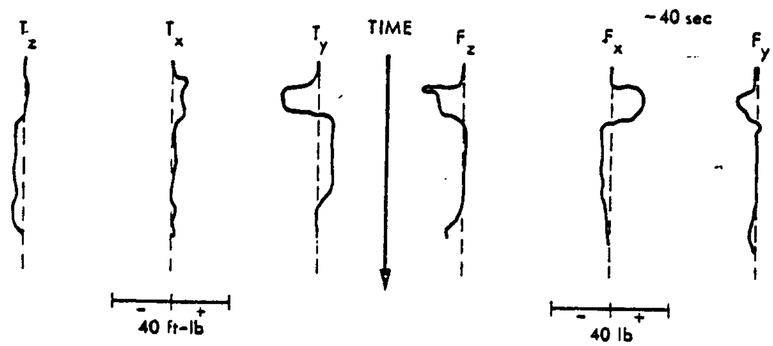
ACCOMPLISHMENTS EXAMPLE

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.

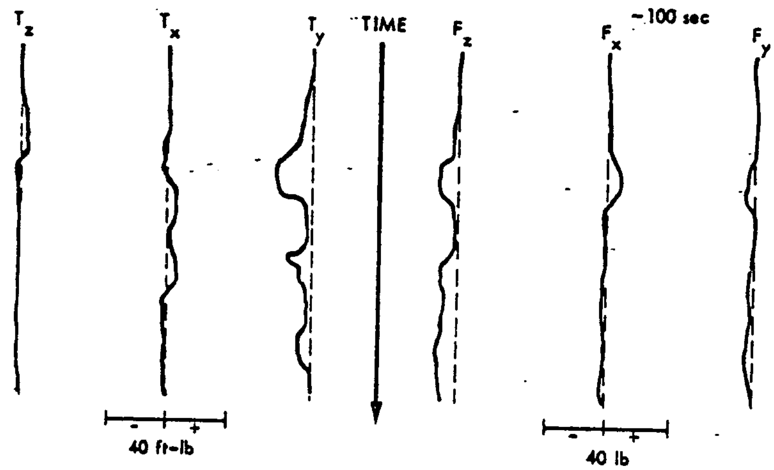
ACCOMPLISHMENTS EXAMPLE

FORCE-TORQUE CONTROL EXPERIMENTS AT JSC MDF

-PERFORMANCE DATA-

-PAYLOAD (PDP) BERTHING-

GRAPHICS + DV + TV



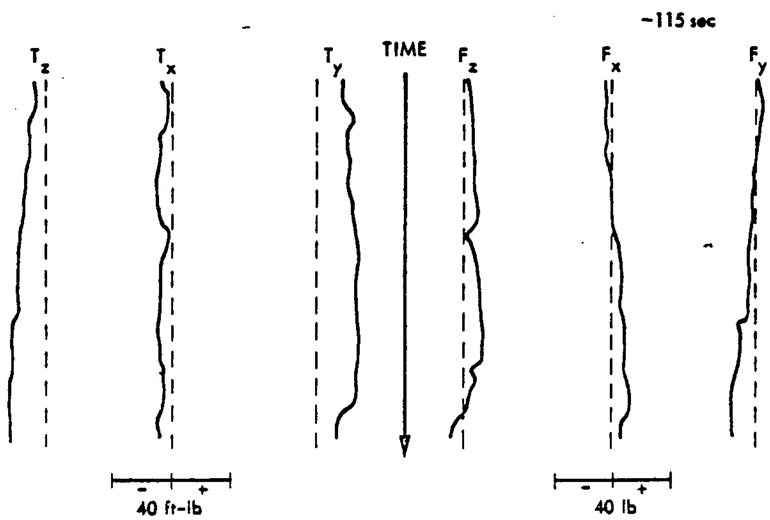
ACCOMPLISHMENTS EXAMPLE

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

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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

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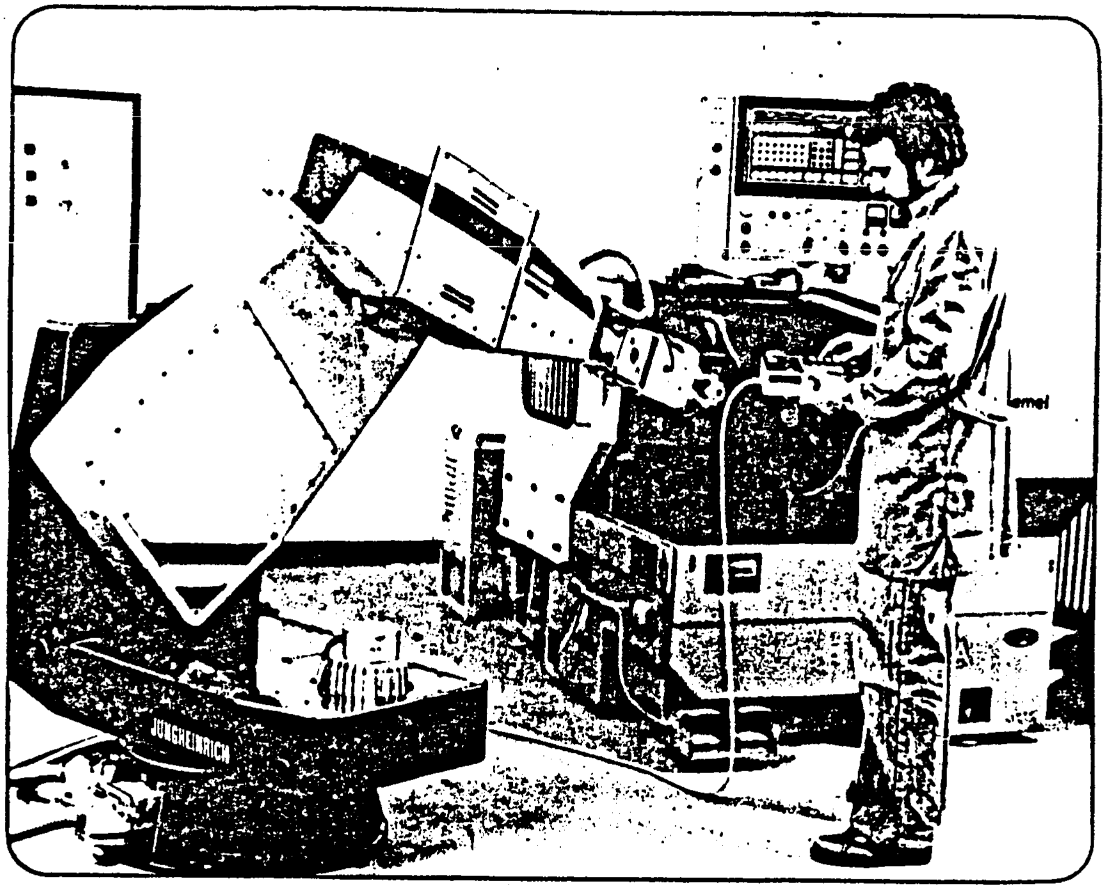
This is representative of the state of the art of industrial robots and the way industrial robots are programmed through teach-in or walk-through methods. Only very few off-lime programming languages are in practical use today. Most have been developed and are applied in a laboratory setting. In practical 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

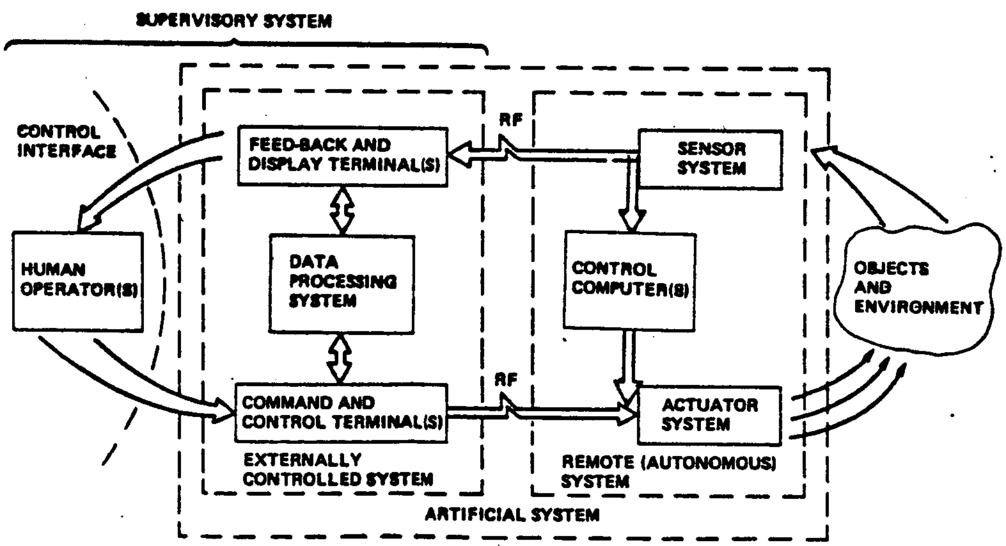
Nine industrial robot programming languages have been evaluated recently with respect to the twelve parameters identified on the left. The most widely used languages as of this date are T3 developed by Cineninaty Milacron and VAL developed by Unimation. T3 is a teach-in language and VAL is a language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

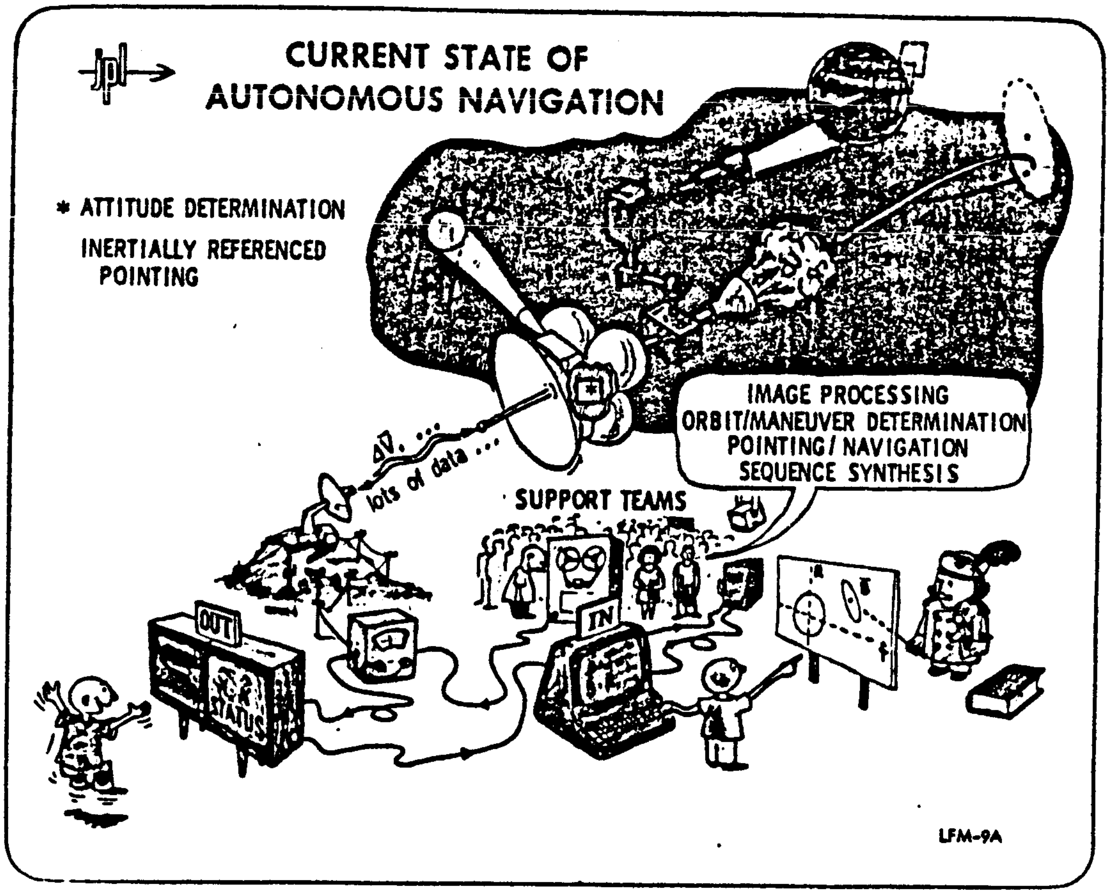
LEVEL 1	SERVO-LOOP FUNCTIONS MEETING EXTERNALLY-SET GOALS
LEVEL 2	EXECUTION OF EXTERNALLY-PLANNED SEQUENCES/PROGRAMS OF ACTIONS
LEVEL 3	ADAPTATION OF SERVO-LOOP PARAMETERS TO ACCOMMODATE ENVIRONMENTAL VARIATIONS
LEVEL 4	TOLERANCE OF SYSTEM FAULTS THROUGH DETECTION, LOCATION, AND RECONFIGURATION TO ISOLATE 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

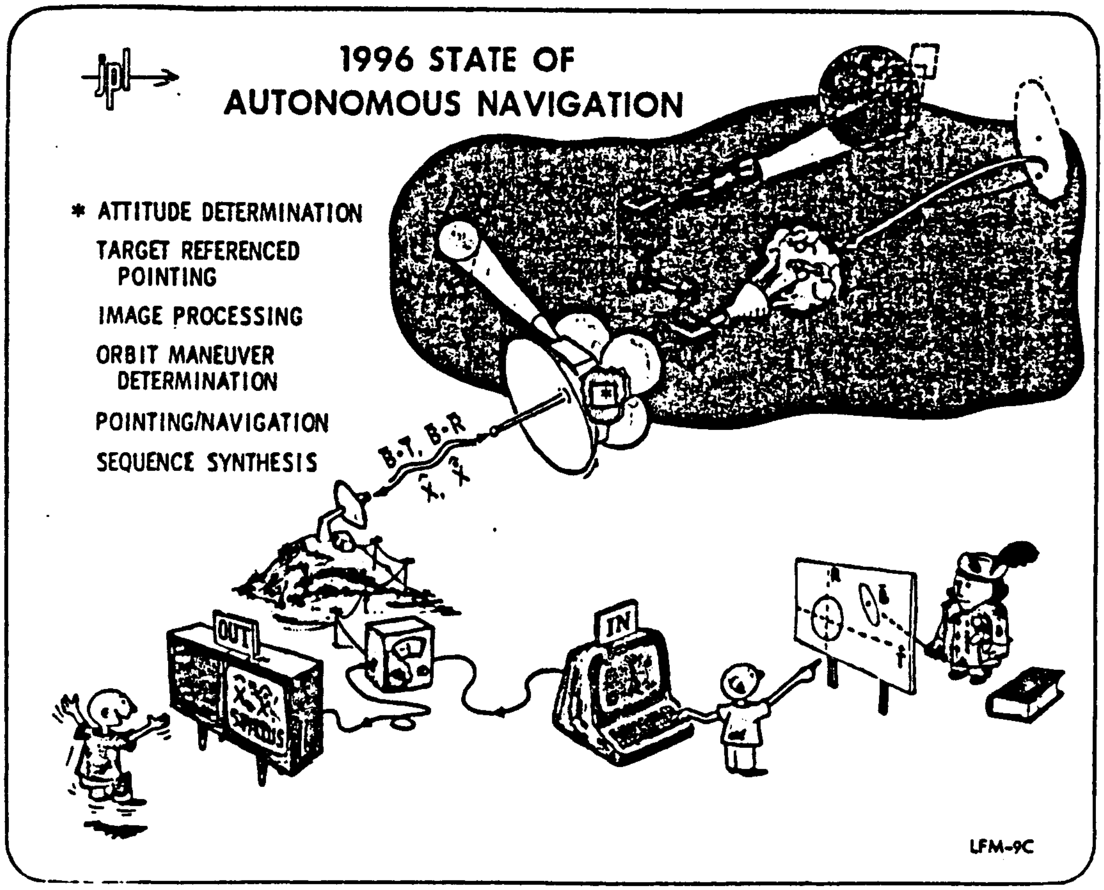
AUTONOMOUS SYSTEMS TECHNOLOGY
REASONS FOR AUTONOMOUS SYSTEMS

- 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

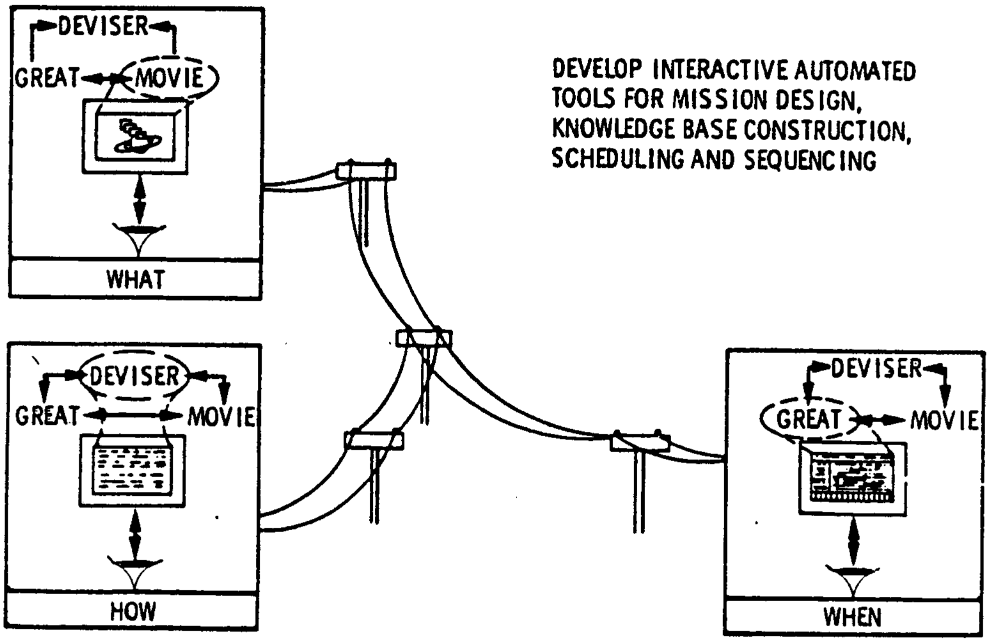
- WELL STRUCTURED PROBLEMS
  - ROUTINE, REPETITIVE DECISIONS
  - PROGRAMABLE DECISION PROCESSES
- ILL STRUCTURED PROBLEMS
  - NOVEL POLICY DECISIONS
  - NONPROGRAMABLE DECISION PROCESSES

- 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

INPUTS

- START STATE DESCRIPTION
- GOALS DESCRIPTION

KNOWLEDGE BASE

ACTION, EVENT, AND INFERENCE DESCRIPTIONS

E.G. ROLL
SLEW
PLATFORM SETTLING

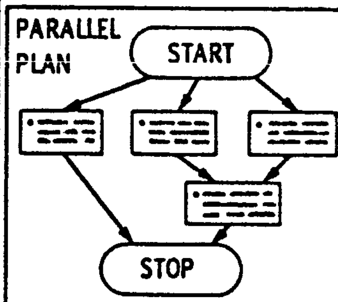
SCHEDULED EVENT DESCRIPTIONS

- OCCULTATIONS
- DATA RATE CAPABILITY CHANGES

⇒ DEVISER ⇒

OUTPUTS

PARALLEL PLAN

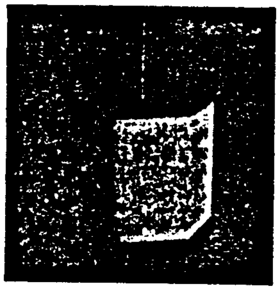


SEQUENCE OF EVENTS

TIME	ACTION/EVENT
00:00	TURN OFF HEATERS
00:19	ROLL
⋮	⋮
01:36	SHUTTER CAMERA

Vere
3/82

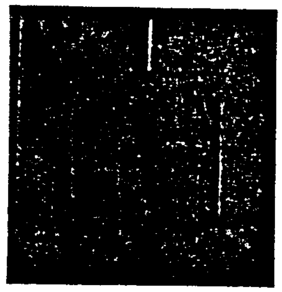
JPL ROBOTICS LABORATORY VISION RESEARCH
ROBUST REAL-TIME 3-D OBJECT TRACKER



DIGITIZED IMAGE OF OBJECT TO BE TRACKED

"IMFEX" R/T PROCESSING
+ TRACKER SOFTWARE

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

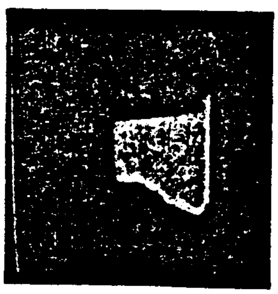


PREVIOUS DETECTION (FAINT LINES)
OBJECT PREDICTS (BRIGHT LINES)
CURRENT/ACTUAL DETECTION (DOTS)
ERROR TRACKING (DOTS VS BRIGHT LINES)

3-D VISION SYSTEM

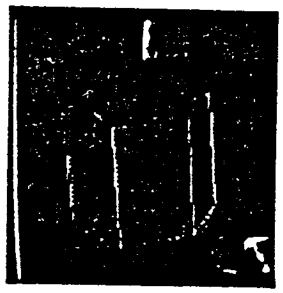
- 2 CID CAMERAS/GE
- "IMFEX" PIPE-LINE IMAGE PROCESSOR/JPL
- 188 x 240 "RAPID" DIGITIZER/JPL
- SPC-16 MINICOMPUTER
- REAL-TIME TRACKER SOFTWARE/JPL
- SUPPORTING SOFTWARE AND PERIPHERALS

OBJECT PARTIALLY OBSCURED



CONCLUSION

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

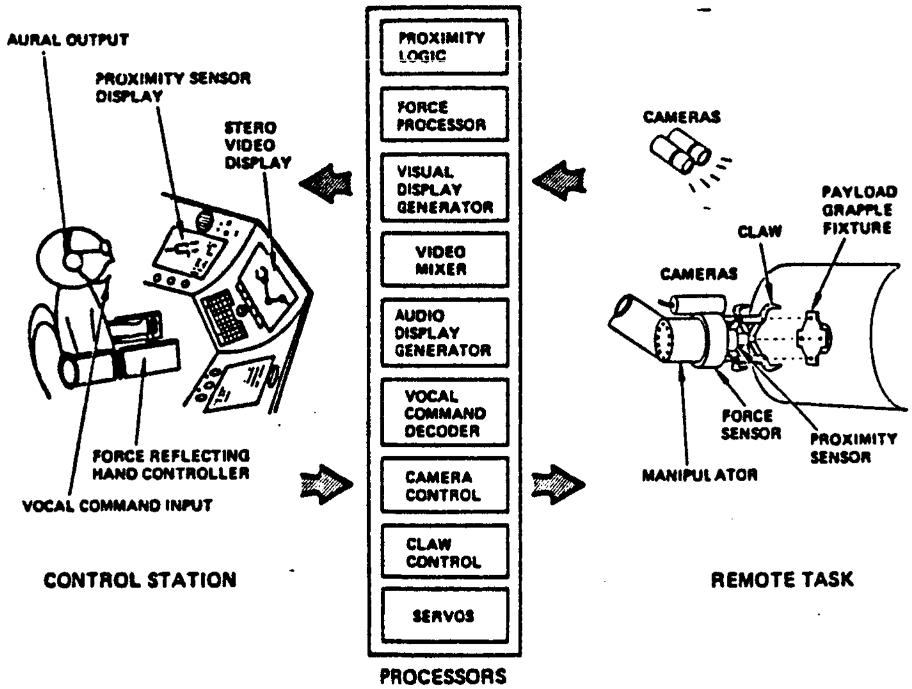


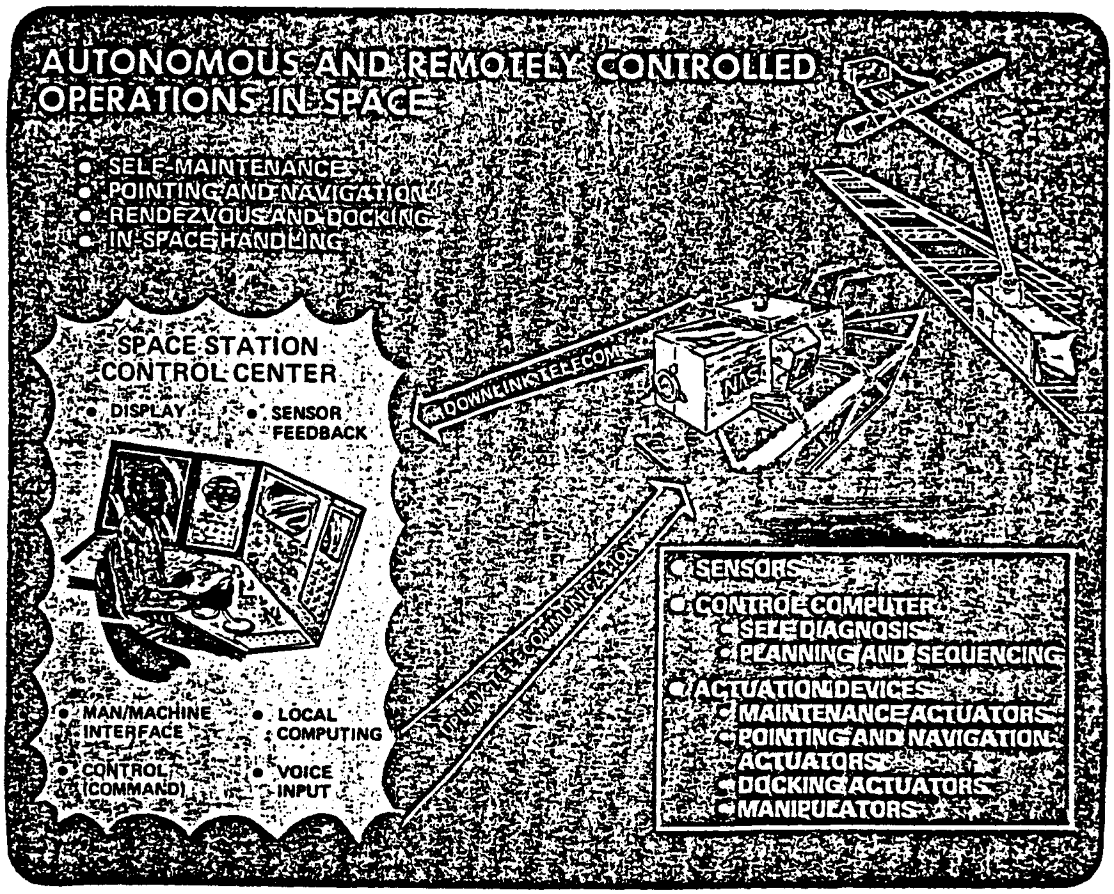
Past years of research in the Jet Propulsion Laboratory Teleoperators Laboratory have been supported by NASA, Office of Life Sciences, Johnson Space Center, and contracts with Oakridge National Laboratory (Department of Energy funds). Research and development thrusts have been in human-machine interfaces,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

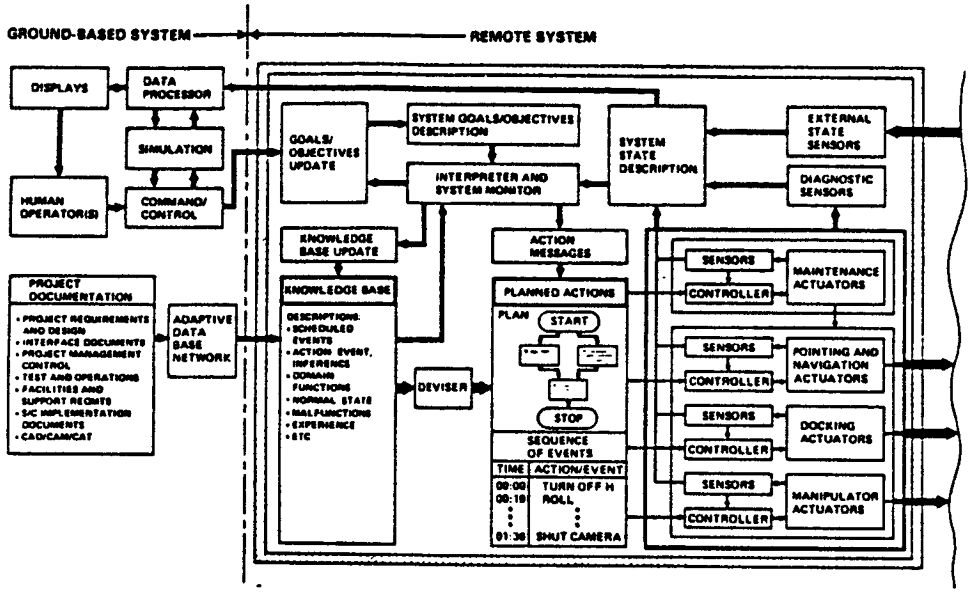




A schematic for the architecture for supervisory system

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.

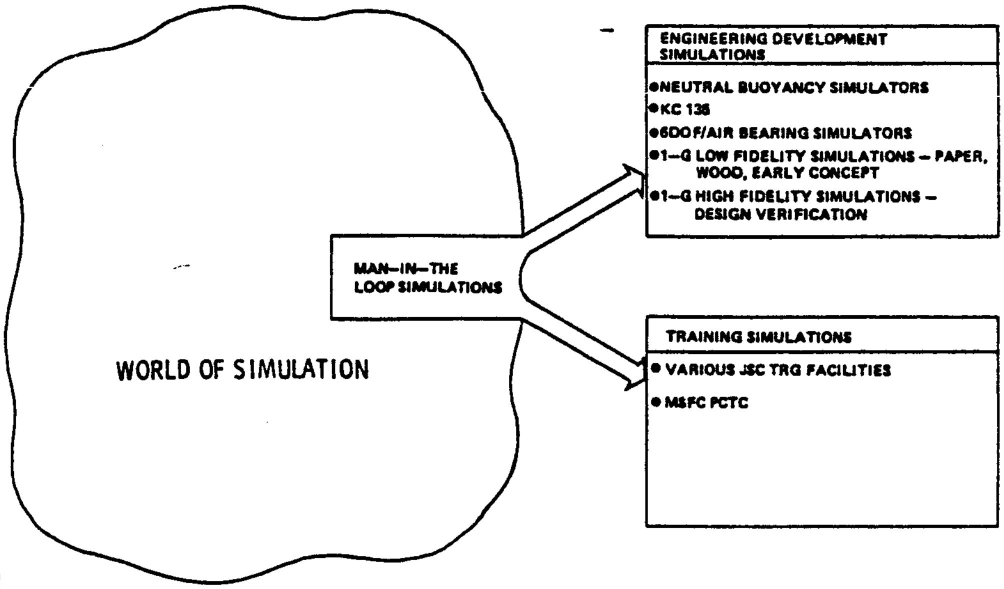
The major utility of such simulation techniques include the performance of basic man/machine research (results for human engineering standards), man/machine concept design/development, man/machine verification testing, and finally operations development. The last is usually not considered as an engineering 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 10305

ORGANIZATION:		NAME:
MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	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:		NAME:
MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	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:

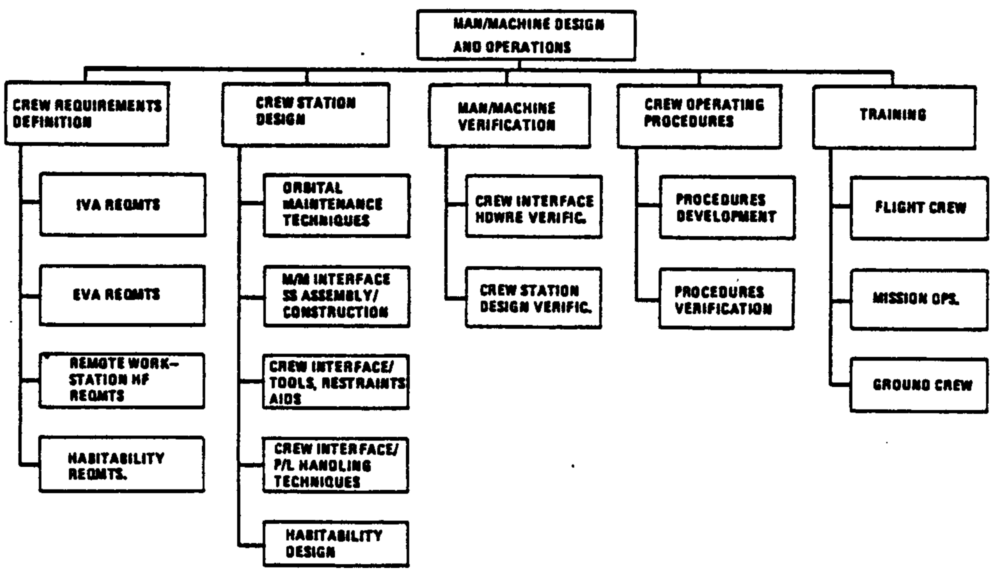
- TO PREPARE FLIGHT AND GROUND PERSONNEL TO PERFORM TASKS/FUNCTIONS NECESSARY FOR MISSION ACCOMPLISHMENT
- VERIFY HUMAN COMPONENT IN MANNED SPACE SYSTEM

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 10312

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.

EL16309

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

EL16310

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

MSFC - Form 3300 (Rev October 1972)

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: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. JONES 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: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES 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

MSFC - Form 3384 (Rev October 1978) 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. Student Station 1
   - 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. Student Station 2
   - 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: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES 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: MSFC/EL15	MARSHALL SPACE FLIGHT CENTER HUMAN ROLE IN SPACE	NAME: J. W. STOKES 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

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

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, & CONTIN–GENCY 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	NAME: J. W. STOKES
	HUMAN ROLE IN SPACE	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

MSFC - Form 3385 (Rev October 1972)

FILE NO. ________

THE ALLOCATION OF MAN/MACHINE FUNCTIONS

Ken Fernandez
NASA-MSFC-EB44

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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

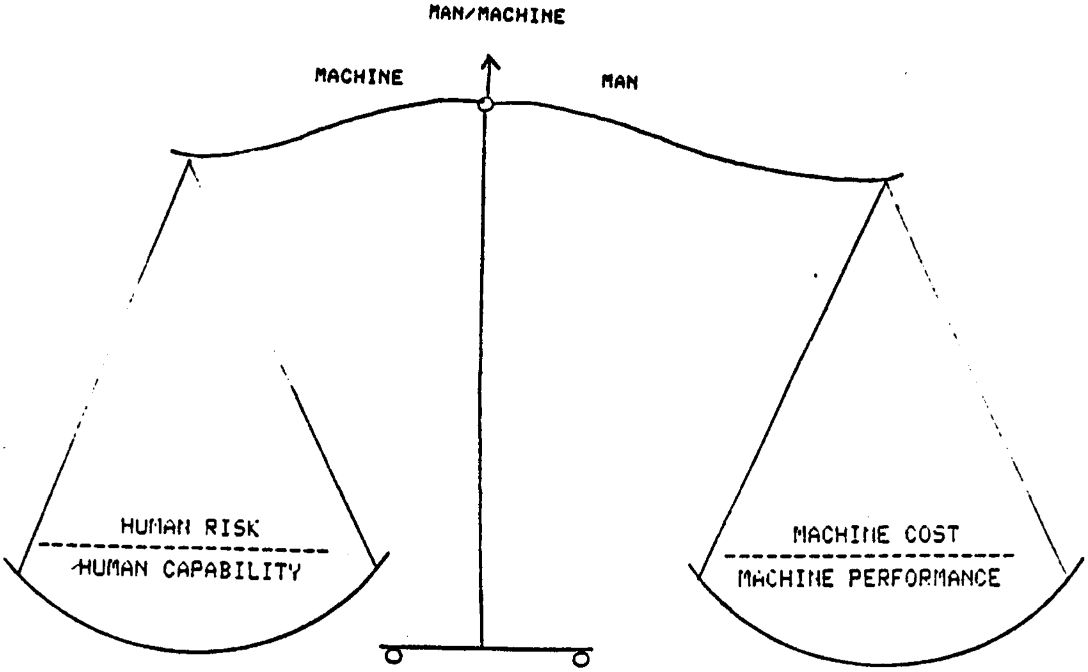

Figure 1 Man/Machine Function Allocation

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

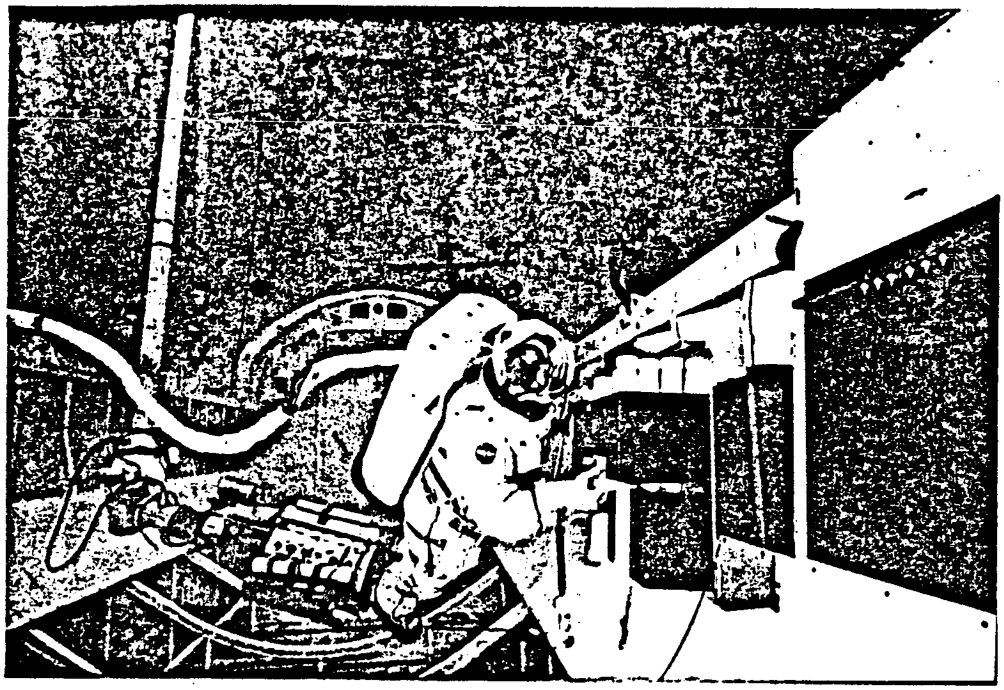

Figure 3 NBS EVA Film Pack Exchange

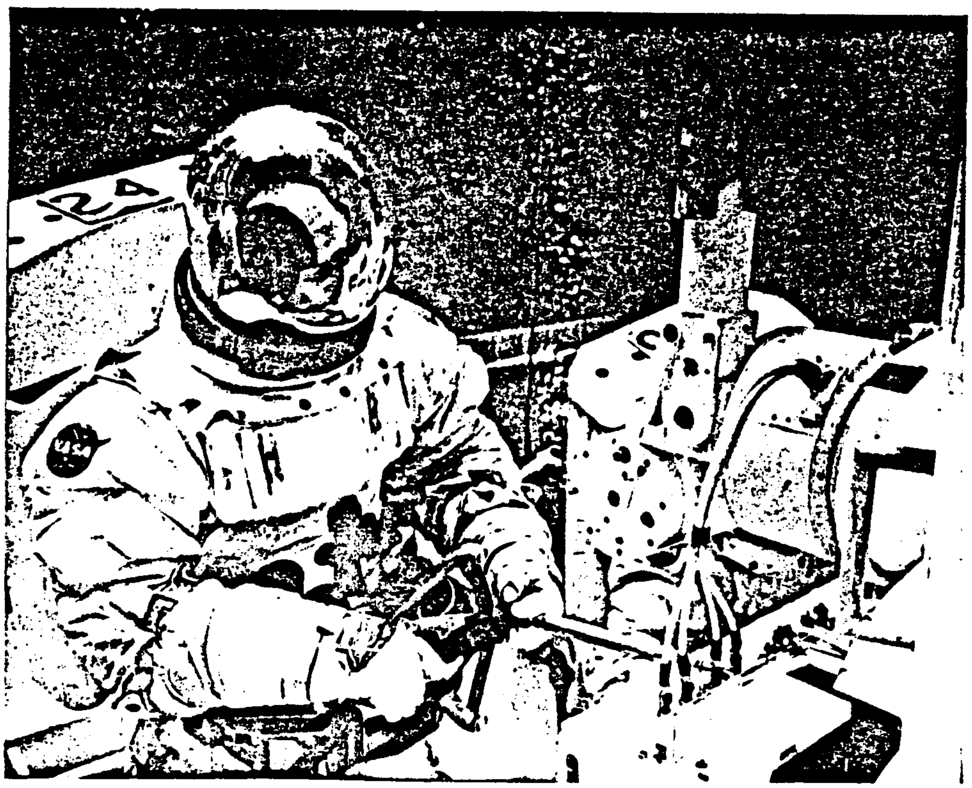

Figure 4 NBS EVA Power Wrench

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

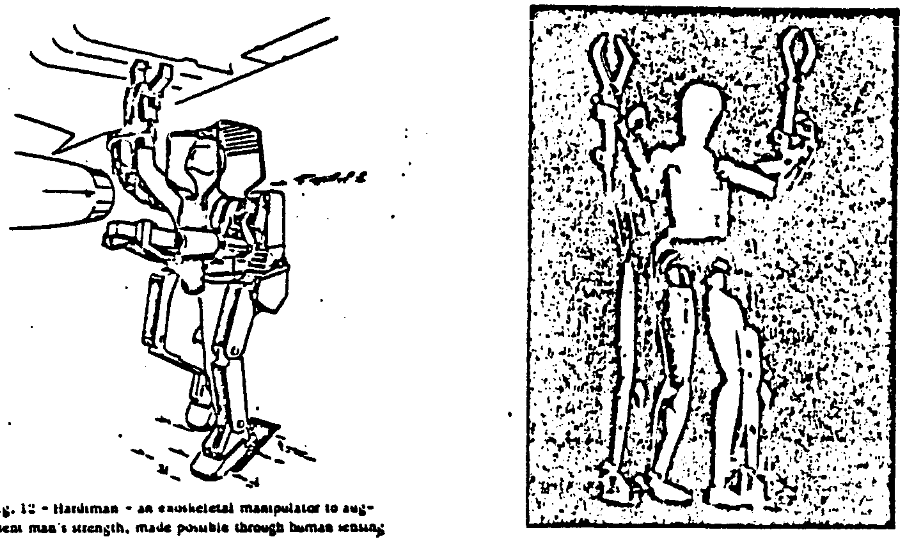

Fig. 12 - Hardiman - an exoskeletal manipulator to augment man's strength, made possible through human sensing control

Figure 5 Mosher's Hardiman System

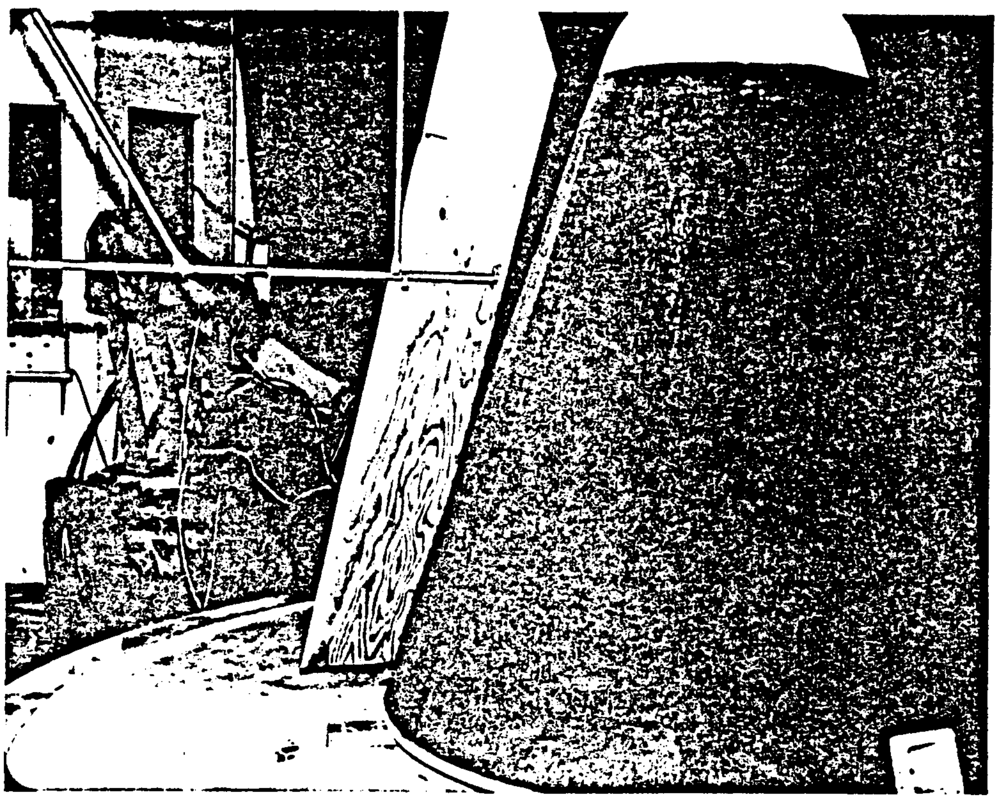

Figure 6 SRB TPS Spray Cell at KSC

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(2) Mosher, R. S.,"Handyman to Hardiman," Society of Automotive Engineers, Inc., Automotive Engineering Congress, Detroit, Michigan, Report # 670088, January 1967.

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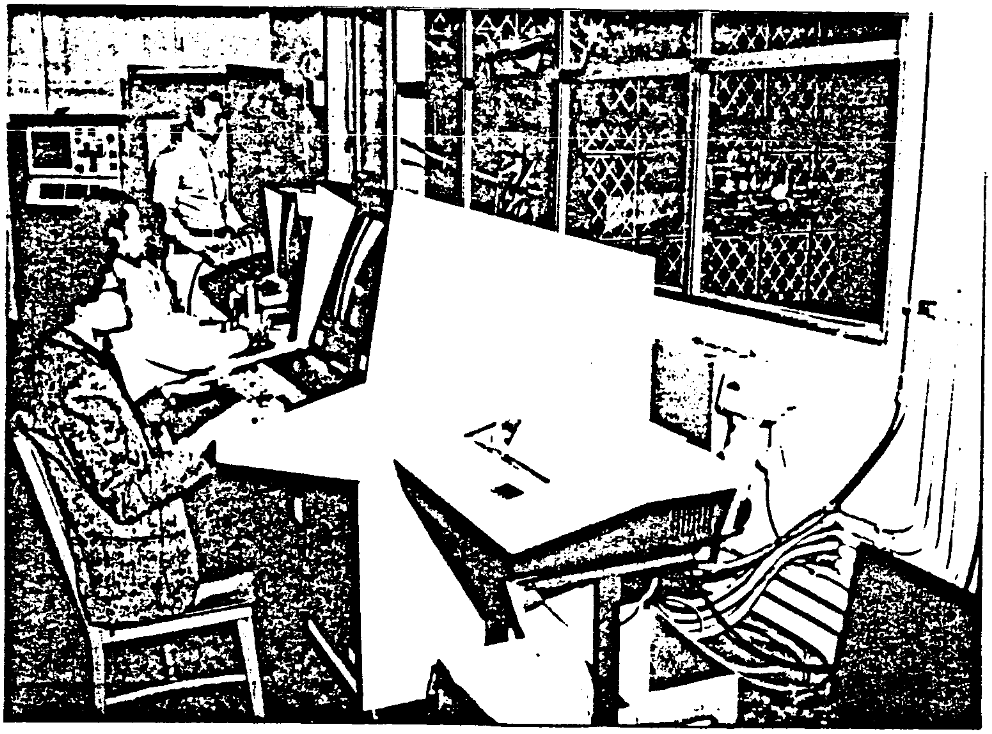

Figure 7 ET SOFI Development Cell at MSFC

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

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

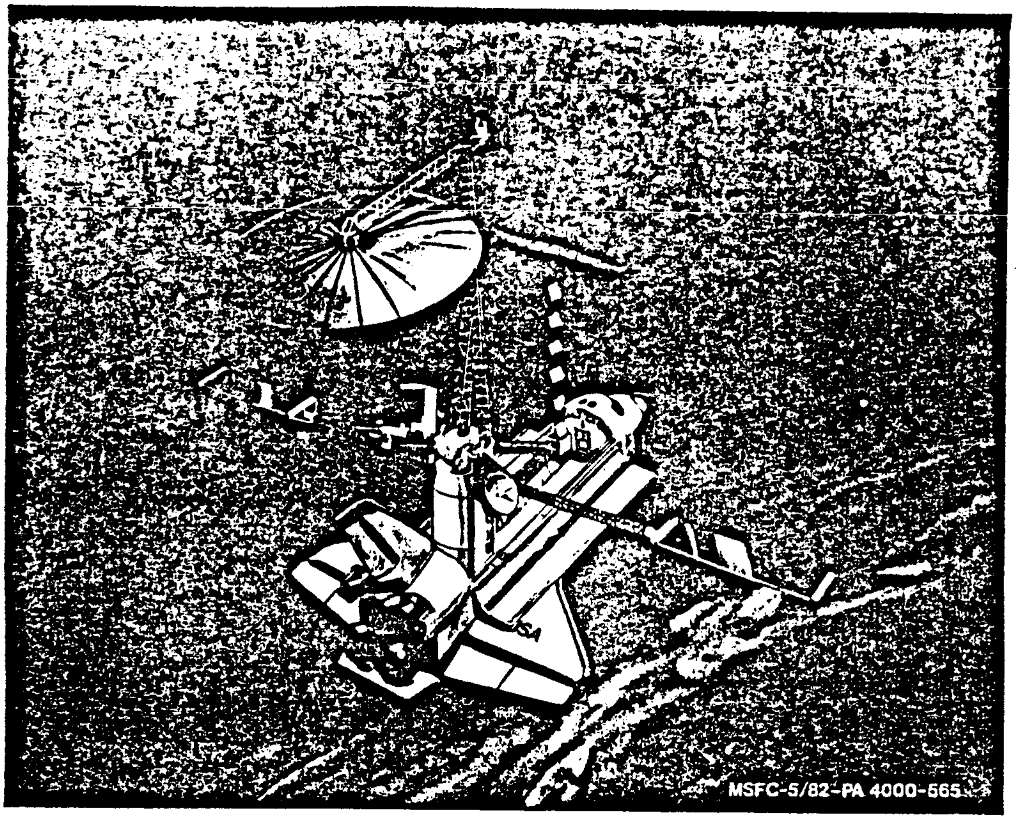

Figure 11 GEO Platform

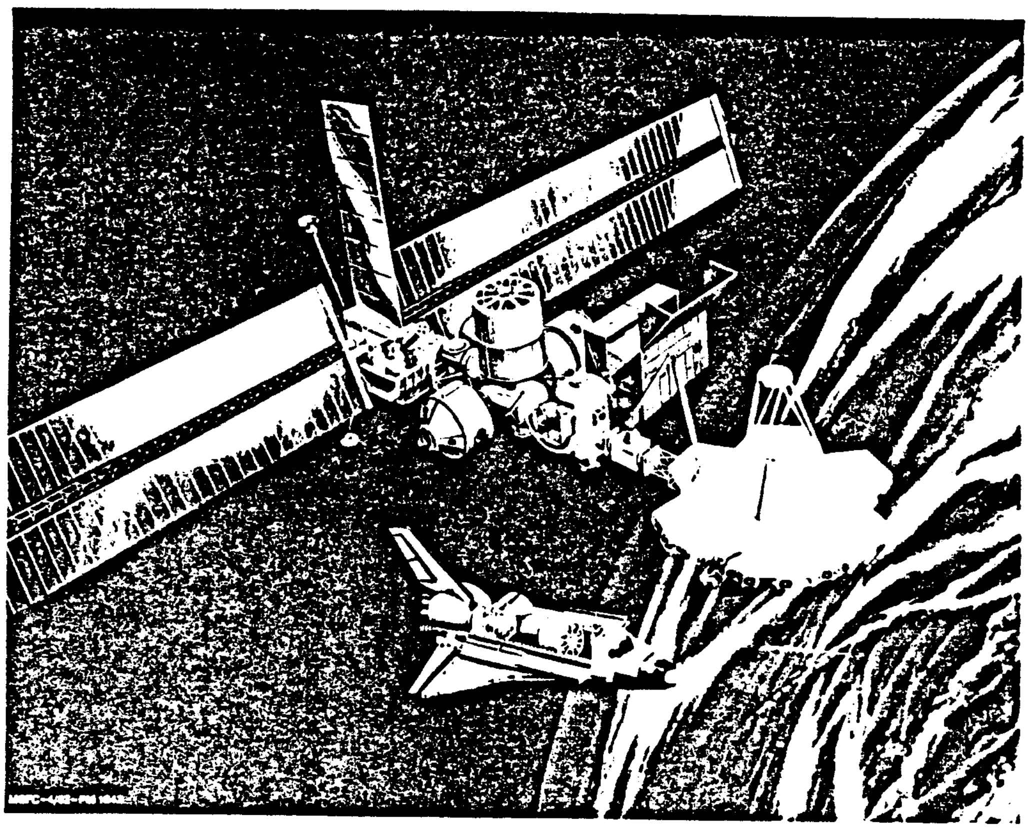

Figure 12 Space Station

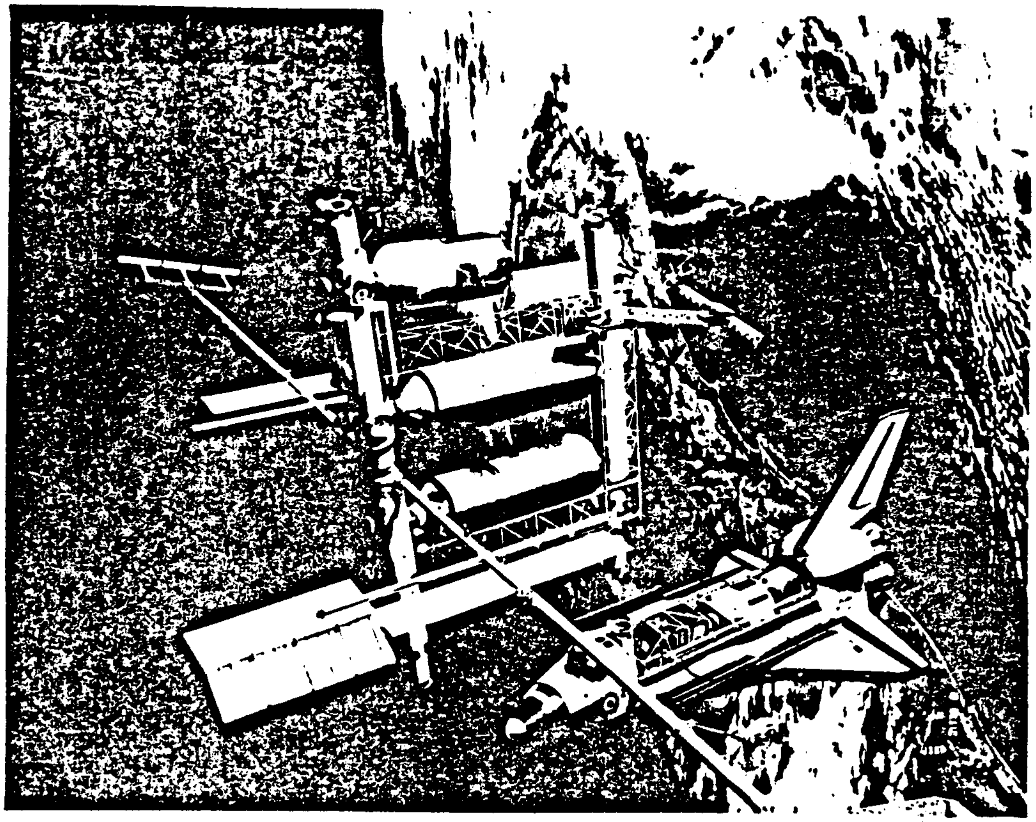

Figure 13 Alternative Space Station

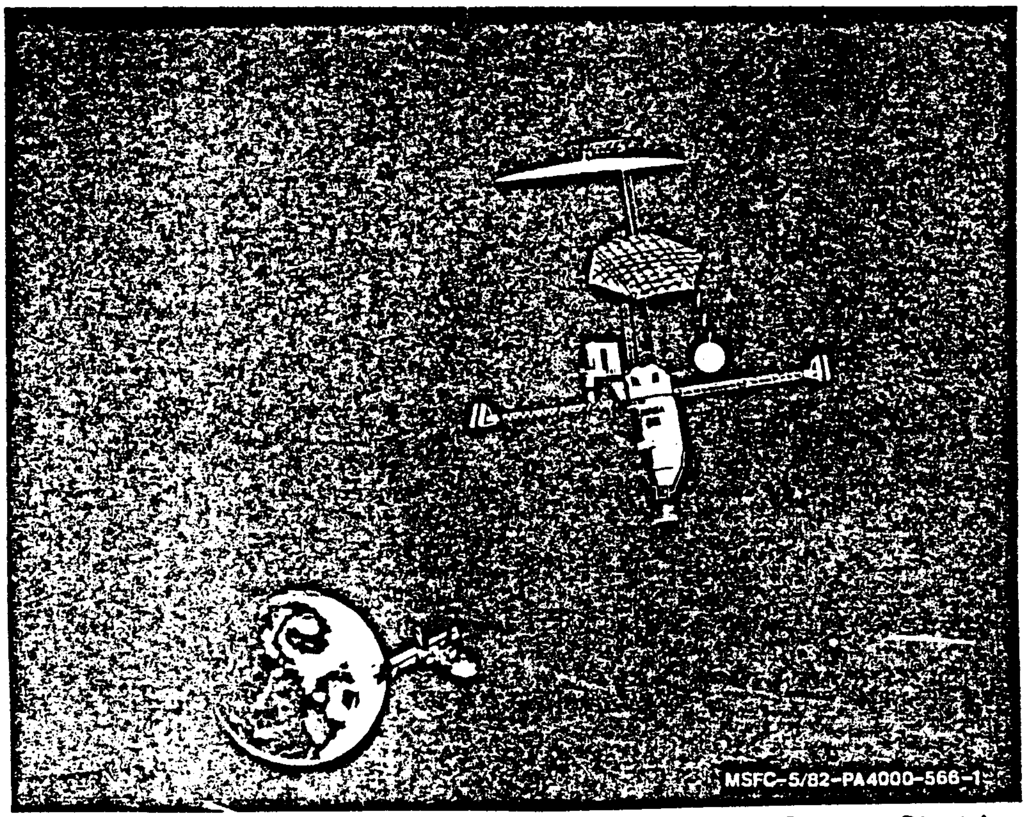

Figure 14 GEO Platform Departing Space Station

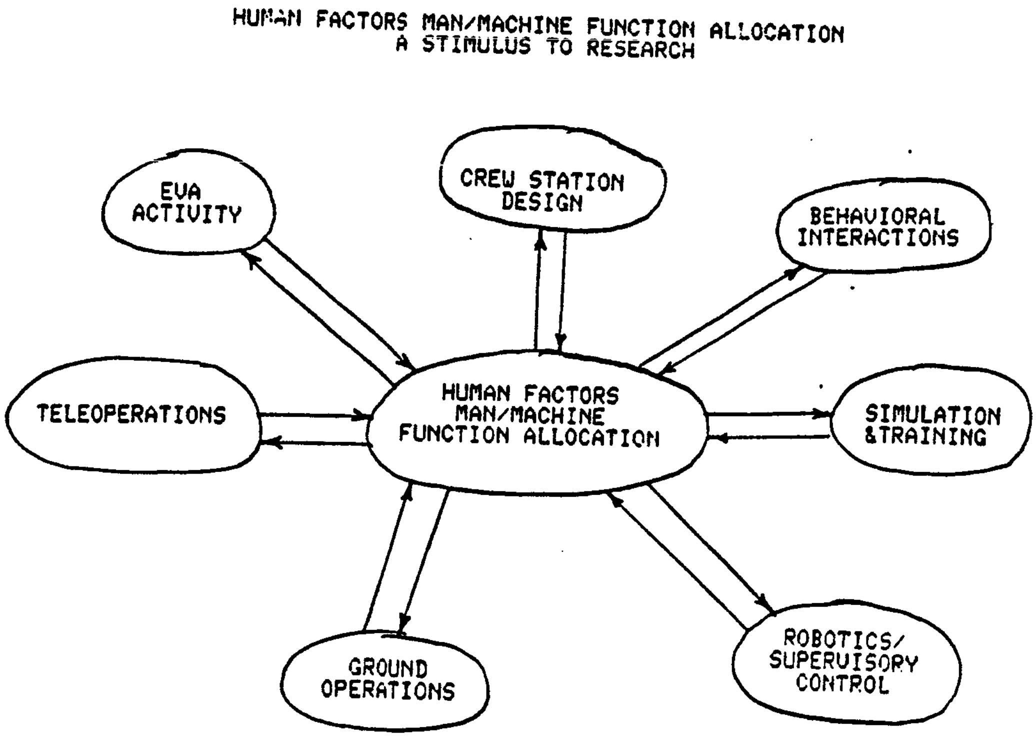

Figure 15 Man/Machine Allocation as a Stimulus to Research

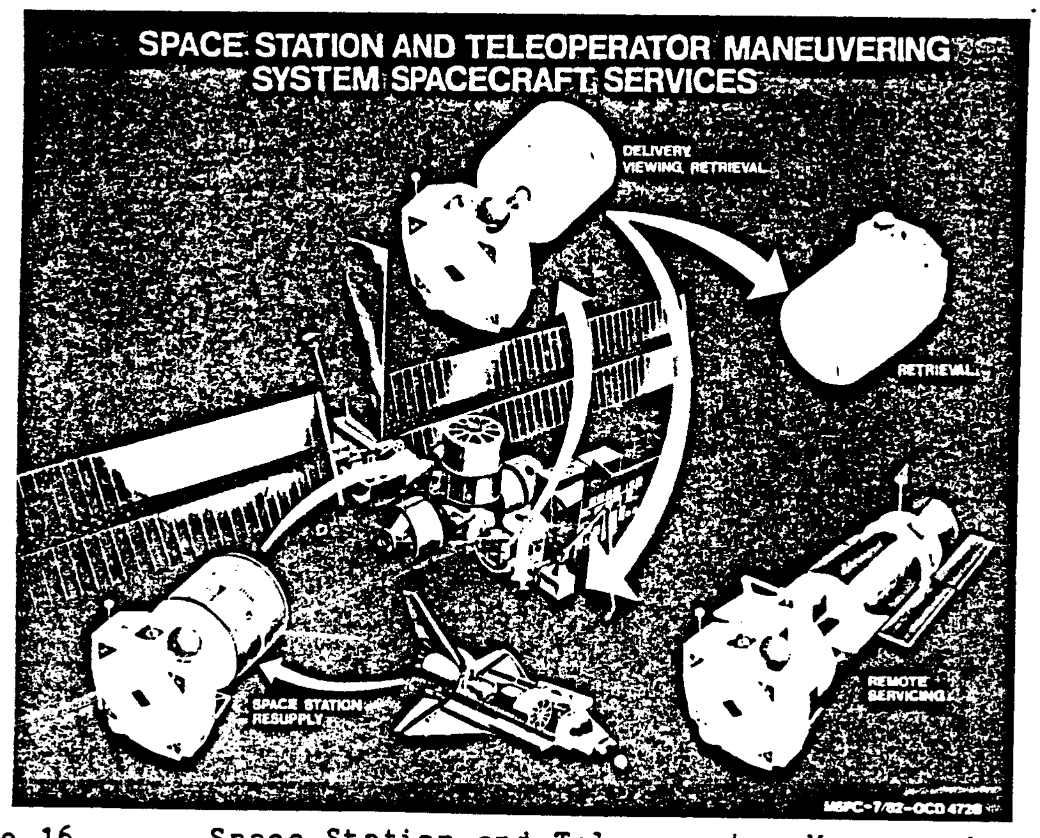

Figure 16 Space Station and Teleoperator Maneuvering System Performing Spacecraft Services