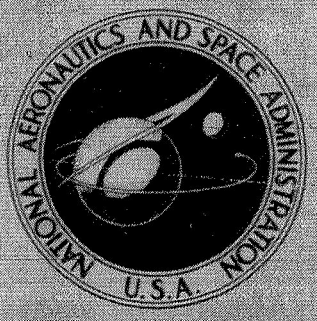
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ASTRONAUT ZERO GRAVITY PERFORMANCE EVALUATION PROGRAM

Detailed Technical Report

by D. G. Norman, G. Miller, M. C. Grohman, and R. W. Jones

Prepared by
GENERAL ELECTRIC COMPANY
Philadelphia, Pa. 19101
for Manned Spacecraft Center

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16. Abstract The Astronaut Zero Gravity Performance Evaluation Program was designed to fill a gap in our knowledge of man's capabilities to perform complex tasks in the zero-gravity environment. The resultant experimental program involved an evaluation of the major facets of astronaut performance while restricted to a limited work-site area. The program was performed during the period July 1968 through February 1970 and encompassed: (1) The definition and preliminary design of Experiment M508, an experiment concerned with astronaut worksite performance evaluation; (2) The fabrication of prototype hardware and collection of simulated astronaut worksite performance data using various ground based zero-gravity simulation modes; (3) The collection of additional data on man's force emission capability to establish 1-g and zero-g baselines; and (4) The preparation and publication of a Handbook of Human Engineering Design Data for Reduced Gravity Conditions.

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PREFACE

The final report on the Astronaut Worksite Performance Program for the development of Experiment M508 is presented in three volumes. The volume designations are:

Volume	Title
I	Summary Technical Report (N70-34195 - CR-108569)
II	Detailed Technical Report
III	Handbook of Human Engineering Design Data for Reduced Gravity Conditions

The analytical, design, manufacturing and certain ground based zero gravity simulation portions of the program were performed by the Space Systems Organization of the General Electric Company Space Division.

In addition, considerable support was provided at the Manned Spacecraft Center, Marshall Space Flight Center and the Aeronautical Systems Division at Wright-Patterson Air Force Base. We would like to acknowledge those personnel who provided this support.

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SECTION 1

INTRODUCTION

The purpose of this final study report is to present the results of the work performed under Contract NAS9-8640, "Astronaut Zero Gravity Performance Evaluation Program". The program was performed during the period July 1968 through February 1970 and encompassed:

a. The definition and preliminary design of Experiment M508, EVA and IVA Hardware Evaluation, concerned with astronaut worksite performance evaluation.

b. The construction of two prototype models of the M508 Task Panel to verify design concepts, develop manufacturing procedures and to collect simulated astronaut worksite performance data.

c. The conduct of Experiment M508 using various ground based zero-gravity simulation modes.

d. The collection of additional data on man's force emission capability to establish 1-g and zero-g baselines.

e. The preparation and publication of a Handbook of Human Engineering Design Data for Reduced Gravity Conditions.

The Astronaut Zero Gravity Performance Evaluation Program was designed to fill a gap in our knowledge of man's capabilities to perform complex tasks in the zero-gravity environment. The resultant experimental program involved an evaluation of the major facets of astronaut performance while restricted to a limited worksite area. The program involved evaluation of the efforts required to install and enter different restraint concepts, remove panels and covers assoicated with gaining access to a work area, performance of specific tasks designed to evaluate the interactions between basic psychomotor behaviors and the parameters of the EVA/IVA, zero-gravity environment and equipment.

The total program efforts and results are summarized in Volume I, Summary Report and presented in detail in Volume II, Detailed Technical Report. Volume III consists of the Handbook of Human Engineering Design Data for Reduced Gravity Conditions and is an entirely independent document suitable for distribution by NASA as a basic handbook.

SECTION 2

PROGRAM SCOPE

This program was designed to broaden the knowledge base concerning man's ability to perform useful work in a zero-gravity environment. The approach in the attainment of this goal involved a three-pronged effort. The first element involved the definition, preliminary design and conduct of Experiment M508, an experimental program to provide data on astronaut orbital EVA and IVA worksite performance capability and support hardware. The objectives of this experiment were to provide:

a. Correlation of ground-based simulation with in-flight conditions.

b. Quantitative human worksite performance capability under zero gravity conditions.

c. Comparative evaluation of IVA/EVA restraints, tools, and pressure suits.

The second element involved the conduct of an experiment for the collection of one-g baseline and zero-g shirtsleeve force emission data through the use of neutral buoyancy simulation techniques. This provides data to supplement those available from the force-emission experiment (Experiment 84) conducted under Contract NAS8-18117 for the NASA/MSFC.

The third element involved the continuation and completion of the handbook also initiated under Contract NAS8-18117. This Handbook of Human Engineering Design Data for Reduced Gravity Conditions provides available subgravity performance data to the designers of spacecraft and was also used as input data for the experiment definition and system design effort above.

The scope and rationale of Experiment M508 merits further consideration and is adequately described in the early experiment definition and implementation plans that are quoted below:

> "The most important end objective will be that associated with the comparison between the results of flight and simulation tests, because simulations are the most productive sources of information available to guide the design work required for future missions. Practically any specific task can be simulated, and thus, the most fruitful human engineering experiments for the near future will be ones that help to establish how the results of simulations relate to experience in actual free flight. The value of the limited amount of experimentation that can be performed in the AAP mission will be multiplied many fold if the results yield generally applicable conclusions on how to conduct and analyze simulations to obtain valid information about how to work efficiently and safely in space. Therefore, the tests selected for the M508 Experiment are ones that are expected to reveal general relations between tests in real and simulated weightlessness, rather than faithful imitations of anticipated operational tasks."

Experiment M508 is comprised of a sequence of four basic human engineering tasks designed to measure man's capabilities for force exertion, eye-hand coordination and manual dexterity in an EVA and IVA environment.

The task sequence designed for this experiment is based on an operational analysis of 16 fundamental EVA experiments which were distilled from an entire spectrum of actual and predicted extravehicular activities. All of the important basic operations identified by the analysis have been included in the M508 task sequence, although it does not closely approximate any of the experiments suggested in the study.

With the four basic tasks configured into a single task panel, two subjects each performed the complete task sequence twice under six experimental conditions: three suit conditions (shirtsleeves, and operational and developmental pressure suits) and three modes of physical restraint. The tasks were suitably instrumented to record quantitative data on forces, torques, accuracy, etc., for each of four simulation modes, including 1-G, Neutral Buoyancy, KC-135 Zero-G aircraft and 6 DOF mechanical simulator.

SECTION 3

EXPERIMENT DEFINITION AND TASK SEQUENCE DEVELOPMENT

The first task of the Astronaut Performance Program was the generation of an experimental task sequence which would measure and yield data on manned performance capabilities in a zero-gravity environment. It was furthermore desired that this task sequence be adaptable for performance in a simulated EVA--specifically, that it be performed inside the Orbital Workshop as Experiment M508.

This section will describe the work performed which resulted in a preliminary task sequence to meet these objectives. Basically, the study involved a detailed examination of various references and input data, summarization of the information in these references, filtering based on frequency and/or criticality, and, finally, development of a functional flow block diagram of a candidate experimental sequence.

3.1 STUDY INPUT DATA ANALYSIS

3.1.1 REFERENCE DOCUMENTS

An assortment of references dealing with simulation, specific experiments requiring EVA, and EVA in general was collected as input data to the Astronaut Performance Program. These references are listed in Table 3-1.

The input data was closely scanned to identify all human performance activities which, at least conceptually if not directly, could constitute manned extravehicular tasks. This list served as a source of candidate tasks and as a check list to insure completeness of the ultimate experimental task sequence.

Particular attention was paid to the study of Extravehicular Engineering Activities by North American Rockwell Corporation (Reference #13). This study comprises an exhaustive look into the requirements for EVA capabilities needed to perform various experiments for the 1968-1980 time period.

3.1.2 EVA TASK DETERMINATION

The reference documents were scanned to extract any items which hint of being a planned or conceived EVA "task". These items are attached as Tables 3-2 and 3-3. The reference numbers indicate the source of each item and correspond to the numbers of the reference documents listed in Table 3-1.

The items listed in Table 3-2 are noted as Functions, Tasks or Operations. This breakdown is purely subjective and is not intended to denote any significance as a classification scheme. The authors of the various study input documents tend to use the word "task" synonymously, but inspection of the list shows that different comprehensive levels of performance are actually identified. "Function" is intended to serve as the most comprehensive category of performance items, and "operation" the least comprehensive, or most elemental. The designations, then, are used simply because it would be improper to label all the items as "tasks".

TABLE 3-1 REFERENCE DOCUMENTS

1. Manned Extravehicular Activities - Hamilton Standard, circa 1964.
   Useful for specific task suggestions.

2. Design, Fabrication and Installation of a Six-Degree-of-Freedom Space Maintenance Simulator - A. E. Holmes, Martin, April, 1965.

3. The Effectiveness of Weightless Simulators (For obtaining maintainability criteria for space systems) - C. B. May, Sept., 1967.
   Discusses simulation modes:
   - KC-135
   - Underwater
   - 6 Degree-of-Freedom (Same as in Reference 2)

   Specific task simulated: tightening a bolt, wearing G-4C suit; bolt instrumented with Torque-force transducer.
   Space power tool and ratchet hand tool described.

4. EVA Simulation for Design Verification - John Duddy, Lockheed, Sept., 1967.
   Discusses EVA requirements for ATM.

5. Maintenance in a Weightless Environment - C. B. May, March, 1965.
   Overview paper on maintenance equipment such as AMU, RMU and Space Shuttle.
   Describes Minimum Reaction Power Tool.

6. Study of Astronaut Capabilities to Perform Extravehicular Maintenance and Assembly Functions in Weightless Conditions - Garrett, Sept., 1967.
   Three major sections:
   1. Analytical Studies
      - Diving Physiology
      - Task Taxonomy
      - EVA Task Classification Charts
      - Mathematical Model of Underwater Simulation (with computer programs)
   2. Facilities and Apparatus
      - Underwater Simulation Facility
      - Mock-ups, Locomotion Aids, Restraints
      - Tools—Off-the-shelf and specially-designed fasteners
   3. Tasks
      - Maintenance
      - Assembly of Beams
      - Assembly of Panels
      - Assembly and Erection of Rigid Modules
      - Assembly and Erection of Inflatable Modules

   Test Plan (for representative purposes) also available.

TABLE 3-1 REFERENCE DOCUMENTS (Continued)

7. Operator/Tool Interface Problem Areas for Space Maintenance
   5 Degree-of-Freedom Simulator
   Typical work performance task board described

8. Summary of Gemini EVA - June, 1967.
   Notable areas of information:
   - Life Support
   - Tasks
   - Restraints
   - Maneuvering Units
   - Simulation and Training

9. EVA Design Criteria - Crew Systems Division, MSC, circa 1967.
   Tabulates EVA equipment system parameters.

10. Study of Extravehicular Protection and Operations - June, 1967.
    General EVA information.

11. "Appendix I - EVA Task Analysis"
    Suggests specific orbital operations and tasks.

12. AAP-2 Astronaut Review Outline
    General information on OWS, MDA.
    Locates M508 in AAP scheme.

13. Extra-Vehicular Engineering Activities (EVEA) Program Requirements Study - North American Rockwell, May, 1968.
    This study comprises an exhaustive look into the requirements for EVA capabilities needed to perform various experiments planned for the 1968 to 1980 period. The study is reported in several volumes:
    - Volume I - Summary Technical Report
    - Volume II - Detailed Technical Report
    - Appendix A - EVA Transfer, Locomotion, and Rescue Experiment Definition
    - Appendix B - Work Performance Experiment Definition
    - Appendix C - Scientific and Technical Experiments Baseline
    - Appendix D - Linkages

14. Experiment Implementation Plan for Experiment M508, Astronaut EVA Hardware Evaluation - Crew Systems Division, MSC, NASA, March, 1968.

TABLE 3-2 EVA FUNCTIONS, TASKS & OPERATIONS

FROM REFERENCE NO.	ITEM	FUNCTION	TASK	OPERATION
1.	Plumbing Leak Correction	X		
1.	Patching		X	
1.	Sealing		X	
3.	Position Self at Site		X	
3.	Attach Restraint		X	
3.	Prepare Tools		X	X
3.	Tighten, Loosen Bolt			
3.	Stow Tools		X	
4.	ATM Film Cassette Removal	X		
7.	Remove & Replace Screws			X
7.	Remove & Replace Amphenol Connector			X
7.	Remove & Replace 3/8" Hex-Nut			X
7.	Remove & Replace Plate		X	
7.	Disassemble & Reassemble Hydraulic Joints		X	
6.	Engage Restraint		X	
6.	Fasten Tool Kit		X	
6.	Remove Four Bolts in Access Panel			X
6.	Clamp Panel to Spacecraft Mock-up			X
6.	Turn-off Valve on Tubing			X
6.	Cut Wires to Maintenance Box			X
6.	Disengage Tube with One Wrench			X
6.	Disengage Tube with Two Wrenches			X
6.	Remove Two Bolts to Maintenance Box			X
6.	Remove Maintenance Box & Secure to S/C Mock-up		X	
6.	Position Access Panel in Opening			X
6.	Finger Tighten Bolts in Access Panel			X
6.	Tighten Bolts in Access Panel with Wrench			X
6.	Punch Rivet on Top of Maintenance Box			X
6.	Drill out Rivet			X
6.	Remove Top from Maintenance Box & Fasten to S/C Mock-up			
6.	Remove Switch from Maintenance Box		X	

TABLE 3-2 EVA FUNCTIONS, TASKS & OPERATIONS (Continued)

GEMINI FLT. #:	FROM REFERENCE NO.	ITEM	FUNCTION	TASK	OPERATION
	6.	Replace Switch in Maintenance Box		X	
	6.	Strip Insulation from Wires			X
	6.	Loop Two Wires & Place Under Screws			X
	6.	Disengage Pipe		X	
	6.	File Notch			X
	6.	Saw Bar			X
	6.	Cut Bolt			X
XI	8.	Remove 7 in ^{2} Velcro Strip		X	
XI, XII	8.	GATV Tether Attachment to S/C Docking Bar		X	
IX-A, X, XI	8.	Deploy/Retrieve Experiment Package		X	
IX-A	8.	Unstow & Extend AMU Controller Arm		X	
XII	8.	Unstow & Install Telescope Handrail		X	
XII	8.	Deploy Experiment Package		X	
XII	8.	Connector Operations		X	
XII	8.	Cutting Operations		X	
XII	8.	Remove 200 in ^{2}Velcro Strip		X	
		ORBITAL OPERATIONS			
		Maintenance & Repair			
	10.	Component and Module Replacement	X		
	10.	Electrical and Electronics Maintenance	X		
	10.	Fluid and Gas System Maintenance	X		
	10.	Propulsion System Maintenance	X		
	10.	Mechanical System Maintenance	X		
	10.	Structural System Maintenance	X		
		ASSEMBLY OPERATIONS			
	10.	Minor Assembly & Erecting	X		
	10.	Assembly of Large Structures	X		
	10.	Positioning & Connecting Large Modules	X		

TABLE 3-2 EVA FUNCTIONS, TASKS & OPERATIONS (Continued)

FROM REFERENCE NO.	ITEM	FUNCTION	TASK	OPERATION
	FOCAL LENGTH CHANGE ON TELESCOPE:			
10.	Secure Work Pack		X	
10.	Detach Connections to Work Pack			X
10.	Set Up TV Monitor		X	
10.	Connect Power & Comm. Lines			X
10.	Turn on Lights			X
10.	Activate Door Opening Mechanism			X
10.	Connect Restraint		X	
10.	Disconnect & Secure F15 Mirror Stowage Clamps		X	
10.	Position & Secure F15 Mirror		X	
11.	Install & Align Cameras	X		
11.	Deploy/Retrieve Meteoroid & Emulsion Panels	X		
11.	Retrieve & Replace Film Cannisters	X		
11.	Change Camera Filters & Exposure Time		X	
11.	Retrieve S/C Components for Return & Analysis	X		
11.	Installation of External Umbilicals from One Module to Another	X		
11.	Solar Panel Deployment	X		
11.	Inspection	X		
11.	Replacement of Faulty Section of Solar Panel	X		
11.	Replacement of Thermal or Radiation Shields	X		
11.	Replacement of Radiator Segments	X		
11.	Clean Optical Surfaces		X	
11.	Realignment of Orbiting Telescopes	X		
11.	Replace Module Components	X		
11.	Repair Damage Done by Micrometeorite	X		
11.	Measure	X		

TABLE 3-3 EVEA STUDY TASK BREAKDOWN

	EXPERIMENT	FUNCTION
1.	80-cm Solar Telescope	Initial Inspection & System Checkout (Usually IVA) Perform EVA Actuation of Focus Mechanism Replace Defective Electronic Module Retrieve Film Cassettes
2.	EMR Payload	EMR Visual Inspection Replace Modular Instrument Retrieve Film Cassettes
3.	1-Meter Telescope (APEP)	Visual Inspection Remove & Replace Film Cassette Remove and Replace Electronic Module Replace Drive Mechanism Replace Thermostatic Control Device
4.	1-Meter Non-Diffraction Limited UV Telescope	Initial Checkout & Inspection of Telescope (Usually IVA) Change Film Cassettes Remove & Replace Electronic Module
5.	X-Ray Focusing Telescope	Correct Deployment Malfunction Remove Turret Restraints Align Laser System Free Wheel & C/O Turret C/O Lens Alignment Monitor Data Link Response Replace ACS Units Replace Solar Panels Replace Sensors Replace Batteries
6.	10 KM Interferometer	Correct Deployment Malfunction Correct Flight Control Malfunction Replace 8 Solar Panels Replace 6 Dipole Modules Refuel ACS Tanks Replace Batteries Replace ACS Regulators

TABLE 3-3 EVEA STUDY TASK BREAKDOWN (Continued)

	EXPERIMENT	FUNCTION
7.	Long-Boom Interferometer	Remove Boom Gimbal Supports Assemble Antenna Heads Checkout Boom Drives Checkout Alignment System Replace Drive Motors Change Antenna Heads Change Antenna Heads
8.	30-45 Motor Antenna	Predeployment Inspection Correct Deployment Failures Inspect Reflector & Truss Adjust Mesh, Webbing Adjust Knee Supports
9.	Effect of Space Environment on Bacterial Spores	Deploy Container Boom Retrieve Container Boom Repair Deployment Mechanism Cover Spore Container
10.	Soft Capture & Culture of Microorganisms	Deploy Container Boom Retrieve Container Boom Repair Deployment Mechanism Cover Spore Container Remove Protective Shroud
11.	Multipurpose Biological Package	Transfer Experiment Modules Install Experiment Modules Connect Power/Life Support Refurbish Biological Modules Disassemble/Retrieve Modules Correct Deployment Failures
12.	Primate Module	Replace TLM Pack Replace ACS Valve/Regulator Replace Batteries Replace LSS Fan Replenish ACS Propellant Replenish O_2 - N_2
13.	Spacecraft Physical Environment	Install Subsatellite Sensors Checkout Sensor Modules Deploy/Retrieve Subsatellite Replace Sensor Modules Retrieve External Panels Operate Hand-Held Sensors Deploy Meteorite Detectors

TABLE 3-3 EVEA STUDY TASK BREAKDOWN (Continued)

	EXPERIMENT	FUNCTION
14.	Conjugate Aurora and Airglow	Magnetometer Boom Repair Accelerometer Mount Repair Equipment Rack Repair Replace Defective Spectrometer
15.	Large Structures Deployment	Remove Launch Support Structure Install Tip Alignment Equipment Photograph Deployment Replace Drive Motors Adjust/Align Boom Tips
16.	Earth Orbital Space Station	Deploy Cargo Transfer Device Transfer Cargo Visual Inspection - EOSS C/O Power & Life Support Systems Subsystems Troubleshoot Solar Panel Deployment Antenna Deployment Repair Meteoroid Punctures Replace Airlock Hatch Drives Repair Hatch Seals Replace ACS Head Assembly Emergency Crew Transfer

3.1.2.1 NAR EVEA

Table 3-3 contains the "Tasks" identified in the North American EVA report. (Per the notation discussed above, these are actually identified as "Functions".) The experiments from which the items were derived are also listed. These functions were tabulated in the EVA Data Matrix of the NAR report, and various physical parameters defining the function are identified. Analysis of these parameters reveals the following:

- o 85% of the functions will require 3-4 hours for completion.
- o Of the functions requiring mass handling, 65% will deal with modules weighing from 5 to 25 lbs., with 20 lbs. being the most predominant size; the remaining 35% range from 30 to 350 lbs.
- o A 2 foot reach envelope capability is required for 74% of the functions.
- o Medium forces (which are not defined), a fine-manipulation capability, and arm-length access depth are required for a majority of the functions.

In the study, 1212 experiments were identified and examined for potential EVA requirements. Approximately one-half of these required some degree of EVA support to satisfy the particular experiment objectives. Two-hundred and eighty experiments were examined in detail because they required EVA support and were planned for the time period of principal interest, 1971-1974. These 280 experiments included many redundancies and common functional requirements which were eliminated by further filtering, leaving 102 experiments for consideration. Finally, 16 experiments were selected as representative and investigated in detail for the specific EVA function required. Figure 3-1 illustrates the analysis which resulted in the selection of the 16 experiments. The 16 experiments are:

1. ATM/80-cm Solar Telescope
2. One-Meter Non-diffraction Limited Telescope
3. One-Meter Telescope, Advanced Princeton Experiment Package
4. X-Ray Focusing Telescope (30-inch Grazing Incidence)
5. Electromagnetic Radiation Payload (Option B)
6. 10 KM Interferometer
7. Soft Capture and Culture of Microorganisms in Near-Earth Orbit
8. Effect of Space Environment on Bacterial Spores
9. Primate Biomodule ("Bio A")
10. Multipurpose Biological Package
11. 45-Meter Antenna Technology and Large Power Supply
12. Long Boom Interferometer
13. Spacecraft Physical Environment
14. Conjugate Aurora and Airglow
15. Large Structures Deployment
16. Earth Orbital Space Station

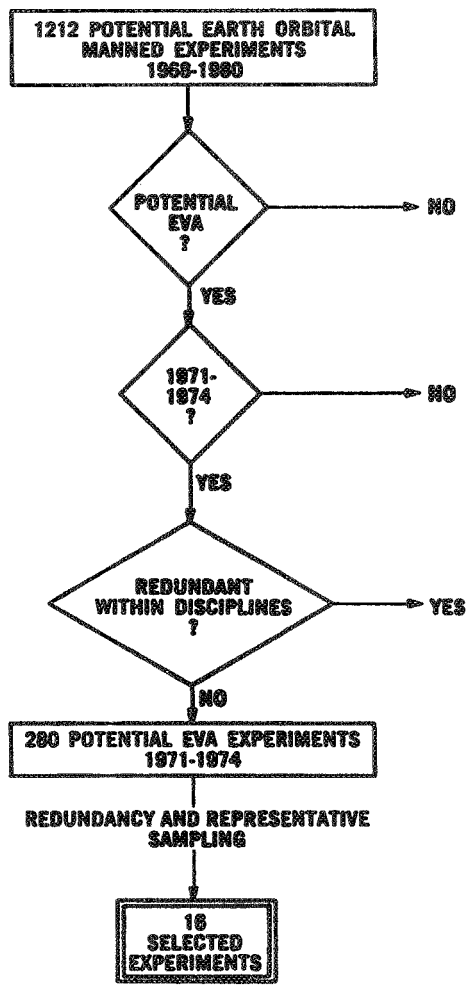


FIGURE 3-1 NAR EVEA STUDY

3.1.2.1 NAR EVEA (Continued)

Eighty-four EVA functions were identified for the performance of these 16 experiments. All 84 functions are listed in the "EVA Data Matrix" - Table 40 of Volume II of that report. Also included in this matrix are the corresponding EVA performance requirements.

Twenty-nine of these 84 functions were selected. It was felt that these 29 functions fully represented the astronaut work performance requirements for the original 84. It was this detailed description of the 29 functions that served as a starting point for the present study.

The report states that there are many optional ways of performing these tasks. All these options were tabulated under the title of "Building Blocks". Building Blocks permit a numerical categorization of EVA Functions, Sub-Functions, Techniques, Equipment and Gross Performance Measures. A logical combination of all these factors describe an EVA activity.

Eighty-eight logical combinations of Building Blocks are identified in the report, 41 of which belong to the Work Performance function.

Of the 88 combinations, 22 are found to account for 90% of all EVA identified in the 16 experiments studied. Ten of these 22 belong to the Work Performance Function, and the Work Performance Experiment is based on these 10. The 10 items are listed below:

1. Astronaut positioning, handholds only.
2. Astronaut positioning, waist restraints only.
3. Astronaut positioning, foot and waist restraints.
4. Light (under 20 pounds) equipment, temporary positioning.
5. Heavy (20-300 lbs.) equipment, temporary positioning.
6. Unassisted astronaut force application, handhold restraint only.
7. Unassisted astronaut force application, foot and waist restraints.
8. Unassisted astronaut force application, SMU plus special restraints.
9. Mechanically assisted astronaut force application, foot and waist restraints.
10. Unassisted astronaut observation.

3.2 TASK ANALYSIS

In order to keep track of the information generated, an Experiment Description form was prepared, and is illustrated in Figures 3-2a through 3-2f.

The first important heading in the Experiment Description sheet is the "EVA Task Description" (Figure 3-2a). Under this heading, the particular function being performed by the astronaut is detailed in a step-by-step procedure. Since the primary interest was in performance at a stationary worksite, translation and egress/ingress functions were not broken down into fundamental movements. All astronaut actions, however, which do take place at a worksite are listed in a sequential order.

FIGURE 3-2a EXPERIMENT DESCRIPTION

SOURCE: EXTRAVEHICULAR ENGINEERING ACTIVITIES (EVEA) PROGRAM REQUIREMENTS STUDY, NORTH AMERICAN ROCKWELL CORPORATION, MAY, 1968.

EXPERIMENT NUMBER:	AE0502RE
EXPERIMENT TITLE:	ONE METER TELESCOPE, ADVANCED PRINCETON EXPERIMENT PACKAGE
FUNCTION:	REMOVE AND REPLACE FILM CASSETTE
FUNCTION DESCRIPTION:	DATA CAPABILITY OF EXPERIMENT IS ENHANCED BY EVA REPLACEMENT OF CASSETTE. ASTRONAUT RETRIEVES FIRST CASSETTE AND INSERTS NEW ONE IN PLACE.
EQUIPMENT DESCRIPTION:	25 LB. FILM CASSETTE, CANISTER TYPE
EVA TASK DESCRIPTION:	ASTRONAUT EGRESSES SPACECRAFT AND TRANSLATES (20 FT.) TO WORK SITE WITH NEW CASSETTE ATTACHED TO CARGO HARNESS: 1. INSTALLS RESTRAINTS 2. RESTRAINS SELF 3. SECURES HARNESS AT WORK SITE 4. OPENS OUTER HATCH 5. OPENS INNER HATCH

FIGURE 3-2b EQUIPMENT REQUIREMENTS

MASS HANDLING:

SIZE	SHAPE	WEIGHT	DISTANCE	MANIPULATION	HANDLING MODE
MEDIUM	CANISTER-SHAPED	25 LB.	2-3 FT.	GROSS POSSIBLY FINE ON REPLACEMENT	NONE GRASPS CASSETTE

RESTRAINT REQUIREMENTS:

MOBILITY	YES	NO	AMOUNT — REPOSITIONING DURING TASK REQUIRED
HAND FREEDOM	ONE	TWO	
RESTRAINT RIGIDITY	NOMINAL	HIGH	

FIGURE 3-2c MAN PERFORMANCE REQUIREMENTS

WORK ENVELOPE REQUIREMENTS:

WORK SPACE DEPTH — ONE HAND — TWO HANDS	CLOSE	OPTIMUM	EXTENDED X
WORK SPACE HEIGHT — ONE HAND — TWO HANDS	HIGH	OPTIMUM X	LOW
WORK SPACE WIDTH — ONE HAND PREF. — TWO HANDS PREF. — ONE-HAND NON-PREF. — TWO-HANDS NON-PREF.	CLOSE	OPTIMUM X	EXTENDED
VISUAL ACUITY REQUIREMENTS	HIGH	MEDIUM X	LOW
LEVEL OF MOTOR ACTIVITY	PRECISE	NOMINAL X	
CUTANEOUS SENSORY & PROPRIOCEPTIVE SYSTEM REQUIREMENTS	HIGH	MEDIUM	LOW X

FIGURE 3-2d ACCESS REQUIREMENTS/CONDITIONS

TWO HAND ACCESS

REACH WITH BOTH HANDS 6 TO 20 INCHES	☐
REACH WITH BOTH HANDS FULL ARMS LENGTH (+20)	☒

ONE HAND ACCESS

EMPTY HAND TO WRIST	☐
CLENCHED HAND TO WRIST	☐
HAND + 1-INCH DIAMETER OBJECT TO WRIST	☐
HAND + OBJECT 1 INCH	☐
ARM TO ELBOW	☐
ARM TO SHOULDER	☐

FINGER ACCESS

PUSH BUTTON	☐
TWO FINGER TWIST	☐
2-INCH DIAMETER OBJECT INSERT	☐
4-INCH DIAMETER OBJECT INSERT	☐

COMMENTS:

HATCH OPENING 26 INCHES WIDE, 7 INCHES HIGH

FIGURE 3-2e TOOL REQUIREMENTS

TYPE	USAGE IN EXP. DEF.	USAGE IN EXP. POS.	UNIT SIZE QUANT.	UNIT SIZE QUAL.	CHARACTERISTICS	FORCE REQ'D. QUANT.	FORCE REQ'D. QUAL.	DESCRIPTION OF TOOL FUNCTION
SCREWDRIVER	—	—	—	—		—	—	
DRILL	—	—	—	—		—	—	
T-HANDLE WRENCH	—	X	—	MEDIUM		—	MEDIUM	USE TO OPEN HATCH
FINGER WRENCH	—	—	—	—		—	—	
CRANK HANDLE	—	X	—	MEDIUM		—	MEDIUM	USE TO OPEN HATCH
CRIMPER-STRIPPER	—	—	—	—		—	—	
LANYARD	—	—	—	—		—	—	
CARGO HARNESS	X	—	100 LB. MAX.	LARGE		—	HIGH	TRANSPORT CASSETTES
TOOL TETHER	—	X	—	SMALL		—	—	
EQUIPMENT BAG	—	—	—	—		—	—	NOTE: ASSUMPTION THAT CASSETTE IS RESTRAINED TO CARGO HARNESS BY TETHER.
OTHER (SPECIFY)	—	—	—	—		—	—	

FIGURE 3-2f MAN/MACHINE INTERFACE (NO TOOLS)

TYPES	USAGE IN EXP. DEF.	USAGE IN EXP. POSS.	SIZE-SHAPE QUANT.	SIZE-SHAPE QUAL.	FORCE QUANT.	FORCE QUAL.	CHARACTERISTICS	DESCRIPTION OF EQUIPMENT FUNCTION
FASTENERS								
LEVER (LATCH)	X			SMALL		LOW		LATCHES SECURE CASSETTE IN POSITION
TURN								
SLIDE		X		SMALL		LOW		FOR LANYARD ATTACHMENT/OR
PUSH-PULL		X		MEDIUM		MEDIUM		FOR RESTRAINT ATTACHMENT
OTHER								
SWITCHES								
TOGGLE								
LEVER								

3.2 TASK ANALYSIS (Continued)

The remainder of the form details support equipment and interface equipment which is used in performing the EVA task. Restraint requirements are defined in terms of functional capabilities which are required. Also noted are work envelope, visual acuity, access requirements, tool requirements, and expected man-equipment interfaces. Much of this information is based on subjective interpretation of the experiment description. However, the reliability of information is probably very good, since interpretation is based on current, state-of-the-art conceptions of experiment hardware.

Figure 3-2b defines the equipment being handled and the restraint requirements.

Figure 3-2c defines the work envelope, and sensory performance requirements.

Figure 3-2d defines the access requirements.

Figure 3-2e identifies the tool requirements.

Figure 3-2f defines additional man/machine interface requirements.

After completing 28 such forms, there existed a comprehensive data bank from which to select the experimental sequence, but in order to be more useful, the data was summarized. In this way, "typical tasks" were determined based on frequency counts, criticality or importance.

Table 3-4 presents a listing of all tasks which were included in the step-by-step breakdown of EVA functions from the North American Rockwell report. The wording of these tasks is precisely as was used in formulating the detailed procedures. No attempt was made here to combine tasks on the basis of commonality, since it was felt that such combination might result in lost information.

Comparisons were made across experiments to discover the frequency of occurrence of each task item. The first column of Table 3-4 lists the total number of times an item was encountered. The second column lists the total number of experiments in which an item was encountered. It is a combination of these two columns which constitutes a "high frequency" occurrence of an item, since considering total occurrences above might yield an item with "many" occurrences but which was germane to only one experiment and therefore not "typical" of EVA requirements.

The remaining columns of Table 3-4 list those items which are determined to be desirable or undesirable for evaluation, and the reasons for such decisions. Three justifications are considered to determine the desirability of a task. First, a task may be desirable on the basis of a high frequency of occurrence. In order to qualify a task as desirable on this basis, an individual item had to satisfy at least one of the following arbitrary criteria: (a) exhibit a total frequency of occurrence of 10 or more (the mean number of occurrences per item in Table 3-4 is 9.3), or (b) occur in at least 7, or 25%, of the experiments detailed.

TABLE 3-4 TASK SUMMARIZATION

			DESIRABILITY					
			DESIRABLE			NOT DESIRABLE		
	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	BASED ON FREQUENCY	BASED ON IMPORTANCE	BASED ON COMMONALITY	NOT AFFECTED BY O-G, ETC.	NOT SUITABLE FOR CABIN SIMULATION	NOT WORKSITE PERFORMANCE
Install Restraints	63	28	X					
Detach & Stow Restraints	63	28	X					
Restrain Self	91	28	X					
Reposition Self	23	10	X					
Release Self	91	28	X					
Secure Cargo Harness	48	16	X					
Release Cargo Harness	48	16	X					
Open Hatch	37	20	X					
Close Hatch	36	19	X					
Attach Equip. Tether	88	19	X					
Release Equip. Tether	88	19	X					
Release Cassette Latch	1	1			X			
Unscrew Three Captive Screws	1	1			X			
Release Three Instrument Lugs	1	1			X			
Release Pip Pins	3	3			X			
Remove(Stowed) Foot Restraints	1	1			X			
Remove(Stowed) Solar Panel Rack	1	1			X			
Remove(Stowed) Handheld Sensors	1	1			X			
Remove(Stowed) Cargo Transp.	3	3			X			
Remove(Stowed) Cargo Module Guide Tether	1	1			X			
Remove(Stowed) ACS Units	2	1			X			
Remove(Stowed) AMU	4	4			X			
Remov-(Stowed) Umbilical Lines	3	2			X			
Remove Module	16	7	X					
Remove Camera	2	2			X			
Remove Cassette	9	4		X				
Remove Solar Panel	6	1		X				
Remove Fastener	1	1		X				
Remove Launch Supports	1	1		X				
Position Focus Plate	1	1		X				
Remove Focus Plate	1	1		X				
Remove Module from Container	1	1				X		

TABLE 3-4 TASK SUMMARIZATION (Continued)

	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	DESIRABILITY: DESIRABLE: BASED ON FREQUENCY	DESIRABLE: BASED ON IMPORTANCE	DESIRABLE: BASED ON COMMONALITY	NOT DESIRABLE: NOT AFFECTED BY O-G, ETC.	NOT DESIRABLE: NOT SUITABLE FOR CABIN SIMULATION	NOT DESIRABLE: NOT WORKSITE PERFORMANCE
Install Module in Container	1	1				X		
Attach Cassette to Cargo Harness	9	4		X				
Attach Foot Restraints to Cargo Harness	1	1		X				
Attach Solar Panel Rack to Cargo Harness	1	1		X				
Attach Module to Cargo Harness	12	5	X					
Attach Handheld Sensors to Cargo Harness	1	1		X				
Release Cassette from Cargo Harness	6	3		X				
Release Module from Cargo Harness	12	5	X					
Release Foot Restraints from Cargo Harness	1	1		X				
Release Handheld Sensors from Cargo Harness	1	1		X				
Restrain Cassette	6	3		X				
Restrain Module	8	5		X				
Restrain Camera	2	2			X			
Restrain Fan	2	1			X			
Restrain Solar Panel	6	1		X				
Restrain Fastener	1	1		X				
Restrain Launch Supports	1	1		X				
Release Solar Panel from Restraint	6	1		X				
Release Module from Restraint	8	5		X				
Release Launch Supports from Restraint	1	1		X				
Release Cassette from Restraint	6	3		X				
Release Camera from Restraint	2	2			X			
Release Fan from Restraint	2	1			X			
Release Fastener from Restraint	1	1		X				
Obtain Boom from Cargo Harness	1	1			X			

TABLE 3-4 TASK SUMMARIZATION (Continued)

	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	DESIRABILITY: DESIRABLE: BASED ON FREQUENCY	DESIRABILITY: DESIRABLE: BASED ON IMPORTANCE	DESIRABILITY: DESIRABLE: BASED ON COMMONALITY	DESIRABILITY: NOT DESIRABLE: NOT AFFECTED BY O-G, ETC.	DESIRABILITY: NOT DESIRABLE: NOT SUITABLE FOR CABIN SIMULATION	DESIRABILITY: NOT DESIRABLE: NOT WORKSITE PERFORMANCE
Obtain Exp. Pkg. from Cargo Harness	5	2			X			
Obtain Tube of Filler Compound	1	1				X		
Obtain Plug & Tool	1	1				X		
Obtain Drill	1	1				X		
Attach Transporter End	7	4					X	
Detach Transporter End	3	2					X	
Attach Module to Transporter	6	4					X	
Release Solar Panel from Rack	14	2	X					
Release Transporter Roll-up Ties	1	1				X		
Operate Gas Bottle Valve	2	1			X			
Adjust Transporter Tension	3	3				X		
Operate Transporter	6	4					X	
Insert Power Tool	2	2		X				
Drill Hole	1	1					X	
Operate Power Tool	1	1		X				
Remove Power Tool	1	1		X				
Secure Drill	1	1				X		
Secure Tube	1	1				X		
Insert Plug & Tool	1	1				X		
Fill Hole	1	1					X	
Install Panel	14	2	X					
Install Cassette	6	3		X				
Latch Cassette	1	1		X				
Install Module	14	6	X					
Install Camera	2	2			X			
Install Boom	1	1			X			
Install Exp. Pkg.	6	3			X			
Install Fan	1	1			X			
Install Fastener	1	1		X				
Make Electrical Connection	12	4	X					
Break Electrical Connection	12	4	X					
Activate Motor	4	1				X		

TABLE 3-4 TASK SUMMARIZATION (Continued)

	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	DESIRABILITY: DESIRABLE: BASED ON FREQUENCY	DESIRABILITY: DESIRABLE: BASED ON IMPORTANCE	DESIRABILITY: DESIRABLE: BASED ON COMMONALITY	DESIRABILITY: NOT DESIRABLE: NOT AFFECTED BY O-G, ETC.	DESIRABILITY: NOT DESIRABLE: NOT SUITABLE FOR CABIN SIMULATION	DESIRABILITY: NOT DESIRABLE: NOT WORKSITE PERFORMANCE
Activate Electrical System	2	1		X				
Activate Life Support System	2	1		X				
Energize Switch	3	1				X		
Checkout Electrical System	2	1		X				
Checkout Life Support System	2	1		X				
Rotate Shaft	2	2		X				
Rotate Turret	1	1		X				
Observe (Fine)	1	1		X				
Observe (Gross)	11	5	X					
Attach Hose to Connector	10	2	X					
Detach Hose from Connector	10	2	X					
Make Sensor Measures	27	1	X					
Adjust Antenna Mesh	1	1				X		
Discard Module	1	1					X	
Extend Boom (Crank)	1	1			X			
Pull Lanyard	15	2	X			X		
Secure Lanyards	4	1				X		
Don AMU	4	4						X
Doff AMU	4	4						X
Stow Equipment	1	1			X			
Stow Lanyard & Shroud	6	2				X		
Stow Transporter	1	1			X			
Stow AMU	4	4			X			
Stow Hose	3	2			X			
Stow Package	1	1			X			
Inspect	6	1		X				

3.2 TASK ANALYSIS (Continued)

Second, a task may be desirable based on its importance and/or uniqueness. A task item was considered "important" because of its criticality to successful completion of an experimental EVA function, or because of its anticipated existence in future EVA.

Finally, a third column is included to note those task items, which, while not necessitating evaluation per se, are nevertheless desirable and are evaluated by virtue of commonality with other, more desirable tasks.

Task items are classified as "Not Desirable" for evaluation either because the Task (1) is not seriously affected by 0-g, restraints, or suits, or (2) cannot be suitably evaluated inside the Orbital Workshop, or (3) does not constitute "performance at a worksite".

3.2.1 CANDIDATE VARIABLE ANALYSIS

In addition to the Task Summarization efforts described above, the remainder of the information contained in the Experiment Description Sheets was analyzed and evaluated to derive potential experimental variables. These data were evaluated for the purpose of identifying potential independent and dependent variables for manipulation and measure in the experiment program. No attempt was made at this time to develop specific variables or measures; rather, the aim was to specify the types and ranges of the potential experimental condition combinations and measures. The most significant results of this effort are summarized below.

- Mass Handling - The most commonly encountered masses were those described as "cassettes" or "modules". The distirbution of weights was essentially tri-modal, with peaks at about 12, 40, and 70 pounds.

- Restraint Requirements - Two combinations of restraint rigidity, hand freedom, and mobility required were frequently needed: either high or nominal rigidity, combined with two-hand freedom, and a requirement for some mobility (usually consisting of the capability to reposition the astronaut's cg by 3-4 feet).

- Work Envelope Requirements - As was expected, a two-hand reach capability to optimum depths, height and width was required. However, an extended-depth reach was also frequently encountered.

- Visual Acuity Requirements - A full range of acuity requirements was found.

- Motor Activity Requirements - Nominal.

- Cutaneous Requirements - Low.

- Access Requirements - Requirements for two-hand access up to 20" and greater than 20" occurred with almost equal frequency.

3.2.1 CANDIDATE VARIABLE ANALYSIS (Continued)

- o Tool Requirements - A T-Wrench, a crank, and a ratchet wrench seemed to have the most general applicability. Also, a cargo harness and equipment tethers were frequently used.

- o Man/Equipment Interface (No Tools) - Most commonly encountered items were: Switches - Push-button and lever.
  Connectors - Bayonet and thread-assist.
  Fasteners - Slide and lever.

3.3 FACTORS AFFECTING EVA PERFORMANCE

Since the purpose of this program is the qualitative and quantitative assessment of astronaut performance as a function of weightlessness, pressurized space suits, various restraint methods, etc., the effects of those characteristics must be identified and delineated to determine their effects on task sequences, experimental and test hardware design. Also, potential interaction effects between the primary variables which might influence astronaut performance were to be specified.

It was recognized that all of the parameters which were discussed could not be incorporated into the program. However, consideration had to be given to each of the identified effectors of performance in order to provide an adequate documented rationale to support the inclusion or exclusion of the various potential performance effectors in question.

Selection of the experiment test parameters was further constrained by the limits imposed by the vehicle, power, volume, mass and flight programming allocations available as well as the physiological and psychological capabilities of the flight crew. It was essential that all potential constraints be diligently identified and quantified and that appropriate trade-offs be performed and documented to provide justification for the "final" selected test program. Further, constraints imposed on the experimental design by the required psychophysiological and psycho-motor condition of the flight crew had to be defined and documented.

Five general categories were considered to affect astronaut work performance:

1. Pressure Suits
2. Restraints and Mobility Aids
3. Geometry
4. Hardware Interfaces
5. Environment

In Table 3-5 these general areas are broken down into more detail to obtain a clearer picture of the behavior elements affect by each factor.

In Table 3-6 an attempt was made to quantify or provide a dimensional range to those factors.

TABLE 3-5 FACTORS AFFECTING PERFORMANCE

FACTORS AFFECTING PERFORMANCE / BEHAVIOR ELEMENTS AFFECTED	REACH ENVELOPE	SENSORY PERCEPTION: TACTILE	SENSORY PERCEPTION: VISUAL	FORCE PRODUCING	INCREASES FATIGUE	RATE OF MOVEMENT	BODY CONTROL CAPABILITY	EYE-HAND COORDINATION	TIME TO PERFORM
1.0 PRESSURE SUITS									
1.1 Suit Types									
a. Hard Suits	X	X	X	X	X	X	X	X	X
b. Soft Suits	X	X	X	X	X	X	X	X	X
c. ExtraVehicular Garments	X	X	X	X	X	X	X	X	X
1.2 Suit Des. Charact.									
a. Work/Reach Envelope	X				X				
b. Mobility					X	X	X		
c. Articulation				X	X	X	X	X	X
d. Manual Dext.		X		X				X	X
e. Tactile Sense Capability		X							X
f. Visual Capab.									
1. Field of View			X					X	X
2. Distortion			X					X	X
3. Glare			X					X	X
g. Location of Electrical & Fluid Connectors	X		X				X		
1.3 Pressurization Method									
1.3.1 Backpack Supply									
a. Mass					X	X	X		
b. Cg Shift							X		X
c. Moment of Inertia							X		X
d. Size	X								
e. Environ. Cont. Capability					X				X

TABLE 3-5 FACTORS AFFECTING PERFORMANCE (Continued)

FACTORS AFFECTING PERFORMANCE \ BEHAVIOR ELEMENTS AFFECTED	REACH ENVELOPE	SENSORY PERCEPTION: TACTILE	SENSORY PERCEPTION: VISUAL	FORCE PRODUCING	INCREASES FATIGUE	RATE OF MOVEMENT	BODY CONTROL CAPABILITY	EYE-HAND COORDINATION	TIME TO PERFORM
1.3.2 Umbilical Supply									
a. Mass					X	X	X		
b. Cg Shift							X		X
c. Moment of Inertia							X		X
d. Whipping				X	X	X	X		X
e. Interference	X				X				X
f. Attach to Suit	X								
1.3.3 Chest Pack Supply									
a. Mass					X	X	X		
b. Cg Shift							X		X
c. Mom. of Inertia							X		X
d. Size	X		X	X	X			X	X
2.0 RESTRAINTS & MOBILITY AIDS									
2.1 Mechanical Restraint System									
a. Body attachment location	X			X			X		X
b. Type of Restraint	X			X		X	X		X
c. Type and method of attachment and release	X			X			X		
d. Type and method of adjustment	X			X	X	X	X		X
e. Restraint setup method					X				X
2.2 Maneuvering Unit - Stabilization Equipment									

TABLE 3-5 FACTORS AFFECTING PERFORMANCE (Continued)

FACTORS AFFECTING PERFORMANCE / BEHAVIOR ELEMENTS AFFECTED	REACH ENVELOPE	SENSORY PERCEPTION: TACTILE	SENSORY PERCEPTION: VISUAL	FORCE PRODUCING	INCREASES FATIGUE	RATE OF MOVEMENT	BODY CONTROL CAPABILITY	EYE-HAND COORDINATION	TIME TO PERFORM
2.2.1 Hardware Definition									
a. Size	X				X		X		
b. Mass					X	X	X		X
c. Cg Shift					X		X		
d. Moment of Inertia					X	X	X		X
e. Stabilization									
1. Dead Band				X			X		X
2. Recov. rate							X		X
3. Overshoot	X			X		X	X		X
4. Settling Time						X	X		X
f. Interference	X			X	X		X		X
2.3 Mobility Aids									
2.3.1 Physical Characteristics									
a. Type					X	X	X		X
b. Size and shape						X	X		X
c. Attachment Methods	X				X	X	X		X
d. Length of Traversal					X				X
2.3.2 Mobility Aid-to-Work Site Transition									
a. Distance					X	X	X		X
b. Method of Transfer					X	X	X		X
c. Method of Attachment to Mobility Aid	X				X		X		X
3.0 GEOMETRY									

TABLE 3-5 FACTORS AFFECTING PERFORMANCE (Continued)

FACTORS AFFECTING PERFORMANCE / BEHAVIOR ELEMENTS AFFECTED	REACH ENVELOPE	SENSORY PERCEPTION: TACTILE	SENSORY PERCEPTION: VISUAL	FORCE PRODUCING	INCREASES FATIGUE	RATE OF MOVEMENT	BODY CONTROL CAPABILITY	EYE-HAND COORDINATION	TIME TO PERFORM
3.1 Available Work Space Envelope									
a. Space and clearance available to accommodate body position and movements	X			X	X		X		X
b. Location of specific task in relation to body			X	X	X		X	X	X
c. Access opening or passage to work point	X		X	X	X	X		X	X
d. Space available for manipulation of hands, arms, tools, etc.				X	X	X		X	X
3.2 Orientation									
a. Relative position or orientation of man and working surface	X		X	X			X	X	X
b. Direction of action		X	X	X			X	X	X
3.3 Working Surface Definition									
a. Configuration	X		X						
b. Color		X	X						
c. Texture		X	X						
4.0 HARDWARE INTERFACE CHARACTERISTICS									
4.1 Mass Handling									
a. Size	X		X		X	X			X
b. Shape	X		X						
c. Mass				X	X	X	X		X
d. Cg Location				X	X	X	X		X
e. Handles	X	X		X	X	X	X	X	X

TABLE 3-5 FACTORS AFFECTING PERFORMANCE (Continued)

FACTORS AFFECTING PERFORMANCE / BEHAVIOR ELEMENTS AFFECTED	REACH ENVELOPE	SENSORY PERCEPTION: TACTILE	SENSORY PERCEPTION: VISUAL	FORCE PRODUCING	INCREASES FATIGUE	RATE OF MOVEMENT	BODY CONTROL CAPABILITY	EYE-HAND COORDINATION	TIME TO PERFORM
4.2 Connective Devices									
4.2.1 Electrical Connectors									
a. Type		X		X					X
b. Size			X	X				X	X
c. Shape			X					X	X'
d. Engagement Method		X							X
e. Cable Whipping					X	X	X		X
4.2.2 Fluid Connectors									
a. Type		X		X					X
b. Size			X	X				X	X
c. Shape			X					X	X
d. Engagement Method		X							X
4.3 Fasteners									
4.3.1 Type									
a. Manually Operated		X	X	X	X			X	X
b. Tool Operated (See 4.7)		X	X	X				X	X
4.3.2 Forces Required to Operate									
a. Magnitude		X		X	X				
b. Direction		X		X					
c. Duration		X		X					
4.3.3 Size and Shape (Fit With Gloved Hand)									
4.3.4 Feedback									
a. Visual		X							X
b. Tactile			X						X

TABLE 3-5 FACTORS AFFECTING PERFORMANCE (Continued)

FACTORS AFFECTING PERFORMANCE / BEHAVIOR ELEMENTS AFFECTED	REACH ENVELOPE	SENSORY PERCEPTION: TACTILE	SENSORY PERCEPTION: VISUAL	FORCE PRODUCING	INCREASES FATIGUE	RATE OF MOVEMENT	BODY CONTROL CAPABILITY	EYE-HAND COORDINATION	TIME TO PERFORM
4.4 Control Manipulation									
4.4.1 Discrete Controls (Switches, Detented Rotors)									
a. Size and Shape		X	X					X	X
b. Forces required to operate				X					
c. Feedback		X						X	X
4.4.2 Continuous Control (Potentiometer Type)									
a. Size and Shape			X					X	X
b. Forces required to operate		X		X					
c. Accuracy required-scale graduations		X						X	X
d. Feedback		X	X					X	X
4.5 Test Points - Test Probes									
a. Location	X							X	X
b. Quantity									X
c. Size				X					
d. Coding			X						X
4.6 Debris									
a. Method of Control									X
b. Quantity									X
c. Size									X
4.7 Tools									
4.7.1 Method of Attachment to Work Object									
a. Fit into									
b. Fit around									

TABLE 3-5 FACTORS AFFECTING PERFORMANCE (Continued)

FACTORS AFFECTING PERFORMANCE / BEHAVIOR ELEMENTS AFFECTED	REACH ENVELOPE	SENSORY PERCEPTION: TACTILE	SENSORY PERCEPTION: VISUAL	FORCE PRODUCING	INCREASES FATIGUE	RATE OF MOVEMENT	BODY CONTROL CAPABILITY	EYE-HAND COORDINATION	TIME TO PERFORM
4.7.2 Method of Actuation									
a. Power									
b. Manual									
4.7.3 Physical Characteristics		X	X	X	X	X		X	X
a. Handles									
b. Size									
c. Mass									
d. Shape									
4.7.4 Feedback		X	X					X	X
4.7.5 Tool Restraint/Retention								X	X
a. Tethers									
b. Bags									
5.0 ENVIRONMENT									
5.1 Illumination (Ref. ONS Lighting Spec) (See MSFC-STD-267A for Definition)									
5.2 Temperature/Humidity) Atmosphere)	NOT TO BE DEFINED AT THIS TIME								
5.3 Vibration)									
5.4 Noise)									

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS

1.2 Suit Design Characteristics

a. Work Reach Envelope*

Reference Point: Upper Chest - Center

	HORIZONTAL ANGLE	VERTICAL ANGLE	RANGE (MAX) INCH
Left	0	0	21.25 - 23.25
Right	0	0	19.25 - 22.50
Left	0	90	0
Right	0	90	0
Left	0	60	13.88 - 18.38
Right	0	45	14.88 - 19.63
Left	90	0	20.88 - 23.38
Right	90	0	19.75 - 22.63

It should be noted that the above dimensions represent maximum reach dimensions and not effective work dimensions.

b. & c. Mobility and Articulation*

Percent of nude joint mobility range retained at 3.7 psig.

Humerus Abduction:
A6L - 74.8 RX-4 - 80.0

Humerus Flexion:
A6L - 71.9 RX-4 - 87.0

Humerus Extension:
A6L - 56.6 RX-4 - 90.0

Elbow Extension:
A6L - 100.0 RX-4 -100.0

Elbow Flexion:
A6L - 89.5 RX-4 - 96.0

Hand/Wrist, Abduction:
A6L - 100.0 RX-4 -100.4

*Data from Evaluation and comparison of three space suit assemblies, R. L. Jones, NASA TN D-3482, July, 1966.

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

Hand/Wrist, Dorsiflexion:
A6L - 90.4 RX-4 - 87.0

Hand/Wrist, Palmar Flexion:
A6L - 93.3 RX-4 -100.0

Femur Flexion:
A6L - 60.7 RX-4 - 90.0

Knee Extension:
A6L - 100.0 RX-4 -100.0

Angle/Foot Dorsiflexion:
A6L - 88.1 RX-4 - 92.5

Angle/Foot Plantar Flexion:
A6L - 94.4 RX-4 - 95.8

d. Manual Dexterity - EV pressurized glove on modified pegboard using A6L and/or RX-4 suits.

Percent of Nude Hand Capability

1/4" Pins -	Right Hand	33%
	Left Hand	19%
	Both Hands	12%
1/2" Pins -	Right Hand	65%
	Left Hand	59%
	Both Hands	42%

e. Tactile Sense Capability - Later

f. Visual Capability

- Helmet

A6L Lexan Bubble	Width = 24.6 cm Depth = 31.3 cm
RX-4 Lexan Dome	Width = 30.4 cm Depth = 30.4 cm

Visual Capabilities:

	A6L	RX-4
Up	90°	130°
Down	105°	100°
Lateral	120° left and right	

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

- Visors - To protect crewman's eyes from UV & IR rays while performaing EV tasks

  Optical Characteristics:

  a. Sun Visor Only: 18-22% transmittance in visible range

  b. Sun visor, impact and pressure visor combined:

  Visible range (0.39 to 0.75 microns) - 10% transmittance
  UV range (0.25 to 0.39 microns) - 1% transmittance
  IR range (0.75 to 2.5 microns) - 5% transmittance

1.3 Pressurization Method

1.3.1 Backpack Supply

	PLSS	OPS	PECS
		(Emergency)	(See 1.3.2 Umbilical Supply)
a. Mass (Lbs.)	86	37.27	93
b. Cg shift c. Moment of Inertia	Depend on size and mass of astronaut and pressure suit.		
d. Size (Inches)	26 x 17.8 x 10.5	18.38 x 10 x 8	26 x 16 x 6
e. Environmental Control Capability			
Rate	1200 BTU/Hr.		2000 BTU/Hr.
Total	4800 BTU		8000 BTU

1.3.2 Umbilical Supply

	Gemini EVA	EVA	IVA
a. Mass			
b. Cg shift c. Moment of Inertia	Depend on size and mass of astronaut and pressure suit		
d. Whipping			

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

		Gemini EVA	EVA	IVA
e.	Interference			
f.	Attachment to Front Suit		PLSS	
g.	Length (Feet)	25	60	60
h.	Size	ID - 3/16 OD - 11/16		
i.	Content	Nylon Cover O_2 hose Electrical leads	O_2 supply Power	2 water lines O_2 Auxiliary Power Biomed.

1.3.3 Chest Pack Supply

Umbilical provides primary O_2, power, communication, biomedical data and tether

a.	Mass	39 Lbs.
b.	Cg shift	Depends on size and mass of astronaut
c.	Moment of Inertia	and pressure suit
d.	Size	18 x 10.25 x 8
e.	Environmental Control Capability	
	Normal	90 minutes @ 1400 BTU/Hr.
	Peak	50 minutes @ 2000 BTU/Hr.

2.0 Restraints & Mobility Aids

2.1 Mechanical Restraint System

a. Body Attachment Location -

1. Foot Restraint - Permits body rotation about the astronauts feet. Body rotation can be considered to be almost 180° Spherical Angle.

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

2.1 Mechanical Restraint System (Continued)

2. Waist Restraint - Permits body roation in pitch. The amount of rotation is limited by the proximity of surfaces near the astronaut and varies as the distance between the astronaut and the surfaces. A small amount of upper torso roll is also permitted.

3. Foot & Waist Restraint Combined - Permits upper torso movement only.

4. Handhold - Permits 180° spherical angle body movement about handhold.

b. Type of Restraint -

1. Rigid - No relative movement between restraint and vehicle mounting point. Example - Dutch Shoes.

2. Flexible - Permits limited amount of relative movement between restraint and vehicle mounting point. Example - soft "window washers belt".

3. Variable Flexibility - Can be used as either rigid, flexible or some state between the two.

c. Type & Method of Attachment & Release

1. Grasping/Griping - These restraints are characterized by the fact that the astronaut grasps the restraint or the restraint grips the astronaut. Example of grasping is the handhold. Example of griping is the Dutch Shoe Restraint.

2. Mechanical Latch - These restraints are characterized by the making of a mechanical attachment to the vehicle structure such as would be done with vise-grip ends of a variable-flexibility tether.

d. Type & Method of Adjustment

e. Restraint Set-Up

2.2 Maneuvering Unit - Stabilization Equipment

2.2.1 Hardware Definition

2.3 Mobility Aids

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

2.3.1 Physical Characteristics

a. Type

Rigid
Flexible

b. Size & Shape

Rigid Bar Type -

Cross Section



c. Attachment Methods

1. Mechanical - Separate hardware device attaches astronaut to mobility aid or object to mobility aid.

2. Manual - Astronaut uses his hands to hold mobility aid.

d. Length of Traversal

3.0 Geometry

3.1 Available Work Space Envelope

a. Space and Clearance available to accommodate body position and movements

Shoulder breadth	22.4 - 23.6
Elbow-Elbow breadth	28.1 - 33.8
Knee	14.5 - 17.0

b. Location of specific task in relation to body - Later

c. Access openings or passage to work point

Aperture Size*		MEAN	RANGE
Both Arms	Breadth	23.60	19.25 - 26.80
	Vertical Dim.	19.75	
Preferred Arm	Breadth	13.09	11.00 - 14.00
	Vertical Dim.	17.75	

*Data from "Aperture Sizes & Depths of Reach for One-and Two-Handed Tasks, AMRL-TR-66-27, October, 1966. Subjects wearing A/P 225-2 Full Pressure Suit @ 3.5 psi.

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

3.1 Available Work Space Envelope (Continued)

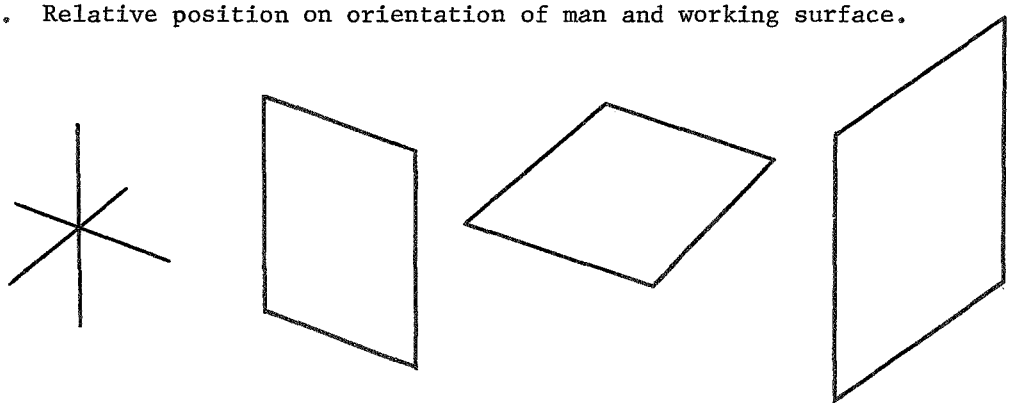
c. Access openings or passage to work point (Continued)

Depth of Reach*

	MEAN	RANGE
Both Arms	11.30	7.5 - 15.75
Preferred Arm	14.46	10.75 - 20.00

3.2 Orientation

a. Relative position on orientation of man and working surface.



b. Direction of Action

See (a) above

-X, +X, -Y, +Y, -Z, +Z

4.0 Hardware Interface Characteristics

4.1 Mass Handling

a. Shape, Size & Mass

1. Regular Geometric Shapes

SHAPE	SIZE	MASS
Parallepipeds	40 x 40 x 20	300 Lbs.
	24 x 24 x 30	100 Lbs.
	20 x 25 x 40	75 Lbs.
	18 x 18 x 18	150 Lbs.
Cylinders	Unknown	

*Data from "Aperture Sizes and Depths of Reach for One-and Two-Handed Tasks, AMRL-TR-66-27, October, 1966. Subjects wearing A/P 225-2 Full Pressure Suit

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

4.1 Mass Handling

a. Shape, Size & Mass (Continued)

2. Irregular Shapes

Cassettes	27 x 18½ x 2½	26.5 Lbs.

b. CG Locations - Unknown

c. Handles

1. Location (Ref. NASA Memo CF131-8M-046, January 24, 1968)

- Along longitudinal axis
- In line with cg
- Closest point to cg

2. Type (See MSFC STD-267A, Page 383) (See Page 3-41)

- Recessed
- Bar

4.2 Connective Devices

4.2.1 Electrical Connectors

a. Type

- Power
- Signal
- RF

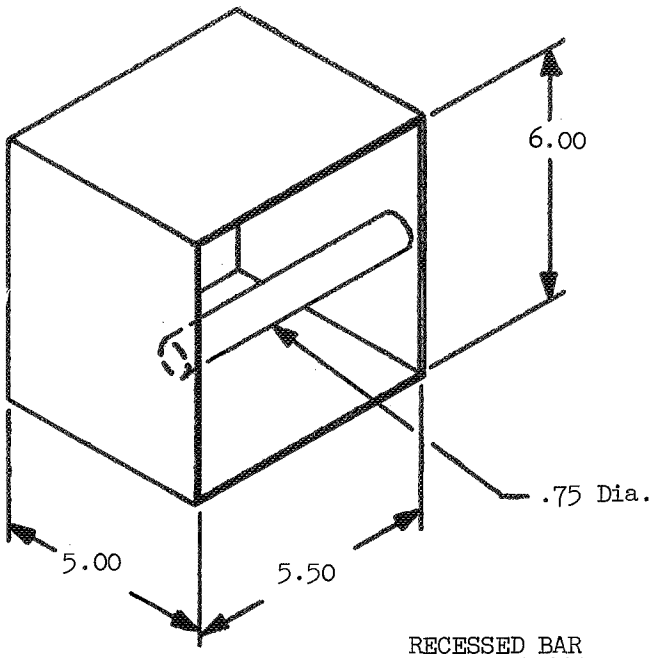
b. Size

- Large
- Medium
- Small

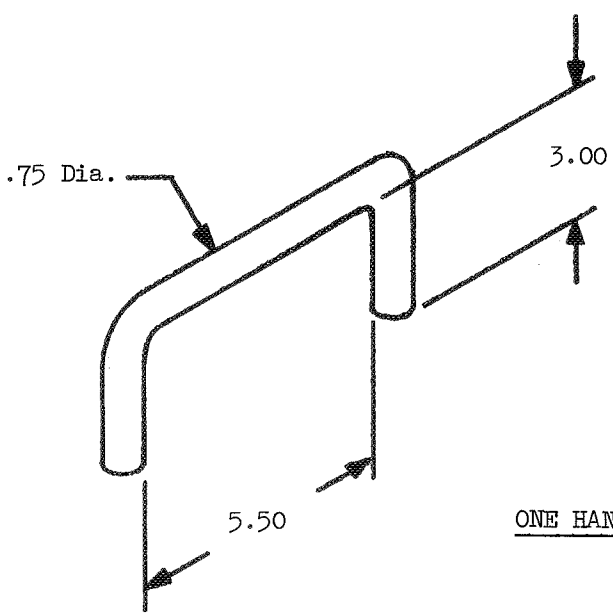
c. Shape

- Cylindrical - AN & MS type
- Parallepiped - Rack and panel type

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)



RECESSED BAR



ONE HAND BAR

1.25 to 1.50 in Diameter
Offset from surface/2.0 minimum
6.75 long

HANDLE TYPES

TABLE 3-6 QUANTIFICATION OF PERFORMANCE FACTORS (Continued)

4.2.1 Electrical Connectors (Continued)

d. Engagement Method

- Cam actuated - Bayonet
- Snap-in, Push-Pull } Quick Release
- Thread Assist, Rack and panel } May require tool

4.2.2 Fluid Connectors (Later)

4.3 Fasteners

4.3.1 Type

a. Manually Operated

- Lever
- Push-Pull
- Slide
- Turn

b. Tool Operated

- Standard Fasteners
  - Bolt or Nut Head Shapes
    External Hex Head
    Internal Hex - Allen
    Screw Driver Slot
    Phillips Type Slot
- Special fasteners using special tool heads

4.3.2 Forces Required to Operate

a. Magnitude (Unknown)

b. Direction

Push-Pull
Up-Down
Left-Right
Clockwise, Counterclockwise } in all planes

TABLE 3-6 QUANTIFICATION PERFORMANCE FACTORS (Continued)

4.3.2 Forces Required to Operate

c. Duration

Impulse - 1 second
Sustained - 4 seconds
Continuous - no limit

4.4 Control Manipulation

4.4.1 Discrete Controls (Switches, Detented Rotors)

TYPE	SIZE & SHAPE	FORCES REQ'D. TO OPERATE	FEEDBACK
Toggle Switch			
Control Tip Dia.	0.125 - 1.00	10-40 oz.	Displacement 30-120°
Lever Arm Length	0.5 - 2.00		Up-On; Down-off
Push Button			
Fingertip(Nude)	0.5 in. dia.(min)	10-40 oz. .125 - 1.5 in disp.	None - other display
Thumb or Heel of Hand(Nude)	0.75 in. dia.(min)		
Legend Switch(Push Button & Display)	.75 - 1.25 (Length or Ht.)	10-45 oz. .125 - .25 in. disp.	Display in switch
Knob			
Pointer Lgth.	1.0 min.	12-48 in. oz	Visual positioning 15°(min) non-vis. posit. 30 min. Max displacement 40°-90° 24 positions(max)
Pointer Width	Equal to Line Width		
Pointer Depth	0.5 min.		

4.4.2 Continuous Control (Potentiometer Type)

a. Size & Shape

Depth (Minimum) (fingertip grasp)	.5 in.
Diameter (fingertip grasp)	.375 - 4.0

TABLE 3-6 QUANTIFICATION PERFORMANCE FACTORS (Continued)

4.4.2 Continuous Control (Potentiometer Type) (Continued)

a. Size & Shape

Diameter (palm grasp)	1.5 - 3.0
Diameter (Thumb & finger encircled)	1.0 - 3.0

b. Forces Required to Operate

For Fingertip operation (Small Knob)	4.5 in-oz.
For Fingertip operation (Large Knob)	6.0 in-oz.

c. Feedback

Gage or calibration on skirt

4.5 Test Points - Test Probes

4.6 Debris

4.7 Tools

4.7.1 Method of Attachment to Work Object

a. Fit Into

Allen Wrench
Screw Driver, Slot & Phillips

b. Fit Around

Wrenches - Box
Socket
Open End

4.7.2 Method of Actuation

a. Power - Torque

75 ft.-lb. max
6 ft.-lb. min.

Rate of Operation - Remove and install 30½-20 bolts or nuts in 3 hours.

3.4 EXPERIMENT DESCRIPTION (GENERAL)

At this point in the experiment definition, a rough estimate was made at structuring an experiment based on the analysis to date. This effort was basically aimed at evolving experimental tasks which reflected the real tasks contained as output of the analysis described above.

The objectives of this effort were:

- o experimental tasks must be capable of being performed at a worksite (eliminating any tasks involving translation, etc.);
- o experimental tasks must bear as close a resemblance as possible to real EVA/IVA tasks;
- o experimental tasks must provide objective, quantifiable measures which permit valid and meaningful comparisons across the major experimental conditions;
- o time, space and weight constraints must be met.

Obviously, the last three objectives presented serious conflicts. For example, the most realistic task involving making and breaking electrical connectors would be to perform that specific operation on a variety of connectors at various positions in the reach envelope. However, such a task presents no objective measures which permit valid comparisons. In all cases, an astronaut could probably perform the task, with only slight time differences resulting. This provides no information on the basic fine-manipulative, eye-hand coordination involved (not only in this task, but in many similar operations) which may be significantly impaired as a function of, say, a suited, 0-g condition versus a shirtsleeve, 1-g condition. The objective of the experiment must be not only to determine that a difference does or does not exist, but to quantify the difference to determine its significance. Only then can it be validly determined if the difference warrants a connector re-design or suit re-design or similar conclusion.

Thus, the tasks included in the task sequence are designed to maintain realism and subject interest, but, at the same time, to realistically represent fundamental human performance parameters and to provide objective measures of these parameters.

The remainder of this section represents the rationale for the inclusion of specific tasks in the experiment sequence. Detailed descriptions of the tasks may be found in Section 5.0.

3.4.1 RESTRAINT INSTALLATION

The vast majority of complex tasks detailed in the analysis begin with the subject having to install his personal restraints at the worksite. In certain cases, these restraints might already be available at the worksite, but in many instances, because of a weight penalty or because pre-installed restraints might compromise the aerodynamic structure, astronauts will have to carry personal restraints to the worksite and install them there.

The restraints chosen for the experiment are the Gemini Dutch Shoes, the Variable Flexibility Waist Tether, and the Capsular Adhesive Handhold. For purposes of restraint evaluation, it was ultimately decided that the task sequence would be performed using only the shoe restraint, or only the waist restraint, or a combination of waist and shoe restraints. The handhold is always used, first to aid in installation of the other restraints, and then to perform other tasks in the sequence.

In addition to personal restraints, an astronaut performing a fairly complex task will need restraints or tethers to anchor various pieces of equipment such as tool kits, spare modules or cassettes, etc. Thus, this first task of the experiment sequence includes the installation of two equipment restraints.

3.4.2 GAIN ACCESS TASK

After tasks which involve some aspect of restraint installation and manipulation, the next most commonly encountered operation was that of gaining access to the work area. Typically, this involved opening or closing a hatch or removing a protective bulkhead. To represent this action, it was decided to remove a cover from the task panel.

The subject is confronted with the problems of tool and fastener manipulation, cover removal, manipulation and stowage. Once this is completed, the astronaut generally has to make a visual inspection of the work area. Because of the frequency of occurrence of operations requiring inspection and activation, a task for this program was initially included in the sequence. But during subsequent revisions the lack of objective measures for such a task and the increased time penalties associated with incorporating this task into the experimental sequence resulted in its deletion as a formal task.

3.4.3 TWO-HAND EYE/HAND COORDINATION TASK

Several tasks were encountered in the task analysis which fundamentally require a static, fine manipulative capability. Typical tasks include electronic checkout, meter reading and adjustment, calibration of sensitive equipment, sensor alignment, telescope pointing and many others. In order to represent the many operations involved in these tasks, the Two-Hand, Eye/Hand Coordination Task was developed.

3.4.3 TWO-HAND EYE/HAND COORDINATION TASK (Continued)

This task requires the subject to use a probe, make and maintain an electrical contact, read a digital display, and carefully set an analog display. Thus, most of the operations involved in the tasks mentioned above are included to some extent. At the same time, this task provides readily quantifiable measures such as task time and setting accuracy which can be used to determine whether suit or restraint differences have significant effects on the operations required.

The task analysis resulted in identification of an additional factor which could compromise performance of many tasks - working through a restricted - access envelope. Thus, to determine if any such effect exists, this task is performed with and without such a restriction. Ideally, of course, one would like to evaluate this condition using many different sizes of access openings and depths of reach. In this experiment such a multitude of conditions would not be feasible, however. Thus, one limiting access condition was chosen such that it would present as great a physical and visual obstacle as possible without actually creating an impossible task. This allows the experimenter to at least determine if limiting access cases create significant problems.

3.4.4 PRECISE HAND MOVEMENT TASK

The Two-Hand Task basically measures static components of eye/hand coordination. To measure the dynamic aspects of this psychomotor capability, the Precise Hand Movement Task was developed. This task requires the subject to perform motions and exhibit precision control movements which typically occur in tasks such as electronic checkout, component handling, sensor operation, etc. The type of tasks that are represented by the Precise Hand Movement task basically involves two operations: first, they reflect an element of manipulative control, such as would be required when aligning a sensitive, fragile component in its receptacle; and second, a significant amount of force is being emitted in varying directions and at constantly changing rates of acceleration.

Thus, the Precise Hand Movement Task was developed to reflect these two operations. The subject is required to trace an irregular path with a small probe. The path is approximately 15 inches long and varies in both direction and width. The width is varied such that at its widest point there is no difficulty in avoiding the edge, while at its narrowest point it is almost impossible to avoid contacts. Changing path direction insures that the subject will have to change both direction and rate of acceleration.

Three constant tension springs may be attached to the probe to vary the force exerted by the subject for each path traversal. The three force values used are 1.25, 2.50 and 5.00 pounds, and were selected based on feasibility tests conducted early in the program.

Two additional parameters are varied in this task. First, as in the Two-Hand Task, the task is performed with and without a limiting access panel to determine if a performance degradation exists. Second, the task is performed with the springs being pulled from the subject's left, and again, with the

3.4.4 PRECISE HAND MOVEMENT TASK (Continued)

springs being pulled from the subject's right. This is done to determine whether any significant differences in performance might exist which result from articulating suit joints in a different manner.

This task also incorporates a module removal/replacement task. As would be expected, module removal/replacement was commonly encountered in the task analysis. It was noted that, of functions requiring mass handling, 65% dealt with modules weighing between 5 and 25 pounds. The Precise Hand Movement module was sized at about 5 pounds. The subject removes the module, re-orients it, and reinstalls it. Thus, while the subject is setting up a new experimental condition (springs left vs. springs right) he is performing a useful, evaluative task.

3.4.5 FORCE EMISSION TASK

Fundamental to just about every task an astronaut performs is a requirement to exert forces in different directions, amounts, and for different periods of time. The Force Emission Task was developed to evaluate this capability. In addition to measuring a meaningful human performance parameter, force emission also allows one to make valid comparisons about restraint utility (as exhibited by its value as a force/energy sink) and to compare performance degradation (if any) caused by the absence of a gravitational field.

The task is structured to evaluate all significant parameters which are part of force emission. Three different force types are studied. Impulse forces allow for emission of instantaneous force peaks. Sustained forces measure an individual's ability to exert a maximum, maintainable force for an extended period of time (four seconds). Precise forces require a subject to exert a fine control on the force being emitted and hold that force constant for a period of time (six seconds). Forces are also evaluated in six orthogonal directions.

This task illustrates again how time constraints must be considered. Ideally, it would be desirable to measure force emission capability in several positions in the subject's reach envelope. But this is not feasible. Two positions were therefore selected - a central, optimal position and a position in the upper right quadrant of the reach envelope.

Like the Precise Hand Movement Task, this task incorporates a module removal/replacement task which again results in utilization of the time required to change experimental conditions. This time the module weight was approximately 40 pounds, which represented the middle peak of the tri-modal distribution of weights identified in the candidate variable analysis described in 3.2.1 above. In addition, the location of the module receptacle in the upper right position was determined during the feasibility tests to be the maximum "practical" reach capability of the subjects in the selected restraint and suit conditions.

3.4.6 TORQUE EMISSION TASK

The Torque Emission Task is almost exactly similar to the Force Emission Task. Three types of torques are evaluated - Precise, Impulse, and Sustained. Two different positions are evaluated - Precise, Impulse, and Sustained. Two different positions are evaluated - a central position, and a position in the lower left quadrant of the reach envelope. Directions evaluated are clockwise and counterclockwise about a shaft perpendicular to the front of the task panel.

The main difference from the Force Task is in the man/machine interface. In the Force Task, the subject grasps a vertically mounted D-handle. In this task, the subject uses two tools which mount directly on the force receiver. One is an L-handle wrench which permits the subject to use a full arm torquing motion. The other is a T-handle which requires a torsion-type motion. These tools were selected because they represent motions required by most of the tool-assisted tasks identified in the task analysis.

3.4.7 OPERATIONAL MAINTENANCE TASK

One important class of operations was discovered in the task analysis which could not really be represented by the tasks so far described. These operations basically involved the handling and manipulation of small components,tools, etc. Thus the Operational Maintenance Task requires the subject to use different tools to remove a small component from a low pressure tubing system. The subject obtains a replacement component and installs this new component.

3.5 DEFINITION AND SELECTION OF INDEPENDENT VARIABLES

The major independent variables for this experiment were originally defined in the M508 Experiment Implementation Plan provided for guidance as part of the study input data. The information provided in that document are listed below:

1. Type of Restraint
    a. Capsular Adhesive Handhold
    b. Variable Flexibility Waist Tether
    c. Gemini Dutch Shoes
2. Suits
    a. Apollo Block II
    b. Litton Hard Suit

The manipulation and combination of these items into an experimental design was one purpose of the program described in this document. As a result of the

analysis performed on the study input data, the following decisions were made concerning the definition of the experimental design. The Waist Tether and Dutch Shoes were to be used separately and in combination and evaluated across all other experimental conditions. The Handhold would be used only for installing the other restraints. The suits were to be used separately and evaluated across all other experimental conditions.

At this point it was considered necessary to re-examine the basic ground rules of the Experiment Implementation Plan concerning the selection of suit and restraint conditions to be evaluated. Two separate analyses were undertaken to perform the re-evaluation. The first of these was to consider the experimental design for its applicability to IVA Tasks; and the second was to consider other types of restraints.

The results of the first analysis (see paragraph 3.5.1) indicated that the experimental design is applicable to both EVA and IVA operations and added the shirtsleeve mode to the list of suit conditions.

The results of the second analysis (see paragraph 3.5.2) indicated that while no single restraint could satisfy all the requirements for an optimum restraint, the three chosen seem to be among the best, and the limitation on available time to perform the experiment would not allow sufficient evaluation of additional restraints should they be added.

3.5.1 IVA TASK EVALUATION

The purpose of this section is to present the results of the analysis performed to determine the suitability of the preliminary experimental task sequence as an indicator of performance capabilities required for intra-vehicular activity (IVA). The sequence developed in the initial phase of the Astronaut Performance Program was primarily the result of an analysis of proposed extra-vehicular experiments predicted for the 1970-1980 time period. Subsequently, it was decided by NASA to incorporate evaluations of IVA tasks into the task sequence. This section presents the results of the analysis performed to determine appropriate task sequences relative to IVA requirements.

3.5.1.1 Methodology

The task sequence was originally developed by the detailed study and analysis of the information and documents described in Para. 3.1, 3.2 and 3.3 above. No similar documents were provided by NASA to initiate and support a study of IVA requirements. As a result, the initial effort for this task consisted of a literature search. A detailed search of NASA Scientific and Technical Abstract Reports from 1966 to the current time was conducted. Headings such as "Biotechnology", "Human Factors", "Human Engineering", "Orbital Worker", and similar items were consulted. Several potentially useful documents were encountered (Table 3-7) and three of these were expected to be most helpful (References 1, 2 and 3). However, these documents were not readily available and could not therefore serve as inputs for the present analysis.

3.5.1.1 Methodology (Continued)

The study team therefore decided to conduct the analysis using Reference as the primary input. This document has the advantage of presenting an extremely large number of potential experiments involving man-in-space. At the same time, it has the disadvantage of presenting experiments in a general way, specifying man-involvement only at a generic level and neglecting any definition of man-machine interfaces or hardware physical (as opposed to functional) descriptions. Nevertheless, this document was felt to be the best source of information available to the study team from which to obtain performance requirements on manned intra-vehicular activities.

TABLE 3-7 REFERENCE DOCUMENTATION FOR

IVA TASK EVALUATION

1. May, C. and Holmes, A. An Evaluation of Man's Capability to Perform Support Functions in Space. AFSC/WPAFB (AFAPL-CONF-67-4), 1967.

2. Vogeley, A. W. Human Factors Aspects of Orbital Operations - Manned Planning Requirements, presented at the Aerospace Medicine Meeting, Belgium, Oct., 1967.

3. Maintainability of Manned Spacecraft for Long-Duration Flights (NASA-CR 73152; D2-113204-3, V-3).

4. Appendix to Proceedings of the Work Sessions on Experiment Definitions and Requirements for Manned Orbital Workshops, July 9, 10, 11, 1968, released by the Payloads Directorate, Advanced Manned Missions Program, Office of Manned Space Flight.

The pertinent data from this source was extracted utilizing a format which is shown by the examples shown in Figures 3-3, 3-4, and 3-5. Seventy-three such forms were prepared. These were then studied to determine the most frequent and/or critical requirements placed on the astronauts. Finally, each man-function identified was analyzed to determine the task-elements required for its performance. It could then be determined which task-elements required for the planned IVA experiments were satisfied by the preliminary experiment sequence and which were not. The results of the analysis are presented below.

3.5.1.2 Results

The IVA Task Analysis form was designed to obtain as much information as possible relative to the performance requirements for the proposed experiments. The experiments themselves were categorized by specific scientific disciplines:

FIGURE 3-3 IVA ANALYSIS FORM

EXAMPLE I

Activity - Astronomy

Functional - Program Element: High Energy Stellar Survey A

Experiment - Data Sheet: Large Area X-Ray Detector

Description -

(a) Locate all X-ray sources of wavelengths between 0.2 and 50 angstroms

(b) Locate 50 of the brighter X-ray sources

(c) Determine X-ray spectra of selected sources

(d) Determine column thickness of absorbing material between earth and many of the detected X-ray sources

(e) Determine existence of any exceptional or ultraviolet brightnesses that may be associated with particular X-ray sources.

(f) Determine the character of short and medium term temporal time fluctuations of the brighter X-ray sources

Equipment -

- Collimated proportional counters
  - Modules

Size: 4800 Lbs.
9 Cu. Ft. (Modules)

Crew Support - Provide initial orientation of scan system axis, turning on the equipment and evaluations in accordance with pre-determined guidelines.

FIGURE 3-4 IVA ANALYSIS FORM

EXAMPLE II

Activity -	Space Physics
Functional - Program Element	Ionospheric Plasma Investigations
Experiment - Data Sheet	Plasma Wave Propagation Experiment
Description -	Perform refined tests of warm magnetoplasma theory. Obtain detailed information on ionospheric plasma parameters.
Equipment -	Transmitter/Receiver
	Size: Receiver 1/2 $Ft.^3$ 50 Lbs.
Crew Support -	Align antennas and monitor apparatus

FIGURE 3-5 IVA ANALYSIS FORM

EXAMPLE III

Activity -	Earth Applications
Functional - Program Element	Earth Resources and Meteorology
Experiment - Data Sheet	Metric Camera
Description -	The purpose of this experiment is to delineate the potential of stellar metric photography for cartographic and geodetic purposes. Data will be collected by a ground looking metric camera coupled with a stellar observation camera. The program will provide data enabling the generation of more accurate base maps to apply to the results of all other orbital sensors.
Equipment -	Camera - 200 Lbs. Replacement Film - 80 Lbs.
Crew Support -	(1) Set up and establish ground contact (2) Check ground cloud cover (3) Acquire Target Start Point (4) Assess target condition (5) Establish auto mode (6) Describe and record target conditions (7) Monitor during auto procedures (8) Checkout and shut down equipment

3.5.1.2 Results (Continued)

Astronomy

Space Physics

Space Biology

Earth Resources

These headings were used as the main activity heading for each form. Each form was then further identified by its functional program element and experiment data sheet. A brief description of the experiment followed this identifying information. Equipment and crew support categories completed the format. Each experimental data sheet from Reference 5 was analyzed using this format. Unfortunately, the equipment and task level of these experiments were not in sufficient detail to readily lend themselves to a definitive man/machine requirements analysis. Particularly lacking was detailed equipment descriptions. It was, therefore, decided to analyze crew support activities at a generic level in relation to the information and knowledge to be gained by the experiment. The first step in such a process was to collect the crew support functions from the analysis form to determine frequencies and/or criticality. The resulting tabulation is contained in Table 3-8.

The crew functions thus identified were then analyzed to select their required task elements and compare them with the task elements evaluated by M508. The method devised for this comparison was to return to the EVA analysis forms used to develop the M508 experiment and extrapolate from them generic man/machine functions previously selected for evaluation by M508. These functions represent basic task-elements and are inherent in the extra-vehicular activities previously studied. They were selected for the M508 experiment based on their importance, criticality, frequency, knowledge-value, etc. The present objective was to review the IVA functions listed in Table 3-8 to determine whether the same task-elements could be considered inherent in these intra-vehicular activities. The IVA task-elements and the specific preliminary experiment task which evaluates them are as follows:

IVA TASK ELEMENT	PRELIMINARY EXPERIMENT M508
• Force Emission	Force/Torque Emission Task
Gross	Sustained, Impulse
Controlled	Precise
• Torque Emission	Force/Torque Emission Task
Gross	Sustained, Impulse
Controlled	Precise

3.5.1.2 Results (Continued)

IVA TASK ELEMENT	PRELIMINARY EXPERIMENT M508
• Parts Operations	
Fasteners	
Manual	Access Panel; Precise Hand Movement Panel
Tool	Gain Access; Operational Maintenance Task; Module Removal/Replacement
Switch	Operational Maintenance Task; Two-Hand Coordination Task
Connector	Module Removal/Replacement
• Module Manipulation	
Removal	Force Receiver Repositioning
Replacement	Precise Hand Movement Module Repositioning
• Reaction Time	
Simple	Two-Hand Coordination Task
Complex	Force Emission Task
• Feedback	
Aural	Operational Maintnenance Task; Precise Hand Movement Task; Two-Hand Coordination Task
Tactile	All
Visual	All, but especially: Precise Force/Torque Emission
• Precise Hand Control	
Static	Two-Hand Coordination
Dynamic	Precise Hand Movement Task
• Body Control	Restraint Installation
• Manipulation	
Small Component	Operational Maintenance Task
Gross	
Fine	

3.5.1.2 Results (Continued)

IVA TASK ELEMENT	PRELIMINARY EXPERIMENT M508
• Manipulation(Continued)	
Controls	Two-Hand Coordination Task
Gross Fine	
• Decision-Making	Force Emission Task
• Time-Stress (Minor)	Operational Maintenance Task
• Support Equipment	Use of Lanyards, Equipment Tethers, Etc.
Management	

These task elements were listed down the side of a two-dimensional matrix, shown in Table 3-9. The IVA functions of Table 3-8 were then listed across the column headings. The next step was to evaluate each IVA task on the basis of professional judgment and insight as to the task elements required. For example, it was hypothesized that the IVA task of "repair" would include both gross and controlled force emissions (removing electronic racks, disassembly, etc.), both gross and controlled torque emissions (using wrenches, nut drivers, etc.) and so forth throughout each task element. In addition, task elements which are not part of M508 but were necessary for particular IVA functions were identified. The task elements that were added are shown in Table 3-9 and are listed below:

- o Higher Cognitive Functions
- o Multiple Fasteners/Connector Evaluations
  (M508 considers only a limited number of fasteners or connectors; Some IVA functions are naturally expected to exceed this number.)
- o Multiple Controls Evaluations
- o Multiple Mass Transfer
- o Locomotion and Translation
- o Multiple Tool Evaluations
  (M508 evaluates only a T-handle wrench, a Ratchet wrench, and an Open-End wrench)

TABLE 3-8

ASTRONAUT FUNCTIONS REQUIRED BY EXPERIMENTS STUDIED

FUNCTION	FREQUENCY OF OCCURRENCE BY NUMBER OF EXPERIMENTS
General Maintenance	36
Repair	32
Target Acquisition	18
Monitoring	15
Film Retrieval/Replacement	14
Data Record/Acquisition	14
Removal/Replacement	13
Operate Cameras	7
Focus/Alignment	5
Checkout	5
Housekeeping	5
Obtaining Biological Specimens	5
Calibration	4
Data Evaluation	3
Assess Target	2
Surveillance	2
Record Target Conditions	2
Detector Replacement	1
Docking	1
Remote Manuevering	1
Film Processing	1
Slave Satellite Operation	1

3.5.1.2 Results (Continued)

Table 3-9 is the completed matrix in which each X denotes the presence of the EVA Task element in the IVA task.

3.5.1.3 Conclusions and Recommendations

The matrix of Table 3-9 indicates the significant finding that a sizable majority of the task elements required for the satisfactory performance of currently planned IVA functions are evaluated by the current design of Experiment M508. In particular, the most frequently encountered IVA functions (from Table 3-8) are well-represented by M508.

It is equally important to realize what is not being stated by this study. No attempt is made here to imply that a task such as "Target Acquisition" is evaluated per se by M508. Such evaluation would require the construction of a separate and entire task representing a typical target-sighting mission. By the same token, it is recognized that the IVA tasks analyzed in this study encounter a multitude of hardware types which are not evaluated by M508. What is evaluated by M508 are those task elements which in combination comprise the IVA function listed.

Experiment M508 must live within the realities of weight, volume and time limitations. It is certainly conceivable that additonal tasks could be added - but at the penalty of increasing the experimental data collection time. Larger masses, more fasteners, switches, connectors could all be added to the current M508 design - but again at very significant weight and time penalties. More importantly, the marginal value of such an addition would be highly questionable. The fundamental elements of target acquisition - visual feedback, precise load control, control manipulation, etc. - are already included for evaluation by M508. Similarly, the elemental operations required for the other IVA tasks are to a large extent already included. Increasing the complexity of the experiment to include additional parameter values or experimental variables would not be justified by the very low marginal return of information-value that would result from the required increases in weight, volume and time.

In conclusion, it is therefore determined that no changes were required to the current design of Experiment M508. Based on currently available information, Experiment M508 will yield data that is of significant value to designers of advanced spacecraft for both IVA and EVA operations and will also provide data on the capabilities of astronauts to perform operations and experiments required on advanced space missions.

3.5.2 RESTRAINT EVALUATION

The purpose of this section is to document the effort and analysis concerned with the restraint selection for the Astronaut Performance Program (M508). The restraints selected for this program were a handhold, the Gemini Dutch Shoes, a rigidizeable/flexible waist tether and the combination of both the shoe and waist restraint. This study was not directed at restraint system design but rather the evaluation of restraints as they affect man's performance in space, both IVA & EVA.

TABLE 3-9 IVA TASK AND ELEMENT COMPARISON

ELEMENTS \ IVA TASKS	GENERAL MAINTENANCE	TARGET ACQUISITION	REPAIR	FOCUS/ALIGNMENT	FILM RETRIEVAL/ REPLACEMENT	DETECTOR REPLACEMENT	DATA EVALUATION	CALIBRATION	MONITORING	C/O	DOCKING	DATA RECORD/ ACQUISITION	REMOVAL/ REPLACEMENT	REMOTE MANEUVERING	OPERATE CAMERA	ASSESS TARGET	SURVEILLANCE	FILM PROCESSING	HOUSEKEEPING	RECORD TARGET CONDITION	SLAVE SAT. OPERATION	OBTAIN BIOLOGICAL SPECIMENS
ELEMENTS EVALUATED IN M508																						
FORCE EMISSION																						
Gross	X		X										X						X			
Controlled	X		X	X	X	X		X			X			X	X						X	X
TORQUE EMISSION																						
Gross	X		X										X						X			
Controlled	X		X			X		X		X	X			X	X						X	X
PARTS OPERATIONS FASTENERS																						
Manual	X		X		X	X							X									
Tool	X		X			X							X									
Switch		X	X				X	X		X	X			X	X		X				X	
Connector			X			X		X		X			X					X				
MODULE MANIPULATION																						
Removal	X		X		X	X							X							X		
Replacement	X		X		X	X							X						X			
REACTION TIME																						
Simple		X		X					X	X	X			X			X			X	X	X
Complex		X		X					X		X			X		X	X			X	X	

TABLE 3-9 IVA TASK AND ELEMENT COMPARISON (Continued)

ELEMENTS \ IVA TASKS	GENERAL MAINTENANCE	TARGET ACQUISITION	REPAIR	FOCUS/ALIGNMENT	FILM RETRIEVAL/ REPLACEMENT	DETECTOR REPLACEMENT	DATA EVALUATION	CALIBRATION	MONITORING	C/O	DOCKING	DATA RECORD/ ACQUISITION	REMOVAL/ REPLACEMENT	REMOTE MANEUVERING	OPERATE CAMERA	ASSESS TARGET	SURVEILLANCE	FILM PROCESSING	HOUSEKEEPING	RECORD TARGET CONDITION	SLAVE SAT. OPERATION	OBTAIN BIOLOGICAL SPECIMENS
ELEMENTS EVALUATED IN M508																						
FEEDBACK																						
Aural							X	X	X	X	X			X		X						
Tactile		X		X				X		X	X											
Visual	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X
PRECISE HAND CONTROL																						
Static	X	X		X				X		X	X			X	X			X				
Dynamic	X		X			X					X		X	X								
BODY CONTROL	X		X		X	X							X						X			
MANIPULATION																						
SMALL COMPONENT																						
Gross	X		X		X								X						X			
Fine			X			X		X														X
CONTROLS																						
Gross	X	X					X											X	X	X	X	
Fine		X		X				X		X	X			X	X	X	X			X	X	
DECISION MAKING			X	X			X	X	X	X	X			X			X	X		X	X	X
TIME-STRESS		X	X				X						X									X
SUPPORT EQUIP. MGMT.	X		X		X	X		X					X									X

TABLE 3-9 IVA TASK AND ELEMENT COMPARISON (Continued)

ELEMENTS \ IVA TASKS	GENERAL MAINTENANCE	TARGET ACQUISITION	REPAIR	FOCUS/ALIGNMENT	FILM RETRIEVAL/ REPLACEMENT	DETECTOR REPLACEMENT	DATA EVALUATION	CALIBRATION	MONITORING	C/O	DOCKING	DATA RECORD/ ACQUISITION	REMOVAL/ REPLACEMENT	REMOTE MANEUVERING	OPERATE CAMERA	ASSESS TARGET	SURVEILLANCE	FILM PROCESSING	HOUSEKEEPING	RECORD TARGET CONDITION	SLAVE SAT. OPERATION	OBTAIN BIOLOGICAL SPECIMENS
ELEMENTS NOT EVALUATED IN M508																						
HIGHER COGNITIVE FUNCTIONS			X				X		X	X						X	X					
MULTIPLE FASTENER/ CONNECTOR EVAL.	X		X										X						X			
MULTIPLE CONTROLS EVAL.	X		X					X		X	X			X							X	
MULTIPLE MASS TRANS.	X		X										X						X			
LOCOMOTION & TRANSLATION	X		X										X						X			
MULTIPLE TOOL EVAL.	X		X										X									

3.5.2.1 Introduction

Restraints of some type are an absolute requirement in the O-gravity environment in order for man to perform work or even to remain stationary at rest at a fixed point. To date the Mercury, Gemini and Apollo flights have been of relatively short duration and the amount of "free-space volume has been limited. Future space flights of long duration and especially the planned AAP orbital flights will provide man with much greater volumes such as the S-IVB Workshop in which to work. In addition he will have a greater variety of work stations both IVA & EVA, and as mission durations increase it can be predicted that more maintenance type EVA tasks will be required.

No one restraint has yet been designed which can be considered optimum or could fulfill all the requirements of a restraint system. Restraint design and evaluation is of primary importance to space station designers. In general, state-of-the-art restraints are of three types: handhold restraints, waist restraints, and foot (shoe) restraints. Variations on these three types have included toe traps, thigh traps, stirrups, rigid and flexible tethers, and recent emphasis has also been directed at "artificial" gravity vector restraints either making use of negator springs or straps for creating the gravity vector.

As previously mentioned, each restraint has merit for a particular type of task but also certain shortcomings in relation to other tasks. The following sections of this report will discuss some of the restraint data available in the literature and list the requirements for restraint systems. A trade-off matrix is included at the conclusion of the report relevant to the restraints selected for the Astronaut Performance Program.

3.5.2.2 Literature Review

There are relatively few reports available which deal with restraints or restraint systems for use at worksites. Rather, the majority of reports have dealt with restraints as they are used for the launch and re-entry environment. This is not to imply that restraint systems are not being designed and evaluated. NASA and the Air Force have studies in progress which are directly applicable to restraint evaluation.

Probably the most comprehensive restraint evaluation document available to date are the Summary of Gemini Extravehicular Activity Report MSC-G-R-67-2, June, 1967 and Extravehicular Activity Design Criteria Revision A, MSC, September 20, 1968. The findings of these reports indicate the following:

- A handrail was found useful as a handhold restraint for making and breaking a nitrogen connector. Pilot preference seemed to indicate a rectangular cross section is preferable to cylindrical cross section.

- Telescoping cylindrical handrails were useful for traversing but the flexibility of this type of device caused the pilot to have a loss of body positioning and attitude.

3.5.2.2 Literature Review (Continued)

- Fixed handholds were useful in flight but again pilot preference tended towards rectangular cross sections over cylindrical cross sections.

- Portable handholds of the velcro interface type were adequate for stationary positioning but poor for controlled maneuvering. They recommend using them only when fixed handholds could not be provided. Possibly a better design of attachment to the vehicle/work station would enhance the use of this type of device.

- Waist tethers of the flexible variety proved useful as restraints for both localized work and rest.

- Pip pin handhold devices were also useful for changing body position. The T-shaped pip pins were a convenient shape and size for hand gripping. Anti-rotation of the pip pins is desirable if the subject is expected to be capable of precise alignment.

- Foot restraints of the stiprup variety were inadequate for body restraint because they offered no heel support. The dutch shoe was far superior to all restraints evaluated. They afforded the pilots a large work envelope and a good energy sink for emitting forces. The pilots were able to very nearly duplicate their one-g baseline proficiencies.

Additional published and unpublished studies are referenced in other sections of this report.

3.5.2.3 Restraint Requirements

The following is a list of restraint requirements which pertains to all possible conditions and considerations for which a restraint system is germane.

3.5.2.3.1 Safety

Restraints must be safe to the point of obviously not injuring the user but in the hazardous environment of space, must not trap the subject, i.e., restraints must be of the quick release of fail-safe variety. The Gemini Dutch Shoes are a good example of this type. Personnel can free themselves of the restraint by simply twisting his foot and pivoting his toe towards his body centerline. Waist restraints generally have the airplane quick release seat belt, snaps, velcro, or other means of quick release. Quick release buckling achieved by looping belt ends back through double ring sets as are used on older SCUBA gear is not advisable. They do not hold as snugly and require greater effort to achieve release. In an emergency condition the least effort and time loss in restraint release is most necessary. Along these same lines donning and doffing, including the quick release feature must be within the capability of the user without help from a second individual.

3.5.2.3.2 Comfort

Restraints at worksites, especially those which require long time durations as in console type worksites, must be comfortable. Two factors of comfort are considered here. The first is that of subject interface. Restraints which provide pressure points to the body of the user are obviously not very desirable even though they provide maximum stability. The second aspect of comfort is that of effort required by personnel to utilize the restraint. A drawback to the artificial gravity restraints, for long usage periods, is the degree of effort required by the user to maintain himself against the force of the gravity vector. Similarly, a handhold restraint provides a tremendous range of motion(equal to the radius of the left hand to right hand span in any direction) but requires a tremendous effort by the user to both move and maintain stability. Preliminary results of the NASA HECMAR (Human Engineering Criteria for Maintenance and Repair of Advanced Space Systems Study, Contract No. NAS8-21429) indicate that the handhold is almost totally useless as a restraint for precision motion and control, especially in the pressure suit condition.

3.5.2.3.3 Range of Motion

Generally speaking, the greater range of motion provided by a restraint, the greater is its application to a variety of tasks. The rigid waist restraint provides the user with great stability and comfort but limits the workspace volume to which the subject has access. The flexible waist tether increases the range of motion but degrades the users stability. A rigidizable, flexible tether appears to be a good compromise between the two extremes. Dutch shoes, in addition to the handhold, provide a surprisingly large work access volume to the front of the subject, to his preferred hand side, and also to his rear. The previously mentioned HECMAR study has results of subjects in the shirtsleeve mode reaching to rear in excess of 90" as measured from the front of the dutch shoe restraint. But here again, after long periods the subjects experienced pain and fatigue in the lower portion of their legs and ankles

3.5.2.3.4 Stability

A prime requirement of a restraint is the degree of stability provided to the user. Console tasks such as reading meters, observing CRT's, and making precise control motions (depressing pushbuttons, turning continuous rotary switches, etc.) require a high degree of stability. Also many maintenance tasks, both IVA and EVA, put high demands on restraint (user) stability. Both the waist restraint and dutch shoes (at close reach points) provide good user stability. The handhold runs an extremely poor third. Similarly, restraints which require subject effort against the artificial gravity vector may tend to induce muscle tremors after prolonged usage.

3.5.2.3.5 Force Application

Another prime requirement of a restraint is to provide an energy sink for force application by the user. This requirement is differentiated from that of stability by the amounts of force exerted by the user. A restraint may provide stability for precise displacements of small force magnitude but be useless in large force applications. Also direction of the force in relation to the energy sink of the restraint has a significant bearing on maximum forces. Types of force (impulse, sustained, precise and etc.) also have a relationship to the type of restraint utilized. The NASA study contract, Human Engineering Data for Maintenance and Repair of Advanced Space Systems, Experiment 84A, NAS8-18117 studied this relationship. Some of the variables considered were type force (impulse versus sustained), force direction (push, pull, up, down, right, left), angle of force application, distance of force application, orientation of handle used to induce the force (vertical versus horizontal), and restraints (hand, waist, shoe, hand and waist, hand and shoes, waist and shoes, and hand, waist and shoes in combination. The conclusions obtained from the performance and analysis of this study are generally as follows:

- Impulse and sustained forces differed significantly across the restraints used. For single restraints, the waist restraint is best for Push/Pull force emissions. Dutch shoes are best for Up/Down force emissions. A handhold is best for left directions. All single restraints are equally poor for assisting in right direction forces. For multiple restraints, the handhold, waist, and shoes combination was best for Push/Pull sustained forces. The handhold and shoes combinations was best for Up/Down and Left/Right sustained force emissions.

- The waist restraint was the only single point restraint in which a significant sustained (above 10 lbs.) mean Push/Pull force could be exerted.

- Handhold restraint provided the capability for sustaining significant (above 10 lbs.) mean forces in only the Left/Right directions.

- The shoe restraint provided the capability for sustaining significant (above 10 lbs.) mean forces in only the Up/Down directions.

3.5.2.3.6 EVA/IVA Usability

A restraint design for IVA considers the man in the shirtsleeve environment while EVA considers the man in the pressure suit mode. The interface of the man to the restraint is significantly different. The pressure suited waist circumference is significantly larger, the dutch shoes are designed to accept the spacesuit boots, and even the handhold diameters are larger for the pressure suited mode because of the difficulty in grasping with the pressurized glove. Still another requirement of EVA restraints are that they be easily installed at the worksite. Unscheduled maintenance activity which requires EVA may be at any place on the surface of the vehicle such as in meteorite puncture repair. It

3.5.2.3.6 EVA/IVA Usability (Continued)

would be impossible to have permanent restraints at all possible sites. The user will have to transport the restraint to the site, install it, don, doff, remove it, and return it to the vehicle. Therefore, it must be of minimum size, yet provide the user with the capability of performing many different tasks which may require mobility, stability, force emission, etc.

3.5.2.3.7 Task Requirements

By far the most restricting or limiting of all restraint requirements is that of "what task is the user required to perform while in the restraint". Console panel tasks in 1-g, which require long duration (excess of 20 minutes) performance, always requires that a seat of some type be provided for the operator. The reason is, of course, fatigue due to the countering of gravity required to stand. Therefore a "standing" console operation in space will not be unusual and has the desirability of increasing the usable console area because of the larger "standing" work envelope. But conversely, this very concept of increased range of motion is defeated if the operation is required to perform precise, controlled displacmments or high force emissions. Many of the planned AAP experiments are of such a special nature that they each have their own pecular restraint requirements. For example, tracking tasks or vision experiments require such extreme subject stability that "sit-down" type chairs with lap harnesses or even head clamps/restraints are required to maintain complete subject stability. Another example of these specialized missions would be where one astronaut serves as a subject and the second astronaut serves as the experimenter. The subject may be immobilized in a rotating litter chair while the experiment monitors a console, maintains visual continuity with the subject, and in the event of an emergency comes to the aid of the subject as quickly as possible.

3.5.2.3.8 Restraint Interfaces

A final requirement for restraints is the interface between the restraint and the vehicle. Permanent restraints do not tend to be a problem in that the design is integrated into the work area. Another requirement for fixed restraints other than those already discussed, is that they be of minimum weight for launch. Portable restraints are more of a problem in that they must attach to a variety of surfaces both IVA & EVA. Portable restraints are practical from the standpoint that a few restraints can serve many locations. Candidates for attaching portable restraints are velcro (nylon, polyester, and steel), pip pin attachments, thermal set adheisve,, electro-adhesive devices, and cam lock devices to mention a few. A number of these have been evaluated on the Gemini flights. Additional work is required in this area.

3.5.2.4 Summary

Restraint systems for IVA and EVA worksites will be required for all future space flights. No one restraint system fulfills all the requirements for the optimum restraint. The Astronaut Performance Program recognizes this problem and

3.5.2.4 Summary (Continued)

has made restraint evaluations a major portion of the study effort. Three restraints have been selected as experiment variables for the evaluation based on a review of the state-of-the-art restraints. The trade-off matrix at the end of this report indicates that a maximum return of data will be realized from using these restraints in that they are the current "best guess" types of restraints which will be used in future space stations. It should be noted that the numerical ratings assigned to the restraints are not intended to represent absolute values but rather are the subjective evaluations and ratings of engineers and psychologists familiar with 0-gravity restraint requirements and as such represent professional judgment data. An explanation of the ratings follows:

Ratings - 1 to 5 - higher numbers indicate the restraint possesses a higher degree of the particular characteristic than theother restraints.

Category Considerations - Safety - degree to which the subject is encumbered by the restraint and time required to free himself from the restraint.

Range of Motion - volumetric area which can be reached by user when in the restraint.

Stability - degree of stability provided to body/limbs for performing precise and controlled limb motions.

Force Application - the energy sink ability of the restraint for exerting forces by the pilot.

EVA Usability - degree of low bulk and weight required to take to the EVA worksite.

Task Applications - degree to which the restraint is versatile for console tasks, maintenance tasks, etc.

State-of-the-Art/Experience - the degree of test and evaluation to which the restraint has been subjected.

Energy Expenditure - the amount of energy not required in utilizing the restraint.

The Gemini Dutch shoes and rigidizeable waist tether were selected for M508 evaluation on the basis of their high ratings on the Restraint Trade-Off Matrix (Table 3-10). Rather than choose a second waist restraint (as would be dictated by the evaluation point totals) or a seat-type restraint (which were to be evaluated in Experiment D020), a combination of the waist and shoe restraints was chosen as a third experiment variable. In addition, a handhold restraint is utilized at various points in the task sequence as a secondary restraint because of a favorable evaluation in the trade-off matrix, ease of installation and use, and because of favorable experience concerning handholds during previous missions.

TABLE 3-10 RESTRAINT TRADE-OFF MATRIX

REQUIREMENTS \ RESTRAINTS	DUTCH SHOES	STIRRUPS	HANDHOLD	WAIST: RIGID	WAIST: FLEXIBLE	WAIST: RIGIDIZABLE	TOE TRAP	SEAT TYPE: THIGH TRAP	SEAT TYPE: PELVIC	SEAT TYPE: LAP BELT	SEAT TYPE: SEAT PLUS FOOT BAR	LEG RESTRAINTS	ARTIFICIAL GRAVITY VECTOR TYPE	ARM RESTRAINTS
SAFETY	4	4	5	3	3	3	4	4	3	3	5	2	3	3
COMFORT	4	2	2	5	4	5	3	4	3	5	3	2	3	2
RANGE OF MOTION	4	3	5	1	3	3	3	1	1	1	2	2	3	3
STABILITY	3	1	2	5	3	5	3	4	5	5	4	4	3	1
FORCE APPLICATION	4	1	2	5	2	4	4	4	5	5	3	4	4	1
EVA/USABILITY	4	5	5	2	3	3	3	1	1	1	1	2	3	1
TASK APPLICATIONS	5	2	2	2	3	4	3	3	3	3	3	3	3	2
STATE-OF-ART/ EXPERIENCE	5	3	5	5	5	4	3	3	3	3	3	2	3	1
ENERGY EXPENDITURE (LOW)	3	2	1	5	3	5	2	5	5	5	3	3	3	2
TOTAL	36	23	29	33	29	36	28	29	29	31	27	24	28	16

3.6 Candidate Task Sequence

The analysis described above resulted in the generation of a sequence of tasks which comprised the definition of the M508 Experiment. The tasks were set into an ordered sequence to approximate an actual manned intra- or extra-vehicular function. The sequence as it ultimately evolved is shown as a Functional Flow Block Diagram in Figure 3-6.

Each performance of the task sequence requires approximately 1 hour of subject time and is to be performed under the following conditions:

Subjects	- 2	
Suit Conditions	- 3	- Shirtsleeves Apollo Block II AES
Restraint Conditions	- 3	- Variable Flexibility Waist Tether Gemini Dutch Shoe Waist Tether and Dutch Shoe
Replications	- 2	

These combine for a total of 36 experiment sessions, which can be performed in zero-g conditions (real or simulated). In a 1-g environment, the "Waist Restraint Only" condition must be deleted, leaving only 24 sessions.

The particular items which comprise the task sequence are outlined below. Detailed descriptions of subject tasks, controlled variables and resulting measures are given in section 5.0.

3.6.1 INSTALLING PERSONAL RESTRAINTS

One of the first tasks facing the astronaut in performing any operation at a worksite will be to secure himself with adequate restraint devices which permit the use of both hands on the job. Large volume space stations and structures are not likely to have restraints available for every potential worksite. Therefore, the astronaut will be required to install and don his own personal restraints. This task is to evaluate the problems, design details, procedures, forces and support equipment required for worksite restraint installation. The task begins with the astronaut at the worksite location, ready to begin the experiment. The equipment required will include: handhold; waist tether and/or Dutch shoe restraint; tools; equipment tethers.

3.6.2 GAIN ACCESS TO THE TASK PANEL

The second area experimentally studied involves the gaining of access to the equipment which must be operated or maintained. In most cases of aircraft and spacecraft design, equipment that is not continuously monitored or operated is

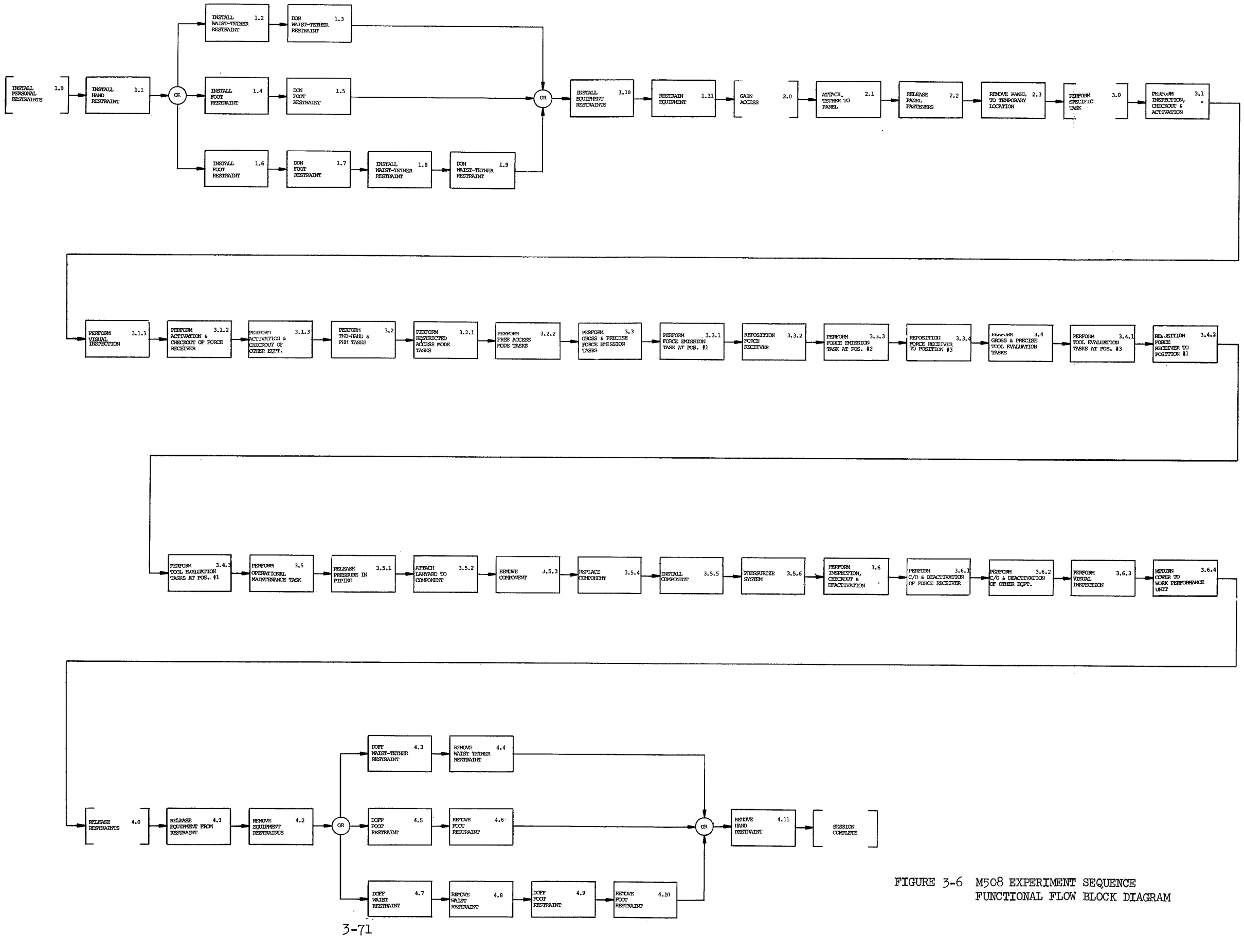


FIGURE 3-6 M508 EXPERIMENT SEQUENCE FUNCTIONAL FLOW BLOCK DIAGRAM

3.6.2 GAIN ACCESS TO THE TASK PANEL Continued)

covered to protect it from damage or undue exposure. This is especially true of equipment accessible only through aerodynamic surfaces or structures. Therefore, this task is designed to evaluate the problems associated with removing and replacing access panels, evaluating various fasteners and connectors and providing suitable interim stowage locations in the zero-g environment. The equipment required includes: panel fasteners and connectors; tools; and interim stowage restraints/tethers/fasteners.

3.6.3 PERFORM SPECIFIC TASKS

This section describes the specific tasks that the subject performs inside the task panel. These tasks are actually sub-experiments contained within the framework of the total experiment. Each of the sub-experiments has its own variables and measures, is designed to provide information on specific questions and is independent of the other sub-experiments. Consequently, the sub-experiments can be modified or replaced without significantly affecting the other sub-experiments.

3.6.3.1 Inspection, Activation and Checkout

Once an astronaut has access to the work area, he may then proceed to perform the specific maintenance, repair or investigation that is required. Such tasks will first require that the astronaut visually scan the work area to generally determine status and integrity, and then checkout the performance of various pieces of equipment. This experiment will require the subject to perform such actions while actually preparing equipment modules for subsequent phases of the experiment.

3.6.3.2 Two-Hand, Eye/Hand Coordination Task

Thw Two-Hand, Eye/Hand Coordination Task is representative of several aspects of operational EVA/IVA maintenance and repair tasks including electrical checkout and calibration procedures. The task is designed to include visual and psychomotor tasks such as eye/hand coordination, fine manipulation, alignment and adjustment of calibration type controls. The experimental design is constructed to assess restraint devices, suit performance characteristics, and degradation due to limited access, using a two-hand coordination task.

The equipment used for the study will include: digital display; electrical contacts -- male, female and solder joint; contact probe, coarse and fine potentiometers, and an analog meter.

3.6.3.3 Precise Hand Movement Task

The Precise Hand Movement Task requires the subject to perform precise hand movements with varying degrees of difficulty and force exertion requirements.

3.6.3.3 Precise Hand Movement Task (Continued)

The specific task the astronaut will perform is to trace a maze path with a stylus probe. The width of the path varies from 1" to 3/32" and the probe is 1/16" in diameter. The lateral forces required to move the stylus are either 1.25, 2.50 or 5.0 lbs. This type of task is inherent in many of the spacecraft EVA/IVA operational procedures and provides an excellent method for reliable and quantitative evaluation of restraint capabilities, suit performance characteristics and access envelopes while performing a fine manipulative control task.

The experimental design is constructed to assess restraint devices, suit performance characteristics and limited access degradation using a preferred hand, precise movement task.

The equipment used for the study will include: hand motion measurement panel; hand stylus; maze path; coupled timers; and a contact detector.

3.6.3.4 Maximum and Precise Force Emission Tasks

One basic task to be performed by man during space flight is the exertion of forces of various types and directions. Typical tasks requiring force exertion are the need to remove and stow, assemble and disassemble, install structural components, and the requirement for man to move himself. This task is designed to evaluate and quantify man's ability to generate impulsive, sustained and precise forces under various conditions of restraint, type of suit and location of force receiver.

The sequence of Figure 3-6 indicates that the force emission task is always performed prior to the tool evaluation task. In fact, the force and torque tasks are alternated to reduce fatigue effects.

This portion of the sequence also includes a module positioning task. The force receiver module is removed from the "optimum", central location in front of the subject, transferred to an alternate location and installed into a receptacle provided as part of the task panel. The manual force emission tasks will be repeated at this additional location.

The equipment used includes: the force receiver module, subject cue panel; D-handle; force readout; and observer test panel.

3.6.3.5 Tool Evaluation Task

During spaceflight maintenance and repair operations, man will be required to use tools to exert torques of various magnitudes. Typical tasks requiring this type of force application are removal and stowage, assembly and disassembly of component parts, and structural component installation. This experiment is designed to measure man's ability to generate impulsive, sustained and precise torques utilizing different types of tools under various conditions of restraint, type of suit and force receiver location.

3.6.3.5 Tool Evaluation Task (Continued)

This portion of the sequence also includes repositioning the force receiver module to an alternate location and repeating the tool evaluation tasks.

The equipment used includes: the force receiver module; cue light system; T-handle and ratchet wrenches; force readout; and observer test panel.

3.6.3.6 Component Assembly Panel

The Operational Maintenance Task requires the astronaut to perform a repair of a pressure valve assembly in a low pressure gas plumbing system. The task requires fault isolation, removal and replacement of a failed component from the system, and return of the system to operational status.

The experiment equipment used for the study includes: plumbing assembly with replaceable component; pressure readout meter; visual cue alarm; hand operated compressor; relief valve, pressure control valves; and appropriate wren wrenches.

3.6.4 SECURING THE WORKSITE

At the end of any operational task, it would be necessary to secure equipment that had been opened for servicing or temporary use, and it is therefore considered worthwhile to take data on the securing of the worksite. Although the tasks are in a sense "mirror images" of those performed at the beginning of the sequences, a number of factors, such as the fatigue induced by the tests, will be different at the end of the sequence.

Table 3-11 is a detailed breakdown of the Functional Flow Block Diagram. In addition to the detailed step-by-step procedures, the table shows the variables and/or conditions for each step, the measures to be taken and the estimated discrete and elapsed time.

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C*	NOTES
Astronaut starts at end of mobility aid with all tools, equipment, and restraint hardware attached to his person.										
1.0 Install Personal Restraints	Order of Installation & Combination used in task performance:	X	X			X	X			Movies must be time coordinated. Physiological data must be time coordinated. Time notes needed at every X.
1.1 Install Hand Restraint		X								
1.1.1 Release handhold from suit tie-down	Hand-Foot or Hand-Waist or Hand-Foot-Waist Tie-down: Velcro, snap, or loops.							4	4	
1.1.2 Activate adhesive and attach handhold to bulkhead for left hand.								30	34	One-hand task, using mobility aid as hand restraint. Time to dry dependent on adhesive.
1.1.3 Release lanyard from handhold.	Lanyard Attachment: Springloaded slide-lever. 4' Lanyard	X						5	39	
1.2 Install Waist-Tether Restraint	length on take-up reel	X								Use handhold as restraint.
1.2.1 Release bulkhead-end of flexible tether from suit attachment on right-hand side	Tether Length: Approx. 36"							5		
1.2.2 Insert end of tether into hole on side of task board.	Bolt with thumb-depressable detent							5		Instrument receptacle for Force Measure
1.2.3 Repeat 1.2.1-1.2.2 for left-hand tether		X						10		
1.3 Don Waist-Tether Restraint										
1.3.1 Adjust rigidity of LHS tether								10		Observer must aid subject to obtain proper spatial relationship.
1.3.2 Adjust rigidity of RHS tether								10		
1.4 Install Foot Restraint		X								This task will not be performed after the waist tether is installed, but either in place of or before donning the waist tether.
1.4.1 Release shoe platform from suit tie-down								4		
1.4.2 Insert platform tongue into pre-installed groove	Tongue-in-Groove Installation							30		
1.4.3 Lock & release handle								5		
1.4.4 Release lanyard from shoe platform		X						5		Instrument for force measurement.

*Cumulative Time, developed for Hand-Foot-Waist Installation

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
1.5 Don Foot Restraint		X								
1.5.1 Insert Right Foot								20		
1.5.2 Insert Left Foot								20		
1.6 Install Foot Restraint Same procedure as 1.4.		X						44	83	
1.7 Don Foot Restraint Same procedure as 1.5		X						40	123	
1.8 Install Waist Restraint Same procedure as 1.2		X						20	143	In this case, waist restraint is installed using both hand and foot restraints, for comparison with 1.2.
1.9 Don Waist Restraint Same procedure as 1.3								20	163	
1.10 Install Equipment Restraints										
1.10.1 Release one end of flexible tether equipment restraint from suit attachment	3'-4' Tether	X						2	165	
1.10.2 Locate end near hole to right of task board	Thumb-depressible detent							4	169	
1.10.3 Depress spring-loaded barb and insert rod into hole	Thumb-depressible detent							5	174	
1.10.4 Release detent								2	176	
1.10.5 Release other end of tether from suit								2	178	
1.10.6 Rigidize tether out of way	Rigidity adjustment-handle squeeze							5	183	
1.10.7 Repeat for tether on left side of board		X						20	203	
1.11 Restrain equipment		X								
1.11.1 De-rigidize right-hand equipment tether								5	208	
1.11.2 Attach tool kit to equipment tether on right								10	223	
1.11.3 Release tool kit from suit										Tool kit contains D-handle, T-handle, ratchet wrench, open-end wrench, & calibration equipment. Tool kit is positioned for accessibility before rigidizing tether
1.11.4 Rigidize tether		X	X				X	5	228	
REST								30	258	258

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
2.0 Gain Access		$\overline{X}$	X			$\overline{X}$	$\overline{X}$			
2.1 Attach tether to panel										
2.1.1 Reach to left-hand side equipment tether								2	2	
2.1.2 De-rigidize tether	Handle-release							4	6	
2.1.3 Attach tether to panel	Spring-loaded detent							3	9	
2.2 Release panel fasteners		X								Tool kit will have bit
2.2.1 Open tool kit and attach free end of lanyard to ratchet wrench								4	13	captived to prevent loss
2.2.2 Attach socket to ratchet wrench	3/8" captive, external wrenching Hex-nuts							2	15	
2.2.3 Remove ratchet wrench from kit								2	17	
2.2.4 Loosen fasteners, one in each corner of panel								20	37	
2.2.5 Change bit on tool (allen-head drive)	5/32" captive, internal wrenching Hex-nuts							6	43	
2.2.6 Repeat 2.2.4								20	63	
2.2.7 Return tool to kit								2	65	
2.2.8 Detach bit from tool								2	67	
2.2.9 Release lanyard from tool		X						2	69	
2.3 Remove panel to temporary location										
2.3.1 Remove panel from fasteners	Panel Size: 30" x 24" x 1/4"							15	84	
2.3.2 Move to temporary location at left of task board								10	94	
2.3.3 Position and rigidize tether			X				$\overline{X}$	5	99	
REST								30	129	387

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUBJECTIVE	PHYSIOLOGICAL	TIME (SECONDS): D	C	NOTES
3.0 Perform specific task			X							
3.1 Perform Inspection, activation & checkout		X				X	X			
3.1.1 Perform visual inspection										
3.1.1.1 Activate supplemental lighting for force emission module & MTP*	General requirement for 20 ft. candles illumination at work surface							2	2	
3.1.1.2 Visually scan force emission module and MTP for status/integrity check								10	12	
3.1.2 Perform activation & checkout of force receiver										
3.1.2.1 Attach lanyard to force receiver calibration device								2	14	
3.1.2.2 Remove force receiver calibration test device from tool kit and transfer to panel								10	24	
3.1.2.3 Install force receiver calibration device on force receiver module								10	34	
3.1.2.4 Activate force receiver								2	36	
3.1.2.5 Observe & call out X, Y, Z readouts for observer to record								5	41	
3.1.2.6 Connect force receiver calibration device to test position $+Y_1$								2	43	
3.1.2.7 Observe $+Y_1$ axis readout	Astro. observer records values							2	45	
3.1.2.8 Recalibrate $+Y_1$ readout by manual adjustment control, if required								5	50	
3.1.2.9 Disconnect force calibration tool from $+Y_1$ position								2	52	
3.1.2.10 Repeat Steps 3.1.2.6 thru 3.1.2.9 for test positions $+Y_2$, $+Y_3$, $+Z_1$, $+Z_2$, and $+Z_3$	Astro. observer records values							55	107	Calibrations are contemplated in + direction for first sequence and - direction for alternate sequences
3.1.2.11 Attach 2nd lanyard to X axis test tripod								2	109	Possible reduction to one axis depending on final selection of instrumentation

*Mission Task Panel

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
3.1.2.12 Remove X axis test tripod from tool kit								5	114	
3.1.2.13 Attach tripod to force receiver module								2	116	
3.1.2.14 Connect force calibration device to tripod $+X_1$ axis test position								2	118	
3.1.2.15 Observe $+X_1$ axis readout								5	123	
3.1.2.16 Recalibrate $+X_1$ axis readout, if required	Astro. observer records values							7	130	
3.1.2.17 Adjust X axis test device to position $+X_2$								4	134	
3.1.2.18 Repeat Steps 3.1.2.15 thru 3.1.2.17 for axis positions $+X_2$ and $+X_3$								22	156	
3.1.2.19 Detach X axis tripod from force receiver module								2	158	
3.1.2.20 Secure X axis tripod in tool kit								2	160	
3.1.2.21 Detach lanyard from tripod								5	165	
3.1.2.22 Attach lanyard to torque calibration arm								2	167	
3.1.2.23 Remove torque calibration arm from tool kit								5	172	
3.1.2.24 Attach torque calibration arm to force receiver								4	176	
3.1.2.25 Attach torque spring of calibration device to hook on calibration arm	Eye hook							2	178	
3.1.2.26 Read torque indicator and manually calibrate if required								10	188	
3.1.2.27 Release torque calibration spring from hook								2	190	
3.1.2.28 Return calibration device to tool kit								5	195	

TABLE 3-11 EXPE[illegible]IAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES						TIME (SECONDS)		NOTES
		TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	D	C	
3.1.2.29 Release lanyard from calibration device								2	197	
3.1.2.30 Remove torque calibration arm from force receiver								2	199	
3.1.2.31 Return torque calibration arm to tool kit								5	204	
3.1.2.32 Release lanyard from torque calibration arm and secure tool kit								2	206	
3.1.2.33 Deactive force receiver								2	208	
3.1.3 Perform activation & checkout of MTP										
3.1.3.1 Activate MTP								2	210	
3.1.3.2 Push Timer Start (Observer)								1	211	
3.1.3.3 Push Timer Stop (Subject)								1	212	
3.1.3.4 Astronaut observer verifies timer function								3	215	
3.1.3.5 Insert and remove test probe in each of 3 positions								10	225	
3.1.3.6 Astronaut observer verifies contact counter function								10	235	
3.1.3.7 Attach lanyard to tension check tool in tool kit								2	237	
3.1.3.8 Remove tension check tool								5	242	
3.1.3.9 Insert stylus in tension receptacle #1								2	244	
3.1.3.10 Attach tension check device to stylus and static ring	Static ring connector							3	247	
3.1.3.11 Verify tension values by reading scale of check tool	Astro. observer records values							5	252	
3.1.3.12 Repeat Steps 9-11 for receptacles #2 & #3								20	272	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
3.1.3.13 Release tensions check device from stylus and static ring								3	275	
3.1.3.14 Secure tension check device in tool kit								5	280	
3.1.3.15 Detach lanyard from check tool								2	282	
3.1.3.16 Deactivate MTP		X	X				X	2	284	
REST								60	344	731
3.2 Perform Mission Task Panel tasks (Free Access & Restricted Access Modes)						X				
3.2.1 Perform restricted access mode tasks										
3.2.1.1 Return panel to task board		X	X				X			
3.2.1.1.1 De-rigidize equipment tether								4	4	
3.2.1.1.2 Transfer panel to original location at work panel								10	14	
3.2.1.1.3 Position panel keyhole openings on lugs								9	23	
3.2.1.1.4 Release tether from rear panel hook								8	31	
3.2.1.1.5 Rigidize tether								5	36	
3.2.1.1.6 Attach lanyard to ratchet wrench								4	40	
3.2.1.1.7 Obtain ratchet wrench from tool kit								4	44	
3.2.1.1.8 Tighten fasteners(4) in each corner								20	64	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
3.2.1.1.9 Change tool bit								15	79	
3.2.1.1.10 Tighten remaining fasteners (4) in each corner								20	99	
3.2.1.1.11 Return ratchet wrench to kit								6	105	
3.2.1.1.12 Detach lanyard from ratchet wrench								2	107	
3.2.1.1.13 Turn access door lever through 180°	Dimensions: _____							5	112	Probable design of access door should be quick release
3.2.1.1.14 Swing open access door to detent position								4	116	type to simulate access door which is designed for frequent use
3.2.1.1.15 Reach through access door and release spring loaded collar connectors at each corner of panel								20	136	
3.2.1.1.16 Move panel out to detent position	Approx. 10" (panel from module)						X	5	141	
3.2.1.1.17 Tighten connectors at corner of panel								20	161	
3.2.1.2 Perform eye-hand co-ordination task through Access Port		X					X			
3.2.1.2.1 Reach through access port and turn panel switch to On	Lever switch-standard							2	163	2 Timers needed
3.2.1.2.2 Obtain test probe from panel (Left Hand) and place hands at ready position								5	168	
3.2.1.2.3 Upon onset of cue light place test probe on contact #1	Receptacles: Male, female & solder joint	X						2	170	1st Timer activated by observer, deactivated by subject. 2nd Timer coupled to
3.2.1.2.4 Observe digital readout	Test Probe -	X						2	172	test probe/receptacle
3.2.1.2.5 Enter readout into meter scale using gang tuner	10.0-99.9 units, one decimal place. Two stage gang tuner,							6	178	Additional measures: number of contacts between probe & receptacle, vernier scale
3.2.1.2.6 Repeat Steps .2 thru .5 for receptacles #2 & #3 for total of 3 values at each receptacle	gross & fine tuner. Vernier scale marked with digits from 10 to 90, .1 resolution 3 values - Stratified random sample to one decimal accuracy							120	298	accuracy

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES						TIME (SECONDS)		NOTES
		TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	D	C	
3.2.1.3 Perform maze tracing task I										
3.2.1.3.1 Insert stylus in tension ring receptacle #1	Tension, constant 3/8#, 2#, 5#							2	300	
3.2.1.3.2 When cue light goes on, trace slotted path from left to right & back to original position		X						20	320	2 Timers needed: 1st Timer activated by observer, deactivated by subject. 2nd timer activated by contact
3.2.1.3.3 Repeat Steps .1 & .2 for tension rings #2 & #3		X						44	364	between stylus and path Additional measures: No. of contacts between stylus and path
3.2.1.4 Reposition maze tracing module										
3.2.1.4.1 Release fasteners								5	369	
3.2.1.4.2 Remove module, rotate, & re-install								20	389	
3.2.1.4.3 Connect fasteners								5	394	
3.2.1.5 Perform maze tracing task II		X								
3.2.1.5.1 Repeat Steps 3.2.1.3.1 thru 3.2.1.3.3							X	66	460	
3.2.2 Perform free access mode tasks		X					X			
3.2.2.1 Remove panel										
3.2.2.1.1 Reach through access door and release spring-loaded collar connectors at each corner of panel								5	465	
3.2.2.1.2 Move panel back								5	470	
3.2.2.1.3 Tighten connectors at corners of panel								20	490	
3.2.2.1.4 Close access door and attach tether to panel hook								5	495	
3.2.2.1.5 Attach lanyard to ratchet wrench								5	500	
3.2.2.1.6 Loosen fasteners in each corner								20	520	
3.2.2.1.7 Change tool bit								5	525	
3.2.2.1.8 Loosen remaining fasteners in each corner								20	545	
3.2.2.1.9 Remove panel to temporary location & rigidize tether								10	555	
3.2.2.1.10 Return tool to kit								5	560	
3.2.2.1.11 Release lanyard from tool		X						2	562	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES						TIME (SECONDS)		NOTES
		TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	D	C	
3.2.2.2 Perform eye-hand co-ordination task		X								
3.2.2.2.1 Repeat Steps 3.2.1.2.2 thru 3.2.1.2.6								135	697	
3.2.2.3 Perform maze tracing task I and II		X								
3.2.2.3.1 Repeat Steps 3.2.1.3.1 thru 3.2.1.5.1							X	162	859	
REST								60	919	1650
3.3 Perform gross and precise force emission tasks			X			X	X			
3.3.1 Perform force emission task at Pos. #1	Position #1: Subject's nipple height; module center 9" from S's centerline.									
3.3.1.1 Attach lanyard to D-handle in tool kit								10	10	
3.3.1.2 Remove handle from tool kit and transfer to panel	D-Handle - 3/4" diameter, 5-3/4" inside dimension, 2½" depth dim.							5	15	
3.3.1.3 Install handle on force receiver module	Socket connector - Spring pin insert							12	27	
3.3.1.4 Disconnect lanyard								2	29	
3.3.1.5 Apply impulse force in plus X direction when indicator light goes on	Maximum force recorder, direction of force, & time from GO signal to start of response.				X			10	39	Randomized presentation controlled by cue panel. Mixture of trials achieved for counterbalancing. Reaction time measured.
3.3.1.6 Repeat for -X, ± Y, & ± Z					X			50	89	
3.3.1.7 Apply sustained force in plus X direction when indicator light goes on and maintain force until light goes off(4 secs.)	Minimum force recorder for + 1 second to + 3.5 seconds				X			15	104	Errors in direction of type force recorded by observer; trial repeated.
3.3.1.8 Repeat for -X, ± Y, & ± Z direction					X			75	179	
3.3.1.9 Apply n pounds force in plus X direction when indicator light goes on (6 seconds)	Force-time history recorded for +1 second to + 5.0 seconds				X			15	194	Force is maintained by subject as close to value as possible. Meter provides visual feedback of force value.
3.3.1.10 Repeat for -X, ± Y, & ± Z directions					X			75	269	
3.3.2 Reposition force receiver		X	X							
3.3.2.1 Attach lanyard to force receiver module							X	2	271	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
3.3.2.2 Deactivate electrical connections								2	273	Force receiver module must represent desired module size, mass & shape
3.3.2.3 Disconnect electrical connector	Bayonet connector				X			4	277	
3.3.2.4 Release module fasteners	Captive fasteners, pip pins				X			6	283	
3.3.2.5 Remove module from panel					X			2	285	
3.3.2.6 Transfer module to Position #2	Position #2: 15-3/4" subject's nipple height; module center 14-3/4" right of S's centerline							5	290	
3.3.2.7 Position and install module					X			2	292	
3.3.2.8 Secure module fasteners					X			6	298	
3.3.2.9 Connect electrical connectors					X			4	302	
3.3.2.10 Activate electrical connectors								2	304	
3.3.2.11 Disconnect lanyard		X	X				X	2	306	
3.3.3 Perform Force Emission Task at Pos. #2										
3.3.3.1 Repeat Steps 3.3.1.5 through 3.3.1.10					X			240	546	
3.3.3.2 Attach lanyard to force receiver handle								2	548	
3.3.3.3 Disconnect force receiver handle from module								12	560	
3.3.3.4 Return handle to tool kit								2	562	
3.3.3.5 Stow handle and detach lanyard								5	567	
3.3.4 Reposition force receiver to Position #3 (Steps are same as function 3.3.2 but module moved from Pos. #2 to Pos.#3 and power not restored to connector)	Position #3: 11-5/8" below Pos. #1, module center 5-7/8" left of subject's centerline	X X	X				X	37	604	
REST								60	664	2314
3.4 Perform gross & precise tool evaluation tasks						X	X			
3.4.1 Perform tool evaluation tasks at Pos. #3			X							Randomized presentation controlled by cue panel.
3.4.1.1 Attach lanyard to ½" hex nut receiver	Tool receiver: ½" hex nut; bolt fastened to torque transducer axis							2	2	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
3.4.1.2 Remove tool receiver from tool kit								2	4	
3.4.1.3 Install tool receiver in torque-measuring receptacle								5	9	Reaction time measured as well as errors for wrong direction or type force. Errors and trials are repeated.
3.4.1.4 Release lanyard								2	11	
3.4.1.5 Attach lanyard to ratchet wrench								2	13	
3.4.1.6 Remove ratchet wrench from tool kit	Ratchet wrench							2	15	
3.4.1.7 Fit ratchet wrench onto tool receiver			X					2 rest	17	
3.4.1.8 Exert maximum torque for 5 seconds cw	Analog record of max torque			X				5+5	27	
3.4.1.9 Exert maximum torque for 5 seconds ccw	Analog record of max torque			X				5+5 rest	37	
3.4.1.10 Exert maximum impulse torque cw	Analog record of max torque			X				2+5	44	
3.4.1.11 Exert maximum impulse torque ccw	Analog record of max torque			X				2+5	51	
3.4.1.12 Exert X-in-lb torque for 5 seconds cw	Analog record of max torque			X				5+5	61	
3.4.1.13 Exert X-in-lb torque for 5 secons ccw	Analog record of max torque		X	X				5+5	71	
3.4.1.14 Remove ratchet wrench from tool receiver								2	73	
3.4.1.15 Return ratchet wrench to tool kit								2	75	
3.4.1.16 Release lanyard								2	77	
3.4.1.17 Attach lanyard to T-wrench	T-wrench							2	79	
3.4.1.18 Remove T-wrench from kit								2	81	
3.4.1.19 Fit T-wrench onto tool receiver								2 rest	83	
3.4.1.20 Exert maximum torque for 5 seconds cw	Analog record of max torque		X	X				5+5	93	
3.4.1.21 Exert maximum torque for 5 seconds ccw	Analog record of max torque			X				5+5	103	
3.4.1.22 Exert maximum impulse torque cw	Analog record of max torque			X				2+5	110	
3.4.1.23 Exert maximum impulse torque ccw	Analog record of max torque			X				2+5	117	
3.4.1.24 Exert X-in-lb torque for 5 seconds cw	Analog record of max torque			X				5+5	127	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS) D	C	NOTES
3.4.1.25 Exert X-in-lb torque for 5 seconds ccw	Analog record of max torque		X	X				5+5	137	
3.4.1.26 Remove T-wrench from tool receiver								2	139	
3.4.1.27 Return T-wrench to tool kit								2	141	
3.4.1.28 Release lanyard								2	143	
3.4.2 Reposition tool torque receiver		X								
3.4.2.1 Attach lanyard to torque receiver	Spring clip, eye loop							2	145	
3.4.2.2 Deactivate electrical connector								2	147	
3.4.2.3 Disconnect electrical connector	Thread assist							4	151	
3.4.2.4 Release module fasteners								6	157	
3.4.2.5 Remove module from panel								2	159	
3.4.2.6 Transfer module to Pos. #1								5	164	
3.4.2.7 Position and install module								2	166	
3.4.2.8 Secure module fasteners								6	172	
3.4.2.9 Connect electrical connectors								4	176	
3.4.2.10 Activate electrical connectors								2	178	
3.4.2.11 Disconnect lanyard		X					X			
3.4.3 Perform tool evaluation tasks at Pos. #1							X			
3.4.3.1 Repeat Steps 3.4.1.1 - 3.4.1.28				X				143	323	
3.4.3.2 Attach lanyard to tool receiver								2	325	
3.4.3.3 Remove tool receiver								10	335	
3.4.3.4 Return tool receiver to tool kit								2	337	
3.4.3.5 Release lanyard								2	339	
3.4.3.6 Secure lanyard								2	341	
3.4.3.7 Power off.		X				X	X	2	343	
REST								60	403	2717

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS) D	C	NOTES
3.5 Perform operational maintenance task		X				X	X			
3.5.1 Release pressure in piping										This task could be an observer-initiated item signaling the subject to stop whatever else he is doing and repair this system.
3.5.1.1 Close air intake valve								4	4	
3.5.1.2 Open pressure relief valve								4	8	
3.5.2 Attach lanyard to component								5	13	Air bottle provides pressure
3.5.3 Remove component										
3.5.3.1 Attach lanyard to ratchet wrench	Ratchet-wrench							4	17	
3.5.3.2 Remove tool from tool kit								3	20	
3.5.3.3 Release component fasteners using ratchet wrench								25	45	
3.5.3.4 Return wrench to tool kit and release lanyard								5	50	
3.5.3.5 Attach lanyard to T-handle wrench								2	52	
3.5.3.6 Remove T-handle from tool kit								2	54	
3.5.3.7 Release component fasteners								10	64	
3.5.3.8 Remove component								5	69	
3.5.4 Replace component										
3.5.4.1 Place component in tool kit								5	74	
3.5.4.2 Release lanyard from component								2	76	
3.5.4.3 Attach lanyard to new comp.								2	78	
3.5.4.4 Remove component from tool kit.								5	83	
3.5.4.5 Transfer comp. to task panel								2	85	
3.5.5 Install component										
3.5.5.1 Position component in line								10	95	
3.5.5.2 Finger-adjust fasteners								10	105	
3.5.5.3 Tighten fasteners with tool								10	115	
3.5.5.4 Switch tools								5	120	
3.5.5.5 Tighten fasteners								10	130	
3.5.5.6 Return tool to tool kit								3	133	
3.5.5.7 Release lanyard from tool								3	136	
3.5.6 Pressurize system										
3.5.6.1 Close pressure relief valve								4	140	Provides measure of performance for total task
3.5.6.2 Open air intake valve								4	144	
3.5.6.3 Pump pressurizing handle								10	154	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHSYIO-LOGICAL	TIME (SECONDS) D	C	NOTES
3.5.6.4 Observe pressure on gauge.								4	158	
3.5.6.5 Release lanyard								2	160	
3.5.6.6 Indicate to observer task completion								2	162	2879
							X			
3.6 Perform inspection C/O & deactivation		X				X	X			
3.6.1 Perform C/O & deactivation of force receiver device										
3.6.1.1 Attach lanyard to force receiver calibration device								2	2	
3.6.1.2 Remove force calibration test device from tool kit and transfer to panel								5	7	
3.6.1.3 Install force calibration device on force receiver module								5	12	
3.6.1.4 Observe and call out X, Y, Z axes readout	Astro observer records							2	14	
3.6.1.5 Connect force calibration device to position +Y	Eyehook or quick connect-disconnect							2	16	
3.6.1.6 Observe $+Y_1$ axis readout	Astro observer records							2	18	
3.6.1.7 Disconnect force calibration tool								2	20	
3.6.1.8 Repeat Steps .5 - .7 for test positions $+Y_2$, $+Y_3$, $+Z_1$, $+Z_2$, $+Z_3$								30	50	
3.6.1.9 Attach 2nd lanyard to X axis tripod								2	52	
3.6.1.10 Remove X axis tripod from tool kit								5	57	
3.6.1.11 Attach X axis tripod to force module								2	59	
3.6.1.12 Connect force emission calibration device to tripod $+X_1$ axis test position								2	61	
3.6.1.13 Observe $+X_1$ axis readout	Astro observer records							2	63	
3.6.1.14 Repeat Steps .12 - .13 for test position $+X_2$, $+X_3$	Astro observer records							8	71	
3.6.1.15 Detach X axis tripod from module								2	73	
3.6.1.16 Secure tripod in tool kit								5	78	
3.6.1.17 Detach lanyard from tripod								2	80	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
3.6.1.18 Attach lanyard to torque calibration arm								2	82	
3.6.1.19 Remove torque calibration arm from tool kit								5	87	
3.6.1.20 Attach torque calibration arm to force receiver calibration device								4	91	
3.6.1.21 Observe torque readout	Astro observer records							2	93	
3.6.1.22 Release torque calibration arm								2	95	
3.6.1.23 Secure calibration arm in tool kit								5	100	
3.6.1.24 Release lanyard from calibration arm								2	102	
3.6.1.25 Return calibration device to tool kit								5	107	
3.6.1.26 Release lanyard from calibration device								5	112	
3.6.1.27 Deactivate force emission receiver								2	114	
3.6.2 Perform C/O & deactivation of MTP										
3.6.2.1 Repeat Steps 3.1.3.7 through 3.1.3.15								42	156	
3.6.2.2 Deactive MTP								2	158	
3.6.3 Perform Visual Inspection										
3.6.3.1 Visually scan force receiver module & MTP for status/integrity check								10	168	
3.6.3.2 Deactivate supplemental lighting								2	170	
3.6.4 Return panel to work performance unit										
3.6.4.1 Obtain panel from temporary location & position on task board								5	175	
3.6.4.2 Attach lanyard to ratchet wrench								3	178	
3.6.4.3 Remove ratchet wrench from tool kit								3	181	
3.6.4.4 Tighten fasteners in each corner & release tether								20	201	
3.6.4.5 Change tool bit								5	206	
3.6.4.6 Tighten remaining fasteners in each corner								20	226	
3.6.4.7 Return ratchet wrench to kit								3	229	
3.6.4.8 Detach lanyard from ratchet wrench		X					X	3	232	
REST								30	262	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
4.0 Release restraints										
4.1 Release equipment from restraints						X	X			
4.1.1 De-rigidize right-hand equipment tether								2	2	
4.1.2 Prepare tool kit ~~from~~ or transfer								10	12	
4.1.3 Release tool kit from tether								3	15	
4.1.4 Transfer tool kit to suit and attach								5	20	
4.2 Remove equipment restraints										
4.2.1 De-rigidize tether on left-hand side of board	Rigidity adjustment-handle release							5	25	
4.2.2 Attach one end of tether to suit								2	27	
4.2.3 Depress thumb-released detent at bulkhead end of restraint	Thumb-depressible detent							2	29	
4.2.4 Remove restraint rod from hole								2	31	
4.2.5 Attach end of tether to suit								2	33	
4.2.6 Repeat for tether on right-hand side								13	46	
4.3 Doff waist-tether restraint										
4.3.1 De-rigidize left-hand restraint								10	56	
4.3.2 De-rigidize right-hand restraint								10	66	
4.4 Remove waist-tether restraint										
4.4.1 Release right-side restraint bolt								10	76	
4.4.2 Attach restraint to suit								5	81	
4.4.3 Release left-side restraint bolt								10	91	
4.4.4 Attach restraint to suit								5	96	
4.5 Doff foot restraint										
4.5.1 Release left foot								5	101	
4.5.2 Release right foot								5	106	
4.6 Remove foot restraint										
4.6.1 Release one end of lanyard from suit attachment	Lanyard attachment-spring-loaded clip							2	108	
4.6.2 Attach lanyard to shoe platform								5	113	
4.6.3 Release platform lock								3	116	
4.6.4 Release platform-tongue from groove								15	131	

TABLE 3-11 EXPERIMENTAL TASK SEQUENCE (Continued)

DETAILED STEPS	SELECTED VARIABLES/CONDITIONS	MEASURES: TIME	FILM	TORQUE	FORCE	SUB-JECTIVE	PHYSIO-LOGICAL	TIME (SECONDS): D	C	NOTES
4.6.5 Attach platform to suit		↓	↓				↓	5	136	
4.6.6 Release lanyard from shoe platform								2	138	
4.6.7 Attach lanyard to suit								2	140	
4.7 Doff waist restraint Same as 4.3								20		
4.8 Remove waist restraint Same as 4.4								30		
4.9 Doff foot restraint Same as 4.5								10		
4.10 Remove foot restraint Same as 4.6								34		
4.11 Remove hand restraint	Peel-strength						↓			Use mobility aid as hand restraint
4.11.1 Peel off adhesive		X	X				X	10	150	
										3291

SECTION 4

TASK PANEL DEVELOPMENT

4.1 TASK PANEL EVOLUTION

The development of the task panel followed an iterative process that closely paralleled the development of the task sequence. An initial candidate task sequence was defined through the analytical steps described in Section 3.0. This sequence was then used as the basis for determining the task panel functional and design requirements. Simultaneous with and integrated into the development of the functional and design requirements was the specification of the man/machine interface criteria to be utilized in the development of the task panel system. The above steps resulted in a task panel conceptual design that specified as many design details as possible and identified design questions that required further investigation. A feasibility test program was accomplished to answer the unresolved design questions and the results were used to finalize the task panel design. The following sections detail the efforts accomplished in the evolution of the task panel hardware design.

4.1.1 FUNCTIONAL AND DESIGN REQUIREMENTS

A Functional and Design Requirements Specification was prepared to provide the interface information between the Candidate Task Sequence data and the equipment design details. It converted experiment requirements into information required for hardware design, and it also served as an initial reference point for identifying equipment required to perform the experiment both in the various ground-based simulation media and in the space situation.

The equipment was described by specifying its function and desired features in accordance with the following definitions and interpretations which are consistent with NPC-500-1 and MSC-KA-D-68-1.

Requirements - Overall term which recommends, limits, defines, dictates, etc., the design approach developed by the contractor for contract compliance. Requirements may consist of Performance Requirements and Design and Construction Requirements.

Performance Requirements - Consists of Functional Characteristics and other items (not immediately pertinent). This document was concerned with Functional Characteristics - what the item does in functional terms, design constraints which direct and limit design but do not preclude design.

Design and Construction Requirements - Consists of General Design Features and other items (not immediately pertinent). This document attempts to specify General Design Features - those features which are experimental variables and dictate design such as size, weight, shape, color, controls, etc.

The information in Table 4-1 identifies the required equipment and the associated functional and design requirements. The Functional Flow Block Number and Title information corresponds to an earlier version of Figure 3-6, M508 Experiment Sequence Functional Flow Block Diagram.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.1 Install Hand Restraint	Mobility Aid	.1 a) Mobility Aid serves as a left hand restraint while right hand is used for hand restraint installation.		GFE
	Hand Restraint	.2 A means is required for providing a hand restraint system that subject installs at work site.		"Capsular Adhesive System" is considered to be GFE
		a) Hand restraint must be capable of one-handed manipulation and installation		Customer definition required, esp. as regards power requirements, reuse, etc.
		b) Must adapt to lanyard attachments (See below)		
		c) If electro-adhesive is used, curing time must be short (less than 30 seconds)		
		d) Must have high tensile strength and shear strength but low peel strength		
		e) A smooth, clean surface must be provided on the bulkhead for installation		Distance by which subject misses the spot measures an "error"
		f) Adhesive must be activated with less than 5# sustained force.		
		g) Tentative values of tension & shear - 100 lbs.		
		h) Desired point of installation must be indicated to subject		Hand restraint must be installed and removed for each experimental sequence

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.1 Install Hand Restraint (Continued)		i) Handle size: 0.75" diameter tubing 5.5" long, 2.5" deep		
	Lanyard	.3 Lanyard provides a safety tether which the subject uses to attach to pieces of hardware when there exists a danger of their "floating" away. One end of lanyard attached to subject.		
		a) Attachment must be operable with one hand (connect & disconnect)		
		b) Attach to suit at conveniently reached location. Both ends attach to suit when lanyard not in use.		
		c) Operable with little or no visual reference	Desired attachment mechanisms One end - slide lever (dog-leash type) Other end - push-button actuated detents on end of rod	Requires all components interfacing with lanyard to have 1) a hook 2) a hole to capture detented rod
		d) Capable of multiple use		
		e) Approximate length - 4' Little or no residual set - highly flexible Non-twisting Non-elastic 50 lb. (tentative) Test		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.2 Install Waist Tether Restraint	Tether	.1 a) Easily attached and detached with one hand b) Installable with limited visual reference c) Tether should be of the flexible, adjustable rigidity type d) Max bending moment -(Later) Max tension - (Later) Minimum length - 3' e) Two tethers required; should be interchangeable from left to right and vice-versa	a) Attachment type: Quick attach - release twist - lock connector. This receptacle should be force-instrumented to record forces in three axes	Waist restraint-suit interface definition required before design can be accomplished; such definition should come from customer.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.3 Don Waist-Tether Restraint	Rigidity Adjustment	.1 A method of adjusting rigidity in tether through a continuous range is required. a) Operable with no visual reference b) Lever operation compatible with pressure suit gloves	.1 Captive ratchet wrench: 4" length - reversible lever. Located at waist attachment point .2 Reversible handle squeeze. Located in center of tether length.	

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.4 Install Foot Restraint	Gemini Dutch shoes mounted on platform	.1 A means is required to mount this platform on the bulkhead. The platform must: a) Be easily attached and detached with one hand b) Contain provision for lanyard attachment c) Firmly lock into place when installed d) Contain provision for attachment to suit or cargo harness during translation e) Support 500 pounds f) Instrument for force measurement in three axes		Maximum weight plus safety factor of item with greatest mass.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.5 - 1.9		No additional requirements		
1.10 Install Equipment Restraints	Equipment Restraints	.1 Two flexible, adjustable restraints are to be used for restraining equipment as necessary during the course of the experiment.		
		a) An attachment point is required on both sides of the task board.	Attachment to bulkhead: spring-loaded barb to be inserted into hole. Thumb-depressant for release.	All equipment to be restrained must accept equipment restraint fastener
		b) Attachment to bulkhead is defined. Other end of equipment restraint may be as required.		
		c) Length required - Maximum 4'	Adjustable rigidity mechanism - handle squeeze	Strength of restraint dependent on mass of equipment to be restrained.
		d) Flexible tether type		Equipment end of restraint may be magnetic fastener. Definition required as to state-of-the-art of magnetic fastener mechanisms

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.11 Restrain Equipment	Cargo Harness	.1 Cargo Harness will contain all tools, fasteners, replacement components, calibration equipment, etc. needed during the experiment. Cargo Harness is to be restrained to equipment restraint on RHS of task board. Restraint must be rigid. Restraint attachment is optional. Cargo harness must not hamper astronaut during translation or hatch access.		Use of cargo harness predicated on assumption that prototype harness exists. Need customer definition. If cargo harness deleted, use of one of the equipment restraints becomes questionable.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
1.12 Adjust Task Board as Required	Adjustment Track for Task Panel	.1 Task Board must be movable in height so as to accommodate astronauts from 5th to 95th percentile in stature, i.e., 10" adjustment a) Adjustment must be positive - detent type with scale such that location is repeatable for subjects.		Location of task panel will be such that when the force receiver is used in the optimum mode, the centerline (point of force application) of the force receiver is perpendicular to the subject's right nipple.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
2.0 Gain Access				
2.1 Attach Tether to Panel	Panel/Equipment Tether	.1 The equipment tether on the LHS of the task board is attached to the panel. Thus: a) The panel must accept the tether attachment mechanism b) The attachment must be made before the panel is released from its fasteners.		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
2.2 Release Panel Fasteners	Fasteners	.2 A means is required to evaluate two different fastener types: Two fasteners, one of each type, will be located in each corner of the panel. The fasteners shall be of the captive type.	Types of fasteners: ½" Externally Mounted Hex Nut Allen-Head Type	
	Power Tool	.3 A power tool will be used to release the fasteners. The power tool must: a) Be usable in a one-hand operation b) Adopt lanyard attachments c) Accept two different bits, easily changeable d) Deliver ____ in-lbs of torque It is preferable that the tool be battery-powered		Power tool requirement dependent on existence of prototype power tool. Alternate: ratchet wrench
	Tool Kit	See 3.3.1		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	ASSOCIATED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
2.3 Remove Panel to Temporary Location	Panel	.1 In addition to the requirements of 2.1, the access panel shall faithfully represent a solar panel. a) The surface of the panel will physically represent the visual and fragile aspects of a solar panel b) The panel shall be removable only by positive action after releasing the fasteners.	Size 30" x 30" x ½"	

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
2.4 Restrain Panel at Temporary Location	Restraint	.1 The (solar) panel shall be restrained to the left of the task board by snapping it into position. The snap retaining mechanism shall represent such installations as are currently planned.		
		a) An electrical connector shall be provided on the panel and at the restraint location		Connector shall be representative of solar panel connectors
2.5 Release Tether from Panel		No additional requirements		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.1 Perform Inspection, Activation, & C/O	Panel Displays & Controls	.1 A means is required for activating the panel and displaying panel status. The mean must		
3.1.1 Perform Visual Inspection		a) Provide on/off power control & associate positive display of status		Power switches should activate individual modules to conserve power during C/O & operations
		b) Displays should be go-no go & indicate general condition of panel		
	Observer's Panel	c) Additional readouts and/or test points at observer's panel for trouble shooting		Maintenance philosophy must be established.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. / TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.1.2 Perform Actuation & C/O of Force Emission Receiver	Force Receiver Calibration Device	.1 A means is required to C/O & calibrate the force receiver and the torque transducers The means must a) Provide calibration C/O in all directions i.e., X, Y, Z & rotational cw & ccw b) Provide C/O at a minumum of 3 points throughout the range of measurement for each direction c) Provide readout capability on device, legible and accurate to degree required for insuring calibration is within tolerance		Calibration device is contained in cargo harness

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.1.3 Perform Activation and C/O of MTP	Subject's Panel	.1 A means is required to verify the operational status of the MTP. This involves: a) Check timer operation manually b) Check operation of automatic timer, which is activated by test probe. c) Check and calibrate tension on tension springs for precision movement test d) Verify recording of contacts between stylus and track e) Verify continuity between test points (See 3.5.7)		
	Observer's Panel	.2 a) Observer must be able to set voltage at test probe contact point b) Observer must have readout of value set by subject.		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL ELEMENT TITLE	EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.2 Perform Gross & Precise Force Emission Tasks 3.2.1 Perform Force Emission Task at Position #1	Force Receiver	.1 A means is required for providing a device which can measure force applications. The means must a) Measure forces in the ± X, Y, Z axes b) Provide a readout and recording of the forces and time history of the forces c) Be located on the experiment panel such that the force receiver's centerline (point of force application) is in line with the subject's right nipple. This necessitates an additional requirement for adjustment within the range of the astronaut population. Nipple to receiver should be 18". d) Provide vernier readout at force receiver through a range of 0-50# e) Provide cue lights for identification of mode and direction subject should apply force f) Provide real time readout at observer's panel g) Sustained forces, gross mode, shall be read & recorded for 0-4 seconds h) Sustained precise forces shall be read and recorded for 0-6 seconds. Force to be sustained-40#.	a) Provide X, Y, Z (plus & minus) display keyed to observer's panel. Individual lights; trans-illuminated, white. Mode select, sustained gross, sustained precise, & impulse-individual, trans-illuminated, white. Sustained precise indicator must be located in visual contiguity with vernier force meter	Data reduction shall only use +1 to +3.5 seconds in sustained gross mode and +1 to +5.0 for the sustained precise mode Observer will select mode & direction from a prepared list of randomized presentations. Subject's time to initiate force will be measured. Cue panel must be located independent of force receiver module.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.2.1 Perform Force Emission Task at Position #1 (Continued)		i) Sustained modes will be time coupled to indicator lights for time lengths as specified above j) Impulse forces shall be measured during a one second period		
	D-Handle	.2 A means is required to provide the interface between the subject and the force receiver. The mean must a) Attach to the force module by a quick release connector b) Attach firmly to the force receiver with an absolute minimum of play in any axis	a) The handle will be a D-handle with the hand-grasping length located in the vertical plane. Dimensions shall be 3/4" diameter 5½" inside diameter 2½" depth dimension	D-handle must adopt lanyard attachments
	Observer Panel	.3 A means must be provided for the observer to control the selection of force mode and planes and monitor the experiment. The means must a) Provide selection of any mode and plane b) Provide status indicator of go conditions		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.2.2 Reposition Force Receiver	Lanyard	.1 A means is required to tether the force receiver module during repositioning a) Provide a point for attaching lanyard at the force receiver		Lanyard requirements have been delineated in function 1.1
	Force Receiver Fasteners	.2 A means is required to mechanically detach the force receiver module and re-attact it at a new location. The means must a) Provide high unit stability in all axes b) Be hand removable, i.e., not require tools	a) Fasteners, hand operated	Fastener-selection may be dictated by strength considerations
	Force Receiver Electrical Connector	.3 A means is required to electrically detach the force receiver module and reattach it at a new location	a) Provide an electrical bayonet connect, approx. 2" diameter	
	Panel Interface Location	.4 A means is required to provide electrical and mechanical interfaces at a second location. The means must a) Be electrically and mechanically identical to original position; to be located at a position (centerline point of force application) 24" to the right of subject's right nipple & 18" above subject's right nipple		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.2.3 Perform Force Emission Tasks at Position #2				Functional requirements same as function 3.2.1
3.3 Perform Gross & Precise Tool Evaluation Tasks				
3.3.1 Perform Tool Evaluation Tasks at Position #1.		.1 A means is required to provide measurement of torques emitted on an instrumented torque receiver, and to record the data. A means is also required to give instructions to the subject.		Position #1 is defined as directly in front of the subject's right nipple and 18" away
	Cue Panel	a) The cue panel should be located at an optimum viewing position. b) The cue panel should indicate: i) Type of Torque: Impulse Sustained Precise ii) Direction of Torque: cw ccw iii) Magnitude of Torque if <u>precise</u> is required iv) "Go" light Cue panel is operated by observer	(Design features of cue panel are similar to cue panel for function 3.2.1)	
	Torque Receiver	.2 a) Torque receiver consists basically of an instrumented axis to measure cw & ccw torques b) Torque receiver must adapt to tool interface		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.3.1 Perform Tool Evaluation Tasks at Position #1 (Continued)		c) Direct readout of torque to subject must be provided for precise sustained mode.		
		d) Must measure torque exerted & provide readout (electrical preferred) for recording		Data must be torque emission profiles, time-coordinated
		e) Max expected torque 400 in-lbs. (50 lbs. @ 8") (Preliminary; No safety factor)		
		f) Time history vs. torque recording is required. See function 3.2.1, requirement .1 g, h, and j.		
	Tool Interface	.3 a) Hex nut (suggested) is fastened to receptacle on torque receiver axis. Attachments for lanyard - both types - required.	Suggest: ½" Hex Nut	
		b) Desire to measure # contacts between hex nut & torque receiver prior to "success". Success occurs at last contact		
	Observer's Panel			Requirement essential same as function 3.2.1
	Ratchet Wrench	.4 a) Desirable to measure # contacts between tool & hex nut before success, if possible	Approx. 8" length of moment arm for ratchet wrench	Maintain clearance for wrench and hand
		b) Must be compatible with tool receptacle		
		c) Must accept both types of lanyard attachment		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.3.1 Perform Tool Evaluation Tasks at Position #1 (Continued)		d) Socket should not exceed 3"		
	T-Wrench	.5 Same as requirements for ratchet-wrench	Approx. 6" length Handle: ½" diameter by 5" long	
	Tool Kit	.6 A receptacle is required to hold tools in place when not in use. a) Must provide positive holding places for: 1. Power Tool 2. Ratchet Wrench 3. T-Handle Wrench 4. D-Handle 5. Force and Torque Calibration Devices		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.3.2 Reposition Tool - Torque Receiver	Lanyard	See 1.1		
	Fasteners	.2 a) Approximately 2.4 fasteners need for evaluation		
		b) Module must accept fasteners	Captive, Hand-operated	
	Electrical Connector	.3 a) Attempt to achieve all connections with one connector (multi-pin)	Bayonet Type	
	Torque Receiver	.4 a) Vary torque receiver size, shape, and mass Nominal Case: Sizes: 12" x 12" x 12" Shapes: Rectangular Mass: 50 lbs.		
		b) Module must simulate realistically an expected module replacement task		
		c) Module must accept lanyard - both attachment types		
		d) Position #2, lower left extreme of waist-restrained astronaut's reach envelope. Approx. 18" to left and 12" below Position #1		
3.3.3 Perform Tool Evaluation Tasks at Position #2		Same as 3.3.1		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.4 Perform Fluidic Component Replacement	Observer Panel	.1 a) Observer must have means to initiate (by pushing a button) a leak in the piping system.		It is intended that the observer will initiate this task by triggering a leak
		b) Initiation of leak must trigger a timer to measure subject's time to repair		
		c) When leak begins it must be apparent to subject by i) a pressure gauge in the system which begins to fall		Range on gauge dependent on selected system pressure
		or ii) a flashing light		
		or iii) other means		
		or iv) all of the above		
3.4.1 Release Pressure in Piping	Compressed Air Bottle	.2 a) A small volume compressed air bottle will maintain pressure in the system		
		b) Bottle must have an accessible close valve		
		c) Bottle must be refillable from spacecraft ECS		
		d) Bottle capacity should be sufficient for at least 6 cycles of pressurization-depressurization		
		e) Maintain pressure in piping of at least 10 psi over ambient		
	Relief Valve	.3 a) Relief valve must be accessible and one-hand operable		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.4.2 Attach Tether to Component	Equipment Tether	.4 See 1.10 Note that component must adopt tether fasteners		
3.4.3 Release Fasteners on Component	Fasteners	.5 Fasteners must be such that: a) Maintain a pressure-tight seal b) Be captive c) Large enough for finger manipulation d) Accept tool manipulation and represent expected space hardware for plumbing fasteners		
	Lanyard	See 1.1		
	Tool	As required to operate fasteners		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.4.4 Remove Component & Stow	Component	.6 Should be fairly complicated valve of some sort, with 3-4 attachment positions .7 Cargo harness must accept component for stowage		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.4.5 Obtain New Component 3.4.6 Install New Component 3.4.7 Pressurize System		No additional requirements		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5 Perform Limited Access Tasks				
3.5.1 Attach Tether to Panel	Equipment Restraint	.1 A means is required to tether the access/solar panel. The means must a) Be attachable to the panel before the panel is physically demated from the temporary location b) Attach to the panel at the rear surface (connector) of the panel c) Be of the rigidizable variety of tether/restraint d) Be able to fasten/unfasten to the panel with a one-hand motion e) Be of the quick-release/quick attachment variety f) Be physically attached at one end to the experiment panel or nearby bulkhead g) Provide flexibility through an arc which allows transport of the panel from the temporary location to its original location		Restraint requirements are also found in 1.10

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.2 Release Panel from Temporary Location	Solar Panel Snap Fasteners	.1 A means is required to release the solar panel from its temporary location. The means must a) Not require the use of tools b) Provide a spring release mechanism which when activated frees the panel c) Provides a method of release which allows personnel to maintain control of the panel d) Represents state-of-the-art large panel connector devices for space application		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.3 Return Panel to Work Performance Unit	Equipment Restraint	.1 A means is required for transfer of the panel from its temporary location to the work performance unit and positioning panel at work performance unit. The means must a) Provide alignment holes on the panel which mate with captive fasteners at work performance panel		NOTE: Transfer function is a requirement on restraint system and physical method of grasping panel which have been defined in function 2.3

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.4 Install Panel to Work Performance Unit	Work Performance Unit Captive Fasteners	.1 A means is required for fastening and securing the solar panel to the work performance unit. The means must		Power tool and fasteners have been specified in function 2.2
	Power Tool, 0-reaction	a) See note		
	Lanyard	.1 A means is required to tether the power tool when in use by test subject. The means must		Design features have been specified in 1.1. Preferably, tether will attach to subject at waist
		a) Attach to one end of subject		
		b) Attach to power tool		
		c) Not interfere with power tool operations		
		d) Be quick release type		
3.5.5 Detach Tether from Panel	Tether	See 1.10		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.6 Release Access Door in Panel	Access Door	.1 A means is required to provide an access port in the solar panel. The means must a) Provide a quick release method for opening door (state-of-the art for exposed access door quick opening fasteners) b) Provide hinge or captive feature for door in open position c) Provide method for maintaining door in open position and not interfere with lateral or vertical motion about the perimeter of the port d) Provide rectangular access port of 18" width and 12" height		Planes are specified as relating to the subject located with frontal plane facing panel. Sizing of access port will depend on spacesuit (s) used and is subject to change as a function of simulated tests.
	Brackets, Fasteners	.2 A means is required to position the panel at a location of 12" from the surface of the experiment panel. Panel must be equidistant at all points from the experiment panel. Position of 12" must be accurately repeatable and provide a physical detent position for locating and securing		Fasteners are same as specified in function 3.5.8 12" reach depth is also subject to spacesuit and simulations

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.7 Perform Manipulative Task Through Access Port	Timer	.1 A means is required to time the discrete tasks performed at this panel. The method must a) Be capable of self-activation by subject b) Be capable of self-deactivation by subject c) Be displayed at observer's panel d) Provide readouts in tenths of a second e) Provide accuracy of ± one tenth of a second f) Provide method of calibration and c/o g) Be capable of coupled activation by other discrete actions i.e., probe/receptacles removal replacement and the force/pattern stylus (See requirement .3) h) Conform to environmental space flight requirements i) Provide reset capability at observer's panel j) Provide subject activation control at optimum panel location	a) Provide a push-button ½" min. diameter for panel b) Provide condition/status feedback information to subject via position of bat c) Provide the switch as a physical part of the manipulative task module	

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.7 Perform Manipulative Task Through Access Port (Continued)	Digital Meter Vernier Meter Gang Tuner Probe & Probe Pin Receptacles & Solder Joint Coupled Timer Observer's Panel Controls & Displays	.2 A means is required to provide a measure of subject's ability to perform a two-handed- eye hand coordinated task. Task consists of placing a probe on a contact, reading a digital readout, and entering the valve into a vernier readout via a tuner. The means must a) Allow subject to initiate the digital readout by contact of the test probe. b) Provide three contact points & three digital readouts (contact points are male pin, female pin connector, and solder joint) c) Provide a range of digital read-out from 0 to 99 d) Provide digital readouts to one decimal place e) Provide a vernier meter display with values corresponding to the digital readout		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.7 Perform Manipulative Task Through Access Port (Continued)			a) Provide a two stage gang tuner for gross and fine tuning b) Provide vernier markings at two tenths, (lines), and numbers at units c) In addition provide a 2 position recessed toggle switch for X1 and X10 range selection	
		f) Provide controls and displays at observer's panel for .1 Changing digital readout series at subject's panel .2 Obtaining vernier meter readout which subject selects .3 Obtaining discrete time values for each digital dual g) Provide test probe and contacts for left hand operation h) Provide digital readout immediately above test receptacles i) Provide two stage gang tuner located for right hand operation j) Provide vernier readout directly above gang tuner k) Provide captive test probe	d) Provide coupled timer (tenth second $\pm$ one-tenth accuracy) which is actuated by insertion of probe and deactivate by probe removal	

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.7 Perform Manipulative Task Through Access Port (Continued)	Coupled Timer Negator Spring Force Hand Stylus Path Maze Contact Recorder	.3 A means is required to measure time and accuracy of subject's ability to perform a precise, dynamic hand movement as a function of force required and movement difficulty. The means must a) Provide a means of counting number and duration of contacts within the path b) Provide a stylus which can be inserted into the gap while coupled to one of the three forces c) Provide a means of timing a complete trial (one force through one complete path movement) to a tenth of a second $\pm$ a tenth d) Provide a method of captivating stylus device e) Provide a means of displaying time and contact history for each trial at the observer's panel f) Provide a means of physically reversing gap path such that gap gets larger (and smaller) in both directions	a) Provide a selection of 3 forces of ½ lb., 2 lbs., and 10 lbs. b) Provide a movement path of approximately 18" linear inches c) Provide a narrowing gap of space within the movement path from 1" to 5/16" of an inch d) Provide the gap in an irregular "saw tooth" pattern along its total distance e) Provide stylus of cross sectional dimension approximately ¼".	

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	NOTES
3.5.8 Reposition Manipulative Task Panel	Solar Panel X Plane Adjustment Brackets Bracket Fasteners	.1 A means is required to relocate the manipulative task panel to a new location. The means provided must a) Provide for adjustment in the X plane relative to the subject b) Provide a mechanical method for limiting the adjustment to a discrete, repeatable value (length of distance from access panel to manipulative panel surface is 20") c) Provide captive fasteners of quick-release type (See Gen. Design Features, a) d) Maintain the panel equidistant from the surface of the experiment panel. e) Require use of only one hand, without tools	a) Provide four fasteners, one at each corner of panel brackets - two fasteners to be lever type - two fasteners to be turn type (at opposite corners) b) Provide brackets at four different locations at corners of solar-panel/experiment panel locations to be approximately: Upper left - 15" Upper right - 25" Lower left - 20" Lower right - 30" from mid-point of access port	20" depth adjustment is subject to evaluation because of suit sizing and simulation results.

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.5.9 Perform Manipulative Task Through Access Port at New Location				Function is identical to 3.5.7 but access port distance from panel surface has been increased

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
3.6 Perform Inspection, Checkout & Deactivation		See 3.1		
3.6.1 Perform C/O & Deactivation of Force Emission Device				
3.6.2 Perform C/O & Deactivation of MTP				
3.6.3 Perform Visual Inspection				
3.6.4 Secure Access Door in Panel		See 3.5.6		

TABLE 4-1 FUNCTIONAL & DESIGN REQUIREMENTS (Continued)

FUNCTIONAL FLOW BLOCK NO. & TITLE	REQUIRED EQUIPMENT	REQUIREMENTS		NOTES
		FUNCTIONAL CHARACTERISTICS	GENERAL DESIGN FEATURES	
4.0 Release Equipment From Restraint				
4.1 Release Equipment From Restraint		See 1.11		
4.2 Remove Equipment Restraints		See 1.10		
4.3 Doff Waist-Tether Restraint		See 1.9		
4.4 Remove Waist-Tether Restraint		See 1.8		
4.5 Doff Foot Restraint		See 1.5		
4.6 Remove Foot Restraint		See 1.4		
4.7 - 4.10 Same as Above				
4.11 Remove Hand Restraint		a) See 1.1 b) Peel strength of hand restraint must be significantly less than tensile or sheer strengths.		

4.1.2 MAN/MACHINE INTERFACE CRITERIA

Fundamental to the Task Panel design requirements were the Man/Machine interface Criteria which were selected both for investigation in the experimental program and for general applicability to the Task Panel design. A document containing this information was prepared from information derived from several pertinent human engineering documents. It is important to note that in a human factors experiment such as this, the requirements of the specifications must be understood completely and applied judiciously--especially in those situations where a definitive requirement in a specification is a variable for manipulation in the experiment.

This section contains the Man/Machine Interface Criteria developed for this program.

4.1.2.1 Controls and Displays

4.1.2.1.1 Functional Relationships and Location

- Whenever possible, the relationship of a control to its associated display shall be apparent through proximity of location.
- Groups of controls and displays shall be located for top to bottom or left to right use.
- For the purpose of maintaining control of variables associated with viewing angles, the cue panel shall be optimumly located (at approximately eye-level) and shall remain in the same position for all force receiver tasks.
- Clockwise movements of a rotary control shall cause a left to right movement of linear scale pointers. In addition, clockwise motion shall cause an increase in magnitude of values.

4.1.2.1.2 Control Display Ratio

- Coarse setting knobs shall provide for approximately 6" of display element movement for one complete turn of knob.
- Fine setting knobs shall provide for approximately 1 to 2 inches of display element movement for one complete turn of knob. (See 4.1.2.1.9 for knob dimensions.)

4.1.2.1.3 Display Orientation

- Display faces shall be perpendicular to the operator's normal line of sight whenever possible.
- Locations and surfacing shall be selected to minimize ambient light reflection.
- Viewing distances shall be approximately 20" (function of location of restraint).

4.1.2.1.4 Transilluminated Light

- Ordinarily, transilluminated light should be avoided as legend lights because of power drain. Critical status lights (go-no/go) and cue lights are best displayed by transilluminated sources but their use should be minimized.
- Brightness of transilluminated indicators shall be at least 10% greater than surround brightness but shall not exceed 300%.
- Color coding shall be as follows:

  Red - Failure, error, no-go (flashing red at 3-5 flashes per second shall be used for emergency conditions such as physiological readouts which approach danger margins).

  Yellow - Caution or marginal conditions as the pre-red physiological readout.

  Green - Go.

  White - Conditions which have no right or wrong connotations.

4.1.2.1.5 Meters

- Moving pointer, fixed-scale indicators shall be used in preference to the converse.
- Whole numbers shall be used for major scale graduations, for instance, 0 through 9.
- Four lines shall be located between whole numbers representing two tenths or units depending on meter select scale.
- Meter select scale shall be 1X and 10X and selection shall be via a labeled two position recessed toggle switch. (See controls 4.1.2.1.9 for toggle switch dimensions.)

4.1.2.1.5 Meters (Continued)

- Meter pointer shall extend to but not obscure scale graduations. Width of the pointer where it intercepts the graduation marks, shall not exceed the width of the intermediate marks. Parallax shall be reduced.
- Calibration adjustments shall be located on meter surface and not be subject to accidental activation.
- Meter shall be isolated from vehicle and/or vehicle subsystem vibrations.

4.1.2.1.6 Alpha-Numeric Displays

- A digital readout shall be used for providing numerical cue data to subject.
- A three digit readout shall be provided including a decimal point. Two digits shall be to the left of the decimal and one digit to the right of the decimal.
- The height to width ratio of numerals shall be 1:1 (excepting number 1).
- Spacing between numerals shall be approximately 3/8 of numeral width.
- Numerals shall change by snap action rather than be continuous.
- If possible, alpha-numeric counters shall be self-illuminated.

4.1.2.1.7 Auditory Warnings

- Auditory warnings shall be present at the observer's panel for critical (physiological) functions.
- Auditory warnings shall consist of two elements, an alerting signal and an identifying signal, unless keyed to a warning indicator.
- Major concentration of energy in audio warning signals shall be between 250 and 2,500 HZ. Sound pressure level shall be at least 20db above maximum anticipated ambient (not to exceed 100 db).

4.1.2.1.8 Toggle Switches

- Toggles shall be recessed to avoid accidental activation.
- Toggles shall provide snap action contacts.

4.1.2.1.8 Toggle Switches (Continued)

- Minimum angular displacement of bat stem shall be 30°.
- Resistance shall be between 10 oz. and 70 oz.
- Toggle bats should provide a curved finger recess to minimize recessed openings. Finger recess shall accommodate a pressurized gloved finger.

4.1.2.1.9 Rotary Knobs

- Rotary knobs shall be used for meter setting tasks.
- Small knobs shall be used for gross settings and large knobs for precise settings.
- Small knobs shall be a minimum of .375 in diameter and large knobs shall be a maximum of 4.0 inches.
- Resistances shall be no more than 4.5 inch-ounces of torque for small knobs (less than 1") and no more than 6 inch-ounces of torque for large knobs.
- Minimum depth of all knobs shall be 0.5".

4.1.2.1.10 Pushbuttons

- Timer activation switch shall be a transilluminated push-on and push-off pushbutton. Indicator will be lit when timer is on and off when timer is off.
- Pushbuttons shall be a minimum of 0.5 inches in diameter.
- Minimum activation and deactivation displacement shall be 0.125".
- Mini-maximum resistances shall be 10 to 40 oz. respectively.
- Buttons shall have a snap-action contact.

4.1.2.2 Fasteners and Connectors

4.1.2.2.1 Hand Operated Fasteners

- Quick release fasteners shall be used for fastening tasks which are performed with a high frequency, loads permitting.

4.1.2.2.1 Hand Operated Fasteners (Continued)

- Quick release fasteners shall be used to release astronaut from waist restraint and other incumbrances which may create a safety hazard in emergency conditions.
- Quick release fasteners shall require no more than a 3/4 turn.
- Quick release fasteners shall be spring-loaded and captive. (Tethered as required.)
- Fasteners which are not quick release shall require no more than 10 turns to fasten/unfasten.
- Fasteners of wing nut and knurled knob variety shall be at least 1" in diameter and 1/2" in depth.
- Maximum torque requirements for finger operated fasteners shall not exceed 80 inch-ounces.
- Thumb press pip pins shall provide a minimum of 0.5" thumb surface and 0.75" finger surface at each finger. Resistance shall not exceed 40 ounces.

4.1.2.2.2 Tool Operated Fasteners

- External and internal hex grasping shall be provided for all fasteners.
- Fasteners shall be captive.
- External diameter (measured from flat to flat) shall be 1/2".
  Internal diameter (measured from flat to flat) shall be 1/4".

4.1.2.2.3 Hand Operated Connectors

- Connectors used for electrical or fluidic line connections shall be of the quick-disconnect variety, i.e., bayonet, cam-lock, thread assist.
- No more than one turn shall be required for connect/disconnect.
- Minimum diameter shall be 1" and 1/2" in depth.
- Maximum torque required shall be 100 inch-ounces.
- Connectors for electrical lines shall be physically keyed.
- The "hot" contacts shall be in the female receptacle.

4.1.2.2.4 Tool Operated Connectors

- Fluidic line connectors may be tool operated when required for seal strength integrity.
- Number of turns required to tighten/loosen should be minimized, not to exceed 10.
- Tool interface shall be an open end wrench.
- Obstructions to tool operation shall permit a minimum of 1/2 turn without repositioning tool.

4.1.2.3 Tools

Power tool requirements shall not be specified in this document because their use shall depend on availability of present devices under development. Power tool devices shall be in compliance with safety requirements specified in the safety section of this report.

4.1.2.3.1 Ratchet Wrench

- Wrench length shall be approximately 8" long and approximately 0.75" in diameter.
- Wrench shall be reversible by standard lever lock switch (positions shall be labeled).
- Sockets shall mate by positive locking force.
- Sockets shall be tethered when not attached to wrench.
- Wrench shall accept a tether.

4.1.2.3.2 T-Handle Wrench

- T-handle wrench shall have a .25" drive, and be approximately 4" in length.
- T-handle shall be .75" in diameter and 5.0" long (grasp section), i.e., Handle portion of "T".
- Wrench shall accept a tether.

4.1.2.3.3 Open-End Wrench

- Wrench shall be adjustable by spring-load detent.
- Wrench shall adjust to positions between 3/8" and 1".
- Wrench locations shall be labeled.
- Wrench shall be 8" long (total length) and approximately 1-1/2" by 5/8" shank size.
- Wrench shall accept a tether.

4.1.2.4 Restraints and Tethers

4.1.2.4.1 Hand Restraints

- Hand restraint shall be 1.25" diameter by 5.5" long by 2.5" deep.
- Hand restraint shall accept a tether.
- Hand restraint shall be attachable (to bulkhead) by one hand.
- Grasp surfaces shall be non-abrasive and non-slip, i.e., coated with a resilent friction material.
- Restraint shall be oriented perpendicular to the surface experiment panel.

4.1.2.4.2 Waist Restraint

- Waist restraint shall consist of a rigidizable flexible tether with connection point extending from right and left side of subject's waist.
- Tethers shall be approximately 2 feet in length.
- Tethers shall tighten by a compression ratchet handle on one end and a ratchet wrench on the other end. Both shall be reversible by lever lock action and positions shall be labeled. NOTE: Ratchet wrench at waist shall have physical coded lever position, i.e., operator shall be able to determine position ratchet lever is in (tighten or loosen mode) by touch rather than visual feedback. Ratchet wrench shall be located at waist and compression ratchet at tether mid-point. Ratchet handle shall be approximately 4" long by 1/2" round. Compression ratchet shall be approximately 5" long and approximately 1/2" round. One member, thumb side, shall be stationary and the finger side shall be movable.

4.1.2.4.2 Waist Restraint (Continued)

- When tethers are not connected to bulkhead they shall attach to spacesuit by appropriate connectors (function of spacesuit).
- Waist-suit interface shall depend on suit configuration. Preliminary data indicates that it be adjustable in width from 16" to 22" and in depth from 12" to 14". It should be approximately 4 inches in width and located just above pelvic height, approximately 42" from bottom of foot.
- Distance of subject from panel is dependent upon pressure suit used. Preliminary analyses indicates that approximately 15" will be the value for two-handed tasks.
- When rigidized, the restraint must provide a reasonable rigid restraint in all axes at a precise location (TBD).
- Waist restraint shall attach to bulkhead by one hand quick-release turn lock connectors.
- Height adjustment required for astronaut population (See anthropometric section).
- Waist restraint must not interfere with functional characteristics of suit.

4.1.2.4.3 Foot Restraint

- Foot restraint system shall attach to bulkhead by tongue and groove slot. (NOTE: Subject to re-evaluation.)
- Restraint shall be installed by hand operated lever lock.
- Restraint shall provide for both feet at approximately 12" between feet.
- Restraint/shoe interface is subject to pressure suit definition (must be quick release and not trap subject).
- Foot restraint shall locate subject such that the centerline of the force receiver is at subject's nipple height and 9.25" to the right of a line drawn through the center of subject's sagittal plane. NOTE: This allows comparison of data to Experiment 84A data which used this reference point. Module height is approximately 50" $\pm$ 2 inches from bottom of foot. Foot restraint must provide adjustment for astronaut population (See anthropometric section).

4.1.2.4.4 Lanyard

- Lanyards shall connect to a point at subject's waist (determined by suit configuration).
- Lanyards shall have "universal" swivels at both ends.
- Lanyards shall connect to all items handled by astronaut which at anytime are not tethered in some other fashion.
- Lanyards shall have a window washers thumb operated spring clip at one end and a spring loaded pin detent connector at the other end. Connector loop and pin sizes must interface with attachment point. Spring clip should provide a minimum of 1/2" travel. Release lever should be a minimum of 1/2" long and 3/8" round. Spring loaded detent should be a minimum of 3/8" round and provide a minimum of 3/8" travel. Release should occur at a point approximately 1/2 of total travel.
- Lanyards shall always provide a quick release capability for subject safety.
- Lanyards shall be approximately 2-1/2' in length.

4.1.2.5 Anthropemetric Data

Data contained in Table 4-2 has been generated from a partial list of NASA astronaut anthropometric data. While it is data pertinent to the design of the man/machine interface for M508, it should be treated as preliminary, subject to change when a more comprehensive list of NASA astronaut measurements is made available. Those values which have asterisks are based on data extracted from MIL-STD-1472 - Human Engineering Design Criteria for Military Systems, Equipment and Facilities. A comparison of actual astronaut data and MIL-STD-1472 data indicates that approximations for mean and range values can be made, in general, for the astronaut population from MIL-STD-1472. The reader is cautioned against using this data for design values which are critical or require extreme tolerance.

TABLE 4-2 MEASUREMENT DATA - NUDE

	MEASUREMENT	MINIMUM	MEAN	MAXIMUM	DESCRIPTION
1.	Stature	66.1	69.5	72.2	Floor to top of head
2.	Eye Height, Standing	60.9	64.6	70.1	Floor to eye level
3.	Crotch Height	30.7*	33.1*	34.8*	Floor to midpoint of crotch

4.1.2.5 Anthropemetric Data (Continued)

TABLE 4-2 MEASUREMENT DATA - NUDE (Continued)

	MEASUREMENT	MINIMUM	MEAN	MAXIMUM	DESCRIPTION
4.	Waist Height	40.4*	42.4*	44.4*	Floor to greatest lateral indentation of waist on right side
5.	Shoulder Height Standing	54.0*	57.6*	59.5*	Floor to highest point on lateral edge of right shoulder bone
6.	Shoulder-Elbow	13.7*	14.7*	15.7*	Bottom of right elbow to highest point on lateral edge of shoulder bone.
7.	Forearm-Hand Length	18.7*	19.6*	22.3*	Tip of right elbow to tip of middle finger.
8.	Hip Breadth Standing	13.2*	14.2*	15.1*	Widest portion of hips
9.	Shoulder Breadth	14.3	18.7	20.8	Maximum muscle bulge of subject
10.	Waist Breadth	11.5*	12.6*	15.3*	Waist breadth at level of greatest lateral indentations
11.	Functional Reach	29.9	30.5	33.9	Tip of right thumb to wall, arm extended horizontally and shoulders on flush surface

4.1.2.6 Force Data

A summary of the results from a previous experiment are provided in Table 4-3 to provide force data which can be expected and factored into the design of equipment for M508.

- o Push/pull impulsive force emission capability is approximately 2-1/2 times as great as sustained push/pull force.
- o Impulsive force emission capability in the Up/down and right/left directions is approximately twice as great as sustained force emission capability in the corresponding directions.

TABLE 4-3 FORCE DATA

	RESTRAINTS															
	NONE		HAND		WAIST		SHOES		HAND & WAIST		HAND & SHOES		WAIST & SHOES		HAND, WAIST & SHOES	
	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max
PUSH	0	35	1	41	15	43	4	46	29	57	30	62	35	58	43	69
PULL	0	43	2	43	22	46	4	48	31	51	33	61	37	57	38	61
UP	0	19	5	21	10	23	17	28	14	23	18	31	17	28	17	29
DOWN	2	23	9	26	10	23	21	33	16	26	26	37	19	30	21	32
RIGHT	0	18	10	22	12	22	9	22	15	25	16	28	14	23	16	27
LEFT	0	18	17	29	12	22	8	23	17	28	21	34	15	25	19	30

	RECEIVER ANGLE					
	-15°		0°		45°	
	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max
PUSH	18	49	19	51	22	54
PULL	20	51	19	50	23	53
UP	13	26	13	25	12	24
DOWN	17	31	15	28	15	27
RIGHT	13	25	12	24	10	21
LEFT	15	28	14	27	12	24

	RECEIVER DISTANCE					
	NEAR		MEDIUM		FAR	
	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max
PUSH	23	53	20	52	17	49
PULL	17	46	21	52	25	56
UP	14	27	12	25	11	24
DOWN	16	29	16	29	15	28
RIGHT	12	24	11	24	11	22
LEFT	15	28	13	26	13	25

	RECEIVER ORIENTATION			
	HORIZONTAL		VERTICAL	
	Sustain Min	Impulse Max	Sustain Min	Impulse Max
PUSH	20	53	19	50
PULL	21	50	21	52
UP	11	21	14	30

	RECEIVER ORIENTATION (Cont'd)			
	HORIZONTAL		VERTICAL	
	Sustain Min	Impulse Max	Sustain Min	Impulse Max
DOWN	14	26	17	31
RIGHT	15	29	9	18
LEFT	14	26	14	26

	OVERALL	
	Sustain Min	Impulse Max
PUSH	20	52
PULL	21	51
UP	12	25
DOWN	16	29
RIGHT	12	23
LEFT	14	26

4.1.2.6 Force Data (Continued)

- Push/pull impulsive force emission capability is approximately twice as great as the up/down, right/left impulsive force emission capability.

- Handle orientation (horizontal vs. vertical) has little apparent effect on force emission capability in the push/pull and left directions. Vertical orientation increases the capability to exert up/down forces and horizontal orientation increases right direction force capability.

- Of the three force receiver angles chosen (0^{o}, -15^{o}, and $+45^{o}$ with 0^{o} position at subjects nipple height and 9.25" to right of subject's sagittal centerline) no significant differences in force emission capability was apparent. This is also true of force receiver from subject distances.

- Impulse and sustained forces differ across some restraints being used. For single restraints, the waist restraint is best for Push/pull force emissions. Dutch shoes are best for Up/down force emissions. A handhold is best for left directions. All single restraints are equally poor for assisting in right direction forces. For multiple restraints, the handhold, waist, and shoes combination were best for push/pull sustained force. Handhold and shoes combination were best for up/down and left/right sustained force emissions. In general, right direction sustained forces should be avoided.

- Waist restraint was only single point restraint in which a significant sustained (above 10 pounds) mean Push/Pull force could be exerted.

- Handhold restraint provided the capability for sustaining significant (above 10 pounds) mean forces in only the left/right directions.

- Shoe restraint provided the capability for sustaining significant (above 10 pounds) mean forces in only the up/down directions.

Maximum impulse forces and minimum sustained forces across the restraints, receiver angles, receiver distance, receiver orientation and across all conditions (overall) are presented below in the following tables. All values are in pounds.

4.1.2.7 Maintainability

The data contained in this section has been extracted from a number of pertinent maintenance documents. These guidelines are provided as a source of general maintainability data for M508 design and procurement guidance. When these requirements conflict with contractual requirements or other AAP configuration requirements, the latter requirements shall apply. This is also true when experiment design includes experiment variables which are specifically chosen as such and not on the basis of optimum design.

4.1.2.7.1 General

a. Standardization

Standard parts shall be incorporated into equipment to the maximum extent feasible. NOTE: It is recognized that a portion of M508 equipment is specialized and no basis for standardization will exist. "To the maximum extent feasible" should be interpreted in light of this, particularly in respect to "GFE" items. When parts are procured and a freedom of selection exists, standardization should be applied.

Standardization shall include provision to facilitate identification and preclude improper mounting and installation as:

1. Physical keying to prevent interchangeability where components are functionally different.

2. Physical keying to prevent improper mounting and facilitate proper mounting.

b. Interchangeability

Interchangeability of like items and replaceability of similar items shall be provided.

c. Modular Replacement

Equipment shall be designed and constructed for:

1. Replacement of small electronic assemblies by replacing modular packages.

2. Removal/replacement at least to the level of the diagnostic capability of the test equipment (or operator).

4.1.2.7.2 Mounting of Components Within Units

a. Use of Two Dimensional Surfaces

Parts shall be mounted in an orderly array on a 2-dimensional surface rather than stacked one on another. Where components must be stacked, the ones requiring less frequent access (high MTBF) should be placed in the rear.

b. Chassis Attachment

Only interconnecting wiring and structural members shall be permanently attached to the basic unit. Electrical parts are replaceable subassemblies which are independently mounted.

4.1.2.7.2 Mounting of Components Within Units (Continued)

c. Delicate Components

Delicate components shall be located (or guarded) so that they will not be susceptible to damage while the unit is being handled or maintained.

d. Equipment Handling

Assemblies, subassemblies, and components must have provisions for handling in the zero gravity environment. Whenever possible lanyard attachment points should be provided on items which require removal for on-board operations and maintenance. When tools are used for disconnecting or removing parts, consideration should be given to utilizing the tool as a handling device for the part.

4.1.2.7.3 Adjustment Controls

a. Calibration

Knobs shall be selected in preference to screwdriver adjustments whenever frequent adjustment must be performed.

b. Reference Scale-Control Limits

A reference scale or other appropriate feedback shall be provided for adjustment controls. Mechanical stops shall be provided for controls which are intended to have a limited degree of motion.

c. Sensitive Adjustments

Sensitive adjustment points shall be located or guarded such that adjustments will not be disturbed inadvertently.

4.1.2.7.4 Maintenance Displays

a. Alarms

An audible alarm shall be provided to indicate an equipment malfunction if the equipment is not constantly monitored.

b. Go-No-Go

If quantitive information is not absolutely required, go-no-go displays shall be used.

4.1.2.7.4 Maintenance Displays (Continued)

c. Failure

Circuits and meters shall be designed so that meter pointers will not stop in an "in tolerance" position if power fails. Also a positive visual and/or auditory display is provided to indicate power failures.

4.1.2.7.5 Fasteners

a. Captive

Captive bolts and nuts shall be used for all cases and access covers requiring routine opening removal, etc. Same type and size should be provided for all cases and covers, whenever feasible.

b. Hand-Operated

Hand-operated fasteners or latches shall be used whenever possible. When fasteners requiring tools must be used, they shall be designed for operation by standard hand tools.

c. Quick-Release

Quick release fasteners shall be used whenever possible for access doors and covers. Fasteners for mounting assemblies and subassemblies shall require only one complete turn, provided that stress and load considerations are not compromised. In all cases the number of turns required for any fastener shall be minimized.

4.1.2.7.6 Pressure Suit Access Requirements

Access requirements are provided here for both pressure suit and shirtsleeve operation. In general, these access requirements pertain to maintenance activities rather than that associated with the experiment tasks which reflect values not necessarily of optimum size but rather of empirical interest.

a. Pressure Suit - Pressurized to 3.5 psi

These values were extracted from a study dealing with access envelopes for the A/P 22S-2 Full Pressure Suit and may not be applicable to other suits. In addition, they are optimal values as measured from the front of subject's chest to curled fingers of hand.

4.1.2.7.6 Pressure Suit Access Requirements (Continued)

b. Two-Handed Tasks - Forward Reach

Depth of Reach:	12"
Breadth of Aperture:	24"
Vertical Dimension:	20"

c. One-Handed Tasks - Forward Reach (Preferred Arm)

Depth of Reach:	14"
Breadth of Aperture:	13"
Vertical Dimensions:	18"

d. One-Handed Tasks - Lateral Reach (Preferred Arm)

Depth of Reach:	20"
Breadth of Aperture:	13"
Vertical Dimension:	16"

4.1.2.7.7 Shirtsleeve Access Requirements

a. Two-Hand Access

Depth:	6 to 19 inches
Width:	8 inches (or depth of reach whichever is larger)
Height:	5 inches

b. One-Hand Access (Preferred)

Arm to Elbow:	4 inches by 4.5 inches
Arm to Shoulder:	5 inches by 5 inches

4.1.2.8 Safety Criteria

4.1.2.8.1 General

Real-time readouts of critical physiological functions shall be required during task performance. A second crew member acting as the experimenter, shall monitor these readouts.

The experimenter shall be in continuous visual contact with the subject and located as near to the subject as possible.

Subject restraints, pressure cuffs, electrode connections, etc. shall be of the quick-release variety.

4.1.2.8.2 Fail-Safe Design

Where equipment failure or malfunction may injure the subject/operator or damage equipment, fail-safe features shall be incorporated into the equipment design. Fail-safe, as used here, refers to: (1) failure in a safe mode, and (2) redundancy in design in the two forms of (a) standby redundancy and (b) continuous redundancy.

Standby involves the use of parallel and similar units, circuits, or components that can be automatically or manually put into operation if the primary item fails.

Continuous involves parallel and similar units, circuits or components that are in continuous operation so that failure of the primary item will result in continuous operation of the system at not less than an acceptable level of performance.

4.1.2.8.3 Equipment-Related Hazards

a. Access

Units shall be so located and mounted that access to them can be achieved without danger to personnel from electrical charge, moving parts, or other sources.

b. Hazardous Access

Where access must be located over dangerous mechanical or electrical components, the access door or cover shall be provided with a highly visible warning label on the outside of the door or cover. Placards shall specifically identify the hazard.

c. Corners and Edges

Exposed corners shall be rounded to a minimum radius of .5 inch. Exposed edges shall be rounded to a minimum radius of .04 inch.

4.1.2.8.4 Alerting Devices

Audio signals shall be provided as necessary to warn personnel of impending danger, to alert an operator to a critical change in system or equipment status, and to remind the operator of a critical action that must be taken.

Audio signals shall consist of two elements, i.e., an alerting signal and an identification signal, i.e., a signal which identifies source or type of danger. The major concentration of energy in audio warning devices shall be between 250 and 2500 hertz. The sound pressure level of the audio warning shall be at least 20 dB above the maximum anticipated noise level, not to exceed 100 db.

4.1.2.8.4 Alerting Devices (Continued)

When used in conjunction with visual displays, auditory warning devices shall be supplementary or supportive in nature. The auditory signal shall be used to alert and direct operator attention to the appropriate visual display.

4.1.2.8.5 Electrical Hazards

Equipment shall be designed to preclude accidental contact with voltages in excess of 24 volts. On accesses that lead to equipment with high voltage (> 70v) safety interlocks shall be provided that de-energize the circuit when the access cover is opened.

All external metal parts shall be at ground potential.

Wiring shall be routed through pins and connectors so that removal of a plug or connector will not expose "hot" leads. Equipment shall be designed so that all hot contacts will be socket contacts.

Personnel protection shall be provided from electrical equipments (physiological monitoring equipment).

4.1.3 CONCEPTUAL DESIGN

The design of the hardware, while starting with no physical constraints, was approached with the intent of being readily adapted to the AAP Orbital Workshop (OWS) as the equipment for Experiment M508. With this in mind, serious efforts were made to determine the requirements imposed on the experiment by the vehicle and factor these into the design within the practicalities of schedule and cost. Several sources of information were used to determine the OWS/Experiment interface requirements. Among those were documents such as the M508 Experiment Implementation Plan (EIP), Experiment Integration Requirements Document (EIRD), and the AAP Experiment General Requirements Document. It was determined from these documents that the stowed volumes allocated for the Task Panel and Restraints Container were 30 x 24 x 24 inches and 12 x 12 x 12 inches, respectively, and it was considered essential to stay within, or if possible, reduce these dimensions. The design of the restraints and task panel was two separate but related and integrated problems and the efforts to achieve a cohesive experiment hardware concept with these two items is discussed individually below.

4.1.3.1 Restraints

Although the restraints were to be GFE, they had to be integrated into the experiment operations to insure successful completion of the experiment. Upon investigation of the experiment requirements and stated GFE capabilities several criteria were established as follows:

4.1.3.1 Restraints (Continued)

1. The subject is to bring the restraints to the worksite.
2. The restraints must be capable of being installed with one hand, within the subjects field of view.
3. The installation must provide positive locking in place; inadvertant or accidental removal of the restraint must be avoided.
4. The subject must don or attach the restraints unassisted.

The restraints defined in the EIP were:

1. Handhold
2. Variable Flexibility Waist Tether
3. Gemini Dutch Shoes

The EIP also indicated the use of an adhesive device for the Handhold Restraint in the flight experiment, but in this program, mechanical attachment was utilized.

The Waist Tether was to consist of two electrically actuated Variable Flexibility units mounted to a single belt. The device supplied for this program was a prototype model with mechanical actuation and Vise Grips mounted to the distal end for attachment at the worksite.

The Gemini Dutch Shoes were to be supplied as an unaltered pair, but in view of the requirement for the subject to bring his restraints to the worksite and install them with one hand, it was decided to mount the shoes on a platform containing a handle and locking device. Figure 4-1 is a picture of the Shoe Restraint and illustrates the handle placement.

Utilizing these restraint concepts, it was determined that the Restraint Container would have to be larger than originally described in the EIP. A container 18 x 18 x 12 inches was determined to be the smallest size capable of holding the restraints. In addition, it was noted that the Restraint Container could serve another purpose as the mounting point for the Shoe Restraint in the flight experiment.

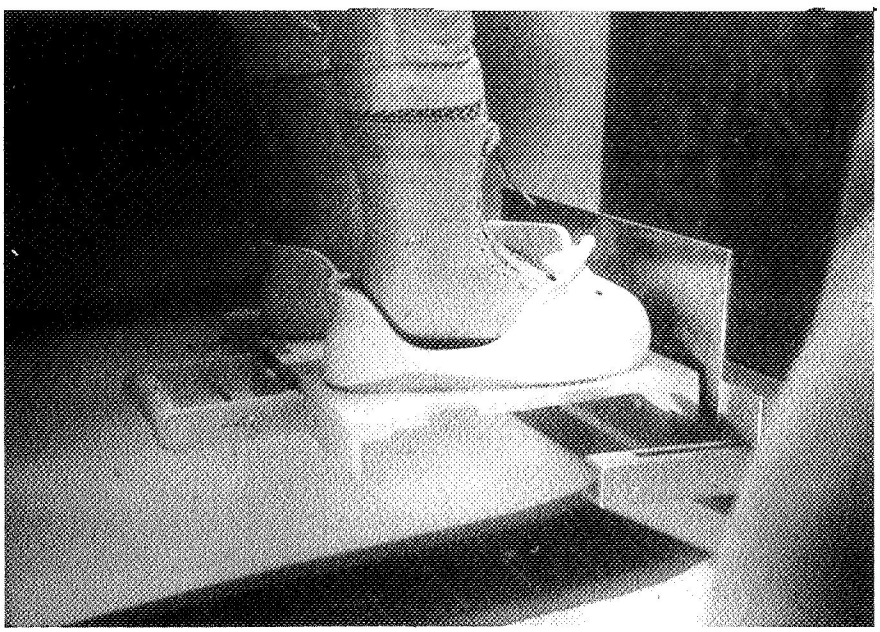


FIGURE 4-1 SHOE RESTRAINT

4.1.3.2 Task Panel

Figure 4-2 illustrates the initial Task Panel concept in the deployed state. The major, working elements were located in one-half of the box mounted to the wall as shown. The other half of the box was split in two sections and mounted to the wall to form receptacles for the module handling task. The remainder of the receptacle boxes would be used to store tools, cargo harness, tethers, and other small items. One of the most serious problems encountered in this design was the placement of the various components in the most appropriate location with respect to the test subject's one- and two-hand reach and visual access. For example, the center of the force receiver handle was to be positioned directly in front of the subject's right nipple, and the displays containing the command and cue indicators were to be located at eye level with unobstructed visual acces

At this point, the decision was reached that the modular concept for the individual tasks was the most desirable since it afforded the highest level of flexibility for the overall experimental design.

The locations selected for the various elements of the Task Panel and its overall layout were based on a series of 1-g static tests using in-house personnel with several mock-up configurations.

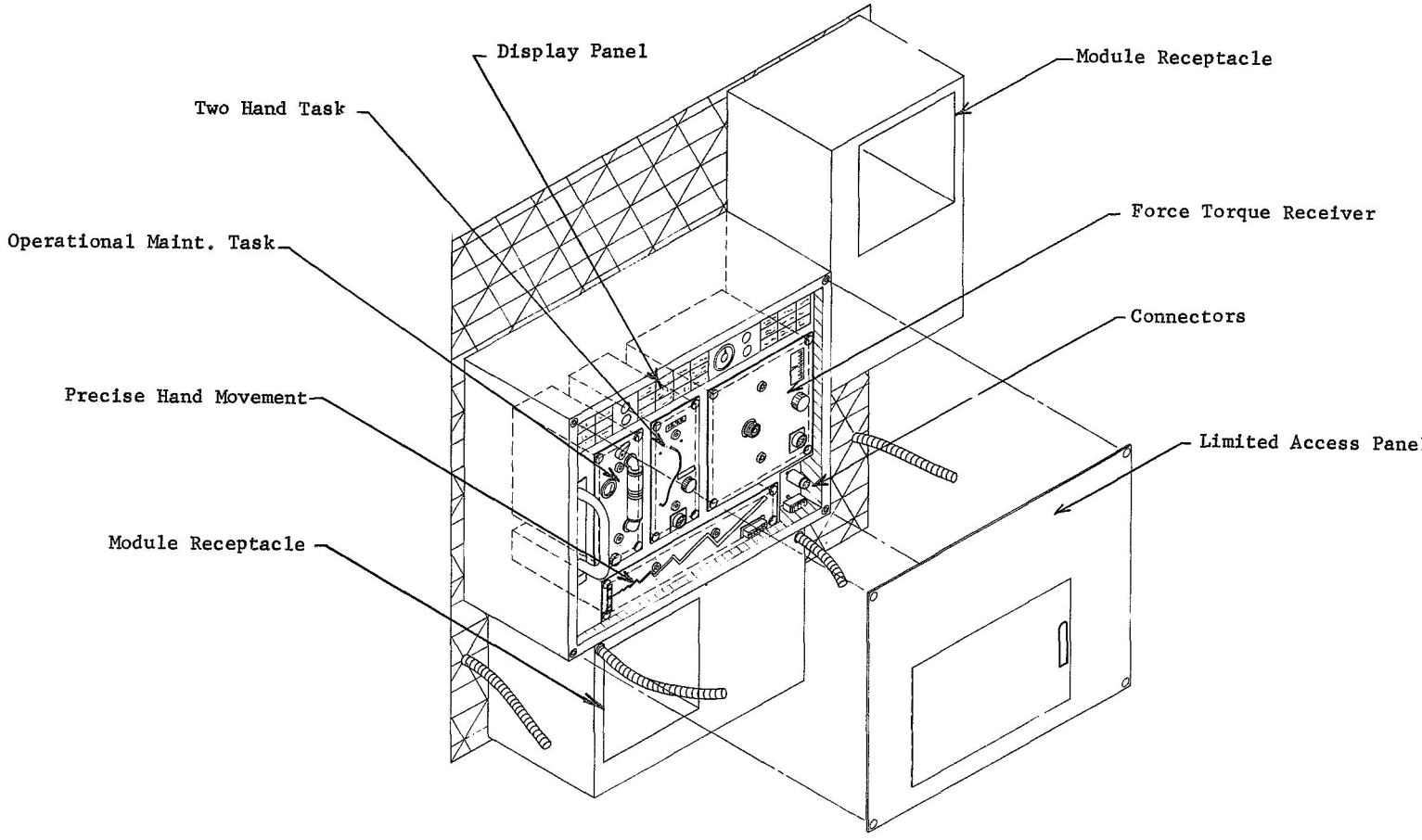


FIGURE 4-2. TASK PANEL CONCEPT

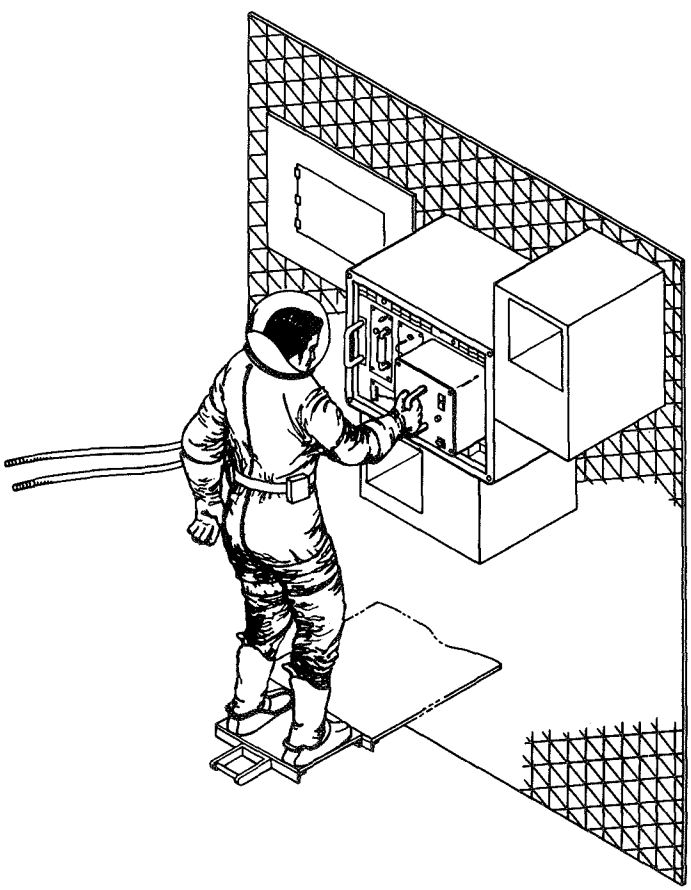


FIGURE 4-3 MODULE REMOVAL CONCEPT

4.1.4 FEASIBILITY TESTING

A series of simulated zero-g tests were conceived and conducted to insure that all the tasks described in the Candidate Task Sequence and then developed into a hardware concept could be performed by a test subject in a pressurized suit within the prescribed limitation of time and work envelope. It was originally planned to perform the feasibility tests once, but sufficient problems were encountered to warrant performing a second test after the data had been analyzed and the necessary changes incorporated. Portions of the tests were performed on two different occasions and were identified as Feasibility Tests Phase I and Phase II.

The tasks selected for feasibility testing were performed in gross fashion only, to determine simply the GO or NO/GO status of the task and some nominal design requirements. The equipment consisted of mass and shape mock-ups necessary to properly simulate the man/machine interface and data recording was in the form of motion pictures, task-times, and subjective comments.

All tests were performed using neutral buoyancy simulation of zero-gravity, with the test subjects (95th percentile) wearing an Apollo A5L spacesuit pressurized to 3.5 $\pm$ .2 psi over ambient. Two-way communication between the subject and the topside test director was provided.

4.1.4.1 Feasibility Test Procedures

The Candidate Task Sequence was reviewed to determine those items about which reasonable doubt existed concerning the potential performance of the item by an experimental subject. These items are identified and described below.

a. Restraint Installation

Only in the most fortuitous circumstances can an extravehicular astronaut expect to perform his work at a site that has pre-installed restraints. In many situations the first task of the astronaut will be to install and don his personal restraints and whatever equipment restraints will be required during the task. The first several minutes of the M508 Task Sequence, therefore, are devoted to this preparation of the worksite. Feasibility of this task is questionable because of the excessive reaches involved, because the task itself is performed in an unrestrained or, at best, hand-only restraint condition, and because of the excessive amount of equipment which the astronaut must have strapped to his person.

The test subject will be positioned perpendicular to the worksite at the end of a mobility aid.

Using his left hand on the mobility aid to stabilize himself, he then installs all restraints in the following order:

1. Handhold restraint
2. Dutch shoe platform

4.1.4.1 Feasibility Test Procedures (Continued)

a. Restraint Installation (Continued)

3. Waist restraint
4. Install equipment restraint to right of task board, and position cargo carrier (if used) on this tether.
5. Install equipment restraint to left of task board.

This order may be varied during feasibility testing if found to be inferior or unsatisfactory.

For each restraint, the installation process will be the same:

1. Release lanyard from attachment point
2. Attach lanyard to restraint
3. Release restraint from attachment point
4. Install restraint
5. Release lanyard from restraint
6. Attach lanyard to waist-attachment point

The restraint installation procedure will be performed under the following conditions:

1. A cargo carrier (12" W x 18" L x 18" H) strapped to the front of the subject.
2. A cargo carrier (12" W x 18" L x 18" H) strapped to the right leg of the subject.
3. No cargo carrier is used and all restraints are strapped directly to the subject.

When the cargo carrier is used, it shall contain:

- A handhold restraint
- A platform with the Gemini Dutch Shoes attached
- A variable-flexibility tether (if available) to serve as an equipment restraint
- A second variable-flexibility tether (if available), one end of which is attached to the cargo carrier.

All of these items shall be attached to the inside of the cargo carrier to prevent floating.

In addition to the above equipment, the subject will have attached to him, in all three runs, the following:

- A waist-belt with the variable-flexibility waist restraints attached
- A rope-lanyard, attached at the waist
- An umbilical and a safety tether attached at the right side of the subject

Data will consist of total time to install all restraints, movies and subjective comments.

4.1.4.1 Feasibility Test Procedures (Continued)

b. Force Receiver Positioning

Three positions were specified to obtain force and torque data as a measure of astronaut performance capability. In the first position, the force receiver module is located directly in front of the subject's right nipple. In the second position, the module is located 16" to the right and 16" above position 1. In the third position the module is located 12" to the left and 20" below position 1. The installation of the 12" x 12" x 12" (anticipated) 50 lb. force module in these positions is expected to be difficult due to the mass of the module, the space-suited subject's size and the mobility and geometry restrictions provided by the restraint systems.

The feasibility test will require the subject to remove the simulated module from the optimal position, and install it in the non-optimal positions. The task will be performed under five conditions:

1. Waist restraint only - Subject may not reposition himself
2. Waist restraint only - Subject may reposition himself
3. Shoe restraint only
4. Waist and shoe restraints - Subject may not reposition himself
5. Waist and shoe restraints - Subject may reposition himself

Data will consist only of movies and subjective comments.

c. Repeatability of Positioning

The M508 Task Sequence requires that several fundamental tasks be performed under varying conditions of suits, subjects, etc. To be able to compare data across conditions it is essential that each subject always perform each task in the same relative spatial position. When using the waist restraints only, it is quite possible that the subject may not be able to rigidize himself in the same position each time he performs a task. A feasibility test item will therefore be performed to obtain some gross measure of this problem.

The subject will be at the worksite with the waist restraints installed but not rigidized. Three telescoping members will be extracted from the face of the task board and locked into place. These members will correspond to spots painted on the subject's chest. His objective will be to rigidize the waist tethers such that the spots and members are aligned. This will be repeated about three times. Data will consist of a measure of the subject's error, movies and subjective comments.

d. Access Capability

A major portion of the Candidate Task Sequence involves fine manipulative operations, one-and two-handed, through an access port at two different depths of reach. Currently, the access port is sized at 18" L x 12" H. The distances from the access port to the work panel are 12"

4.1.4.1 Feasibility Test Procedures (Continued)

d. Access Capability (Continued)

and 20". This feasibility test item will investigate these dimensions.

The subject will be restrained in the waist and shoe restraints. The work panel will contain a two-dimensional mock-up of the manipulative task panel. The subject will reach through the access port with one hand and the technician will vary the access size until the subject indicates that a near-minimal size is achieved. This will occur when the subject's visual feedback is, in his opinion, barely sufficient to complete the task. This will be repeated with both hands through the access port.

The nature of this test item is such that it does not require neutral buoyancy simulation to simply determine a nominal access size. At the same time, the capability of two-way voice communication with the subject in a pressurized suit is highly desirable. For these reasons, this test item will be performed in an air-pressurized suit in 1-g.

e. Reach Envelope

Basic reach envelope data will be needed throughout the design of the experiment. Feasibility testing will be used to obtain a gross evaluation of reach data.

The subject will indicate, using his right arm, the maximum point on the surface of the worksite bulkhead which he can reach in each of eight primary directions: $\pm$ X, $\pm$ Y, and along the 45° lines, X=Y and X= -Y. These axes should be indicated on the bulkhead, and intersect at the midpoint of the subject's waist. The diving technician will measure and record the data using a tape measure and notify the two points (X, Y) necessary to define the location of the subject's right hand in the outstretched position. This data will be recorded for the five conditions noted in 2.2.

4.1.4.2 Feasibility Test Equipment Requirements

a. Restraint Installation

1. Mobility Aid - Located perpendicular to the bulkhead.

2. Cargo Carrier - One cargo carrier is required. It shall be attachable to the front of the subject, about waist-high, and to the right thigh of the subject. The carrier may be open-top box, with the shape represented by a framework covered with a mesh material.

Dimensions of cargo carrier: 1. 12" W x 18" L x 18" H

4.1.4.2 Feasibility Test Equipment Requirements (Continued)

a. Restraint Installation (Continued)

3. D-Handle for Hand Restraint - Installable to bulkhead with positive-locking mechanism. Attachable to cargo carrier. Accept lanyard attachment.

4. Gemini Dutch Shoes Mounted on 18" x 14" Platform - Installable to bulkhead with positive-locking mechanism. Attachable to cargo carrier. Accept lanyard attachment.

5. Cube - 5.25" on the side. Simulates a mass of 40 lbs. Attachable to cargo carrier.

6. Two Equipment Restraints - Variable-flexibility tethers preferred Both restraints attachable to cargo carrier and installable to bulkhead.

The equipment in 3, 4 and 6 above must also be attachable directly to the subject.

7. Variable-Flexibility Waist Tether

8. A rope lanyard, 4' long and attachable near subject's waist.

9. An umbilical hose from the surface to provide breathing air.

10. A rope from the surface to represent the astronaut's safety tether.

11. In addition a bulkhead will be required to provide attachment points for all restraints and tethers.

b. Force Receiver Positioning

1. A 6.85" cube surrounded by a 12" x 12" x 12" framework will represent the expected module.

2. The bulkhead must provide three receptacles for the module at positions noted in 4.1.4.1.b

c. Repeatability of Positioning

1. Three telescoping members must be extendable from the bulkhead, and lock into position.

d. Access Capability

1. Access port adjustable in size.

2. A full-scale mock-up of the manipulative task panel.

4.1.4.2 Feasibility Test Equipment Requirements (Continued)

e. Reach Envelope

1. Bulkhead must have axes, described in 4.1.4.1.e, indicated for measurement references.

f. General

The following equipment will also be needed to conduct the feasibility tests.

SCUBA gear for 4 divers	Air for subject
Water Pressurization Backpack	Power for Backpack
Underwater camera and film	Slate and grease pencil
Stop-watch	
Tape-measure	

4.1.4.3 Phase I - Feasibility Test Results and Recommendations

a. Restraint Installation

To the extent possible, task times were recorded during the feasibility tests and are listed in Table 4-4. It must be realized that these times are crude and could hardly be subjected to statistical analysis. However, they do provide useful information concerning trends and magnitudes.

The predicted times are listed in Table 4-4 together with the times actually encountered for each subject. Inspection of the list reveals that some items compare favorably (e.g., "Retrieve and Install Handhold") while other items were poorly estimated (e.g., "Install Waist Restraint"). But the total times are reasonably close for each subject, and, more importantly, are significantly less than the predicted time. From this it may be inferred that the current time estimates for these items in the preliminary task sequence are at least reasonable, indicating some degree of validity in the M508 experiment time predictions. An important time consideration, however, is rest periods, and this consideration is not included in either the actual or predicted times in Table 4-4. It is therefore recommended that the preliminary task sequence be revised to include rest periods, and the effect of this inclusion be studied to determine the effect on time considerations.

This item of feasibility testing also revealed the following specific information:

- Cargo Carrier - The cargo carrier utilized was highly unsatisfactory as a restraint container. The subject, using only the mobility aid as a hand restraint, was unable to remove from the carrier, and install, the other restraints. It

4.1.4.3 Phase I - Feasibility Test Results and Recommendations (Continued)

a. Restraint Installation (Continued)

is therefore recommended that the subject have his restraints connected to him by rope lanyards, either loose or on wind-up reels. This was tested and found to be satisfactory. Other equipment could be carried in a cargo carrier, but it should be attached to the subject so that no interference with the process of restraint installation occurs. (See Figure 4-4)

- Mobility Aid - The subject's mobility aid serves as a hand restraint for use in installing other restraints. It must therefore be located close to the point where the first restraint is installed.

- Lanyards - Rope lanyards, attached to the subject, were used to transport various restraints. These lanyards, with their slide-lever connectors, were very satisfactory. The connector was operated with no difficulty, even with the pressurized, gloved hand. While no entanglements were encountered from equipment trailing loosely on the lanyards, a take-up reel is recommended.

  On two occasions subjects forgot to release the lanyard after the restraint was installed, and this was concluded to be a training problem.

- Dutch Shoes - The installation of the Dutch Shoes platform into the bulkhead proved difficult. Subjects had difficulty finding the insertion points for the pip pins. It is suggested that the pins and their receptacles be conical-shaped to improve this condition. The retarding mechanism and the operation of the pip pins was very satisfactory. Donning the Dutch Shoes was cumbersome, but this was felt to be partially a training problem. The subject must rely entirely on tactile cues for this process. (See Figure 4-4)

- Handhold - Installation of the handhold was similar to installation of the Dutch Shoes. Again, the subject had difficulty aligning the pip pins in the holes. A single pin-shaped to provide resistance in torsion-or conical-shaped pins would improve this situation.

  Thought should be given to the possibility of providing two handholds, as this significantly aids the process of donning the Dutch Shoes. Multiple locations for a handhold should be provided at the work area.

4.1.4.3 Phase I - Feasibility Test Results and Recommendations (Continued)

a. Restraint Installation (Continued)

- Waist Restraint - Vice grips, provided as the distal-end connector on the waist restraints, were difficult to align and attach. The subject was entirely dependent on tactile cues to position the grips. A longer tether length might allow for increased visual feedback. Once fastened, the vice-grips provided excellent holding power.

  The tension adjustment levers should be restricted to a 135° arc, starting at a forward, horizontal position and swinging downward. The rigidity of the tethers was only fair but it should be noted that the particular tether used was a prototype model that had been previously damaged. (Figure 4-5)

Visibility proved to be a problem throughout the feasibility tests. Subjects were too often entirely dependent upon tactile cues. This situation is in part caused by the necessity for the subject to wear a face mask. A larger mask may help. Also, there was some feeling that the subject may have been too close to the bulkhead, limiting peripheral vision. The distances involved should be examined to determine the magnitude of this problem. Finally, in the event that visibility cannot be improved, more tactile cues should be provided. Subjects reported that tactile feedback was easily sensed and interpreted, in spite of the pressurized gloves.

A more detailed evaluation of the vision envelope would be valuable. Superimposing the vision envelope on the reach envelope would show prime and secondary work areas.

The procedural order of restraint installation as currently specified in the Candidate Task Sequence is Handhold, Shoes, and/or Waist Tether. It was found that the Dutch Shoes restraint could be installed utilizing the handhold. However, it was discovered in the Feasibility Tests that two handholds are necessary for the subject to don the Dutch Shoes after they have been installed. It was also noted that the waist tether could not be installed using only a handhold restraint. The conclusion drawn is that substantial revision must be made to the concepts of restraint installation as currently envisioned in the task sequence. The method of installation for each restraint is feasible, but does not yet satisfy the criterion of being readily installable anywhere on the external portion of a spacecraft. The order of restraint installation is questionable because of the objections noted above.

b. Force Receiver Positioning

Times required for the subject to move the simulated force receiver module from one position to another are listed in Table 4-4. Again, these times are crude, but do provide order-of-magnitude insight. Note

TABLE 4-4

TASK TIMES - ASTRONAUT PERFORMANCE PROGRAM FEASIBILITY TESTS

TEST DATE: DECEMBER 11 SUIT: APOLLO A5L, 3.5 ± .2 PSI

TASK DESCRIPTION	ACTUAL TIME SUB. 1	ACTUAL TIME SUB. 2	PREDICTED TIME	COMMENTS SUB. 1	COMMENTS SUB. 2
	SECONDS		SECONDS		
Translation for approximately 9 ft. along hand rail	19	20	--		
Retrieve & install foot restraint	25	49	54		
Retrieve & install handhold	61	53	57	Subject to release lanyard to shoe restraint. This added more than 30 sec. to time	
Insert feet into dutch shoes	85	110	20	Required direction from surface. Had difficulty feeling if he was in.	Required direction from surface.
Install waist restraint	125	120	50	Two hands required on each side due to limited feasibility	Grips required adjustment.
Tighten waist restraint	34	40	20		Difficulty reaching adjust lever.
Module positioning while in Dutch Shoes (No handhold):					
Center to Upper Right	11.5	10.5	31		
Upper Right to Center	9.5	6.5	31		

TABLE 4-4

TASK TIMES - ASTRONAUT PERFORMANCE PROGRAM FEASIBILITY TESTS (Continued)

TEST DATE: DECEMBER 11 SUIT: APOLLO A5L, 3.5 ± .2 PSI

TASK DESCRIPTION	ACTUAL TIME SUB. 1	ACTUAL TIME SUB. 2	PREDICTED TIME	COMMENTS SUB. 1	COMMENTS SUB. 2
	SECONDS		SECONDS		
Module positioning while in Dutch Shoes (No handhold): Continued:					
Center to Lower Left	42	20	129[1]	Subject experienced extreme difficulty due to lack of vision. Required 2 hands, 1 for locating.	Subject used left hand, & did not release module.
Lower Left to Center	17	11.1	129		
Module positioning in waist Tether (No handhold):					
Upper Right to Middle	53	11.5	31	Could not see center hole. Used handhold.	
Middle to Upper Right	9.5	11.5	31		
Lower Left Position - NOT POSSIBLE TO REACH					
Remove Hand Restraint	-0-	35	10		

TABLE 4-4

TASK TIMES - ASTRONAUT PERFORMANCE PROGRAM FEASIBILITY TESTS (Continued)

TEST DATE: DECEMBER 11 SUIT: APOLLO A5L, 3.5 ± .2 PSI

TASK DESCRIPTION	ACTUAL TIME SUB. 1	ACTUAL TIME SUB. 2	PREDICTED TIME	COMMENTS SUB. 1	COMMENTS SUB. 2
	SECONDS		SECONDS		
Module positioning in waist Tether (No handhold):					
Remove Foot Restraint	-0-	44.5	34		
TOTALS[2]	472.5	522.6	627		

[1]The original task sequence from which these predicted timeesare taken envisioned the module positioning task from center to upper right as less involved than from center to lower left. The latter would use more elaborate fasteners and connectors. The module positioning task has since been changed to use the same hardware in both positions, but this change has not yet been included in the predicted times of 31 sec. and 129 sec.

[2]Does not include Translation Task.



FIGURE 4-4 INSTALLATION OF SHOE RESTRAINT

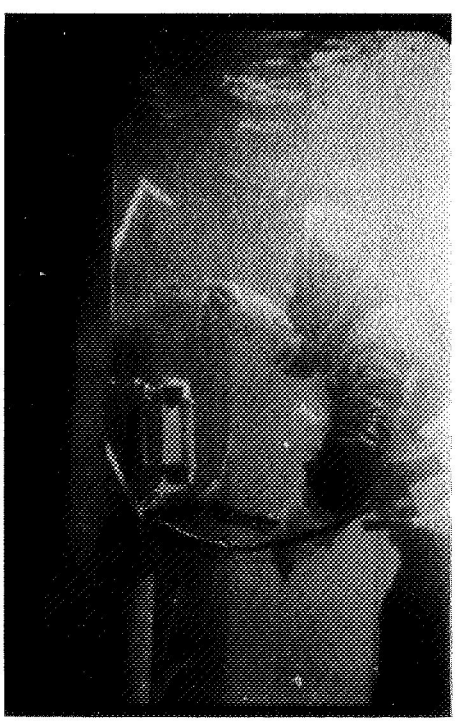


FIGURE 4-5 WAIST RESTRAINT

4.1.4.3 Phase I - Feasibility Test Results and Recommendations (Continued)

b. Force Receiver Positioning (Continued)

that the experimental times do not include time to release mechanical fasteners and electrical connectors. Also, rest periods are again neglected.

In both restraint conditions used, Dutch Shoes and Waist Tether, the upper right position was excellent (Figure 4-6), indicating that the positioning and installation of the module was within his reach capability. In the Dutch Shoe restraint, the center position (Figure 4-7) was also easily accessible. In the Waist Tether, however, the center position was very difficult for Subject 1, but not for Subject 2. This apparently reflects the fact that the subjects were not restrained in the same spatial relationship relative to the work area. Subject 1 was apparently positioned too high to see the center hole. This points out the need to accomplish the test item described in 4.1.4.1.c above.

The lower left position was very difficult to reach in the Dutch Shoe restraint. Subjects had to rely on tactile feedback to position the module. The time data for this item are very inconclusive, since chance played such a great part in whether or not the module was successfully positioned. In the waist restraint (Figure 4-8), this position was impossible to reach. The task sequence must be revised to reflect this information.

c. Reach Envelope

The reach envelope data obtained is shown in Figures 4-9 and 4-10. As with all quantitative data obtained in these tests, the reader is cautioned to use such data as indicative of trends or magnitude, but not as absolute value.

Subject 2 indicated a much more restricted left-hand reach than Subject 1. Subjective comments from Subject 2 revealed that this was apparently due to a misunderstanding of instructions, so that the subject, with his left hand, reached only to a comfortable distance and not to a maximum distance.

d. General

The following general comments may be made about various phases of the Feasibility Tests. The recommendations are especially important to bear in mind for Design Verification Testing.



FIGURE 4-6 MODULE POSITIONING-UPPER RIGHT

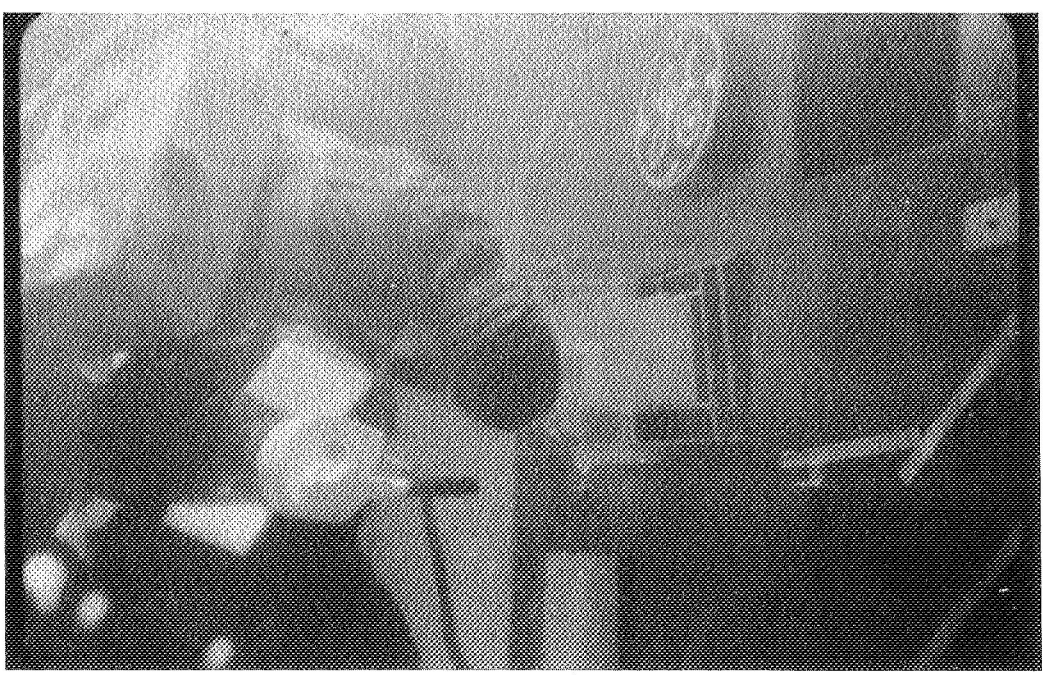


FIGURE 4-7 MODULE POSITIONING-CENTER POSITION

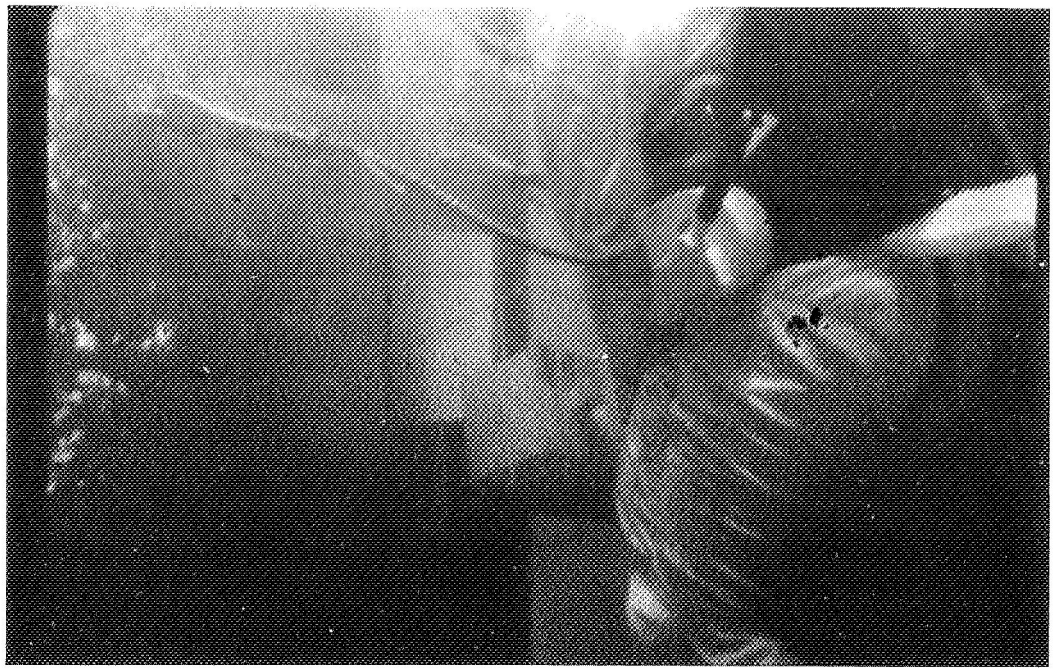


FIGURE 4-8 MODULE POSITIONING-LOWER LEFT

4.1.4.3 Phase I - Feasibility Test Results and Recommendations (Continued)

d. General (Continued)

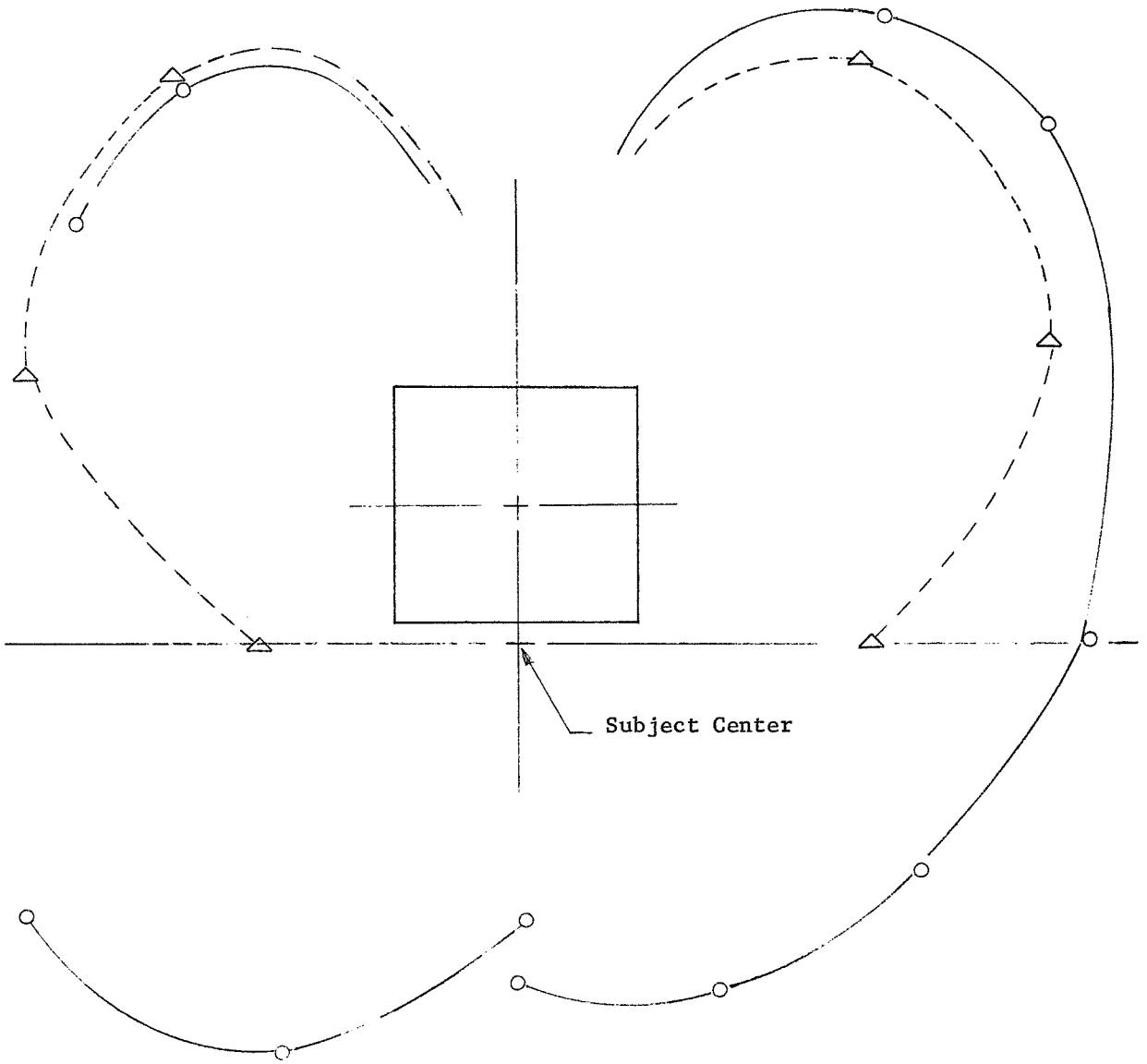
1. Simulation Technique

The simulated module exhibited a rotational damping tendency. While this was not detrimental to this simulation, a spherical center body would significantly reduce this tendency.

The Dutch Shoes should be fabricated from an open mesh material to reduce drag and hydrodynamic moments.

A face mask with a wider field of view is required for water pressurized suit operations.

From Table 4-4, it was noted that the subjects traversed the mobility aid at slightly less than .5 ft/sec. without any instructions regarding the rate of movement. Based on previous analysis, the drag effects are estimated to be less than 1 pound, at this rate.



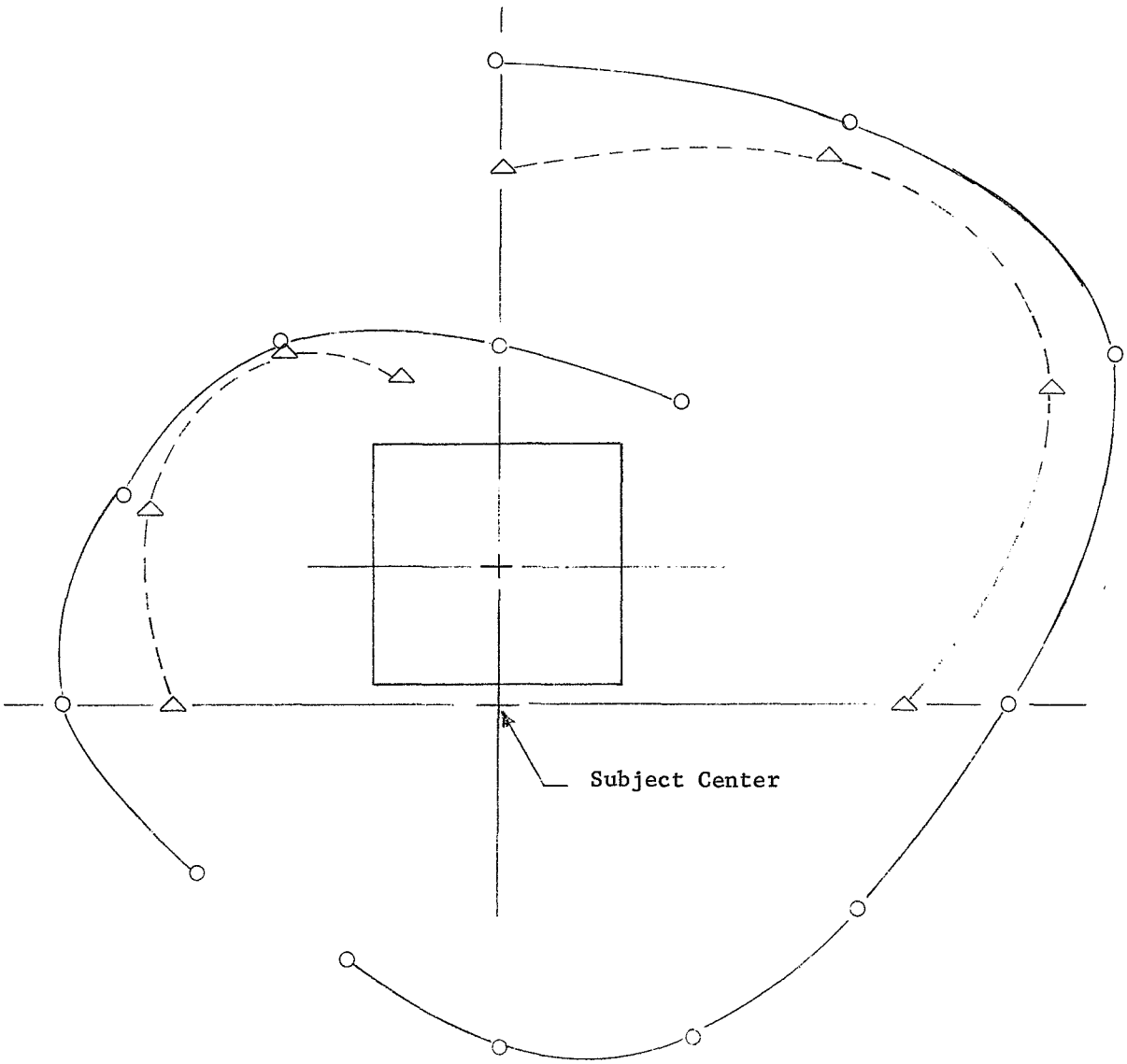
SUBJECT: 1

SUIT: APOLLO - 3 PSI

FOOT RESTRAINT O—O

WAIST RESTRAINT ---

FIGURE 4-9 REACH ENVELOPE-SUBJECT 1



SUBJECT: 2

SUIT: APOLLO - 3 PSI

FOOT RESTRAINT O—O

WAIST RESTRAINT ---

FIGURE 4-10 REACH ENVELOPE-SUBJECT 2

4.1.4.3 Phase I - Feasibility Test Results and Recommendations (Continued)

d. General (Continued)

2. Training

Subjects should be trained to attach lanyard or equipment tether to equipment prior to equipment release.

Occasionally, subjects forgot to remove the lanyard from installed equipment.

As already noted, subjects need training in donning the Dutch Shoes.

3. Test Planning and Data Taking

Continuous tape recording is vital. A speed of 3-3/4 ips is adequate.

Two-way communication between the subject and the topside test director is vital. Communication to underwater personnel is desirable. Movies should be time coordinated with tape.

4.1.4.4 Phase II Feasibility Test Results and Recommendations

Additional feasibility testing was conducted to complete the test procedures described in 4.1.4.1 above and to evaluate equipment modifications resulting from the Phase I testing. The changes involved primarily modifications to the restraint system. The distal end connectors on the waist restraint were changed from vice grips to ball-lock pins actuated by a thumb lever (Figure 4-11). The two ball-lock pins located at the ends of the original handhold were replaced by one centrally located pin. Other equipment changes included the elimination of the cargo carrier and the use of lanyards for carrying the restraints and equipment to the worksite.

Figure 4-12 presents an overall view of the test hardware, waist restraint and pressurized space suit used in the Phase II feasibility testing. The specific results of this testing effort are presented below.

a. Hardware comments:

1. Lanyard lengths were too short. A minimum length of 4' on a take-up reel is recommended. The take-up reels should be mounted on the front of the waist tether belt when the waist restraint is used, and on a separate belt when it is not used.

2. The handle on the Dutch Shoe Platform provides very little control. The handle should be remounted at the front of the shoes, as near as possible to the attachment pins.

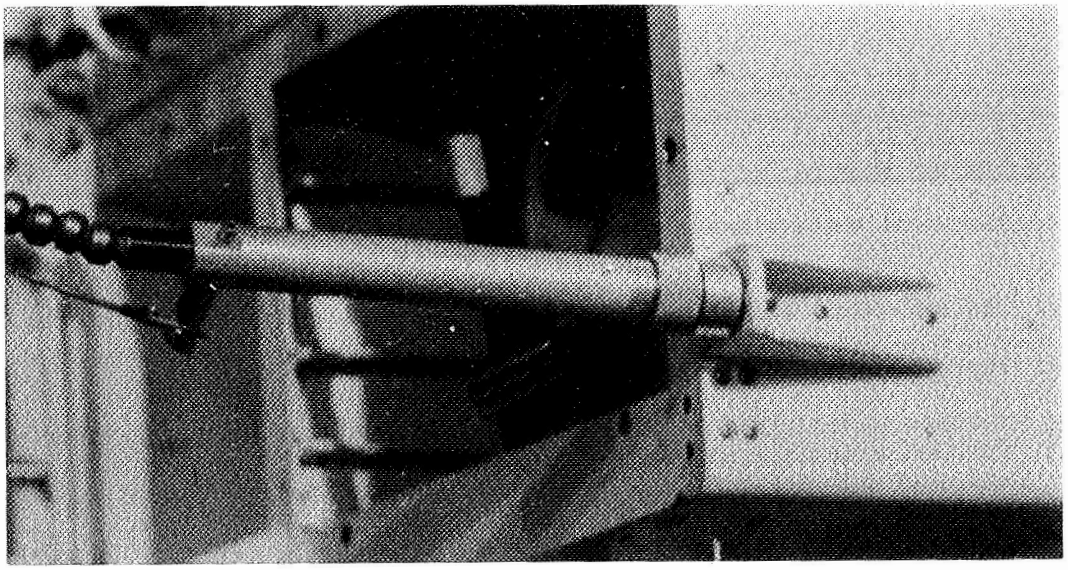


FIGURE 4-11 WAIST PESTRAINT-MODIFIED

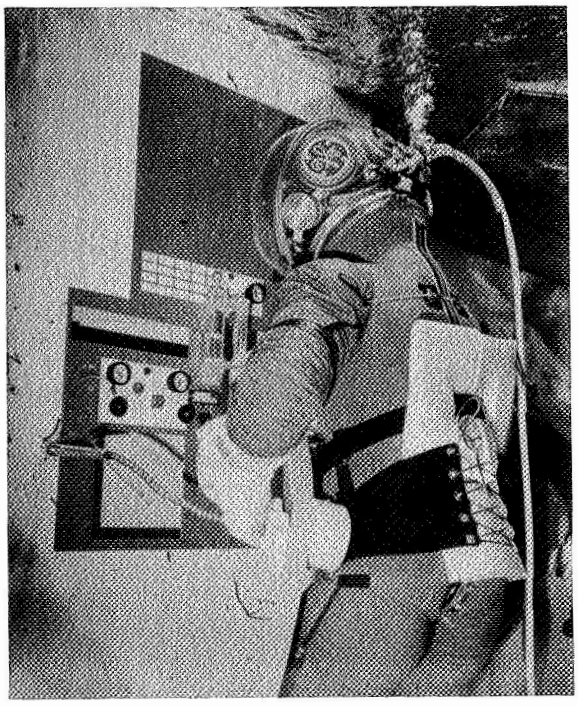


FIGURE 4-12 FEASIBILITY TEST-PHASE 2

a. Hardware comments: (Continued)

3. The distance between the waist restraint mounting locations was increased approximately 8" from the positions that had been previously defined. No noticeable difficulty with the new position was encountered.

4. The waist tethers must be longer. A minimum of 3' on each side is required.

5. The new module positions are acceptable.

6. The entire layout of all tasks is acceptable.

7. The new installation mechanism for the waist tether is acceptable. The smooth surface on the thumb-depressant resulted in the subject repeatedly losing control of the mechanism. This surface should be knurled.

8. The meter displays for the two-hand eye-hand coordination task will have to be tilted upward.

b. Experiment Procedure Comments

1. Subjects could not reach the position for the handhold installation while gripping the mobility aid with the left hand. This position may be lowered slightly or additional handholds will be required.

2. One handhold in a central position was sufficient to don the shoes. Both subjects, however, expressed a preference for having two-handholds.

3. One subject exhibited a tendency to grasp the operating rod on the handhold. This could result in accidental release of the handhold. The problem can probably be solved by training.

4. In the waist restraint only, the subject cannot be expected to accurately position himself. If accuracy is to be maintained, the observer will have to assist the subject in this condition.

c. Access Panel

An access panel, Figure 4-13, depth of 10' was found to be acceptable. Dimensions for the opening panel as selected by each subject are shown in Figure 4-14. Under these conditions, reach and vision envelopes for the access tasks were satisfactory.

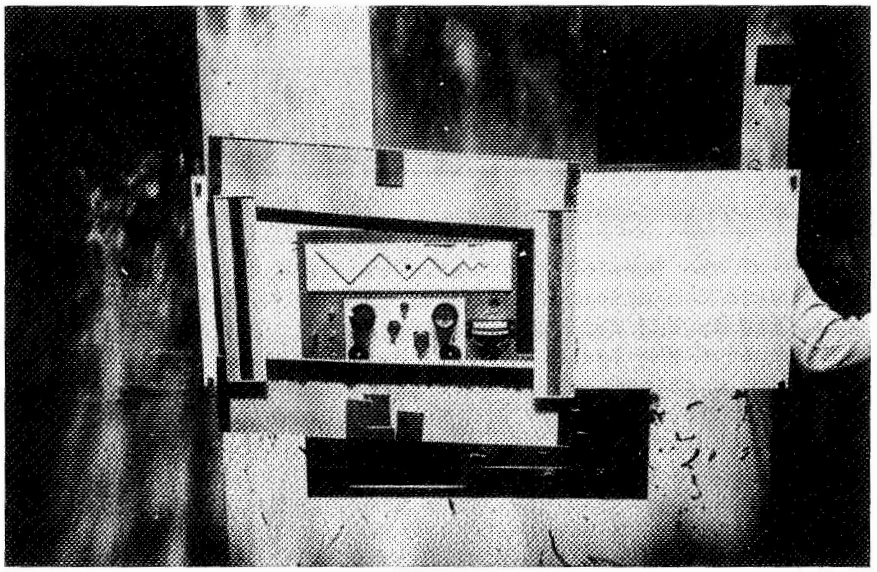


FIGURE 4-13 ACCESS PANEL-SIZE DETERMINATION

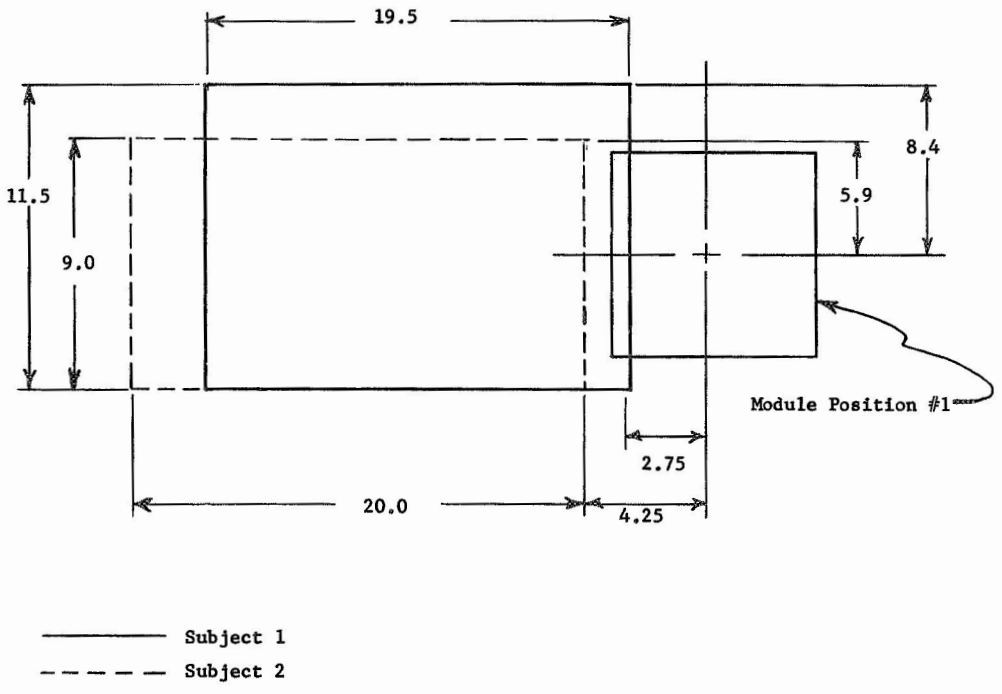


FIGURE 4-14 ACCESS PANEL-DIMENSIONSIONS AND LOCATION

4.2 TASK PANEL DESIGN

This section describes the Task Panel Design in detail. Starting with the general design features and main frame design, each task/module is discussed in depth to facilitate an understanding of its design, construction and operation.

4.2.1 GENERAL DESIGN CONSIDERATIONS

The results of the Feasibility Tests described above provided information for major changes to the original concept. Figure 4-15 depicts the final Task Panel configuration in the deployed configuration. The first of the changes was a reduction in size of the Force Receiver Module from 12" x 12" x 12" to 10" x 10" x 9.5" deep and a change in location of the two extreme receptacle positions. The lower-left receptacle was elevated to a position within the main frame, while the upper-right receptacle was moved toward the center from its originally conceived position. These changes allowed a reduction in the overall depth of the Task Panel from 24 to 20 inches. The two other major changes were the relocation of the Precise Hand Movement Task Module to the upper level and the Force/Torque Task Cue Panel to a position on top of the main frame. These changes also meant that there would be an increase in the time required to deploy and set-up the Task Panel for operation.

Figure 4-16 shows the stowed configuration of the Task Panel with the cover opened. Inside the cover is the Limited Access Panel (Para. 4.2.8) and the four adjustable mounting rods. The panel is attached to the cover with four "Expando-Grip" fasteners, and the rods mount to brackets on the panel door. The rods are mounted to the Task Panel at the points marked "A".

Point "B" is the attachment for the Handhold Restraint.

The four main task modules, the Force/Torque Receiver, Precise Hand Movement, Operational Maintenance and Two Hand Task are located in the upper part of the Task Panel. This is a direct result of the Feasibility Tests and was done to optimize the location of each task. The lower portion contains the Cue Panel, upper-right position receptacle and the observers panels. The position occupied by the Cue Panel becomes the lower-left receptacle for the Force/Torque Receiver.

It should be specifically noted that the design of the Task Panel described here was mainly for use in the four simulation modes; neutral buoyancy, KC-135 Keplerian flights, 6 degree-of-freedom mechanical, and 1-g. The requirements of the first two of these established the environmental design parameters for models built in this program. That is, the neutral buoyancy mode required that all electrical and electronic parts and/or connections be sealed or otherwise operable underwater, and the KC-135 required structural integrity that would survive the impact of a crash landing. The results of these requirements can be partly observed in Figure 4-15. For instance, the Cue Panel is a sealed pressurized can as is the Force/Torque Receiver Module.

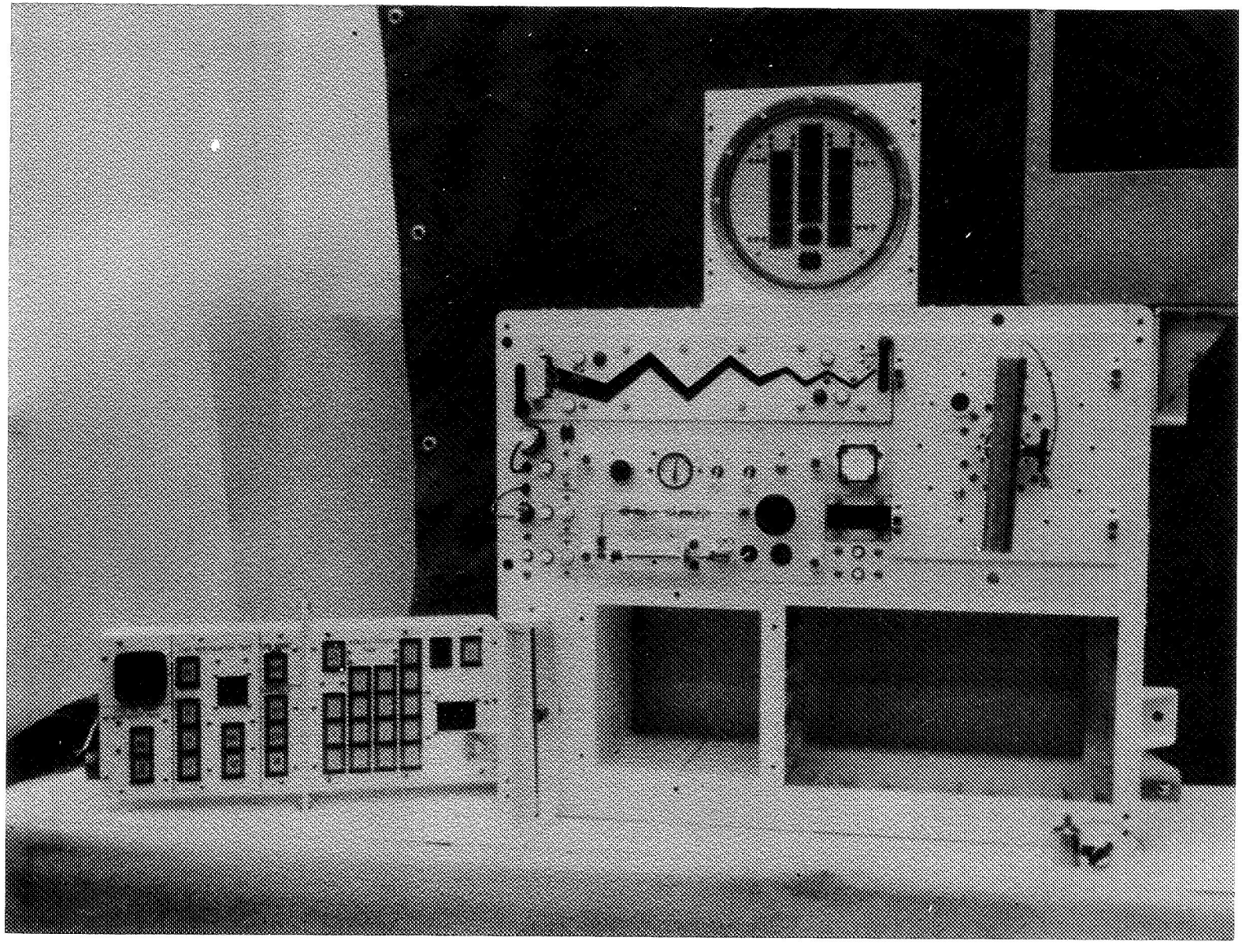


FIGURE 4-15 TASK PANEL-DEPLOYED CONFIGURATION

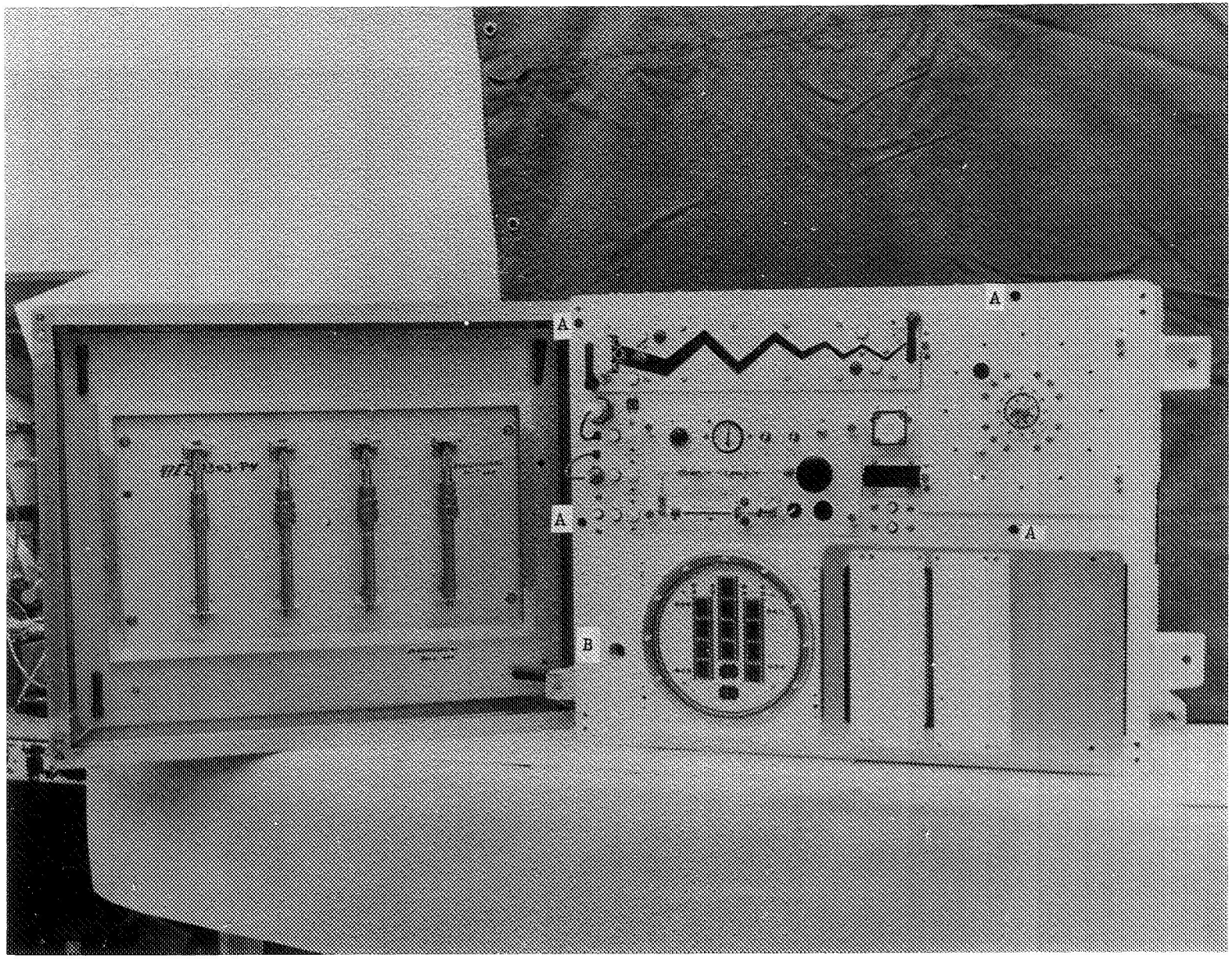


FIGURE 4-16. TASK PANEL-STOWED CONFIGURATION

4.2.1 GENERAL DESIGN CONSIDERATIONS (Continued)

The design also incorporates the concept of using parts of the Task Panel for more than one purpose. For instance, the cover, while protecting the face of the Task Panel during non-operating conditions, also serves as a part of the experiment as described in paragraph 4.2.2, and as noted above, also provides the stowage for the Limited Access equipment described in paragraph 4.2.8. The Force Receiver (Para. 4.2.4) serves as the equipment for the Module Removal/ Replacement Task.

The Main Frame is a welded, riveted structure which provides the main load carrying members of the entire Task Panel including the mounting. Removable covers are provided on the back, sides, top and bottom, with side covers containing recessed carrying handles. The front face is a sheet metal skin which is riveted to the main structure.

4.2.2 RESTRAINT INSTALLATION

As stated previously, the restraints used in this program were a Handhold, Variable Flexibility Waist Tether, and Gemini Dutch Shoes. All three were designed and/or modified so that the attachment to the worksite was by means of double-acting ball-lock pins.

4.2.2.1 Handhold Restraint

Figure 4-17 shows the Hand Restraint, and Figure 4-18 shows it mounted in the Task Panel cover. This is the first restraint to be installed in the Task Sequence and is used to assist in donning the other restraints. The long thin rod is used to unlock the pin. After the cover is removed the restraint is placed on the lower, left side of the Task Panel face, as shown in Figure 4-19, as an assist to the subject should he need it.

4.2.2.2 Variable Flexibility Waist Tether

The variable flexibility tether can be varied from a state of ropelike flexibility to a degree of rigidity that effectively restrains a pressure-suited astronaut while he is performing any work tasks within his current task spectrum. Additionally, the tether may be rigidized to an intermediate "plastic" state to permit minute changes in its configuration. This permits the astronaut to make precise adjustments in his position relative to his task site while he is adequately restrained by the partially rigidized tether.

These characteristics are achieved by forming a tether from a number of ball and socket links strung on a central cable (Figure 4-20). Adjacent links

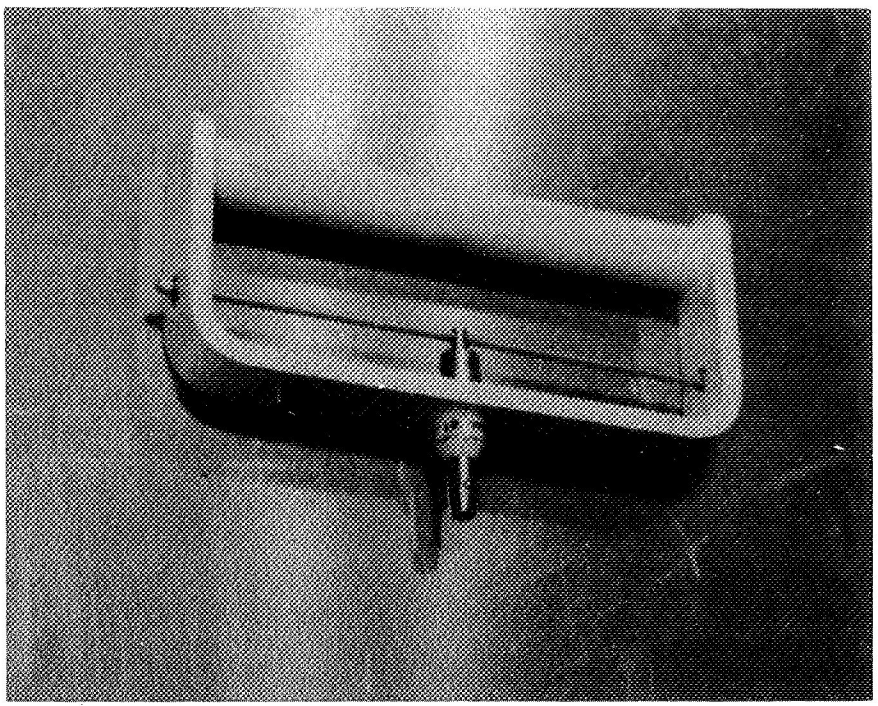


FIGURE 4-17 HAND RESTRAINT

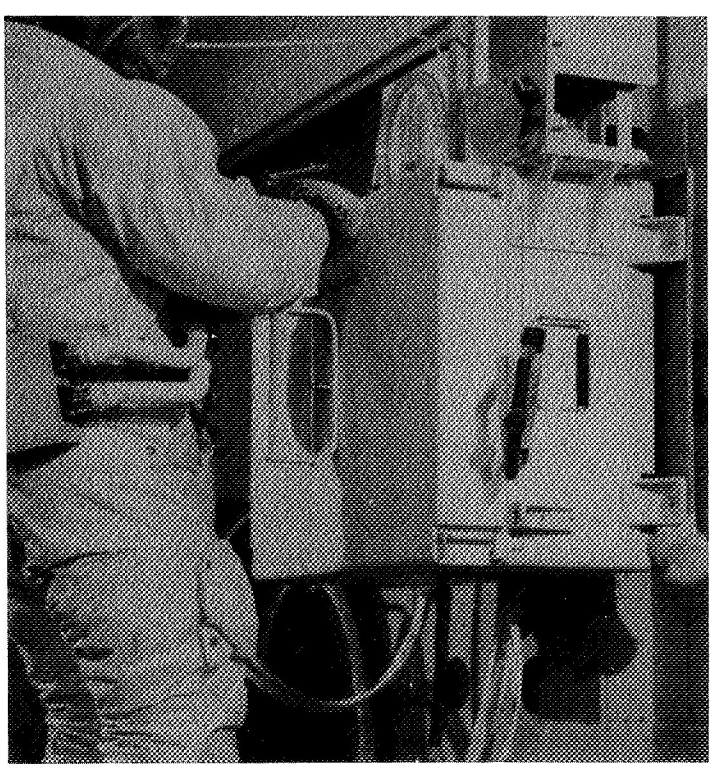


FIGURE 4-18 HAND RESTRAINT MOUNTED IN COVER

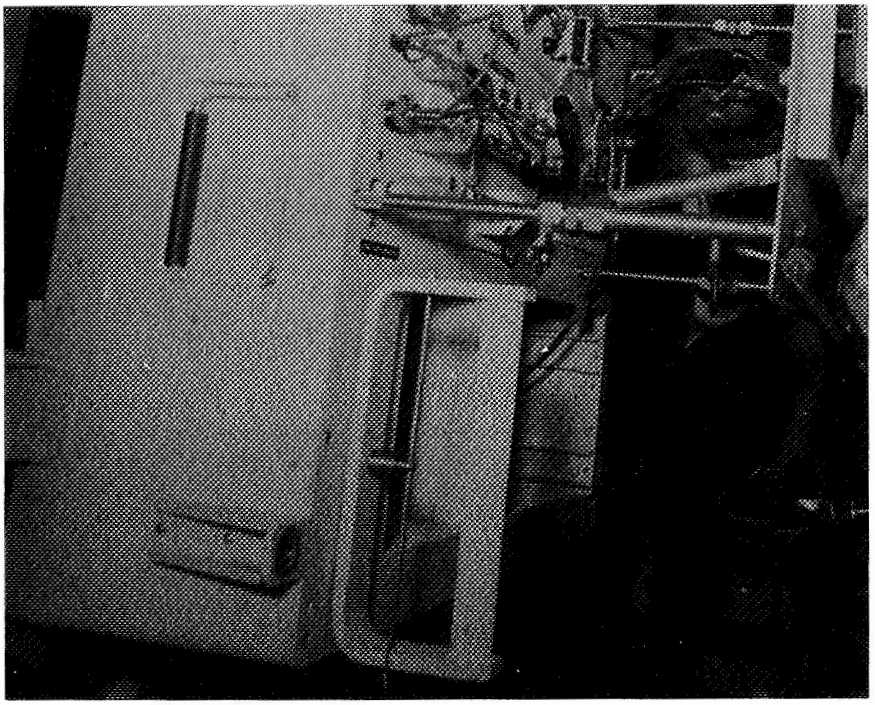


FIGURE 4-19 HAND RESTRAINT MOUNTED IN TASK PANEL

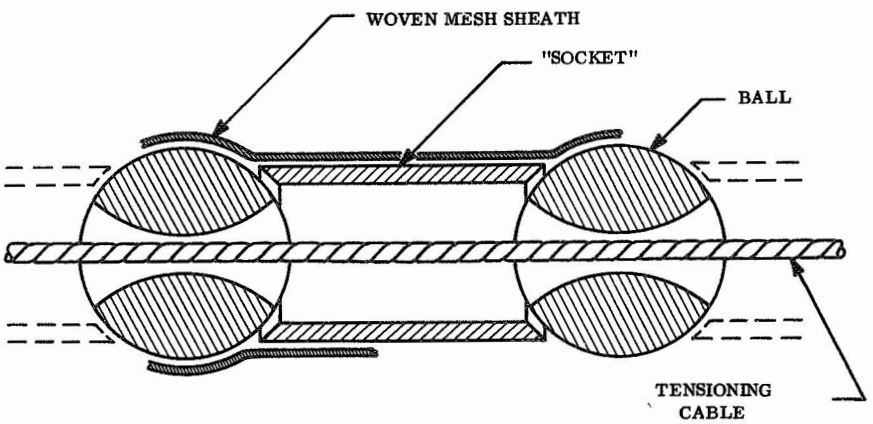


FIGURE 4-20 VARIABLE FLEXIBILITY TETHER CONCEPT

4.2.2.2 Variable Flexibility Waist Tether (Continued)

bear upon one another in compression. The magnitude of this compression force is a direct function of the central cable tension, which is variable by means of an actuator. The frictional forces between adjacent link surfaces, which also vary in direct relation to the compression forces, resist relative motion between links. Thus, the greater the cable tension, the greater is the tether's ability to resist deformation. By varying the cable tension from slack to its working tensile limit, the tether's degree of rigidity may be varied as a continuous function over a wide range. No change in relative position between any of the tether links takes place when the cable tension is varied. In other words, the tether will retain its shape as long as there is intralink friction. Changes in shape can only be effected by externally applied bending moments sufficient to "yield" the tether by overcoming intralink friction. Thus, degree of restraint and restraint geometry are independently controllable in minute increments.

The Variable Flexibility Waist Tether used in this program is shown in Figure 4-21. The mechanism with the handle at the subject's side is the take-up and release mechanism. Also shown in this picture are the retractable lanyards on the subject's waist and wrist used to retain the shoe restraint during transport and the tools required for the experiment operations, respectively.

4.2.2.3 Foot Restraint

Figure 4-22 illustrates the foot restraint. The Handle over the toes is for installation and release. The shoes used were developed to accomodate the Gemini suit boot and, consequently, fit the A7L suit. However, the boots of the AES suit did not interface properly, and therefore, it was necessary to remove the back section of the shoes whenever that suit was utilized.

4.2.3 GAINING ACCESS TO WORK SITE (FRONT COVER)

This part of the Task Sequence consists of removing the cover of the Task Panel using 2 different tools, a ratchet wrench and a "T" handle wrench, after the subject has installed and donned his personal restraints. The cover appears as a smooth surface with a hole in the center and 2 fasteners at each corner (a hex head and a socket head bolt). The hole in the center is an attachment point for the hand restraints (See Figure 4-23).

The cover is approximately 4.25" deep and was designed so that the attachment bolts were within the envelope of the cover, hence the "notched" corners. Standard bolts were originally utilized with their heads well below the surface. However, it was soon realized that the subject would not be able to see the bolts on the left side and have difficulty seeing the bolts at the lower-right corner, making the cover removal a significantly larger task. To alleviate this condition, special captive, shoulder bolts were made so that the heads would be flush with the surface cover.

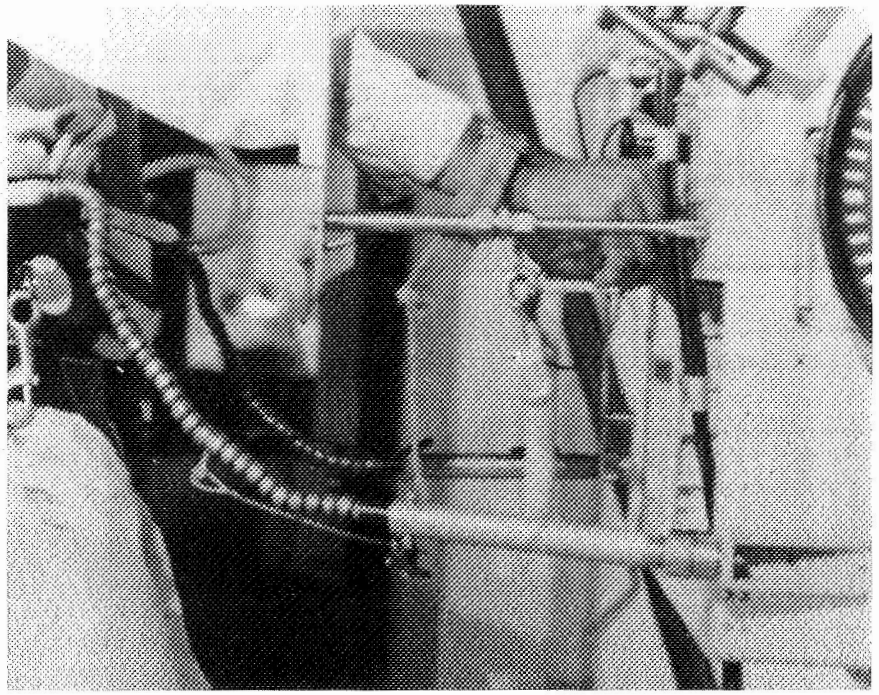


FIGURE 4-21 VARIABLE FLEXIBILITY WAIST TETHER

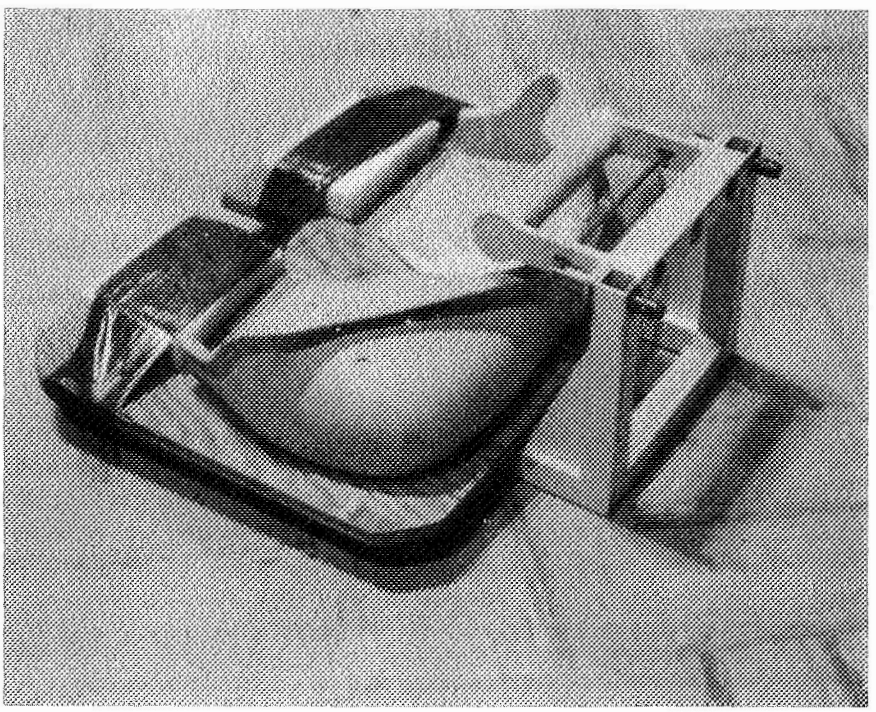


FIGURE 4-22 FOOT RESTRAINT

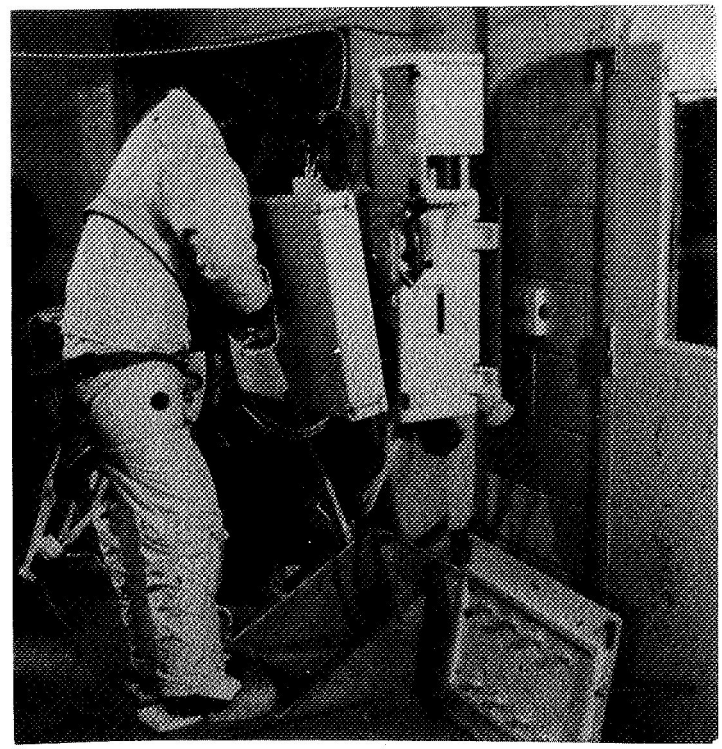


FIGURE 4-23 COVER REMOVAL

4.2.3 GAINING ACCESS TO WORK SITE (FRONT COVER) - (Continued)

load carrying capacity during transport and to retain the cover in position after the corner bolts are released.

The cover also provides a storage place for the Limited Access Panel and Support Rods (See para. 4.2.7).

4.2.4 FORCE/TORQUE MODULE

The Force/Torque Receiver is a device which will measure forces and torques applied to it either manually, in the three orthogonal axes or with tools, in clockwise and counterclockwise directions. Basically the unit consists of an instrumented shaft capable of accepting either a "D" shaped handle or tool adapter, Figure 4-24. The shaft is in two parts, connected by a precision universal joint. This was done to assure that none of the forces or energy imparted to the shaft would be required to deflect the shaft, and therefore all energy is applied directly to the force sensors.

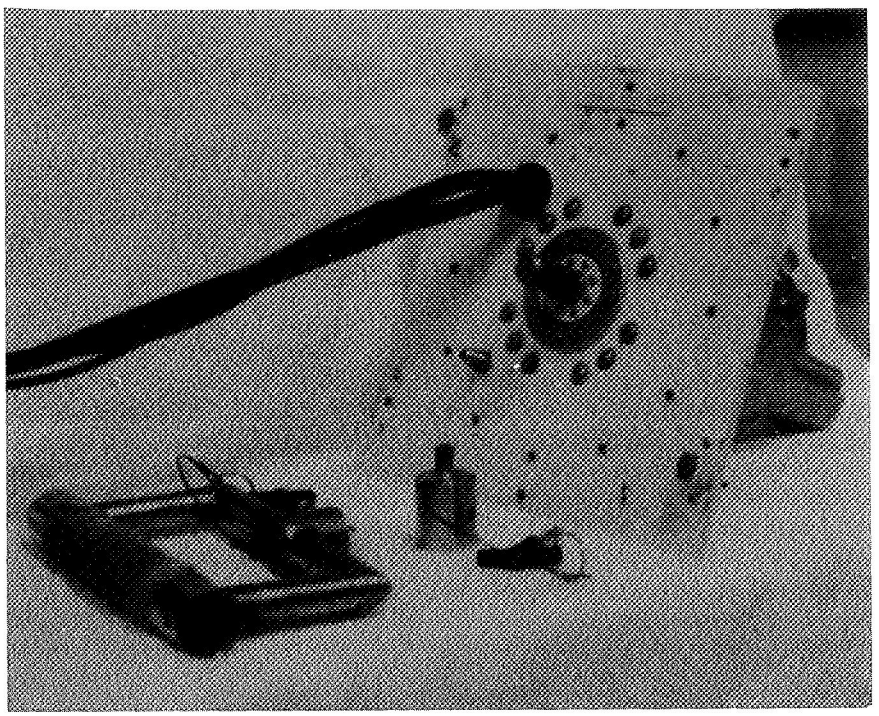


FIGURE 4-24 FORCE RECEIVER

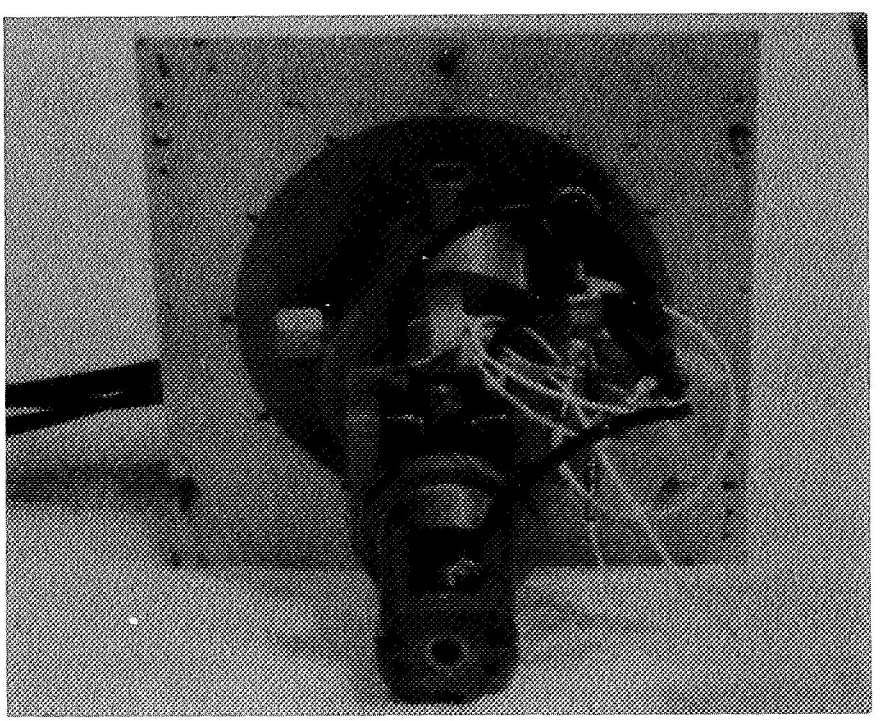


FIGURE 4-25 FORCE RECEIVER-REAR VIEW

Seven quartz-crystal force sensors, Kistler Model 912, are located internally. One of these measures the ±X (push, pull) forces. The other six are used to measure the ±Y (left, right) and ±Z (up, down) forces and the CW and CCW torques, Figure 4-25.

The shaft is inserted in a housing which contains two precision ball bushings. These bushings guide the shaft movement in the ±X and CW and CCW directions. Although the shaft movement is less than 0.002 inch, it was necessary to include the bushings because the starting friction of any shaft movement can be considerable, and result in a significant amount of data error. The housing also provides the mounting for the force transducers. The single, ±X direction transducer is mounted in the rear end of the housing. The ±Y, -Y, ±Z, -Z transducers are mounted near the forward end of the housing, at right angles to the shaft. The transducers measuring the CW and CCW torques are located midway between the two bearings on the rear shaft, offset 2.0 inches from the shaft center. An arm was placed in the shaft at right angles to transmit the load. Since the sensors, except for the ±X sensor, are located so that the force vector does not pass directly through the sensor, a conversion factor must be applied to the output of the transducer. (See Figures 4-26 and 4-27.)

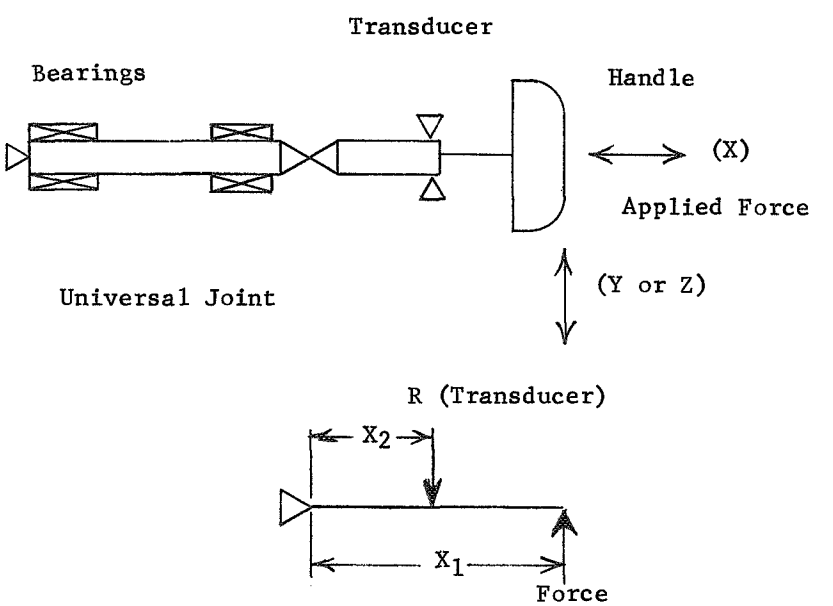


FIGURE 4-26 TRANSDUCER ARRANGEMENT

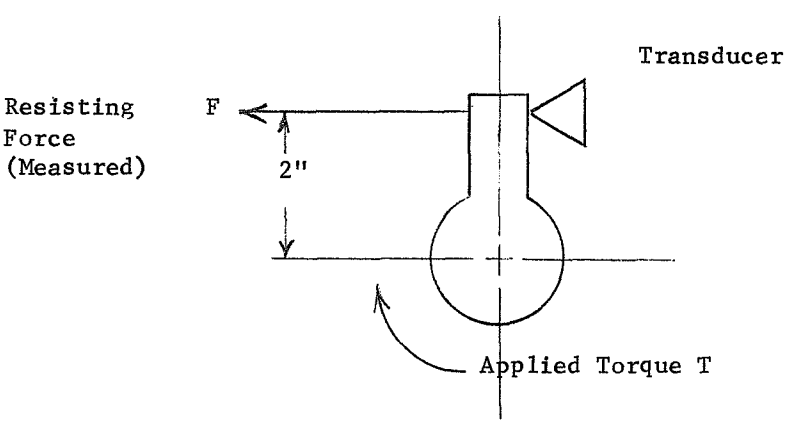
Since there is essentially no movement in the shaft, the forces on the load cell can be calculated as follows:

$$\text{Tu-joint} = 0$$

$$\text{Applied Force} \times X_1 = R \times X_2$$

$$R = \frac{X_1}{X_2} \quad \text{(Applied Force)}$$

In a similar manner, the output of the transducers measuring the CW and CCW torques must be adjusted. The offset of torque transducers is 2.0 inches. Therefore they will be measuring torques one-half as great as are actually applied. These compensations were readily performed with the Charge Amplifiers by applying a known load and setting the output accordingly.



$$T = 2F$$

$$F = \frac{T}{2}$$

FIGURE 4-27 TORQUE MEASUREMENT

4.2.4 FORCE/TORQUE MODULE (Continued)

One of the problems encountered in measuring forces is the determination of the actual point of force application, because the errors introduced in the data are considerable when that point is incorrectly identified.

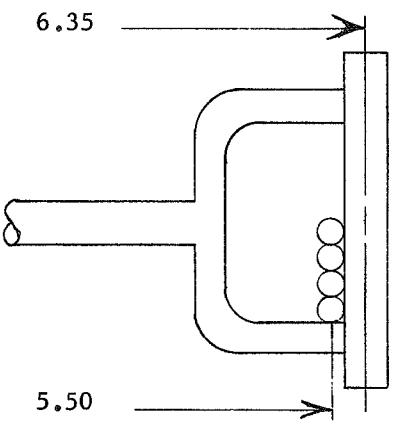


FIGURE 4-28 HAND PLACEMENT ON HANDLE

In Figure 4-28, it is seen that the correct point of force application should be through the centerline of the handle. However, should the subject grasp the handle too low, his fingers will be pressing on the bottom bar, shifting the point of force application by almost 1.0 inch. To eliminate this source of error from the data, the handle span was made much larger than actually required, and then tape was applied to the center portion of the handle. The subject was instructed to grasp the taped section of the handle.

To enable its reliable use underwater, the Force Receiver was mounted in a sealed can, and then pressurized to about 4 psi. Other precautions were taken in the design of this device for underwater use. These include a bladder-type seal between the shaft and front panel face and potting the cable passage through the front face. This latter feature represents a compromise with the Task Sequence since it was originally conceived to have a connector there for the subject to de-mate and mate when performing the module removal task.

The output of each force transducer was in input to charge amplifiers mounted outside the force receiver. The output of the charge amplifiers is a direct analog of the force applied and was recorded directly (See Section 4.2.9). The Cue Panel, Figure 4-29 which was also made as a sealed pressurized unit, provides the commands to the test subject for the Force/Torque Tasks. Separate indicator lights are provided for the three force types (Impulse, Sustain,

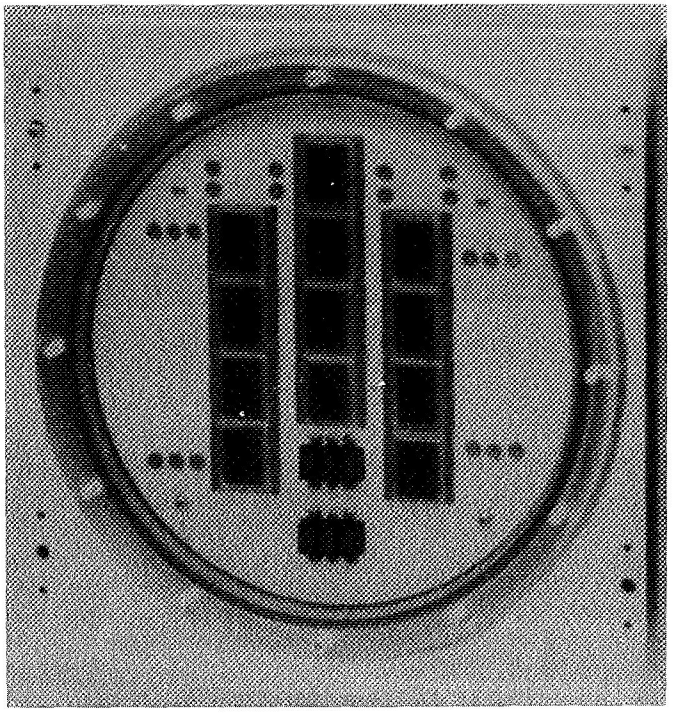


FIGURE 4-29 CUE PANEL

4.2.4 FORCE/TORQUE MODULE (Continued)

Precise) and the 8 force directions (+X, -X, +Y, -Y, +Z, -Z, CW and CCW). In addition, one light provides a "Ready signal. Two 3-digit numerical displays are provided for use in the Precise Force/Torque Mode; the upper for the force quantity commanded; and the lower for the force quantity emitted. The force or torque quantity commanded is supplied by the observer thru a 3-digit, thumbwheel switch. Each switch provides a decimal-to-binary conversion of the numbers 0 thru 9. The output of each switch is connected directly to its respective decoder and alpha-numeric display on the cue panel. Thus the same digits can be used for the Force Task as the Torque Task.

In order to display the force emitted on the Cue Panel, an analog-to-digital conversion of the force output of the change amplifier is used. The digital work is decoded to provide the three place digital readout. The decoding is performed in the Pen-Lite decoder which uses a Fairchild monolithic circuit.

The actual digital-to-analog conversion is performed using the comparator-counter approach. In this approach, the analog signal (Charge Amplifier Output) is the input to an integrator circuit. The output of the integrator is fed to a comparator which gates the clock signal to the counter. When the integrator signal is below the reference voltage, the clock signal is being fed to the counter. When the reference voltage is exceeded, the comparator changes state and inhibits the transmission of pulses to the decoder. The clock is a 10 KHZ

oscillator which means that it requires approximately 100 milliseconds to count 1000 pulses, which is the largest number to be converted. After 100 milliseconds the number is displayed on the panel, and the counter continues to receive pulses for 411 milliseconds. At this time the counter and integrator are reset and the process repeats.

4.2.4.1 Module Removal/Replacement

The Force/Torque Module (FTM) is also used for the Module Removal/Replacement Task. Three receptacles are provided in the Task Panel for the FTM, Figure 4-15. The center location (position 1) is the stowed location of the module, and the lower left location (position 3) is the stowage position of the Cue Panel. The upper right location (position 2) is a specially designed receptacle which is stowed in the lower right section of the Main Task Panel.

Four captive bolts with 3/8 hex heads were used to fasten the FTM in each of the 3 positions. These were released and fastened with the ratchet wrench. The "D" Handle was used to remove and insert the FTM in each of the three positions. In practice, it was found that the releasing and fastening of the four bolts required more time than was allowed, and therefore, two bolts, at opposite corners were removed.

4.2.5 PRECISE HAND MOVEMENT

This removable module contains 3 independent negator spring motors, each of which turns a cable take-up drum and a potentiometer. A cable attached to each drum is passed over a series of pulleys and terminates in an eyelet at the front of the module. The spring tensions were adjusted to give loads of 1-1/4, 2-1/2 and 5 lbs.

The front panel, Figure 4-30, of the module is made of plexiglass and is slotted with a variable width, saw-tooth shaped opening. The widest part of the opening is located at the side where the eyelets are retained. Separate conductive surfaces were applied to the top and bottom edges of the saw tooth.

The third part of this task is a conductive probe, with an insulated handle. At the free end of the probe, the handle is shaped so that it can enter and be retained in the eyelets. Extending from the insulated handle is the conductive contactor. A cable attached to the contactor passes out the other end of the handle into the Task Panel where it terminates in a ground connection.

During the experiment, the subject removes the probe from its receptacle in the Task Panel and inserts the free end into one of the eyelets. The cable is pulled out slightly, and the subject touches the probe to a switch located behind the widest part of the slotted opening. This causes a pair of lights at that end panel to go on, and at the same time, puts a time mark on the recorder, indicating that the subject is now being timed and turns on a light on the observer

panel to indicate that the task is underway. The subject then traverses the slotted opening pulling the spring loaded cable, making sure that it is approximately parallel to the front panel, which keeps the conductor-part of the probe within the slot. Should the probe make contact with either the top or bottom edge of the slotted opening, a corresponding red light goes on and remains on until the contact is broken.

Another switch located at the narrowest part of the saw tooth is contacted by the probe turning on another pair of white lights. This indicates to the subject that he has reached the end of the traverse, and he now should start the return. A time mark is also recorded then. At the conclusion of the return traverse, the probe is again touched to the first switch turning off all lights. Thus the time for each part of the traverse is recorded.

The module is retained in the Task Panel by means of two quick-release, Expando-Grip fasteners located at opposite corners of the front plate. When the module is inverted, that is, with the loads coming from the opposite direction, the fasteners also locate in the opposite holes.

The contact detector circuit, Figure 4-31 of the Precise Hand Movement Task is designed to prevent arcing when the contact is made (or broken). The circuit consists of a voltage divider network which puts +41 mv through a 10 K resistor into the inverting input of a differential amplifier. The non-inverting input

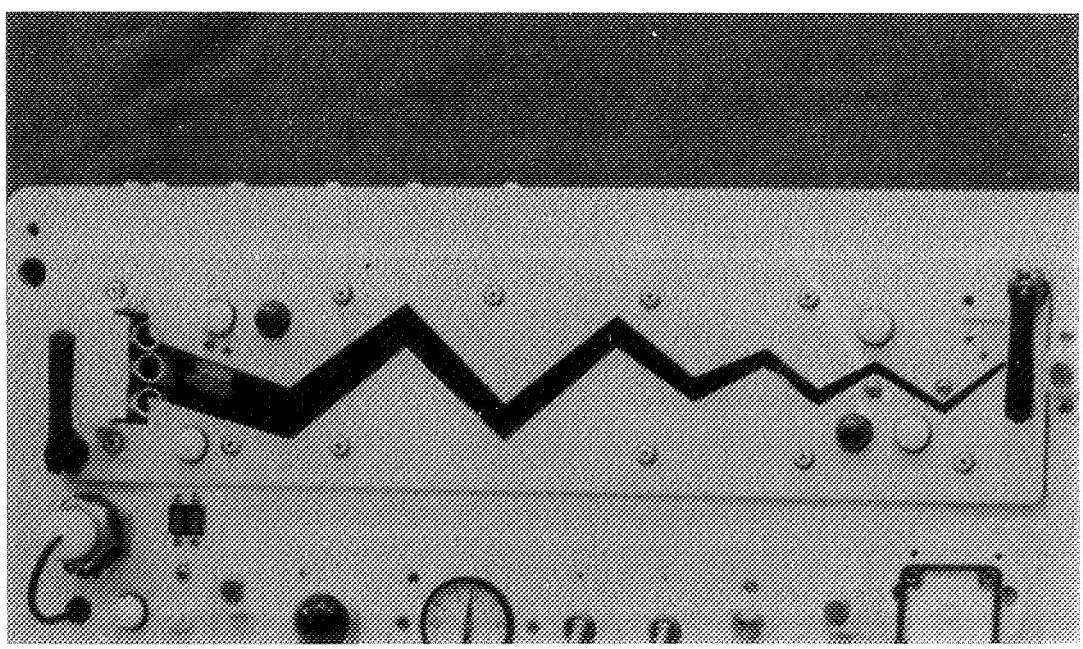


FIGURE 4-30 PRECISE HAND MOVEMENT TASK

has a potential of +21 mv applied to it. With the contact open the differential amplifier is in negative saturation and the voltage at the summing junction (inverting input) is at +35 mv. The contact is tied to the summing junction through a 100 resistor. When the contact is grounded the summing junction or inverting input of the amplifier is pulled to ground potential, and the amplifier output goes to positive saturation.

The maximum voltage seen at the contact is 35 mv from a source impedance of approximately 10 K; thus limiting the energy available at the contact to such as low value that no sparking can occur. Because of the small voltages involved, the two elements of the contact (probe and surface) should be of the same metal to prevent false operation due to potentials generated by galvanic action.

4.2.6 TWO-HAND EYE/HAND COORDINATION

The elements of this task are mounted directly into the Task Panel as opposed to being a separate module, and are located on either side of the Operational Maintenance Task Module (See Figure 4-15).

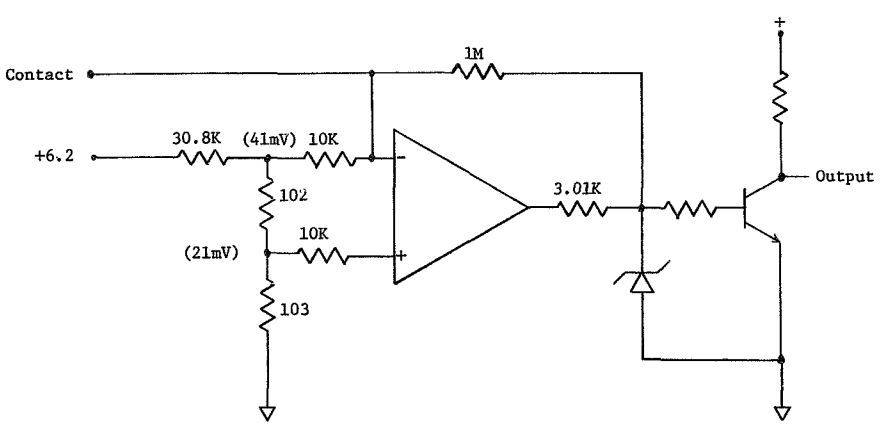


FIGURE 4-31 SCHEMATIC CONTACT DETECTOR CIRCUIT

4.2.6 TWO-HAND EYE/HAND COORDINATION (Continued)

The three test points are representative of a male connector pin, a female connector pin and a solder terminal such as would be found on a printed circuit board. All three are identical in operation, and each is operated by the closure of a hermetically sealed miniature switch located within the housing. The original contact sensor was a Clark Microducer which is an extremely sensitive force sensor whose impedance changed from several hundred thousand ohms to a very low value upon the application of a small force. It was intended to compare this method of contact detection with the method used in the Precise Hand Movement Task (Para. 4.2.4 above). It was determined, however, that the Clark Microducer while having the proper electrical characteristics, was physically too delicate and difficult to use in an underwater environment.

The probe used as the contact device approximates the size and shape of a large test instrument probe, but is a dummy and has a dummy cable which is tied-off inside the Task Panel. The probe is stored in a receptacle in the Task Panel.

The digital display consists of two decade counters which are subminiature modules used for counting, decoding, and two 7 segment alpha-numeric readout devices provide the display. The input command voltage to the subjects digital display is set by the observer using a two-digit thumbwheel switch assembly. Each switch provides a decimal-to-binary conversion of the numbers 0 through 9. The output of each switch is connected directly to the respective decoder and alpha-numeric display located in the task panel.

On the other side of the Operational Maintenance Task Module are located the analog voltmeter and the voltage adjustment pots. The major problem encountered with the selection of a suitable voltmeter was the attempt to provide a sufficiently large scale, while keeping the overall meter size small enough to fit within the limited space available. Also the meter had to be completely waterproof to allow its use underwater, and although the supply voltage available was 5V, the scale had to read to 10. This was because the digital display was capable of reading to 99, and the experimental design required the use of the full range. The voltage adjustment consisted of two pots; a 1 turn pot as the coarse adjustment and a 10 turn pot as the fine adjustment. The adjusted voltage was also recorded via the telemetry system.

At the conclusion of the task, when the subject feels he has set the voltage properly, the Task Complete button is pressed, resetting all the circuits to a zero state and turning off the digital display. This is also indicated on the telemetry giving the capability to measure the total elapsed time for the task.

4.2.7 OPERATIONAL MAINTENANCE TASK

This module, Figure 4-32, contains a network of pneumatic components, fittings and tubing arranged in a manner which allows the subject to pressurize the network manually and remove and replace a particular component upon depressurization by the observer.

4.2.7 OPERATIONAL MAINTENANCE TASK (Continued)

Figure 4-33 is a schematic diagram of the network employed in this task. Upon pressurization, the piston of the cylinder opens a pair of switches. The pressure is released by the Test Observer pressing a button on his panel opening the solenoid valve. When this occurs, the piston releases its pressure against the switches, turning on a 3 cps oscillator which operates the light on the module at that frequency, and also turning on the buzzer at the same frequency. The two manual switches on the module are each connected in series with the switches operated by the piston. The subject opens those switches to turn off the flashing light and the buzzer, indicating he has recognized the alarms and will take corrective action.

When the "failure" occurs, the subject uses the open-end wrench to remove the nut that connects the cylinder to the rest of the circuit, and the T-handle wrench to remove 2 socket-head cap screws that hold the cylinder to the front panel.

The Hand Pump is a single acting, spring loaded, air cylinder which was fitted with a knob on the piston to allow the subject to pressurize the circuit during the initial test set-up, and also after he has completed the repair without relying on outside sources.

The Snorkel Connector shown in the schematic was used to enable the network to be air pressurized during the Neutral Buoyancy Simulation Tests.

4.2.8 LIMITED ACCESS

The Limited Access Panel provides a restricted opening for the test subjects reach and visual access to the Task Panel (See Figures 4-34 and 4-35).

It was determined, during the Feasibility Tests para. 4.1.3, that the opening in the panel should be approximately 20 inches wide by 11.5 inches high, and should be positioned in the upper left of the Task Panel so that the opening exposes the Precise Hand Movement and Two-Hand Tasks. To be representative of a real limited access situation, this Panel need be more than a simple frame restricting reach access only. It must also prevent the subject from seeing his task by looking over or around. The requirement to stow this panel inside the cover also was considered. These resulted in an overall size of 26.88 wide x 20.88 high with the opening centered in the panel as noted above. The opening in the panel is normally closed with a plate which is removed for operation by releasing four quick release fasteners.

The Limited Access Panel is attached to the Task Panel by means of 4 telescoping rods. The telescoping feature allows the Limited Access Panel distance from the Task Panel to be adjusted between 8 and 12 inches. The attachment to the Task Panel is by means of threaded ends of the rods, while attachment of the Limited Access Panel is by means of snap-in type pins. The telescoping rods are stowed on the panel when not in use (See Figure 4-16).

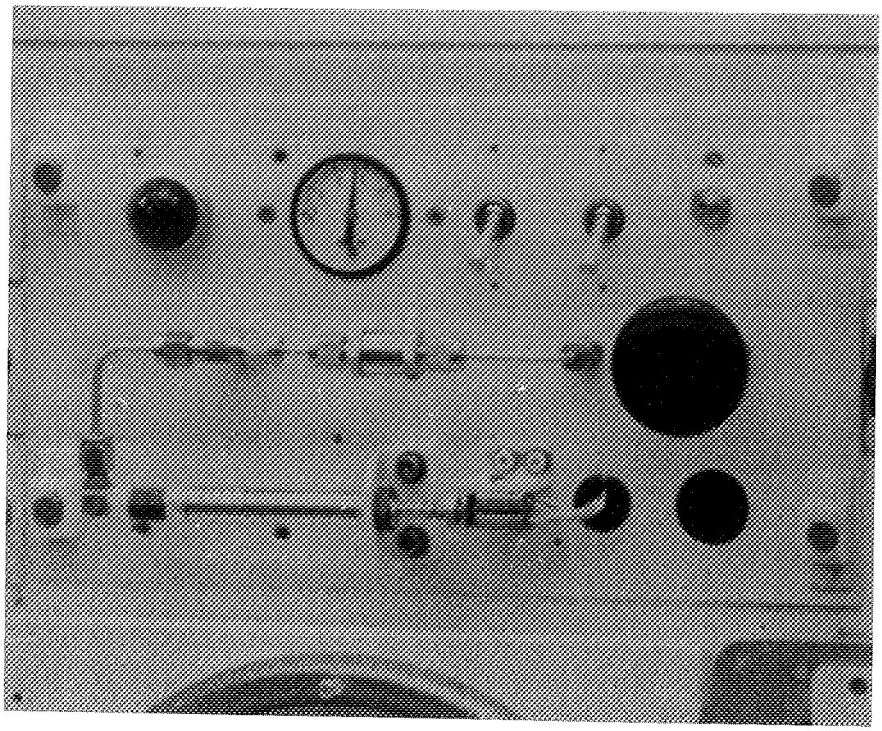


FIGURE 4-32. OPERATIONAL TASK MODULE

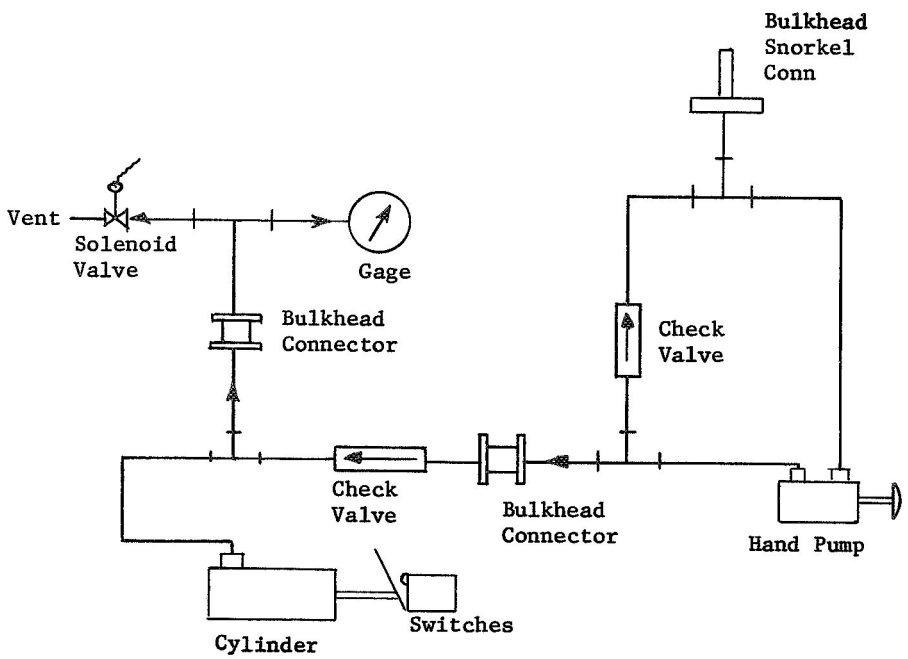


FIGURE 4-33 SCHEMATIC-OPERATIONAL MAINTENANCE TASK

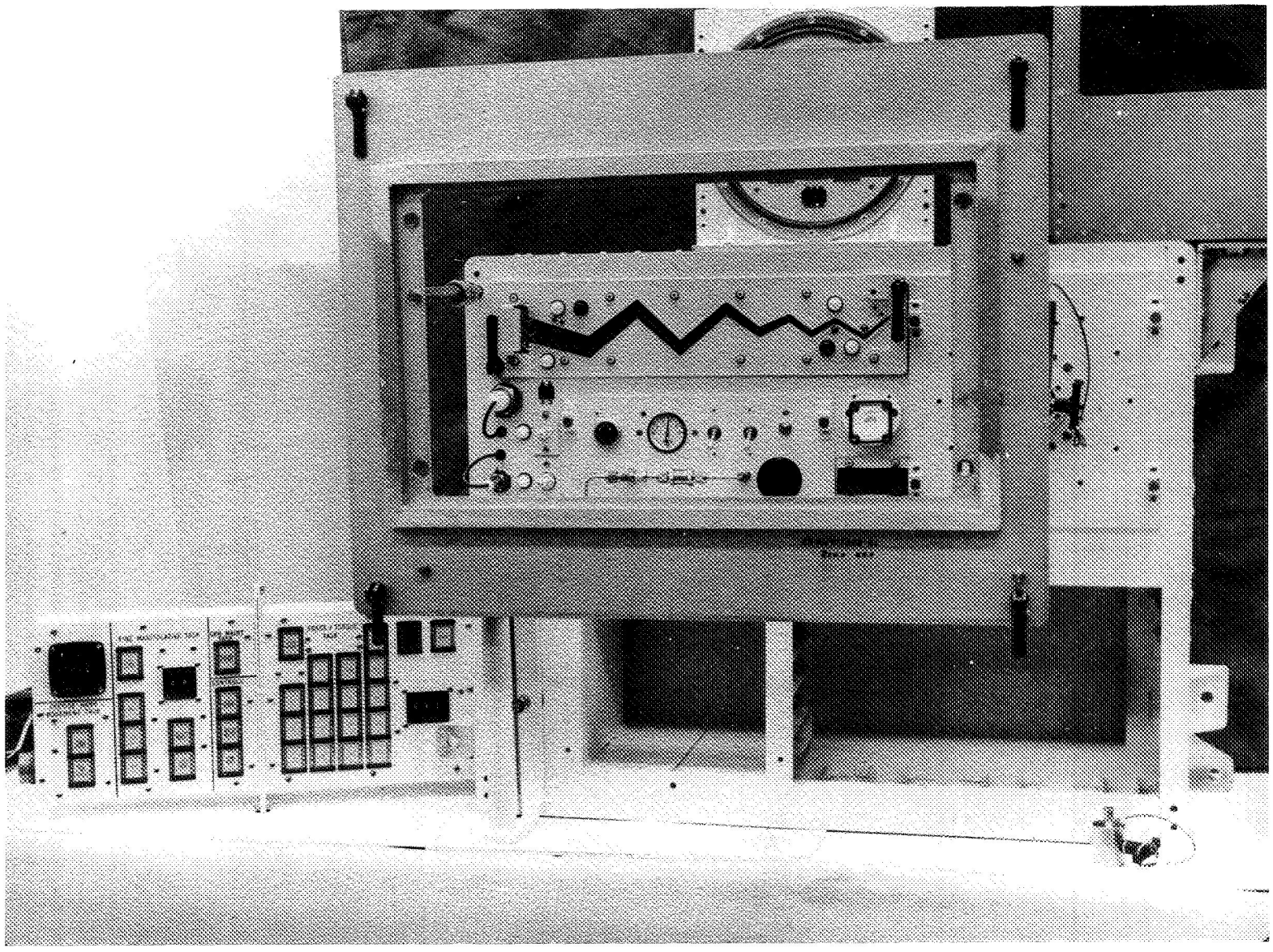


FIGURE 4-34 LIMITED ACCESS PANEL-INSTALLED

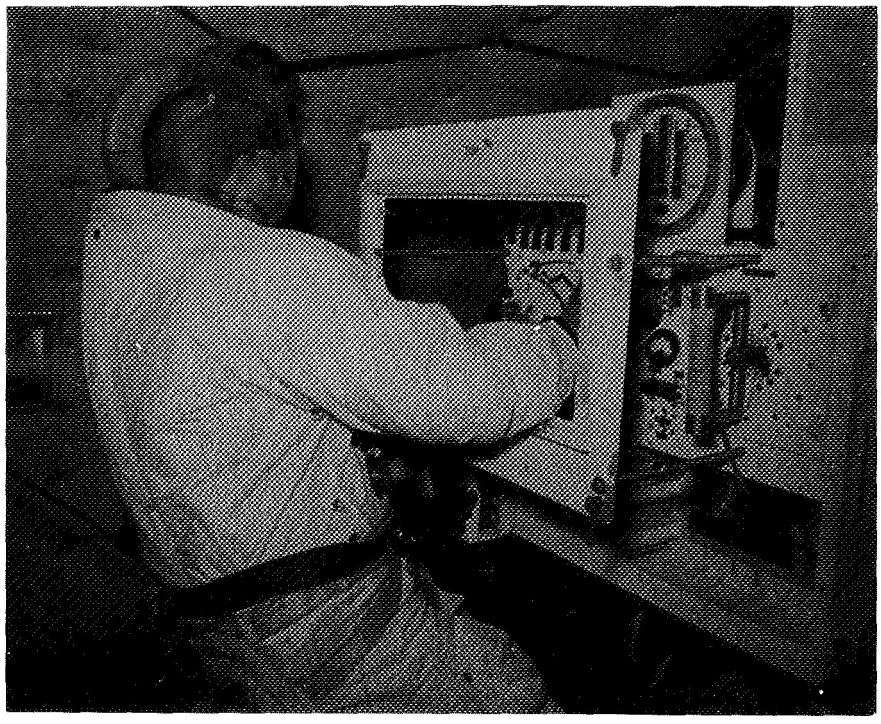


FIGURE 4-35 LIMITED ACCESS PANEL

4.2.9 ELECTRONICS PACKAGE

An exception was made to the Task Panel volume limitations, noted in section 4.1.3, with the electronics packaged separately, Figure 4-36. This was done for several reasons:

1. The cost and time required to package the electronics within the Task Panel envelope would have been prohibitive. This would have entailed the use of flight hardware design and manufacturing techniques; specifically the use of multilayer printed circuit boards and cordwood modules.

2. Checkout, maintenance and repair time and costs are significantly lower with the configuration utilized.

3. Modifications, when and if required, are much simpler.

4. The design of sealed, waterproof packages would have been required incurring additional costs and schedule delays.

However, sufficient volume was retained inside the Task Panel to allow the electronics to be packaged therein to satisfy the volumetric requirements as stated above.

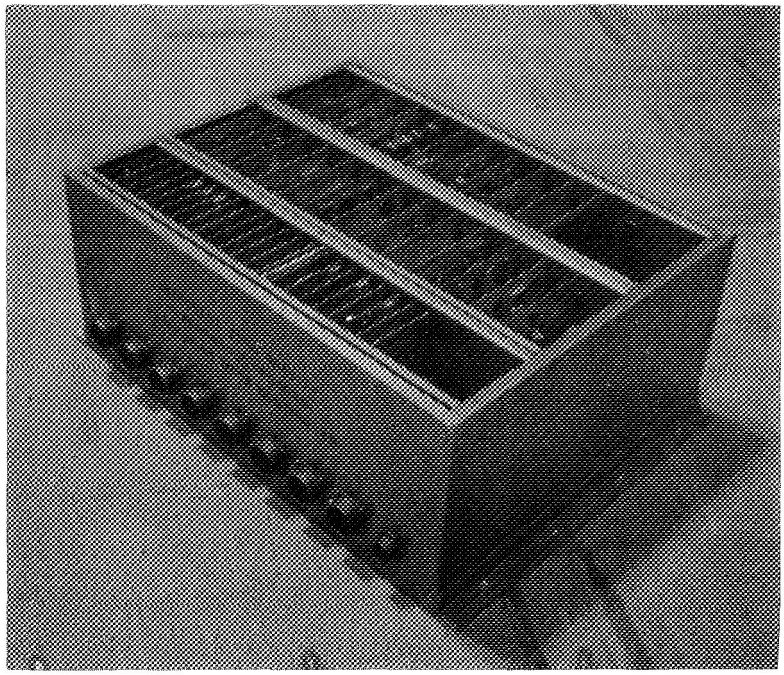


FIGURE 4-36 ELECTRONICS BOX

4.2.9 ELECTRONICS PACKAGE (Continued)

Figures 4-37 and 4-38 are typical of the digital and analog circuit boards used in this configuration. The digital circuit boards are standard printed circuit boards capable of mounting six 14-lead flat-sacks or 6 TO-5 cans. The analog circuit boards are commercially available pre-punched boards with printed surfaces to mate with connectors.

Figure 4-39 is a typical power consumption profile for 1 experimental session. The total energy consumption was approximately 16.7 watt-hrs./session. Momentary peaks of 18.2 watts were reached during the Precise Hand Movement Task when contacts are made. During the Force/Torque Task peaks of approximately 42 watts were reached when the Forces or Torques are applied (2, 4 or 6 sec. each). The total accumulated time for the forces and torques is 4 minutes/session. This has been accounted for in the total energy calculations. The dumping of th pressure in the Operational Maintenance Task causes a spike of about 27 watts, but the duration of the signal is less than 1 second.

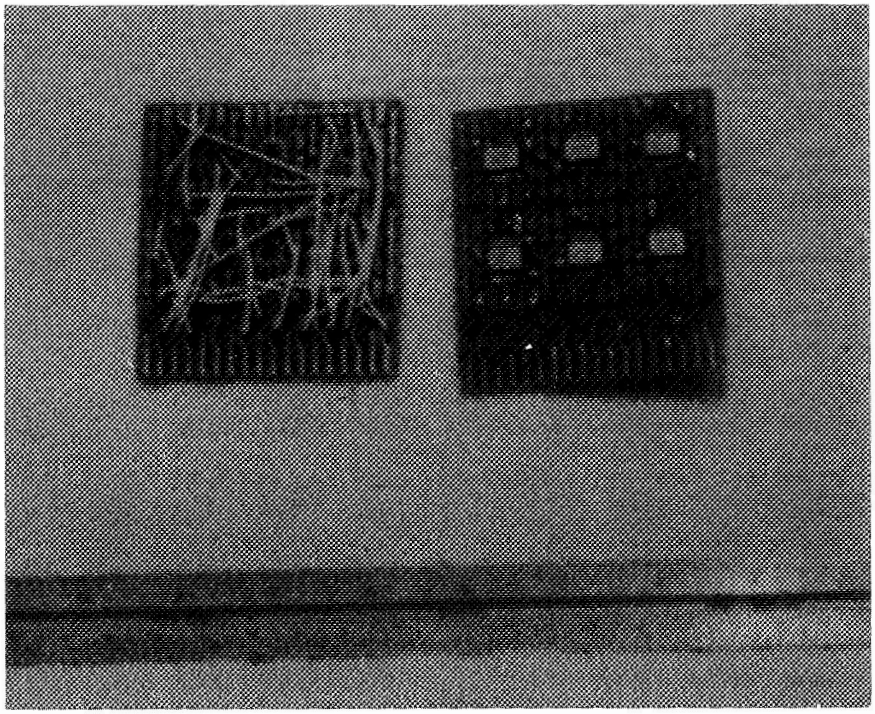


FIGURE 4-37 TYPICAL DIGITAL CIRCUIT BOARDS

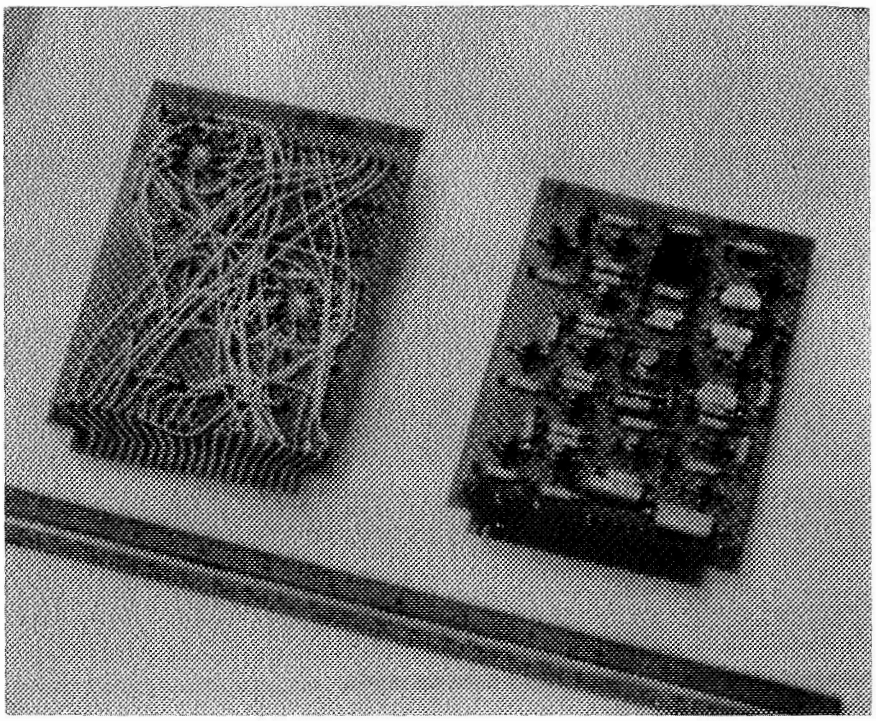


FIGURE 4-38 TYPICAL ANALOG CIRCUIT BOARDS

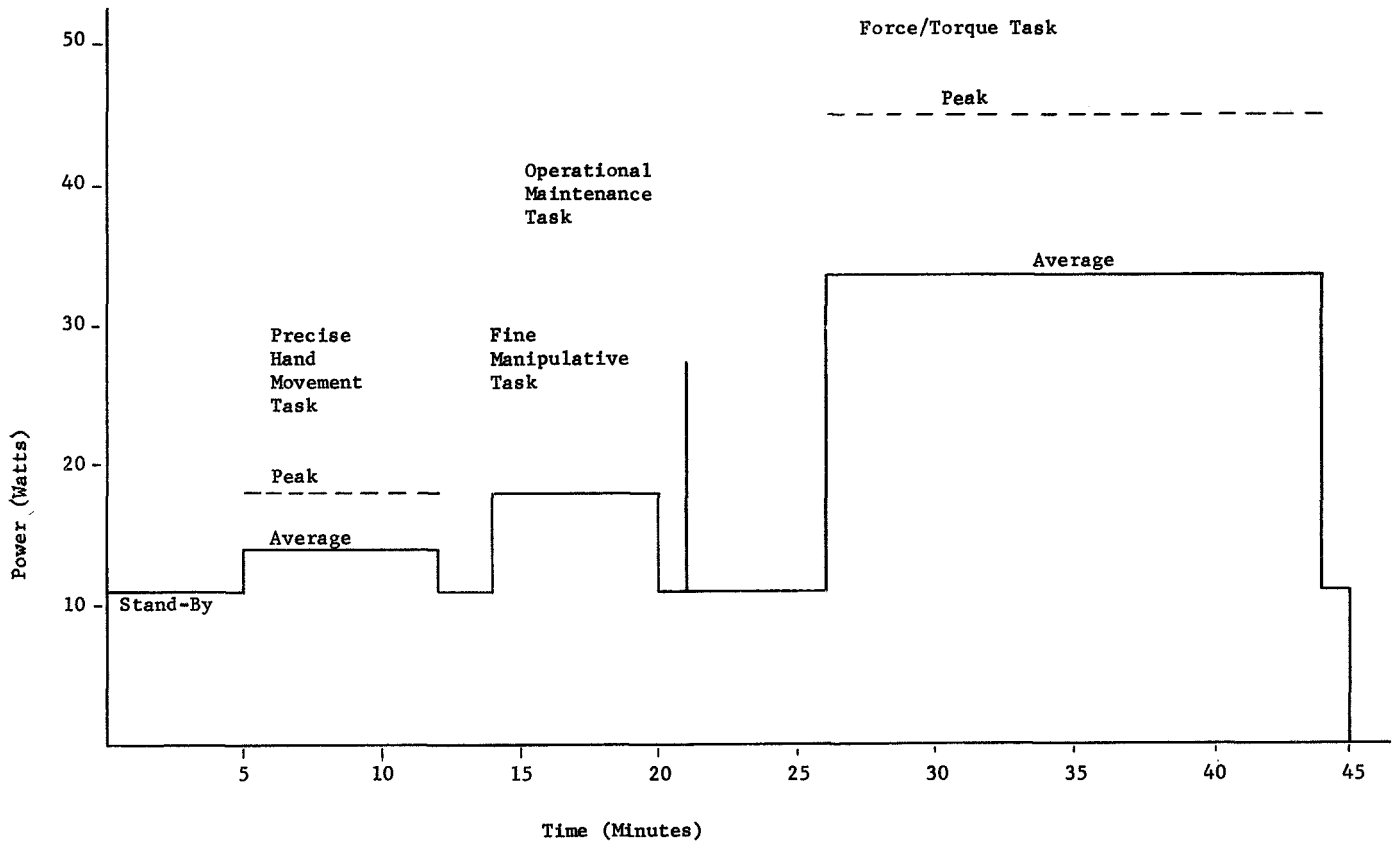


FIGURE 4-39 POWER CONSUMPTION PROFILE

4.2.9 ELECTRONICS PACKAGE (Continued)

The electronics package, contains all of the power supplies, command logic, control and signal processing circuits associated with the Task Panel. The input power to the Task Panel was specified in the AAP Experiment General Requirements Specification as 28 VDC unregulated, ranging from 24 to 32 volts. This input voltage is reduced to -15V, +5V, +3V with solid state power supplies for use in the system, thus keeping well under the lowest point of the input supply tolerance, and independent of primary power variations. The only components using the raw input power were selected to operate over a wide range of voltage so an additional power supply is not required. Each task module has its own circuitry i.e. power supplies, command logic, and output signal processing. Thus, a failure in one will not preclude operation, and thus, data collection from the others.

Typical of the command circuits is the Two-Hand Task Test Point Command Logic Schematic Diagram shown in Figure 4-40. This circuit allows the observer to select a specific Test Point (Male or Female Connector Pin or Solder Terminal), and then start the task when the subject's ready. Also included in the circuit is a reset capability to allow the observer to change the Test Point Selection before starting the task. The specific test point selected is also identified in the data output.

4.2.9.1 Data Output Signal Characteristics

Twenty-four separate signals were generated by the electronics package for use in data analysis. Several of these signals turned out to be redundant, but to be certain of including all necessary information no attempt was made to eliminate such signals until testing was conducted to determine the most easily read and most reliable. All 24 signals are listed in Table 4-5, together with their functional operation and electrical characteristics. All signals are DC.

4.2.10 OBSERVER'S PANEL

The Observer's Panel Figure 4-41 contains the controls to provide command inputs and cues to the test subject. The panel was made in 2 sections to demonstrate the storage concept, Figure 4-16. One section contains the controls for the Force/Torque Task, while the other section contains the controls for the other tasks plus the timer. The controls are lighted push-button switches using 2 incandescent lamps each. The redundant lighting was done to prevent shut-down of a test in progress in the event of a lamp failure.

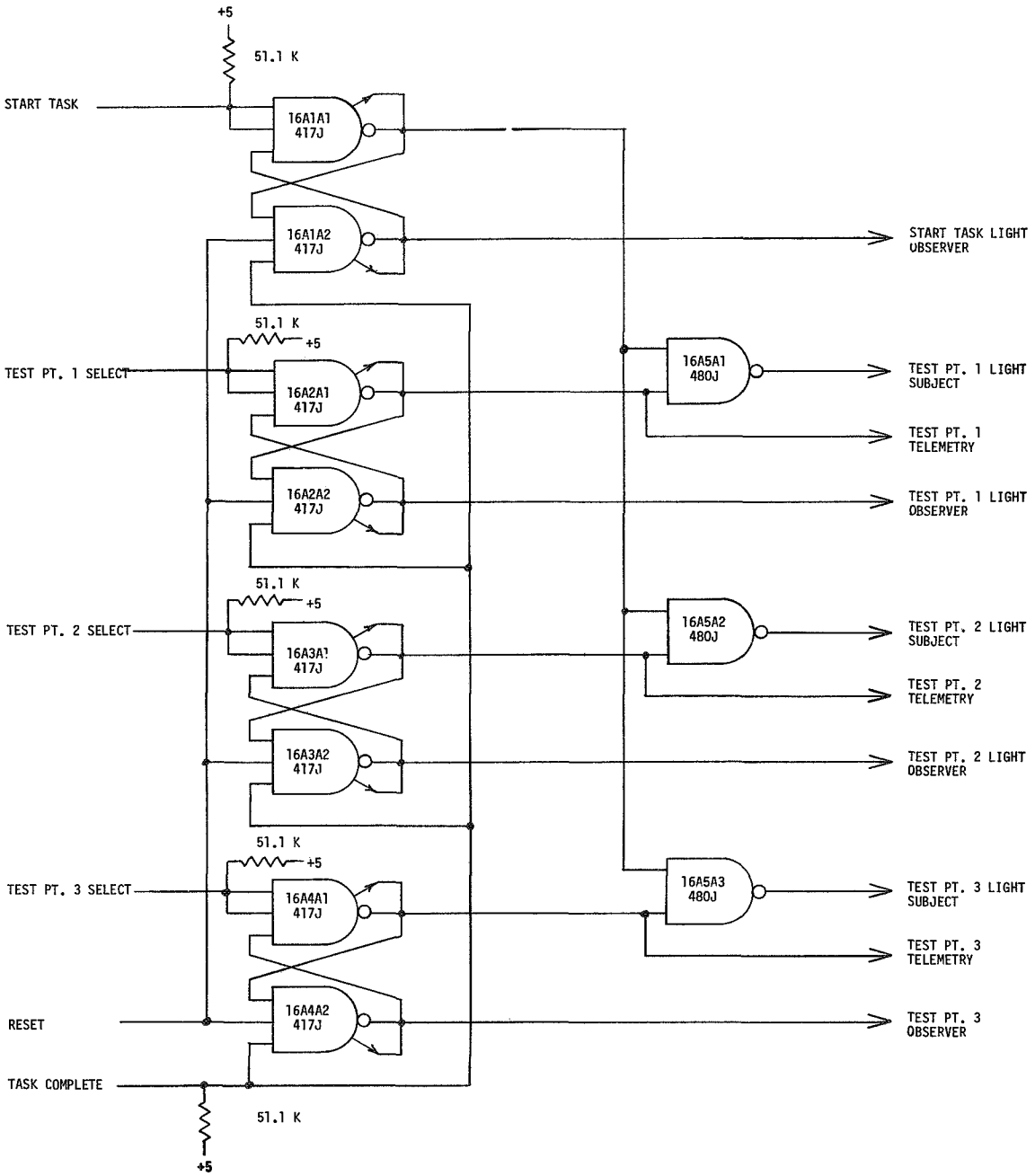


FIGURE 4-40 SCHEMATIC-TEST POINT COMMAND LOGIC

TABLE 4-5

TELEMETRY SIGNALS

TASK	SIGNAL	USE	OPERATION	ELECTRICAL CHARACTERISTICS	
				TYPE*	VOLTAGE
Two-Hand Eye/Hand coordination	1. Test point command	a. Identify commanded test point b. Trial Time	"On" at trial start to one of three voltage levels "Off" when trial completed by subject.	A	.8V (Male) 1.2V (Female) 2.5V (Solder)
	2. DVM Input	Identify commanded digital value	"On" at first contact between probe and test point to level proportional to input. "Off" when trial completed by subject	A	0-5V
	3. Subject Voltage	Analog Voltmeter Setting	Follows and displays setting on analog meter.	A	0-5V
	4. Test Point Contacts	Count number of broken contacts	Rises to 15V whenever contact is broken. Returns to 0V when contact remade.	D	0/15V
	5. Test Point Contact Duration	Duration of broken contacts	Ramp function increases at rate of 2.5V/sec each time contact is broken.	A	0-5V
	6. Subject's first contact	Calculate response time	"On" at first contact between probe and test point. "Off" when trial completed by subject.	D	0/15V
Precise-Hand Movement	1. Spring #2 displacement	Identify location of contacts	Signal proportional to amount of displacement: 0V at beginning, 5V at maximum length of path.	A	0-5V
	2. Spring #2 displacement	Identify location of contacts	Signal proportional to amount of displacement: 0V at beginning, 5V at maximum length of path.	A	0-5V

*Digital or Analog

TABLE 4-5

TELEMETRY SIGNALS (Continued)

TASK	SIGNAL	USE	OPERATION	ELECTRICAL CHARACTERISTICS	
				TYPE*	VOLTAGE
Precise Hand Movement Cont'd	3. Spring #3 displacement	Identify location of contacts	Signal proportional to amount of displacement: OV at beginning, 5V at maximum length of path.	A	0-5V
	4. Trial Time	Trial time, by direction	Rise to 5V at trial start; drop to 2.5V at maximum displacement; drop to O.V at trial complete.	A	0-5V
	5. Top Contact A	Number of contacts on top edge	Rises to 15V whenever contact is made. Return to OV when contact is broken.	D	0/15V
	6. Top contact B	Duration of contacts on top edge	Ramp function increases at rate of 2.5V/sec. each time a contact is made.	A	0-5V
	7. Bottom Contact-A	Number of contacts on bottom edge	Rises to 15V whenever contact is made. Return to OV when contact is broken.	D	0/15V
	8. Bottom Contact-B	Duration of contacts on bottom edge	Ramp function increases at rate of 2.5V/sec each time a contact is made.	A	0-5V
Force/ Torque Emission	1. Command	Identify force type and direction commanded.	"On" to one of 8 levels (depending on $\pm$X, $\pm$Y, $\pm$Z, cw, or ccw). "Off" after 2 seconds (for Impulse), 4 seconds (for Sustained), or 6 seconds (for Precise).	A	0-5V
	2. Precise command	Identify command magnitude of precise force/torque.	Signal is proportional to three-digit command (5V=999).	A	0-5V
	3. +X (Pull) Output	Force profile	"On" during entire task. Proportionality: 5V=125 lb.	A	0-5V

*Digital or Analog

TABLE 4-5

TELEMETRY SIGNALS (Continued)

TASK	SIGNAL	USE	OPERATION	ELECTRICAL CHARACTERISTICS	
				TYPE*	VOLTAGE
Force/ Torque Emission Cont'd	4. -X (Push) Output	Force profile	"On" during entire task. Proportionality: 5V=125 lb.	A	0-5V
	5. +Y (Right) Output	Force profile	"On"during entire task. Proportionality: 5V=125 lb.	A	0-5V
	6. -Y (Left) Output	Force profile	"On" during entire task. Proportionality: 5V=125 lb.	A	0-5V
	7. +Z (Up) Output	Force profile	"On" during entire task. Proportionality: 5V=125 lb.	A	0-5V
	8. -Z (Down) Output	Force profile	"On" during entire task. Proportionality: 5V=125 lb.	A	0-5V
	9. CW Output	Torque profile	"On" during entire task. Proportionality: 5V=1000 in-lb.	A	0-5V
	10. CCW Output	Torque profile	"On" during entire task. Proportionality: 5V=1000 in-lb.	A	0-5V

*Digital or Analog

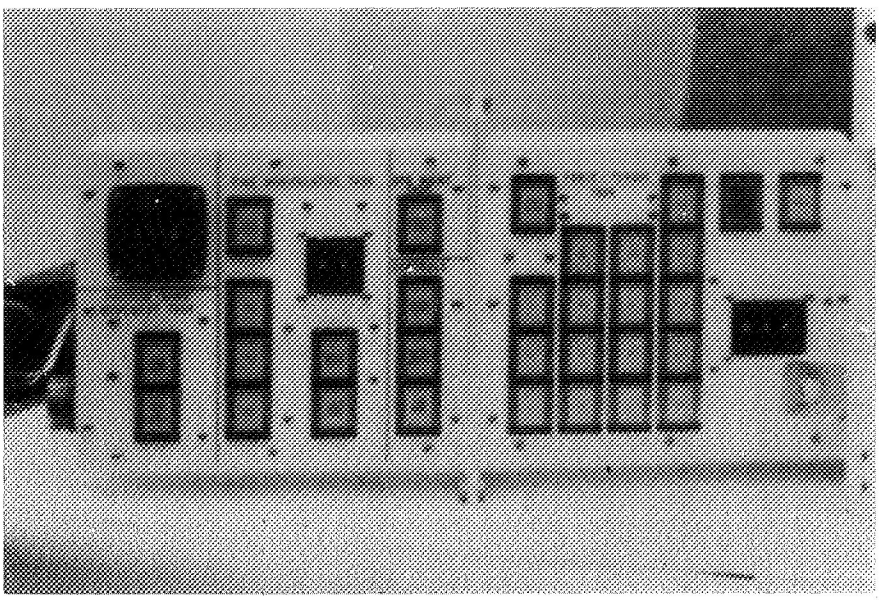


FIGURE 4-41 OBSERVER'S PANEL

4.2.11 AAP VEHICLE AND OTHER EXPERIMENTS INTEGRATION

Early in the Task Panel development phase of the program, efforts were undertaken to identify and define the requirements for integrating the Task Panel into the AAP OWS. There were two areas of consideration; stowage for launch in the MDA, and deployment for operation in the experiments area of the Workshop. Since there was no planned use of the Task Panel in the MDA, the interfaces to be considered there were weight, volume, mounting, and environmentally induced loads. The interfaces to be considered for operations in the Workshop were those mentioned above, and in addition, Input Power, Data Output signal characteristics, (interface with vehicle data system), test subject work envelopes lighting, etc. It was determined that the only interface requirements that could be satisfied within the scope of the program were the stowed (MDA) volume, mounting dimensions and the input power requirements. The information obtained on the other interface requirements was not lost, since the knowledge of these requirements and the known capabilities and limitation of the Task Panel have suggested various methods of satisfying the vehicle interface requirements.

Coupled with the efforts to establish the Task Panel/Vehicle interface requirements, efforts were instituted to integrate the requirements of several experiments so that a single Task Panel could be used for all.

Experiment D020, Alternate Restraints Evaluation, was being planned to utilize the entire Task Panel, and it was a requirement on this program to insure the compatibility of the Task Panel with the D020 tool kit, and to insure that the Task Panel could be easily re-located to the D020 Work Station.

Experiment M171, Metabolic Costs of Inflight Tasks, had a requirement for 2 tasks. The first was a maintenance task requiring the use of hand tools and of 10-15 minute duration. The second was a Constant Work Task Requiring the test subject to exercise against a known load for about 5 minutes. For the first task, the Operational Maintenance Task Module was suggested as a suitable device. The module is constructed with several fittings and readily lends itself to disassembly. It was established that while the task is suitable, several changes in construction were required. Those changes were noted and plans made to incorporate them at a later date.

The Experiment M171 Constant Work Task differs from the M508 Force/Torque Emission Task in that the latter is essentially a static force emission, that there is little or no arm movement during the force emission, while the former required large arm movements. In addition, the Experiment M171 requires a subject pacing signal, such as a metronome, which is not available in the current Task Panel. While the Task Panel did not appear capable of satisfying these requirements, it was suggested that the stud on the face of the Force Receiver be used to mount the "D" handle and tool adapter be used as a mounting point for the Constant Work Device. This suggestion was accepted. It was also suggested that the Force Receiver instrumentation be used to obtain quantifiable force profiles especially rise times, but this was not considered appropriate for that experiment.

Experiment M507, Gravity Substitute Work Bench had a requirement for an object that can be disassembled into small parts which would be temporarily stored on the Work Bench, and then reassembled. The Operational Maintenance Task Module was suggested as a candidate object especially when it was demonstrated that the back cover of the module could be removed exposing additional small components for disassembly. This suggestion was accepted.

Experiment M151, Time and Motion Study, in the source of motion picture data in the Work Shop. Since motion pictures are an important data source for M508, an effort was initiated to integrate the requirements and capabilities of M508 and M151. Camera locations in the OWS were established and film requirements were defined.

SECTION 5

EXPERIMENT DESCRIPTION

This section describes in detail the experiment which was outlined in Section 3.6 and modified by the Feasibility Tests described in Section 4.1.4. Step-by-step procedures for experimental subjects, variables which were manipulated within each task, and the data to be taken for each task are presented. The descriptions contained here refer to the conceptual Experimental Task Sequence presented in Table 3-11. During the ground-based data collection portions of this program, certain changes in this sequence were necessary. These changes will be noted as they are encountered.

5.1 MAJOR EXPERIMENTAL CONDITIONS

5.1.1 RESTRAINT CONDITIONS

The entire experimental sequence is performed under three major restraint conditions. In the first case, a platform with the Gemini Dutch Shoes mounted on it provides a foot-anchoring restraint. The second restraint is a mechanically-operated, variable flexibility waist tether. The tethers are installed to the bulkhead by thumb-activated tapered pins on the distal end. (A prototype of the manually-operated unit was used for ground-based data collection.) The third restraint condition consists of a combination of the waist and shoe restraints.

An additional restraint is utilized in the experiment, but not as a major independent variable. A handhold is provided for use by the subject during installation of other restraints, removal of the task board cover and at various times during other tasks. The handhold contains a squeeze mechanism to activate attachment pins, which are installed in holes on the task board cover and on the Task Panel itself after the cover is removed.

5.1.2 PRESSURE SUIT CONDITIONS

The entire experiment sequence, including restraint installation, is performed under three suit conditions. They are the Apollo A7L (Block II) Suit, the Advanced Extra-Vehicular Suit (AES), and a no-suit (shirtsleeve) condition for IVA comparisons.

5.2 RESTRAINT INSTALLATION

5.2.1 PROCEDURE

An experiment session begins with the subject positioned in front of the work-site. All restraints are attached to the subject by lanyards--small cables on take-up devices. At a given signal, the subject proceeds through the following steps (assuming a waist and shoe restraint condition):

1. Remove handhold from suit tie-down with right hand.
2. Position, insert, and lock handhold in center of task panel cover.
3. Release lanyard from handhold and rewind.
4. Grasp handhold in left hand.
5. Release shoe restraint from suit tie-down.
6. Position and install shoe restraint on bulkhead.

5.2.1 PROCEDURE (Continued)

7. Release lanyard from shoe restraint and rewind.
8. Grasp handhold with both hands.
9. Don shoes.
10. Release right-hand end of waist tether from suit tie-down.
11. Attach to right panel receptacle.
12. Release left-hand end of waist tether from suit tie-down.
13. Attach to left panel receptacle.
14. Position and tighten tethers.

The procedure for the waist-only or shoe-only restraint conditions is simply a portion of the above steps.

In addition to his personal restraints, analysis leading to the definition of the task sequence indicated a need for equipment restraints to anchor tools, replacement parts, etc. Thus, this part of the sequence included installation of two equipment tethers, similar in procedure to installation of the waist tethers. Due to the unavailability of such equipment, however, this task was not performed during the ground-based data collection program.

5.2.2 MEASURES

Data taken during this task consists mainly of part task times, subjective and physiological data. Part task times taken are as follows:

- Install handhold - steps 1 to 3 above
- Install shoe restraint - steps 4 to 7 above
- Don shoe restraint - steps 8 and 9 above
- Install and don waist restraint - steps 10 to 14 above

Subjective data is accumulated by means of a post-test Questionnaire Rating Form, a copy of which is provided in Table 5-1. Physiological data (not taken for <u>any</u> tasks during the ground-based data collection effort) consists of such measures as EKG, respiration rate, O_2 consumption, CO_2 production, and body temperature.

5.3 <u>GAIN ACCESS TASK</u>

5.3.1 PROCEDURE

Having secured himself at the worksite, the subject now proceeds to remove and stow the protective cover on the task panel. The steps involved are as follows:

1. Grasp free end of left equipment tether.
2. Loosen tether.
3. Move tether in contact with cover.
4. Attach to cover.
5. Grasp free end of lanyard on right wrist with left hand.
6. Reel out lanyard.
7. Attach lanyard to ratchet wrench*.

*Tools (ratchet wrench, T-handle wrench, open-end wrench, sockets and extensions) were placed in a small holder atop the task board during ground-based data collection. Alternatively, the subject should be expected to carry a tool kit to the worksite.

TABLE 5-1

QUESTIONNAIRE RATING FORM

NAME:_____
DATE:_____
PRESSURE SUIT:_____
RESTRAINT(S):_____
SIMULATION:_____

This form has been designed to obtain your opinion of the suits, restraints, tools, etc. This data is of extreme importance in obtaining your personal ratings of the items listed. Each question deals with a particular aspect of the total experiment and the answers are in the form of a subjective rating of each element. The rating scale is based on a numerical score of 1 to 7. Low numbers indicate the item possesses little or none of the particular quality indicated. High numbers indicate the item possessed a great deal of the quality indicated. Each numerical selection represents your subjective opinion of the item.

Example: How do you rate the driver's seat of your automobile in terms of comfort?

Circle One Number

1 2 3 4 5 6 7

The selection of 1 would indicate the seat had little or no comfort while 7 would indicate the seat was extremely comfortable. Values in between would be essentially your opinion of the degree of comfort which the seat afforded.

After each question a space has been left for any comments you may wish to add to the answer.

Circle One Number

A. Suit Evaluations: (Based on comparisons with other suits you have worn.)

1. How do you rate the pressure suit in terms of physical comfort?

1 2 3 4 5 6 7

COMMENTS:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

2. How do you rate the mobility of the suit for each of the following parts of the body?

a. Hands

Low Mobility 1 2 3 4 5 6 7 High Mobility

COMMENTS:

b. Arms

1 2 3 4 5 6 7

COMMENTS:

c. Legs

1 2 3 4 5 6 7

COMMENTS:

d. Torso

1 2 3 4 5 6 7

COMMENTS:

e. Head-Neck Area

1 2 3 4 5 6 7

COMMENTS:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

3. How do you rate the visibility of items in the sectors listed when looking through the helmet?

a. Straight Ahead

Low Visibility 1 2 3 4 5 6 7 High Visibility

COMMENTS:

b. Extreme Left-Right

1 2 3 4 5 6 7

COMMENTS:

c. Extreme Up

1 2 3 4 5 6 7

COMMENTS:

d. Extreme Down

1 2 3 4 5 6 7

COMMENTS:

4. How do you rate the suit in relation to the ability to place your arms/hands in the access port for performing restricted access measurements?

Very Constraining 1 2 3 4 5 6 7 Not at all Constraining

COMMENTS:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

5. How do you rate the dexterity of the suit when manipulating small items?

Low Dexterity 1 2 3 4 5 6 7 High Dexterity

COMMENTS:

6. How do you rate the tactile feedback afforded by the suit gloves?

Low 1 2 3 4 5 6 7 High

COMMENTS:

7. Rate the suit in terms of effort required to overcome the incumberance of the suit.

Little Effort 1 2 3 4 5 6 7 High Degree of Effort

COMMENTS:

8. Please comment briefly.

a. In your opinion, what advantages did the suit have?

COMMENT:

b. In your opinion, what disadvantages did the suit have?

COMMENT:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

B. Personal Restraint(s) Evaluation: (Exclude handhold from consideration unless specifically identified; if hand and shoes were used in this session, evaluate the combination).

1. How do you rate the restraint(s) in terms of physical comfort during force task performance?

Low Comfort 1 2 3 4 5 6 7 High Comfort

COMMENTS:

2. How do you rate the restraint(s) in terms of physical comfort during fine manipulative task performance?

Low Comfort 1 2 3 4 5 6 7 High Comfort

COMMENTS:

3. Rate the restraint in terms of overall effort required to perform force emission tasks while utilizing the restraint(s).

.ittle Effort 1 2 3 4 5 6 7 High Degree of Effort

COMMENTS:

4. Rate the restraint in terms of overall effort required to perform fine manipulative tasks while utilizing the restraint(s).

.ittle Effort 1 2 3 4 5 6 7 High Degree of Effort

COMMENTS:

5. Rate the ease of restraint installation for the restraints used in this session.

asy Hand Difficult

1 2 3 4 5 6 7

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

5. Rate the ease of restraint installation for the restraints used in this session. (Continued)

Easy — Waist — Difficult

1 2 3 4 5 6 7

Easy — Shoes — Difficult

1 2 3 4 5 6 7

COMMENTS:

6. Rate the handhold in terms of its utility as a restraint for body control and installing additional restraints.

Low Utility — 1 2 3 4 5 6 7 — High Utilit

COMMENTS:

C. Tool Evaluations:

1. Rate the utility of the T-Handle used to install the force receiver bolts.

Low Utility — 1 2 3 4 5 6 7 — High Utilit

COMMENTS:

2. Rate the utility of the socket-wrench used to install the force receiver bolts.

Low Utility — 1 2 3 4 5 6 7 — High Utilit

COMMENTS:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

3. Rate the utility of the squeeze-clamps used to tighten equipment tethers.

Low Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

4. Rate the utility of the D-Handle as a means for removing and replacing modules.

Low Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

5. Rate the T-Handle as a tool for performing clockwise and counterclockwise force emissions.

Poor 1 2 3 4 5 6 7 Excellent

COMMENTS:

6. Rate the ratchet wrench as a tool for performing clockwise and counterclockwise force emissions.

Poor 1 2 3 4 5 6 7 Excellent

COMMENTS:

7. Rate the utility of the open end wrench used in the operational maintenance task.

Low Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

D. Fasteners, Connectors, and Switch Evaluations:

1. Rate the utility of the cam lever lock fasteners used to secure the access panel.

Low Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

2. Rate the utility of the fastener used to connect the equipment tether to the task board cover.

Low Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

3. Rate the utility of the fasteners used to connect lanyards to hand tools.

Low Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

4. Rate the utility of the external hex fasteners used to secure the cover to the task panel.

Low Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

5. Rate the utility of the internal hex fasteners used to secure the cover to the task panel.

.ow Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

6. Rate the utility of the two position toggle switches used on the task panel.

.ow Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

7. Rate the utility of the pushbuttons used on the task panel.

.ow Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

8. Rate the utility of the rotary gang tuner used to set in meter values.

ow Utility 1 2 3 4 5 6 7 High Utility

COMMENTS:

TABLE 5-1

QUESTIONNAIRE RATING FORM (Continued)

9. Rate the utility of the captive bolts used to mechanically connect the force receiver to the panel.

Low Utility 1 2 3 4 5 6 7 High Utilit

COMMENTS:

E. Miscellaneous Evaluations:

1. Rate the utility of the wrist lanyards.

Low Utility 1 2 3 4 5 6 7 High Utilit

COMMENTS:

2. Rate the utility of the waist lanyards.

Low Utility 1 2 3 4 5 6 7 High Utilit

COMMENTS:

3. Rate the utility of the suit tiedowns used to secure equipment to the suit.

Low Utility 1 2 3 4 5 6 7 High Utilit

COMMENTS:

F. General Comments:

In the space provided, add any other comments you may have concerning the suits, restraints, equipment, etc.

5.3.1 PROCEDURE (Continued)

8. Attach wrench to 3/8" socket.
9. Remove from tool kit.
10. Position wrench at top right cover fastener (external hex).
11. Loosen external hex fastener.
12. Position wrench at top left cover fastener.
13. Loosen fastener.
14. Position wrench at lower left cover fastener.
15. Loosen fastener.
16. Position wrench at lower right cover fastener.
17. Loosen fastener.
18. Return 3/8" socket to tool kit.
19. Return wrench to tool kit.
20. Release lanyard from wrench.
21. Attach lanyard to T-handle wrench.
22. Remove T-handle from tool kit.
23. Position wrench at top right cover fastener.
24. Loosen fastener (internal hex).
25. Position wrench at top left cover fastener.
26. Loosen fastener.
27. Position wrench at lower left cover fastener.
28. Loosen fastener.
29. Position wrench at lower right cover fastener.
30. Loosen fastener.
31. Return wrench to tool kit.
32. Secure wrench in tool kit.
33. Detach lanyard and allow it to reel up.
34. Grasp cover using handhold.
35. Transfer cover to position at left side of task panel in out-of-way position.
36. Tighten tether.
37. Reel out lanyard from left sleeve.
38. Attach to handhold.
39. Remove handhold from cover.
40. Install handhold at left of task board.
41. Release lanyard and allow to reel up.

During the ground-based data collection effort, it was discovered that the use of two different fasteners on the cover was superfluous and of marginal informational value. Steps 21 through 32 were therefore deleted, resulting in a time saving of approximately 3-5 minutes. Also, since equipment tethers were not available, the subject simply handed the cover to an experiment technician.

5.3.2 MEASURES

As in the restraint installation task, the data collected during this task consists mainly of part-task times, subjective and physiological data. Part-task times taken are as follows:

- Release cover fasteners - Steps 7-20
- Remove cover - Steps 34-41

5.3.2 MEASURES (Continued)

Subjective data is accumulated via the questionnaire in Table 5-1, and physiological data would consist of the measures noted in Section 5.2.2.

5.4 INSPECTION, ACTIVATION AND CHECKOUT

The task sequence developed in Section 3.0 included a task to be representative of various inspection and checkout procedures commonly encountered. A task was detailed which included calibration of various modules (including the force/torque emission receiver), operational checkout of all electrical functions, status of operational maintenance task, and other steps. Ultimately, however, this task was eliminated from the experiment sequence for three reasons:

1. The nature of the equipment was such that frequent calibration was not required. Most electrical functions were simply on/off types and hence checkout was an intuitively simplistic task.

2. No objective, quantifiable measures other than time could be identified for this task. Hence, the informational return was of low value.

3. Performance of the task would inflict a serious time penalty on the total session time.

5.5 TWO-HAND EYE/HAND COORDINATION TASK

5.5.1 PROCEDURE

This task requires the subject to perform steps representative of electronic equipment checkout and associated tasks. The subject uses a probe and, upon command, places it on one of three test points, which are designed to resemble a male electrical connector contact, a female electrical connector contact, and a printed circuit board solder joint. When contact is made, a digital display device displays a two-digit number. The subject must then set the analog device to the displayed number using coarse and fine potentiometers.

The specific steps are as follows:

1. Remove test probe from panel with left hand.
2. Place left and right thumbs on ready position pushbuttons.
3. Observe cue light.
4. Upon illumination of cue light, release pushbuttons and place probe on contact point commanded.
5. Observe digital readout while maintaining probe on contact point.
6. With right hand, enter digital value into analog meter by setting potentiometer.
7. Press task complete pushbutton when satisfied with setting.
8. Return analog meter to zero.

These steps are repeated a total of nine times, so that each point is presented three times. The two-digit numbers are randomly selected subject to two conditions:

5.5.1 PROCEDURE (Continued)

1. the numbers must be odd, so that the subject is required to make an interpolation on the analog meter which is scored at even-numbered intervals;

2. the numbers must be such that task-time comparisons across contact points are valid. This is accomplished by requiring that, for any succession of three trials on the same test point, the three numbers will total to 149. This corresponds to a total of 1-1/2 sweeps over the entire range of the analog meter.

One additional parameter is altered during this task: access condition. Nine trials are performed with no access restrictions, as described above. A limiting-access panel is then installed which restricts the subject's visual field and arm movements. Nine trials are then performed exactly as described above.

In all trials for this task, the subject is expected to maintain a firm contact with the test point. Broken contacts are indicated by an auditory signal.

5.5.2 MEASURES

The data taken for this task provide measures of speed and accuracy. Trial time is the elapsed time from steps 4-7 above. As noted, trial time is significant only when the times for three successive trials of the same test point are combined.

A measure of response time is also taken. Response time is here defined as the time from the onset of the cue light to the first contact with the test point.

Two measures of accuracy are recorded. The first notes the ability of the subject to maintain a firm contact with the test point by counting the number of times contact is broken. The second compares the two-digit command value with the value set on the analog meter. The absolute value of setting error is computed.

All of these measures are computed and displayed such that comparisons, by test point, can be made across access conditions, restraints, suits, subjects, and simulation modes. Figure 5-1 shows the combination of conditions to be evaluated in the two hand task.

Subjective data is accumulated via the Questionnaire Rating Form in Table 5-1 and physiological measures, such as those listed in Section 5.2.2, may also be recorded.

5.6 PRECISE HAND MOVEMENT TASK

5.6.1 PROCEDURE

The Precise Hand Movement Task requires the subject to perform precise hand movements with varying degrees of difficulty and force emission requirements. This task does not directly simulate a spacecraft operational procedure but it does require the subject to perform a precise dynamic hand movement at different

SIMULATION MODE:

SUIT CONDITION / RESTRAINT	ADVANCED EV SUIT		APOLLO BLOCK II SUIT		IVA SHIRTSLEEVE	
	LIMITED ACCESS	FREE ACCESS	LIMITED ACCESS	FREE ACCESS	LIMITED ACCESS	FREE ACCESS
DUTCH SHOES						
VARIABLE FLEXIBILITY WAIST RESTRAINT						
VARIABLE FLEXIBILITY WAIST RESTRAINT & DUTCH SHOES						

FIGURE 5-1 TWO HAND TASK DATA MATRIX

5.6.1 PROCEDURE (Continued)

force emission levels. This type of task is inherent in many of the spacecraft EVA/IVA operational procedures and provides an excellent method for reliable and quantitative evaluation of restraint capabilities, suit performance characteristics and access envelopes.

The task consists of tracing an irregular, sawtooth path with three different tension loads on the probe - 1.25, 2.50 and 5.00 lbs. Constant tension loads are provided by the use of Negator Springs. As the path is traced, the tension cable also causes a signal to be generated which is proportional to the distance traced. A separate contact circuit between the path and the probe is provided for the top portion of the path and the bottom portion. Thus, it is possible to record not only the number of contacts made, but also precisely where each contact is made.

Since response time is not measured on this task, no "start" cue lights are provided on the panel. Lights are provided for the following purposes:

- To indicate to the subject that he has begun the task and a timer is now running (activated by having the subject touch a defined point with the probe).
- To indicate to the subject that he is in contact with the path, either on the top edge or the bottom edge.

5.6.1 PROCEDURE (Continued)

- To indicate to the subject that he has reached the far end of the path (activated by having the subject touch a defined point with the probe.)

- To indicate completion of the task (activated by having the subject touch a defined point with the probe).

An auditory signal is also used to indicate to the subject that he is in contact with the path edges.

The specific steps performed by the subject are as follows:

1. Remove stylus from stowed location.
2. Insert stylus in Negator Spring ring #1.
3. Press probe to switch #1.
4. Note illumination of light which indicates timing of trial has commenced.
5. Trace path from left to right as quickly and accurately as possible. Illumination of contact light and auditory signal indicates probe in contact with sides.
6. At end of path, press switch #2 and note illumination of right hand light indicating automatic time mark.
7. Immediately trace path to left as quickly and accurately as possible.
8. At end of path, press switch #1, resetting all lights.
9. Remove probe from static ring #1 and insert in Negator Spring ring #2.

The above steps are repeated for all three spring loads. When this is completed, a module removal and replacement task is performed by reversing the orientation of the precise hand movement module:

1. Reel out lanyard from left sleeve.
2. Attach lanyard to panel at right side eye hook.
3. Lift cam lever lock fasteners up.
4. Remove panel, rotate in clockwise direction and replace in panel.
5. Close cam lever lock fasteners.

The Precise Hand Movement Task is now repeated with the module in the new orientation. that is, with the springs at the subject's right. At the conclusion of these three trials, the module is reversed again to its original position.

Finally, <u>all</u> of the above procedures are repeated with the limiting access panel in place. Thus both the Two Hand Task and the Precise Hand Movement Task are performed under free and restricted access conditions.

5.6.2 MEASURES

As with the Two-Hand Task, the data recorded for this task provides measures of speed and accuracy. The basic parameters recorded are as follows:

- Trial Time, split into two segments: steps 4-6 in the tracing procedure above, and steps 6-8. This permits time comparisons for the very different psychomotor operations of pulling the spring out versus allowing the spring to pull the arm back.

5.6.2 MEASURES (Continued)

- Position Profile of Contacts - profile depicts where in the path a contact occurs, whether it is on the top or bottom edge, and how long the contacts last.

These parameters permit several computations leading to significant measures. First, trial time per se is a meaningful indicator of degradation due to the limiting access envelope, as well as suit and restraint differences. Second, the absolute number of contacts occurring during a trial provides a direct measure of subject accuracy. In addition, calculation of the time spent in contact as a percentage of total traverse time provides a measure of accuracy relative to subject speed. This permits the non-restricting introduction to the subject of "traverse the path as quickly and as accurately as possible".

All of these measures provide quantitative, objective, and reliable indications of differences across the major experimental variables, as summarized in Figure 5-2.

The only measurement taken during the module removal/replacement aspect of this task is time, measured from step 1 to step 5 in the replacement sequence above.

Subjective data from the Questionnaire Rating Form in Table 5-1 and physiologica data (similar to the measures in 5.2.2) may also be taken.

SIMULATION MODE:

SUIT CONDITION	ADVANCED EV SUIT				APOLLO BLOCK II SUIT				IVA SHIRTSLEEVE			
ACCESS COND.	LIMITED ACCESS		FREE ACCESS		LIMITED ACCESS		FREE ACCESS		LIMITED ACCESS		FREE ACCESS	
MODULE ORIENTATION*	1	2	1	2	1	2	1	2	1	2	1	2
RESTRAINT / DUTCH SHOES												
VARIABLE FLEXIBILITY WAIST RESTRAINT												
VARIABLE FLEXIBILITY WAIST RESTRAINT & DUTCH SHOES												

* Module Orientation: 1 = Springs on subject's left.

2 = Springs on subject's right.

FIGURE 5-2 PRECISE HAND MOVEMENT TASK DATA MATRIX

5.7 FORCE EMISSION AND MODULE REPLACEMENT TASK

5.7.1 PROCEDURE

This task is designed to evaluate and quantify man's ability to generate impulsive, sustained and precise forces under various conditions of restraint, type of suit and force receiver location.

The three types of forces are defined as follows:

Sustained - Subject exerts maximum force he can sustain from cue-signal ON to cue-signal OFF (4 seconds).
Impulse - Subject exerts maximum possible instantaneous force upon receipt of cue-signal (signal remains ON for 2 seconds).
Precise - Subject is required to match a commanded force value and maintain that value until cue-signal OFF (6 seconds).

Forces are applied through a D-handle mounted vertically on the shaft of the force receiver module. Forces are exerted in six directions: +X (Pull); -X (Push); +Y (Left); -Y (Right); +Z (Up); and -Z (Down). A panel directly in front of the subject provides cue indications. Twelve sustained and impulsive forces are presented in a randomized fashion. For each trial, the subject must perceive the cue, decide upon the force type and force direction, and exert the proper force. The cues are presented in this manner in order to provide a task in the sequence requiring a cognitive decision making analysis and response.

Precise forces are presented in separate blocks of six trials each and are random only with respect to direction. When a precise force is commanded, the subject is also given a force value which he must match. Two digital readouts -- one for the commanded value and one for the required force output -- provide a means of comparison. The commanded force values are given in Table 5-2. These values were selected from analysis of the results of previous force emission studies, in particular the Study for the Collection of Human Engineering Data for Maintenance and Repair of Advanced Space Systems (General Electric Co., December 31, 1967). The values were selected to meaningfully tax subject capabilities, yet still be within the range of feasibility.

The specific steps for conducting these 18 force trials are as follows:

1. Reel out lanyard from right wrist.
2. Attach D-handle to lanyard from stowed location.
3. Transfer handle to force receiver.
4. Attach handle to force receiver stud.
5. Disconnect lanyard.
6. Request force receiver and cue panel power on.
7. Grasp D-handle and prepare for cue.
8. Perform force emissions of type and direction as indicated. Ready light will indicate cue panel lights will provide information in 2-4 seconds. When cue lights go out, trial is complete.

TABLE 5-2 COMMANDED PRECISE FORCE VALUES

RESTRAINT: / DIRECTION	WAIST	SHOE	WAIST & SHOE
Push	15.0 lbs	5.0	18.0
Pull	15.0	5.0	18.0
Left	11.0	11.0	11.0
Right	11.0	11.0	11.0
Up	11.0	20.0	24.0
Down	11.0	20.0	24.0

5.7.1 PROCEDURE (Continued)

At the conclusion of these steps, the force receiver is moved to a new position in the upper right quadrant of the subject's reach envelope. This task constitutes a module removal/replacement task. The steps are:

1. Request panel power off.
2. Attach lanyard to D-handle.
3. Reel out lanyard from left wrist.
4. Transfer to tool kit and attach to ratchet wrench.
5. Connect wrench to socket.
6. Transfer wrench to force receiver.
7. Remove captive bolts in each corner starting at top right and going clockwise.
8. Pull out module and transfer to upper right location.
9. Install module and insert captive bolts by hand starting at top right and going clockwise.
10. Using wrench, tighten bolts in each corner starting at top right and going clockwise.
11. Restrain wrench at left tie-down on suit sleeve.
12. Disconnect lanyard from D-handle and allow lanyard to reel up.
13. Request panel power on.
14. Grasp D-handle and prepare for cue.

The force emission task is now repeated at this new location. Thus, the force emission task comprises three force types and six force directions performed in two separate positions across the major experiment variables.

5.7.2 MEASURES

Analog profiles of the forces exerted in all directions are recorded for every trial. These profiles are used to define several measures which describe the subject's force emission capability. For sustained-type forces, two parameters are calculated. MIN describes the minimum force which the subject exerts over the last two seconds of the four-second sustained force signal. Analysis of the force exerted over the last two seconds of the trial insures that the subject has had sufficient time to reach his maximum force output level. Therefore, a MIN reading during the rise time of the force profile is precluded. FIN describes the force value which the subject is maintaining at the instant the cue signal goes out, or after 4 seconds of maximum force emission. Both of these parameters provide different interpretations of a subject's ability to "sustain" a force.

For impulse-type forces, MAX describes the maximum force which the subject emits in response to the two-second impulsive force cue signal. In addition the two seconds following the cue signal will be analyzed to insure reading the maximum force for the slower responses.

When reducing precise force data, six readings over the last 2.5 seconds of the 6-sec. profile are taken. These readings are averaged, and the mean is compared to the commanded value. The absolute value of the deviation from the command provides the desired measure of accuracy.

Two time measures are also used to describe the force emission process. The first is a response time which is calculated by determining the time from cue-signal ON until an increase in force profile of 3 pounds is noted for both the impulse and sustained force case. The second is the time at which the peak force occurs in the impulse type force trials.

Figure 5-3 presents the combination of conditions to be evaluated.

The only measure taken during the force receiver module removal/replacement is task time, which is measured from steps 3 to 12 in the replacement sequence above.

Subjective data from the Questionnaire Rating Form in Table 5-1 and physiological data (similar to the measures in 5.2.2) may also be taken.

5.8 TORQUE EMISSION TASK

5.8.1 PROCEDURE

During spaceflight maintenance and repair operations, man will be required to use tools to exert forces of various magnitudes. This task is designed to evaluate and quantify man's ability to generate impulsive and sustained forces utilizing tools under various conditions of restraint, type of suit and location of force receiver.

The conditions evaluated are similar to those in the Force Emission Task and Figure 5-3 also summarizes the conditions for this task. The torque types are sustained, impulse and precise and are defined as before. Two positions are

SIMULATION MODE:

SUIT CONDITIONS / RESTRAINT	EV CONSTANT VOL. SUIT		APOLLO BLOCK II SUIT		IVA SHIRTSLEEVE	
	MODULE POS. #1	MODULE POS. #2	MODULE POS. #1	MODULE POS. #2	MODULE POS. #1	MODULE POS. #2
DUTCH SHOES						
VARIABLE FLEXIBILITY WAIST RESTRAINT						
VARIABLE FLEXIBILITY WAIST RESTRAINT AND DUTCH SHOES						

FIGURE 5-3 FORCE EMISSION TASK DATA MATRIX

5.8.1 PROCEDURE (Continued)

again evaluated -- a center position and a position in the lower left portion of the subject's reach envelope. Only two torque directions are evaluated--clockwise and counterclockwise about the force receiver center shaft.

Two different tools are used for torque emissions. One is an L-handle wrench which allows the subject to exert a true torquing force. The other is a T-handle wrench which requires the subject to exert a torsion-like motion.

Precise torques are performed similar to precise forces. The commanded values used are presented in Table 5-3.

The step-by-step procedure used for the torque emission task is as follows:

1. Reel out lanyard from right wrist.
2. Attach lanyard to L-handle wrench.
3. Attach L-handle wrench to force receiver socket.
4. Transfer to force receiver and connect socket/wrench to stud.
5. Grasp wrench and observe cue panel for force information.
6. Upon onset of go light exert torque as specified.
7. Repeat for a total of 6 trials.
8. Disconnect wrench and socket from force receiver.
9. Return to tool box.
10. Disconnect lanyard from wrench and attach to T-handle.

TABLE 5-3 COMMANDED PRECISE TORQUE VALUES

RESTRAINT / TOOL	WAIST	SHOE	WAIST & SHOES
T-HANDLE			
CW	25.0 In.-Lb.	25.0	25.0
CCW	25.0	25.0	25.0
RATCHET			
CW	60.0 In.-Lb.	120.0	144.0
CCW	60.0	120.0	144.0

5.8.1 PROCEDURE (Continued)

11. Transfer to force receiver.
12. Attach T-handle to force receiver stud.
13. Grasp T-handle and observe cue panel for force information.
14. Upon onset of cue light exert force as specified.
15. Repeat for a total of 6 times.

5.8.2 MEASURES

Measures for the torque emission task are basically the same as those recorded for the force emission task and described in 5.7.2 above. The only difference is that response time is not computed for the torque task.

5.8.3 FORCE/TORQUE EMISSION TASKS PROTOCOL

Figure 5-4 presents a copy of a computer generated procedure for performing the force and torque emission task. This print-out is presented here because it reflects important procedural steps that cannot be discussed within either task separately.

The force and torque protocol is the result of random combinations of the task parameters. The two tasks, force and torque tasks, are performed randomly insofar as is possible without adding serious time penalties to the overall task sequence. This constraint results in several limitations upon the process of randomization. First, only two sequences of force/torque combinations are acceptable. These sequences are as follows:

FIGURE 5-4. FORCE/TORQUE TASK PROTOCOL

TASK ITEM	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN	SESSION TIME SEC	REMARKS
3.3&3.4 FORCE/TORQUE EMISSION		"STAND-BY"			PRESS. SUIT
		RCDR ON			
		LIGHTS ON			
		CAMERA ON			
	INSTALL D-HANDLE OR TOOL AS RQRD	FR PWR ON			INFORM S OF TYPE OF TRIALS TO BEGIN

FOR USE WITH W&S RESTRAINTS

FORCES POS 1			TORQUES POS 1				FORCES POS 2			TORQUES POS 3			
T	D	DL	W	T	D	DL	T	D	DL	W	T	D	DL
S	+Y	2.5	L	S	CW	2.0	I	+Z	4.0	T	I	CCW	2.0
S	+X	3.5	L	I	CW	2.0	I	+Y	2.5	T	*P	CW	2.0
S	+Z	3.0	L	S	CCW	2.0	S	-Z	2.0	T	I	CW	2.0
S	-X	3.5	L	*P	CW	2.0	S	+Z	2.0	T	S	CW	2.0
I	-Z	3.0	L	I	CCW	2.0	S	-X	2.5	T	S	CCW	2.0
I	+Z	2.0	L	*P	CCW	2.0	I	-Z	3.0	T	*P	CCW	2.0
			*P TORQUE=144. IN-LB							*P TORQUE= 25. IN-LB			
REST 10 SECONDS			REST 10 SECONDS				REST 10 SECONDS			REST 10 SECONDS			
S	-Y	2.5	T	*P	CW	2.0	S	+X	4.0	L	*P	CW	2.0
I	-Y	4.0	T	S	CCW	2.0	I	-Y	4.0	L	I	CW	2.0
I	+Y	3.0	T	*P	CCW	2.0	S	+Y	2.0	L	S	CCW	2.0
S	-Z	3.0	T	I	CW	2.0	I	+X	3.0	L	*P	CCW	2.0
I	+X	2.0	T	S	CW	2.0	I	-X	3.5	L	S	CW	2.0
I	-X	2.0	T	I	CCW	2.0	S	-Y	4.0	L	I	CCW	2.0
			*P TORQUE= 25. IN-LB							*P TORQUE=144. IN-LB			
REST 10 SECONDS			REST 10 SECONDS				REST 10 SECONDS			REST 10 SECONDS			
*P	+Z	24. LB					*P	-X	18. LB				
*P	-Z	24. LB					*P	+X	18. LB				
*P	+X	18. LB					*P	-Z	24. LB				
*P	-Y	11. LB					*P	+Z	24. LB				
*P	+Y	11. LB					*P	-Y	11. LB				
*P	-X	18. LB					*P	+Y	11. LB				

5.8.3 FORCE/TORQUE EMISSION TASKS PROTOCOL (Continued)

SEQUENCE 1		SEQUENCE 2	
Task	Position	Task	Position
Forces	Center	Torques	Center
Torques	Center	Forces	Center
Forces	Upper Right	Torques	Lower Left
Torques	Lower Left	Forces	Upper Right

These sequences minimize force receiver module movements and also prevent fatigue effects resulting from back-to-back force (on torque) emissions at two different positions. Note that both forces and torques are performed at the center position, but in the upper right position only forces are performed and in the lower left position only torques are performed. Ideally, of course, one would like to evaluate forces and torques in various positions in the reach envelope, but time constraints limit evaluation to the current structure.

Additional constraints on randomization of variables also exist within the force task and within the torque task. During force emissions, response time is measured for sustained and impulse force trials. Thus, precise forces are performed in a block independent of the sustained and impulse trials, and may occur, with equal probability, either at the beginning or the end of a series of force trials. During torque trials, since response time is not recorded, the sustained, impulse and precise trials are randomly combined. However, the two different tools are split into blocks of six trials each, since it would not be practical to change tools on every trial. The L-handle or the T-handle wrench may occur first, at a given position, with equal probability.

Force receiver module removal/replacement is accomplished when it is necessary to change the module from one position to another for a new series of trials.

5.9 OPERATIONAL MAINTENANCE TASK

5.9.1 PROCEDURE

The Operational Maintenance Task requires the subject to remove and replace a component from a gas plumbing system when the assembly has "failed". The task is activated by a control switch on the observer's panel. This switch causes a solenoid valve on the task panel to operate which results in dumping the pressure in the system. A meter on the panel will indicate the pressure drop, and a warning signal - consisting of a flashing light and an auditory alarm - will be activated. The subject is expected to recognize the failure and proceed with the corrective action.

The specific steps required are as follows:

1. Observe onset of flashing light and audio alarm.
2. Turn off light and alarm.
3. Reel out lanyard from right wrist and attach to T-handle.

5.9.1 PROCEDURE (Continued)

4. Obtain T-handle wrench from tool kit.
5. Reel out lanyard from left wrist.
6. Attach to component.
7. Release allen-head nuts that hold component in place.
8. Allow T-handle wrench lanyard to reel up.
9. Reel out lanyard from waist and attach to open-end wrench in tool kit.
10. Remove open-end wrench from tool kit.
11. Release hex fastener on component.
12. Remove component.
13. Return to tool kit.
14. Release lanyard.
15. Attach lanyard to new component.
16. Remove new component from tool kit.
17. Using wrench tighten nuts.
18. Restrain wrench temporarily at suit tie-down.
19. Pressurize system to 10 psig using manual pump.
20. Return wrenches to tool kit.
21. Disconnect lanyard from component to allow to reel up.
22. Disconnect tool lanyards and allow to reel up.

5.9.2 MEASURES

The basic measure accumulated in this task is task time from steps 7 to 19 above. Subjective data from the Questionnaire Rating Form in Table 5-1 and physiological data (such as the measures of 5.2.2) may also be collected.

5.10 CONCLUDING TASK

The remainder of the task sequence was designed to simulate required operations that would successfully conclude any EVA/IVA task. Thus, the subject is required to return the cover to the Task Panel and install it. When this is completed, the subject removes his personal restraints, fastens them to lanyards and to suit tie-down, and leaves the worksite.

These tasks were found to be especially time consuming and were performed only in 1-G and in parts of the 6 DOF simulation.

SECTION 6

DATA COLLECTION ACTIVITIES

Four ground-based simulation techniques were utilized to collect the data required to satisfy the objectives of the experiment. These techniques involved three zero-gravity simulation methods as well as performance of the experiment in the one-gravity environment. For ease of writing, the one-gravity data collection is also considered to be a ground-based simulation technique.

The one-g and neutral buoyancy simulations were performed at the Controlled Buoyancy Facility, located at the General Electric Space Division Complex at King of Prussia, Pennsylvania. The 6 Degree-of-Freedom mechanical simulations were performed at the NASA, Marshall Space Flight Center utilizing the Action-Reaction Free Fall Simulator. The final mode of zero-gravity simulation was the Keplerian Trajectories performed in the KC-135 aircraft supplied by the Aeronautical Systems Division at Wright-Patterson Air Force Base, Dayton, Ohio.

The following paragraphs in this section describe the details of the data collection activities and instrumentation and data recording equipment associated with each of the simulation modes.

6.1 INSTRUMENTATION AND DATA RECORDING

The instrumentation for the ground-based data collection effort was designed to provide a permanent record of the data gathered during the test programs and provide the capability for data reduction and analysis on a non-real time basis. Figure 6-1 illustrates the test set-up used in all four simulation test modes.

The signal conditioning equipment contained in the Electronics Box was described in Section 4.2.9. The equipment described here provided the interface between the Electronics Box and the data collection and recording equipment.

An eight-channel oscillographic recorder (Brush Mark 200) was used for data recording, since no more than eight signals were necessary for display or recording during any one task. Depending on the task being performed, the test director changed the signal inputs to the recorder by using small patch boards which could quickly and easily be changed during subject rest periods. The recorder was situated in close proximity to the test director to provide a real-time display of the operational status of all telemetry signals.

The Brush Mark 200 recorder was not suitable for use aboard the KC-135 0-g aircraft. Hence, for that mode only, a GFE, 24-channel Visicorder was used. Since that recorder tends to overlap signals, all redundant signals were eliminated from the display.

Figures 6-2 through 6-6 illustrate typical traces of the telemetry signals obtained for all tasks. The last three figures only show examples of force task telemetry. The torque task signals are exactly the same except that the clockwise and counterclockwise signals are displayed instead of the $\pm X$, $\pm Y$, and $\pm Z$ outputs.

Figure 6-2, describes the data collected for the Two-Hand Task. Six channels were utilized for recording the subjects performance. Channel 1 provided a 0-5 volt signal whose magnitude identified which test point was used and whose duration determined total trial time. Channel 2 provided a 0-5 volt signal whose

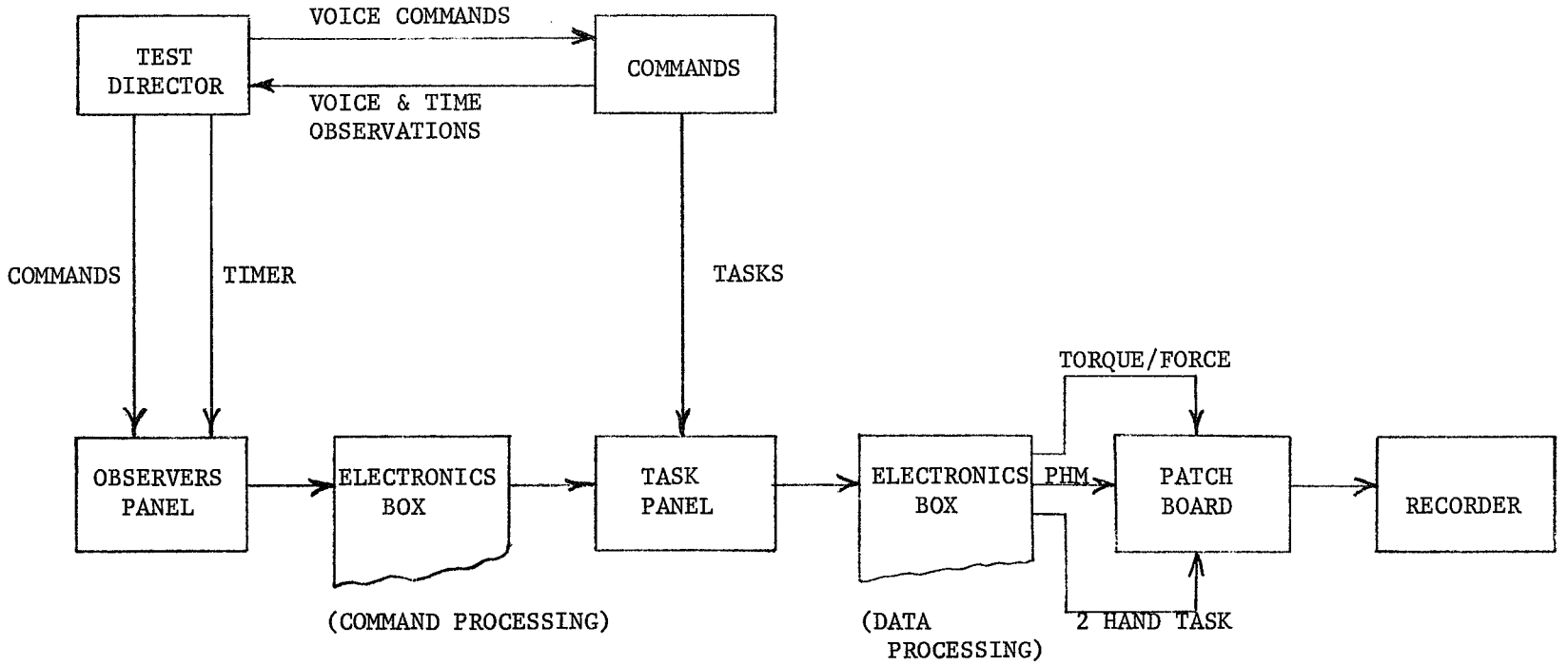


FIGURE 6-1 DATA COLLECTION TEST SETUP

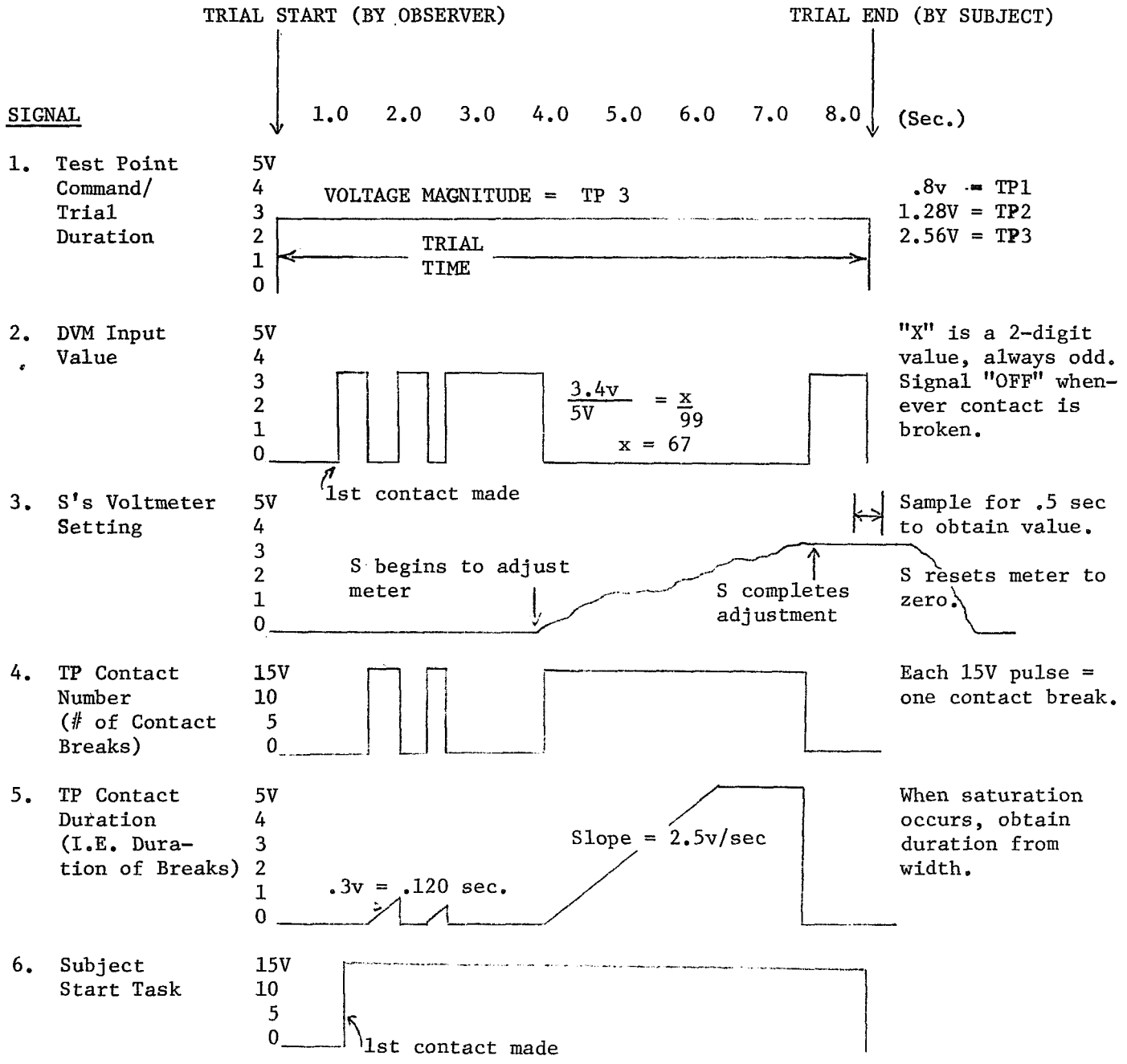


FIGURE 6-2 TWO-HAND COORDINATION TASK TELEMETRY

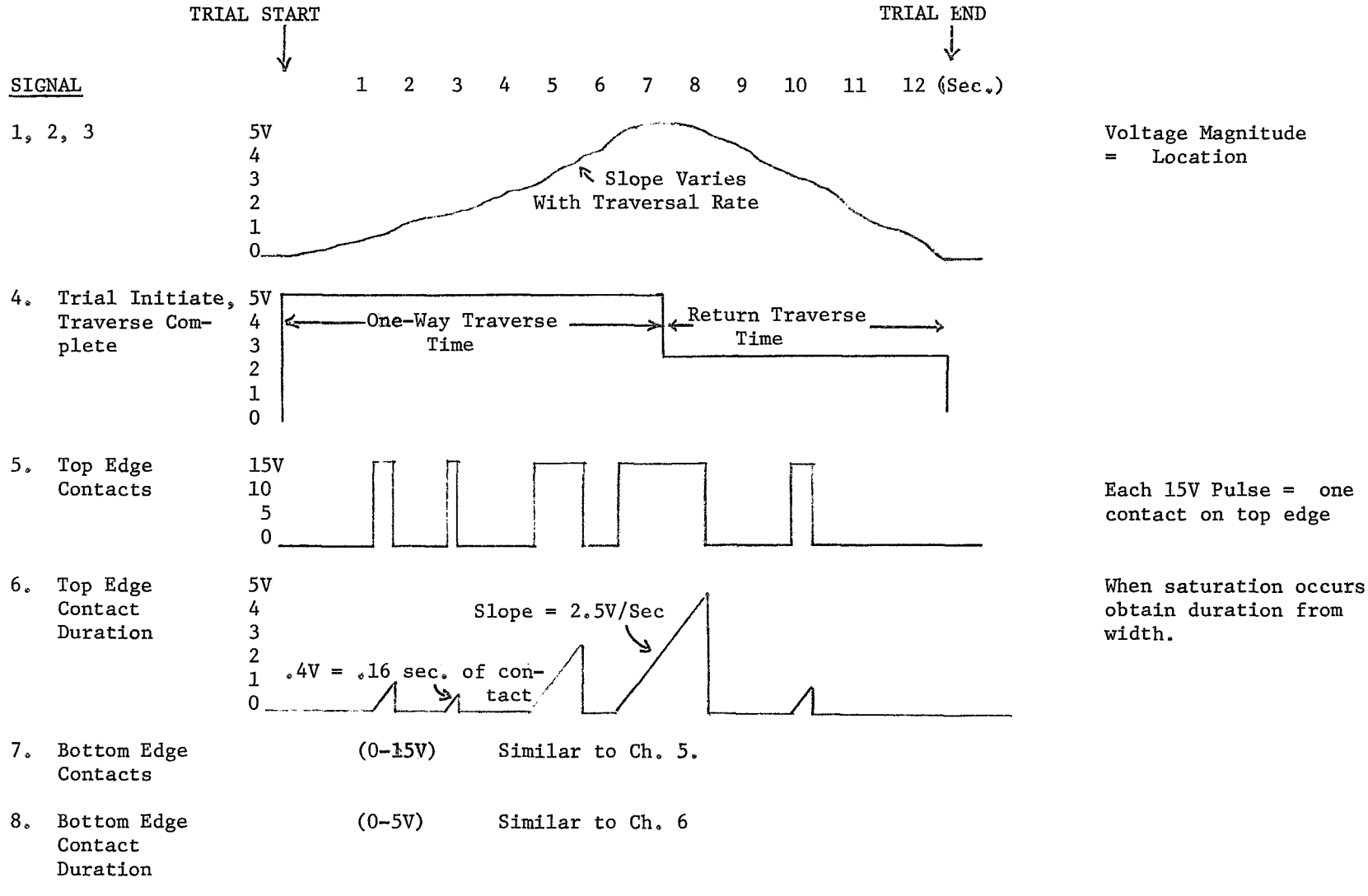


FIGURE 6-3 PRECISE HAND MOVEMENT TASK TELEMETRY

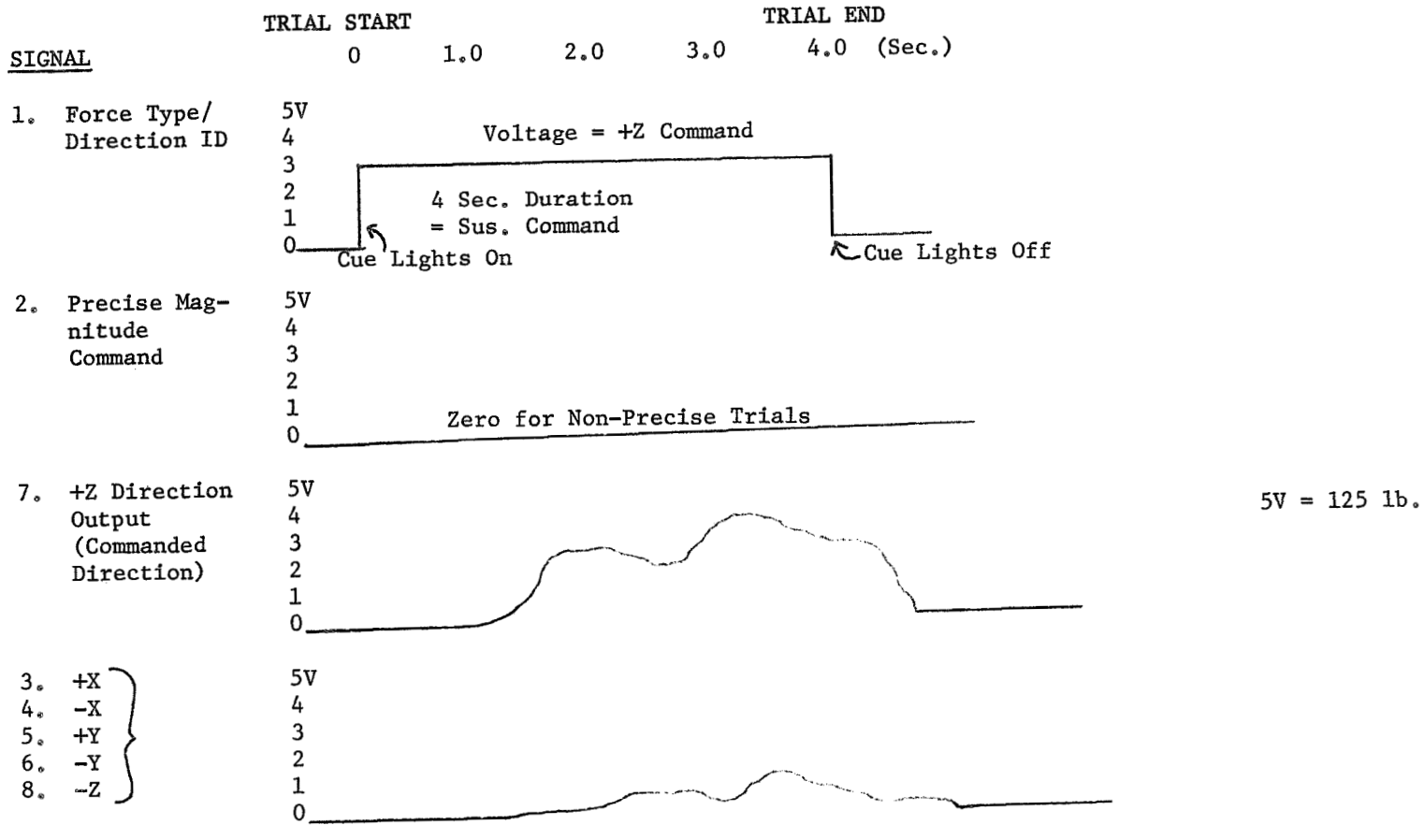


FIGURE 6-4 FORCE/TORQUE EMISSION TASK - SUST. FORCE EXAMPLE

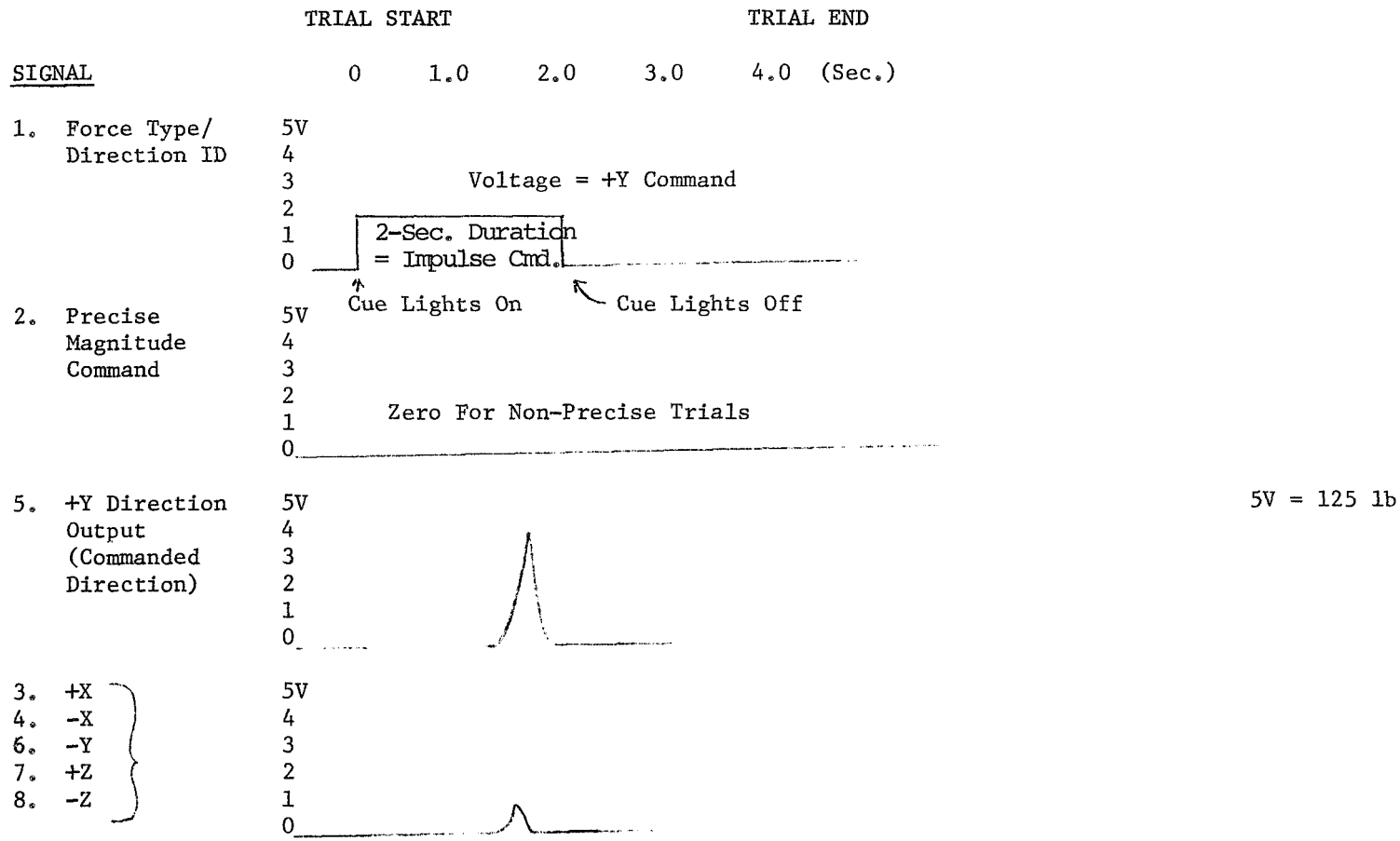


FIGURE 6-5 FORCE/TORQUE EMISSION TASK - IMPULSE FORCE EXAMPLE

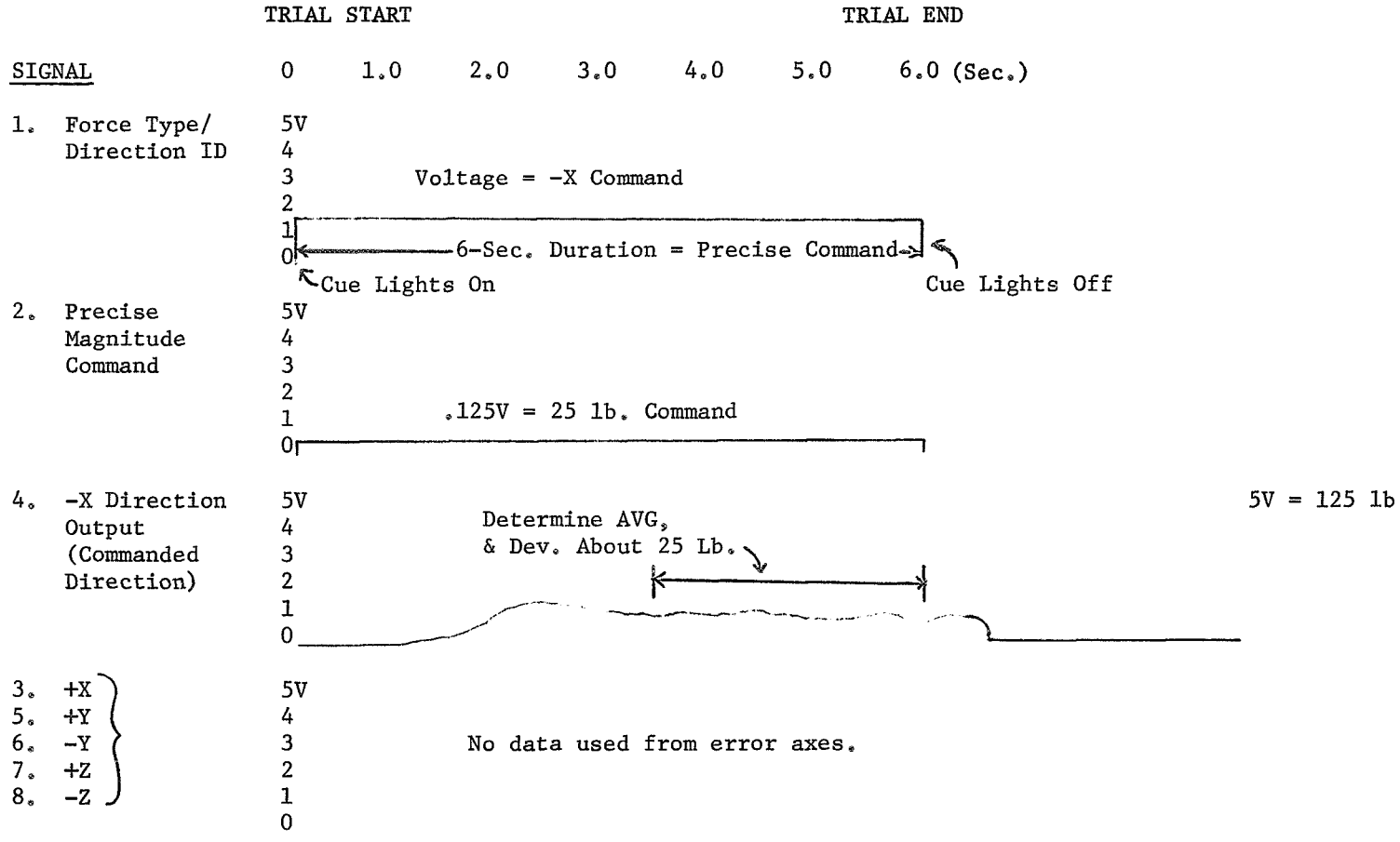


FIGURE 6-6 FORCE/TORQUE EMISSION TASK - PRECISE FORCE EXAMPLE

6.1 INSTRUMENTATION AND DATA RECORDING (Continued)

magnitude identified the value of the two-digit (0-99) input to be displayed to and matched by the test subject. Channel 3 provided a 0-5 volt trace history of the subjects matching of the digitally displayed value on the vernier display. Channel 4 provided a 15 volt signal whenever the subject broke contact with the test point during the conduct of a trial. Channel 5 provided a 0-5 volt signal, whose slope was 2.5 volts/second, used to record the contact break time. Channel 6 provided a 15 volt signal which was used to record the duration of the trial.

Figure 6-3 describes the data collected for the Precise Hand Movement Task. Eight channels were utilized for recording the data. Channels 1, 2 and 3 provided a 0-5 volt trace, for each of the three spring tensions, whose slope and magnitude indicated the subjects' traversal rate and location on the path, respectively. Channel 4 provided a 0-5 volt full-scale pulse during traversal time in one direction and a half full scale pulse during traversal time back to the starting point. Channels 5 and 7 provided full scale, 0-15 volt, pulse whenever a contact was made with the top or bottom edge of the traversal path. Channels 6 and 8 provided 0-5 volt traces whose magnitude and slope indicated the top and bottom contact durations, respectively.

Figures 6-4, 6-5, and 6-6 describe the data collected for the Force/Torque Emission Task Sustained, Impulse and Precise force trials respectively. Channel 1 in all cases provided a 0-5 volt signal whose magnitude identified the required force direction and whose duration identified the force type. Channel 2 provided a 0-5 volt signal whose magnitude identified the value of the commanded precise force to be matched by the subject. This channel was inactive during the sustained and impulsive forces. Channels 3 through 8 provided a 0-5 volt trace of the force profile in each of the six possible directions of $\pm X$, $\pm Y$ and $\pm Z$. The magnitude of the force profiles indicated the amount and the duration of the force being exerted in the commanded direction.

6.2 ONE-G DATA COLLECTION ACTIVITIES

The one-g test series was conducted at the GE Valley Forge Facility. In order to utilize the same instrumentation and recording equipment as the neutral buoyancy tests, the one-g testing was done adjacent to the Controlled Buoyancy Facility. The task panel was attached to an adaptor plate which was mounted to a structural I-beam in the wall. The foot restraint was attached in a similar fashion by using a platform as shown on Figure 6-7.

The total experiment required the performance of 36 sessions to complete the condition combinations of restraints, suits, subjects and replications. The one-g testing reduced the 36 sessions to 24 because the waist restraint only condition was impossible in this mode. The 24 remaining sessions evaluated two restraint conditions (shoes only and waist and shoes), 3 suited conditions(Shirtsleeve, Apollo Suit, and Litton (AES) suit), and 2 subjects with each condition replicated.

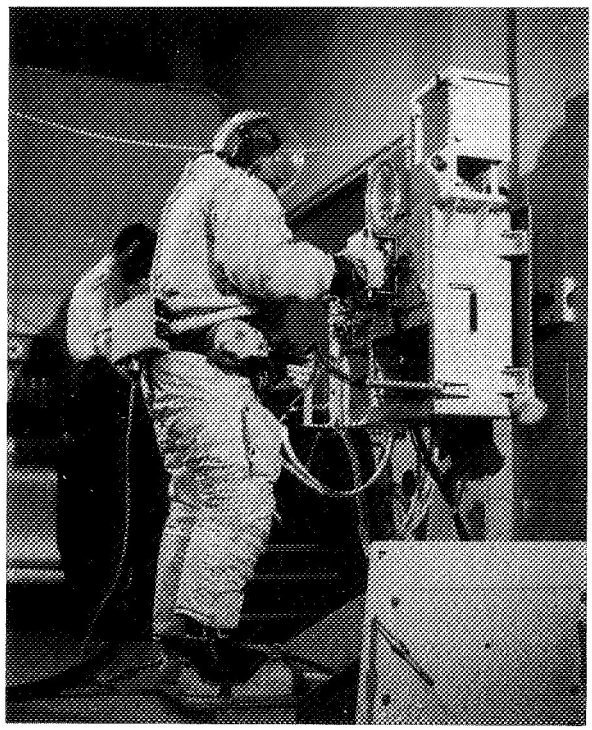


FIGURE 6-7 ONE-G TEST SETUP

6.2 ONE-G DATA COLLECTION ACTIVITIES (Continued)

The testing deviated from the actual EVA condition in that the following items were not available for evaluation in the suited condition:

- o EVVA (Extravehicular Visor Assembly)
- o EV Gloves
- o PLSS (Portable Life Support System)
- o LCG (Liquid Cooling Garment)

The suits used were an A6L, Medium Long and an A7L, Large Long. The Litton Advanced Extravehicular Suit was comparable in size to the Apollo, Large Long and had enough built in adjustment capability to accommodate the subject who wore the A6L suit.

The pressurization system for the suited operations is shown on Figure 6-8 and consists of the airbank, 2 stage regulator and AAP controller which varies the pressure and flow rate within the suit. During testing the pressure was maintained at 3.5 psi and the flow rate at 10 cfm minimum.

Two-way communication between the test director and the subject was available by utilizing the communications carrier in the suited condition and a headset in the shirtsleeve condition. A buzzer was also connected between the task panel and the subject. It would indicate when contact was broken on the Two-Hand Task, when contact was made with the path of the Precise Hand Movement Task or when a pressure drop developed in the Operational Maintenance Task.

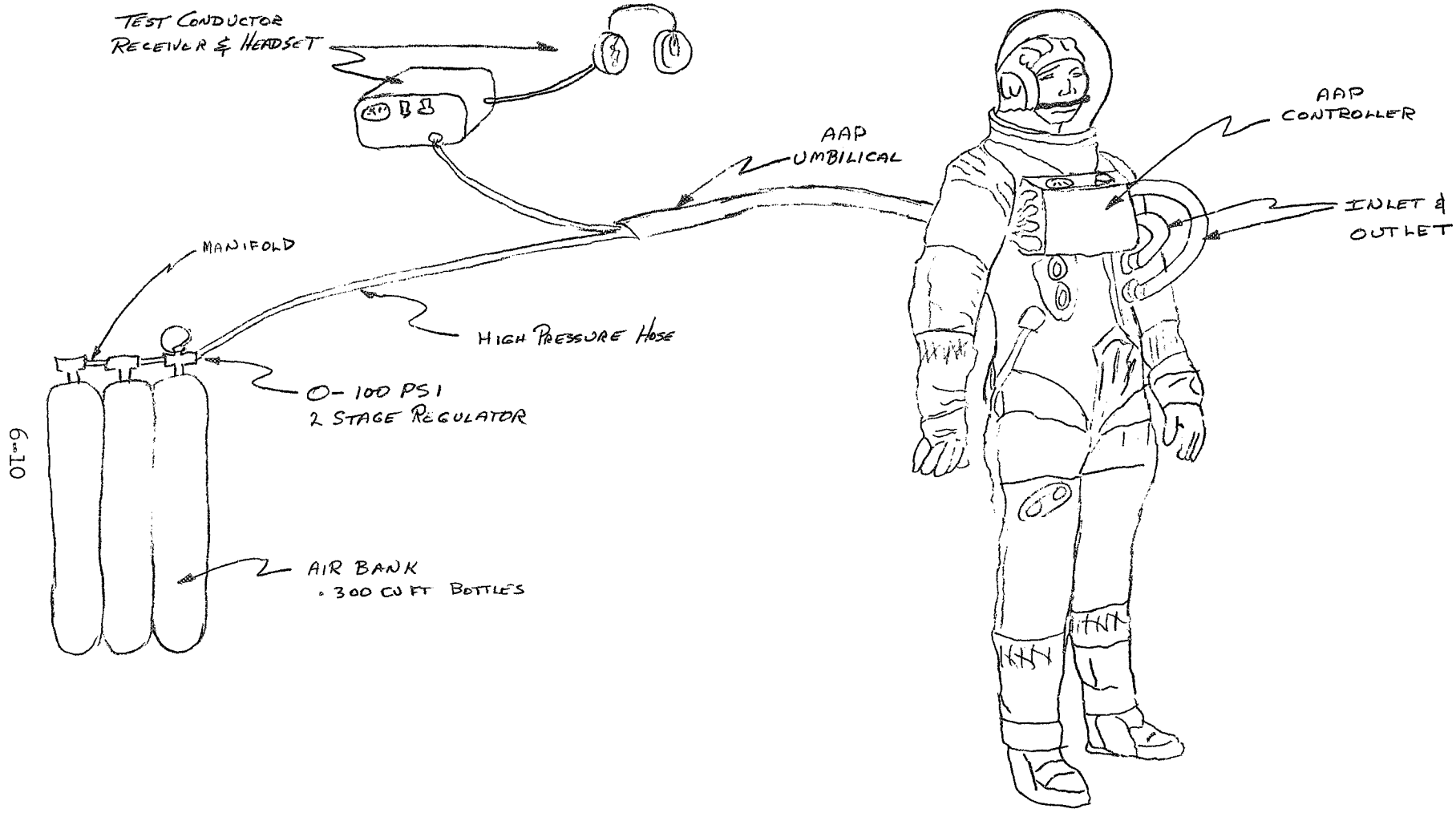


FIGURE 6-8 ONE-G TEST - SUIT PRESSURIZATION & COMMUNICATIONS

6.2 ONE-G DATA COLLECTION ACTIVITIES (Continued)

Data collection during the one-g testing was accomplished by recording the outputs of the task panel as described in para. 6.1. Comments applicable to the test were identified on the chart paper, and also logged in the session instruction sheets. Photographic data was collected using a Mauer 16 mm camera at 8 frames/sec.

Support personnel assisting in the experiment included a suit technician and nurse. The suit technician was responsible for assisting the subject in donning and doffing the suits, and also, monitoring the pressurization system during the test sessions. As a safety precaution, a nurse trained in hyperbaric medicine was on-site during all pressure suited operations, and a hyperbaric chamber was available at the facility.

6.3 ACTION-REACTION FREE-FALL SIMULATOR (6 DEGREES-OF-FREEDOM)

This test series was performed at the Marshall Space Flight Center, Huntsville, Alabama. The action-reaction free-fall simulator (Figure 6-9) was developed by the Manufacturing Engineering Laboratory at MSFC for the purpose of determining the design integrity of space-oriented equipment. Naturally, this simulator cannot prevent the test subject from feeling the gravitational pull as it forces him against the harness straps. In order to simulate a believable zero gravity condition, the test subject and the simulator must be considered as one entity. In this way, the six degree-of-freedom, action-reaction, zero gravity phenomena can be observed.

The Task Panel and the Foot Restraint platform were mounted to a frame structure made available at the facility. Although this structure required little modification to accommodate the task panel, which at the time was expedient, it would have been desirable to have a more rigid, stable mounting platform.

The number of tests planned in the 6 Degree-of-Freedom mode was minimized by eliminating the replication of each session. This effectively reduced the test plan from 36 to 18 sessions, thus collecting data on 2 subjects across 3 suits across 3 restraints. Further reduction of the test plan was later realized when the AES suit would not conform to the simulator harness assembly (Figure 6-10). The major problem area was the cycle seat, which would not permit the legs to come together, thereby eliminating the opportunity to utilize the shoe restraint (Figure 6-11). Further attempts at trying to collect data in the waist restraint only condition were aborted because of the risk of damaging the suit. In addition, the full potential of the suit could not be realized because of the harness and waist restraint restricting the suit mobility as shown in Figures 6-12 and 6-13.

The effect of gravitational forces on peripheral equipment such as the force receiver, foot restraint, hand restraint and cover affected the balance of the system and tended to tilt the subjects. Therefore, this equipment had to be handled by an assistant.

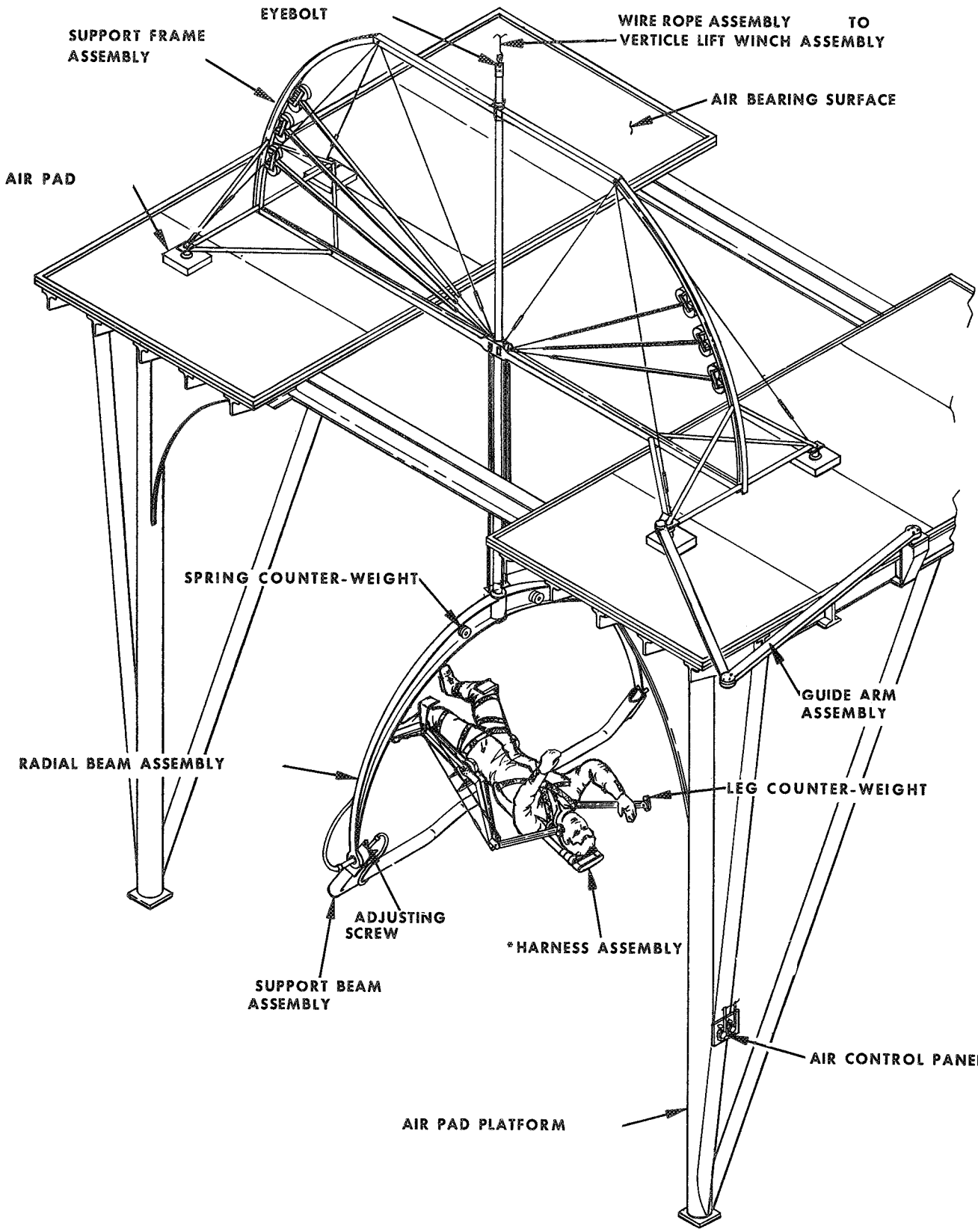


FIGURE 6-9 ACTION-REACTION, FREE FALL SIMULATOR

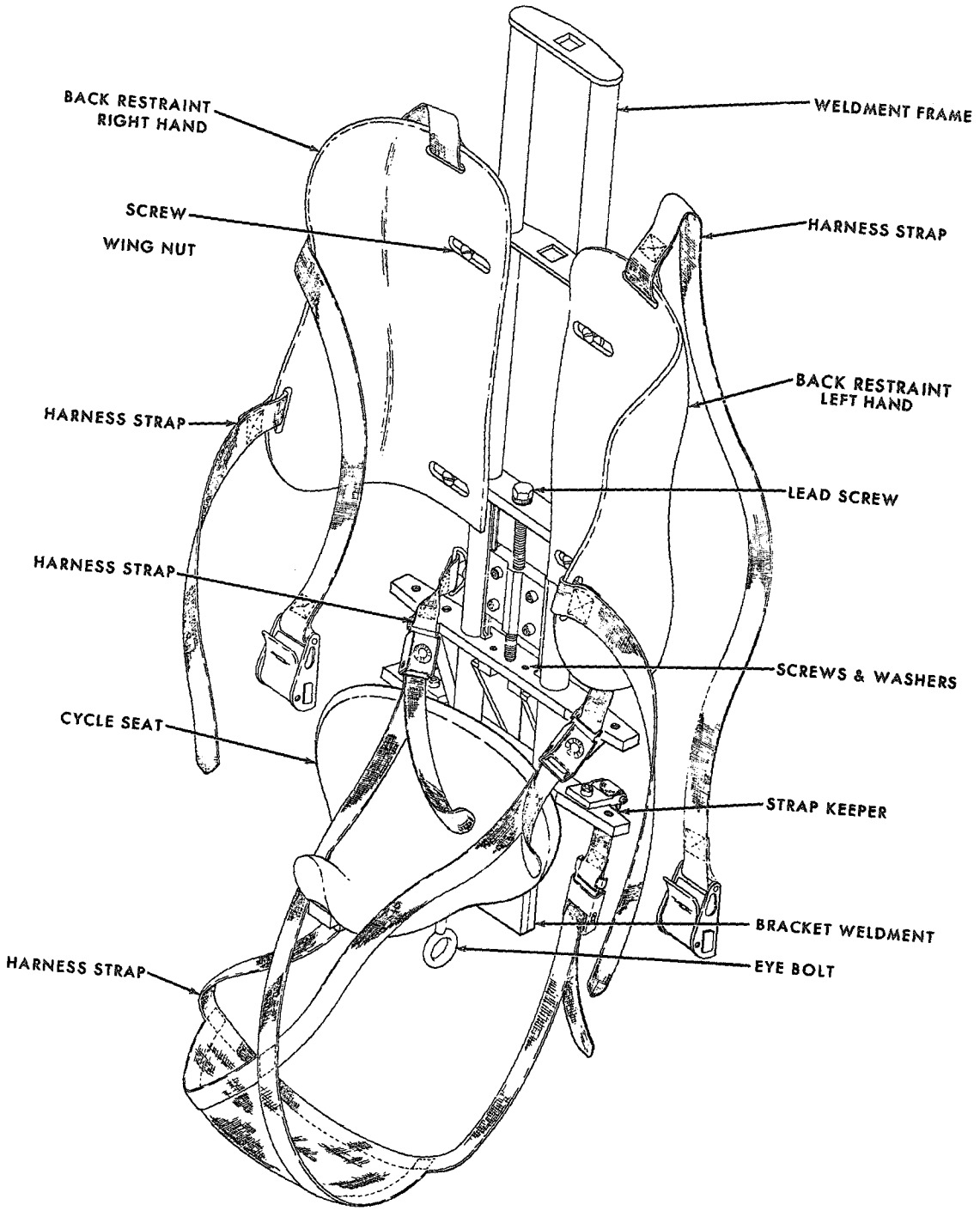


FIGURE 6-10 HARNESS ASSEMBLY

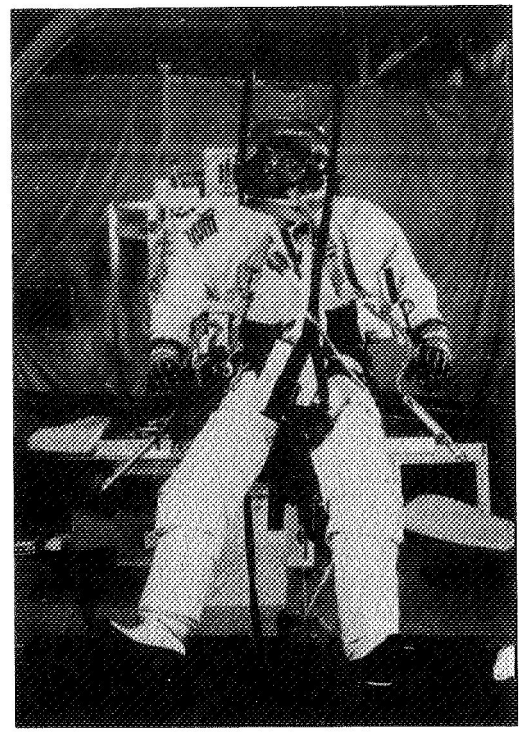


FIGURE 6-11 AES SUIT IN 6 DOF SIMULATOR



FIGURE 6-12 WAIST RESTRAINT/HARNESS RESTRICTION

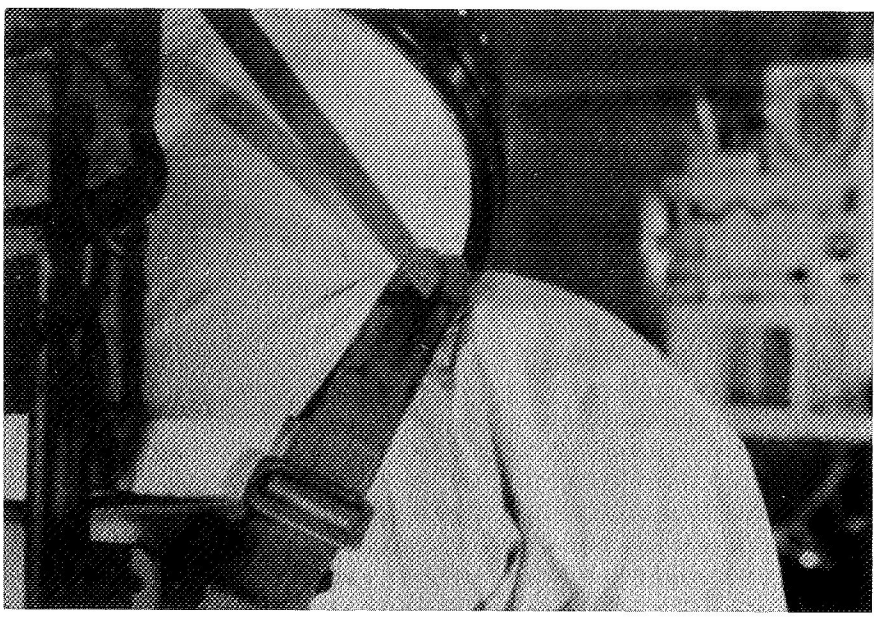


FIGURE 6-13 SHOULDER MOBILITY RESTRICTION

6.3 ACTION-REACTION FREE-FALL SIMULATOR (6 DEGREE-OF-FREEDOM) (Continued)

During this test series, a Liquid Cooling Garment (LCG) was used in all the pressure suited sessions and was a definite factor in reducing fatigue and adding to the comfort of the subjects.

The pressurization system was essentially the same as in the one-g mode with the exception of the air source. The air was tapped from the shop air supply, and then filtered until it was certified as breathing air.

The communication system utilized the communication carrier in the pressure suited mode, but in the shirtsleeve mode the subjects were required to wear protective helmets that would not accommodate the headset used in the one-g test series. Although this eliminated the interconnecting warning buzzer, voice communication between Test Director and subject was audible and no difficulty was encountered in conducting the test.

Data collection and film coverage during this series was identical to the one-g simulation.

Support personnel included a suit technician to assist the test subject, a simulator technician to aid in adjusting, balancing and operating the simulator and a medical office representative who was present, or on call, during the pressurized suit tests.

6.4 NEUTRAL BUOYANCY

The facility used for the conduct of the neutral buoyancy simulation portion of the experiments is a part of the General Electric Space Division Complex located at King of Prussia, Pennsylvania. The facility is designated the Controlled Buoyancy Facility and consists of the pool area, locker and shower rooms, experiment preparation area, pressure suit storage and drying area, experiment control area, medical/first aid area, and peripheral pool support equipment and shops.

The pool area, Figure 6-14, is in an environmentally controlled room which maintains ambient temperature at $85^{o}F \pm 1^{o}F$. The pool is 60 ft. long, 28 ft. wide, and 25 ft. deep throughout. Two 25 foot ladders afford personnel access to the pool with a 4 ft. by 6 ft. entrance platform located at one end adjacent to a ladder at 4 feet below the water surface. At approximately 15 ft. below surface, another 10 ft. by 12 ft. platform is located for conducting experiments which do not require the full 25 foot depth. The pool water can be controlled at any temperature between $60^{o}F$ and $100^{o}F$. The water is continuously filtered by a diatomaceous earth filter system and purified by a chlorinel bromine system which maintains pool clarity and purity at an extremely high degree. The basic concept of neutral buoyancy involves the establishment of a buoyant force equal to the weight of the subject (plus pressure suit), with the center of buoyancy coincidin with the center of gravity to preclude or reduce any orientational bias. When this state is achieved, a reasonable simulation of zero-g reaction dynamics is possible.

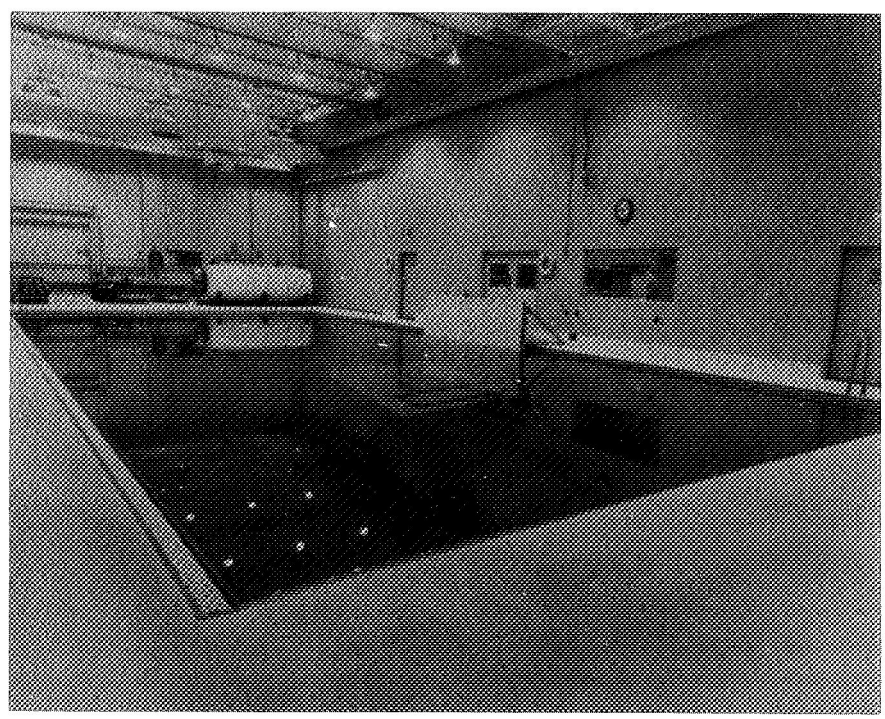


FIGURE 6-14 CONTROLLED BUOYANCY FACILITY

6.4 NEUTRAL BUOYANCY (Continued)

The Task Panel was mounted on a 12' x 12' panel that was installed in the pool via a track which was affixed to the side of the pool. An overhead hoist was used to lower the panel into the water or remove it. The task panel was installed in the pool at a depth of 10 ft. below the water surface level, Figure 6-15.

The test plan for the neutral buoyancy testing was revised in the following manner. By eliminating the Apollo A7L suit, from the underwater activities, the neutral buoyancy test plan was reduced from 36 sessions to 24 sessions. Further reduction in the test plan resulted from delays associated with equipment and pressure suit failures and subject illness during the underwater portion of the program. The Task Panel is the most intricate equipment ever operated in the G.E. underwater facility, consequently, unforeseen problems developed which were resolved but without undue loss of valuable testing time. One of the two subjects used throughout the test program developed an ear infection and was restricted from underwater activities for several days. The failure of the Advanced Extra-Vehicular Suit resulted from a leak in the connector of the suit electrical harness. Upon investigation, it was evident that the wrong O-ring was used in sealing the connector to the suit torso. A total of 15 sessions were completed in the underwater neutral buoyancy mode before terminating the program.

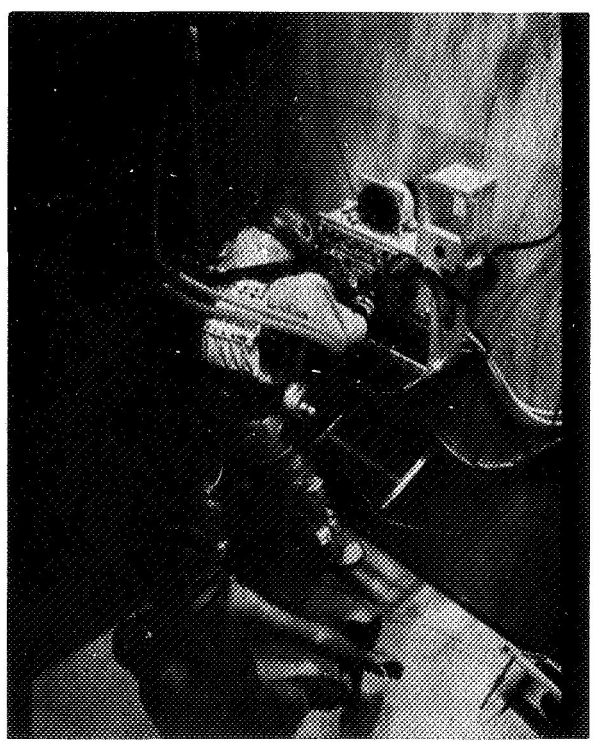


FIGURE 6-15 NEUTRAL BUOYANCY SIMULATION TEST SETUP

6.4 NEUTRAL BUOYANCY (Continued)

The pressurization system (Figure 6-16) for the neutral buoyancy simulation program consisted of the air bank, 2 stage regulator, backpack, surface flowmeter, and pressure gage. The backpack was originally designed and developed by the General Electric Company as a water pressurization device to be used in conjunction with a specially designed quick-disconnect helmet. This system proved to be safe, reliable and efficient in previous test programs conducted by General Electric. (See HEMAR, NAS8-18117, 31 December 1967, HECMAR, NAS8-21429, 15 June 1969.) The backpack was easily modified to be used as an air pressurization device without destroying its capability for water pressurization. The backpack compensates for pressure differentials as the subject descends to working depth. However, the pressure could also be controlled manually by the safety diver to assist the subject's ingress and egress. The air flow rate and pressure were maintained at 10 cfm and 3.5 psi (gage) respectively and continually monitored on the surface to insure the safety of the subject.

Each subject was neutrally buoyed at the start of each experiment session. Lead weights were added as required to the weight harness, Figure 6-17, to adjust for the individual subject's weight and center of gravity. The weight harness, approximately 130 pounds, not only compromised the mobility of the suit, but also had a very fatiguing effect on the subjects during ingress, egress, weight attachment and neutrally buoying.

The shirtsleeve sessions utilized a standard scuba regulator attached to a hookah line. A simple back-mounted harness consisting of a shoulder harness worn over the thorax was used to maintain the regulator hose at a fixed position. Neutral buoyancy was obtained by adding weights or flotation material to the subject prior to each experimental session.

The communication system available to the test director included the communications carrier in the suited mode (director to subject only) and one way voice communication (surface to subsurface) to instruct underwater personnel and direct operations. The latter was the only means of communication utilized in the shirtsleeve mode. An underwater TV system was also used throughout the testing program to assure the test director that proper experimental protocol and safety measures were being followed.

Photographic coverage consisted of motion picture films and stills. Data collection for the neutral buoyancy simulation consisted of recording data outputs on an 8 channel brush recorder as described in Paragraph 6.2. Support personnel required for the underwater testing included a safety diver, 2 underwater technicians, photographer, and surface technician. These personnel were required to maintain rigid adherence to safety and diving protocols along with their specific duties associated with the data collection program.

Subject availability was lost on several occasions as a result of ear inflammations. While no pathogenic analyses were taken to delineate the infectious organisms involved, it is felt that the problem may have been due to the tendency

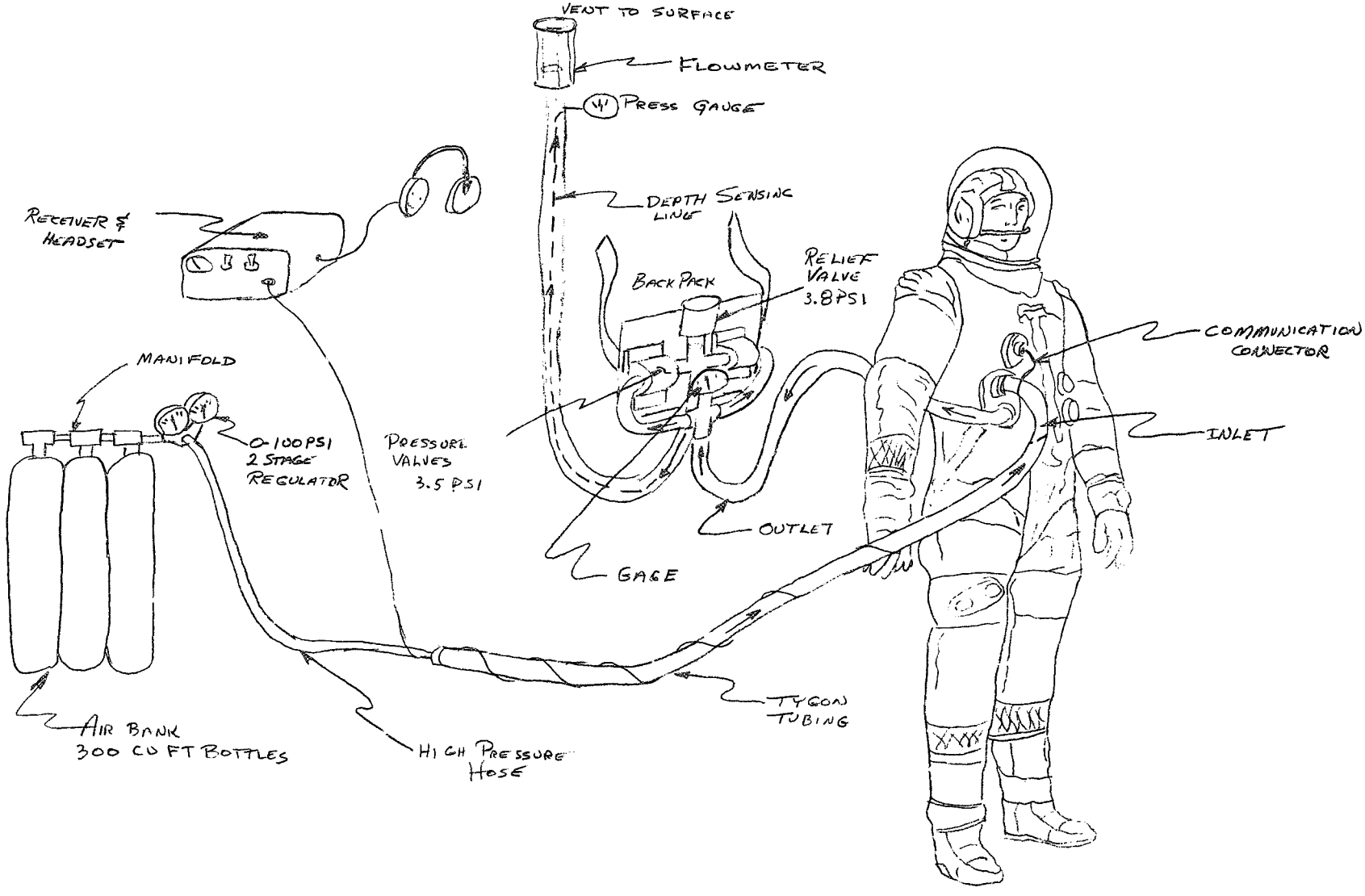


FIGURE 6-16 NEUTRAL BUOYANCY SIMULATION PRESSURIZATION - COMMUNICATIONS

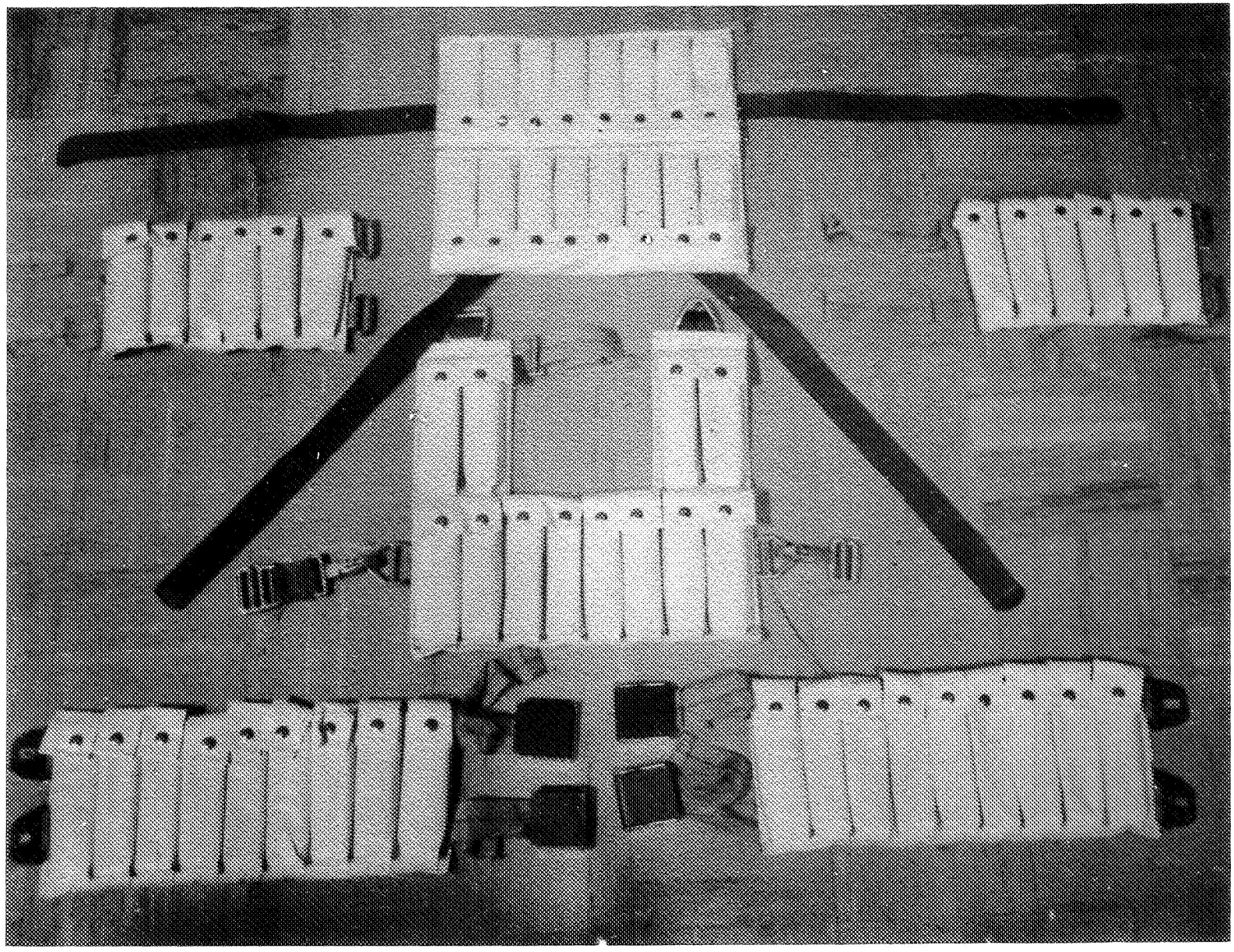


FIGURE 6-17 WEIGHT HARNESS

of the subjects to fail to adequately clean and dry their ears following continued extended diving procedures. This provided a warm moist environment that caused ambient pathogens to flourish and create the inflammation. Continuous water samples indicated an almost sterile water condition with no detectable toxins. As a result, the probability of water introduced pathogens or irritants seems remote.

6.5 KC-135 ZERO GRAVITY

This portion of the test program was performed at Wright-Patterson Air Force Base with the support of the Aeronautical Systems Division (ASD). The testing was conducted during weightless simulation flights using the Air Force KC-135 Zero-G test aircraft. In these flights, the aircraft followed a ballistic trajectory so that objects inside the aircraft were in a state of free-fall, thus being effectively weightless. The period of weightlessness produced was nominally 25 seconds. The degree of accuracy was $\pm$ .01G and depended primarily on pilot profiency and prevailing weather conditions. The zero-gravity maneuver is shown on Figure 6-18.

All GE personnel engaged in the test flights were required to meet the following qualifications:

1. Establish proper security clearance at Wright-Patterson Air Force Base.
2. Successfully pass a Class III flight physical.
3. Complete physiological training which consisted of:
   a. Altitude chamber indoctrination.
   b. Explosive decompression
4. Complete survival training.

The Task Panel and foot restraint support were mounted to a frame structure that was specifically designed to meet the interface requirements of the aircraft. All test equipment was mounted to the floor of the aircraft on a 20-in. grid pattern which straddled the aircraft centerline.

The test plan for this portion of the program had to be drastically modified to accommodate the limited time available aboard the aircraft. In order to accomplish this, the number of sessions and the time required for each session had to be reduced. The test plan of 36 sessions was reduced to 18 by eliminating each replication, and the time-line for each session was reduced by eliminating the following tasks:

1. Foot restraint installation
2. Cover removal
3. Installation of access panel
4. Removal of access panel
5. Cover replacement

Seven reduced time-line sessions requiring approximately 55 parabolas per session were completed during the 2 weeks in which the aircraft was available for the program. The aircraft made 8 flights and accumulated a total of 375 parabolas.

6.5 KC-135 ZERO GRAVITY (Continued)

The suit pressurization system was identical to the one-g system, utilizing an air bank and the AAP controller.

Communications during the KC-135 testing utilized the aircraft's inter-comm for the shirtsleeve mode. Documentary photography (motion pictures and slides) was provided by an Air Force photographer throughout the KC-135 testing.

Complete recalibration of the output circuitry in the electronics was required to use the Visicorder available on the aircraft. The Visicorder is a 24 channel recording instrument that utilizes light sensitive paper rather than ink and it is not affected by the zero-gravity maneuver.

Support personnel required aboard the aircraft exclusive of the crew and ASD representative included a G.E. test technician, NASA suit technicians, and an Air Force photographer.

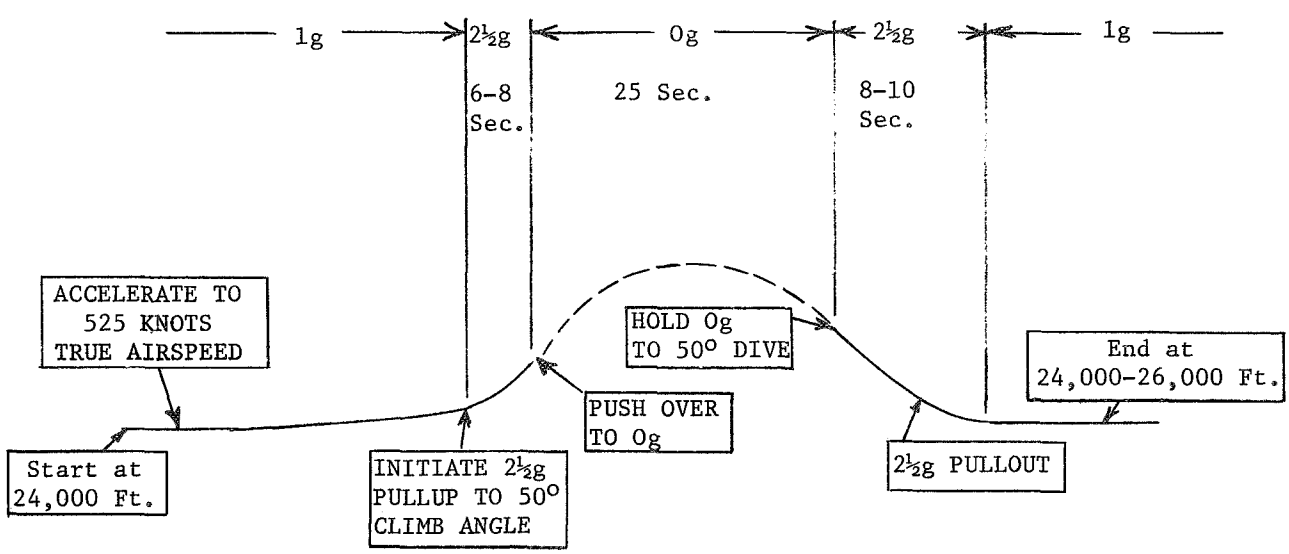


FIGURE 6-18 ZERO-GRAVITY MANEUVER

SECTION 7

DATA ANALYSIS AND RESULTS

7.1 DATA REDUCTION

This section describes the technique utilized to convert the raw data resulting from the data collection activities described in Section 6 into the measures defined in Section 5. All voltage data was read and manually converted to engineering units. The converted data was then tabulated on computer-compatible formats, illustrated in Figure 7-1, and discussed below. Five basic task divisions were identified: Two-Hand Data, Precise Hand Movement Data, Precise Force Data, Impulse and Sustained Force Data and Torque Data. The sixth format illustrated was used to tabulate task-time data. These divisions were established mainly for ease of analysis and consistency of computational techniques required. For each of the five categories, a computer program was written to permit analysis on the GE-605 Desk-Side Time-Shared (DSTS) computer system. This method of analysis allows the experimenter to use the data bank in a "conversational mode", combining various data points in ways that permit comparisons about performance parameters across different combinations of experimental conditions.

7.1.1 DATA PREPARATION

The first six columns of the data formats (Figure 7-1) contain the same descriptive and identification data for all tasks. These columns contain integer digits which indicate the experimental conditions under which the associated data point was collected. Table 7-1 presents the information and corresponding codes used in these columns.

TABLE 7-1 EXPERIMENTAL CONDITION DESCRIPTIVE CODES

COLUMN	EXPERIMENTAL CONDITION	CODES USED
1	Simulation Mode	1 = One-G 2 = KC-135 3 = Neutral Buoyancy 4 = 6 Degree-of-Freedom
2-3	Session Number	01 to 36, corresponding to session protocols
4	Subject	1 = Subject 1 2 = Subject 2
5	Suit	1 = Shirtsleeve 2 = Apollo Block II (A7L) 3 = Advanced Extravehicular Suit (AES)
6	Restraint	1 = Waist Tether 2 = Dutch Shoes 3 = Waist and Shoes

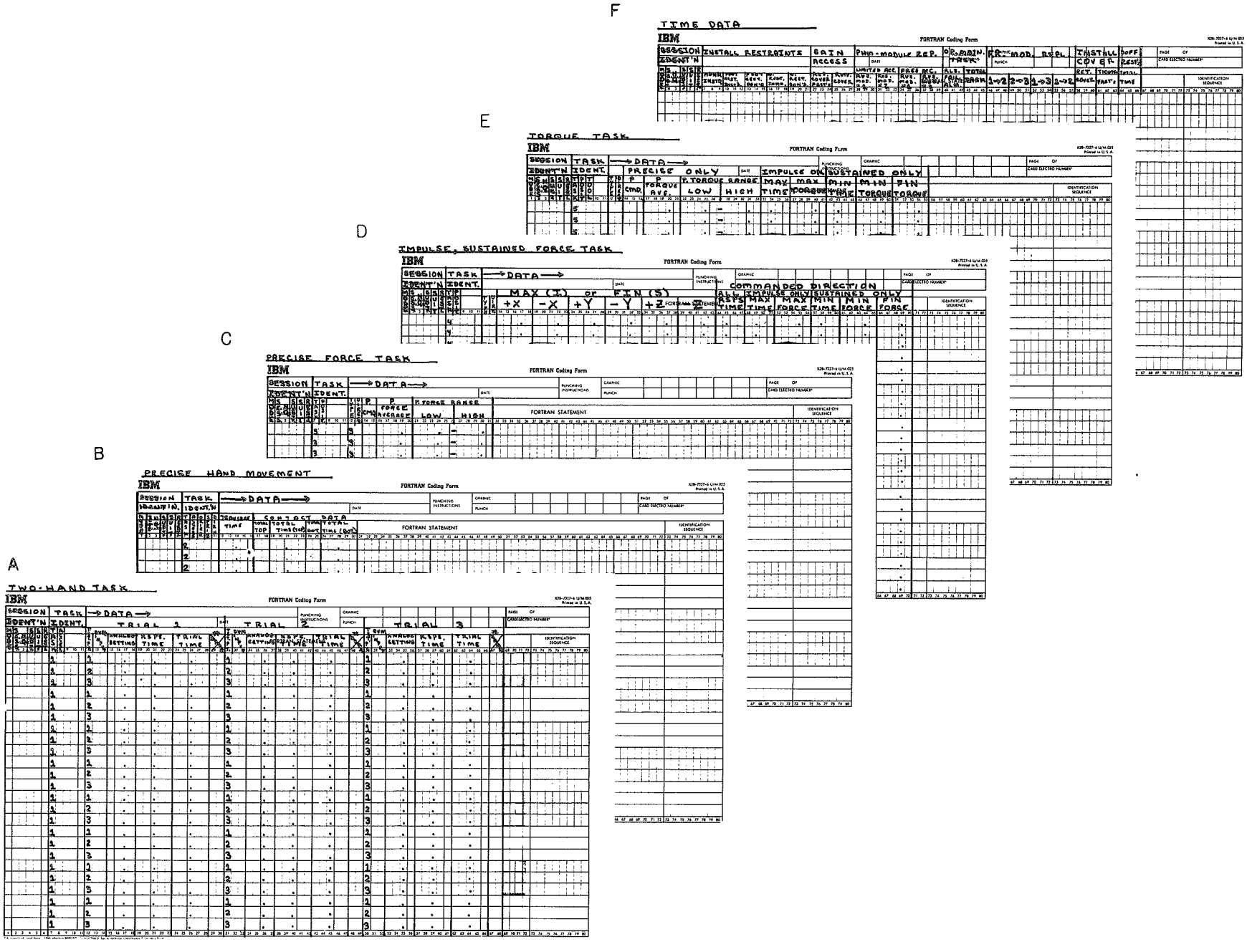


FIGURE 7-1 DATA FORMATS

7.1.1 DATA PREPARATION (Continued)

Thus, every data point collected in the program is identified by its corresponding experiment conditions and can be readily traced to its originating session.

The next five columns of the data formats contain additional identifying information that is applicable to a particular task. Thus column 7 contains a digit identifying the data as belonging to one of the five major task divisions identified above. Columns 8 through 11 (not all of which are always used) identify such experimental conditions as access condition, force receiver position, etc. Table 7-2 presents the information and coding used for these columns.

The remaining columns contain the actual values of the data entries. The mechanics of obtaining these entries are described below for each of the six format sheets.

7.1.1.1 Two-Hand Task

The Two-Hand Task is always performed in a block of nine trials -- 3 trials for each test point. Thus, the data format in Figure 7-1A was structured so that each line contained data from the three trials of a particular test point. The test point was identified in columns 12, 31, and 50 by a one-digit number, where "1" was used for the male test point, "2" for the female test point, and "3" for the solder point. The remaining entries for each test point were obtained from the traces of Figure 6-2 in Section 6 as follows:

DVM INPUT - Determined from the amplitude of signal 2.

ANALOG SETTING - Determined from the amplitude of signal 3.

RESPONSE TIME - Determined from the difference in duration of signals 1 and 6.

TRIAL TIME - Determined from the duration of signal 1.

NUMBER OF BREAKS - Determined by counting the pulses of signal 4.

Approximately 1050 trials were recorded for the Two-Hand Task.

7.1.1.2 Precise Hand Movement

In the original experiment definition, measures for the Precise Hand Movement Task included a position profile indicating where contacts occurred. However, due to technical difficulties with the spring displacement signals during neutral buoyancy and KC-135 testing, this data was available for only two modes. Thus, contact data was recorded only by totals, using the format of Figure 7-1B. The entries in columns 12 through 30 were obtained from the traces of Figure 6-3 as follows:

TABLE 7-2 TASK CONDITION DESCRIPTIVE CODES

TASK	COLUMN	EXPERIMENT CONDITION	CODES USED
All	7	Task Name	1 = Two Hand Task 2 = Precise Hand Movement Task 3 = Precise Force Task 4 = Sustained and Impulse Force Task 5 = Torque Task
Two-Hand-Task	8	Access Condition	1 = Free Access 2 = Limited Access
Precise Hand Movement	8	Access Condition	1 = Free Access 2 = Limited Access
	9	Module Orientation	1 = Springs Left 2 = Springs Right
	10	Spring Tension	1 = 1.25 lbs. 2 = 2.50 lbs. 3 = 5.00 lbs.
	11	Traverse Direction	1 = First Half 2 = Second Half
Precise Force	8	Force Receiver Position	1 = Center 2 = Upper Right
Sustained, Impulse Force	8	Force Receiver Position	1 = Center 2 = Upper Right
Torque	8	Force Receiver Position	1 = Center 3 = Lower Left
	9	Tool	1 = L-Handle 2 = T-Handle

7.1.1.2 Precise Hand Movement (Continued)

TRAVERSE TIME - Duration of 5V-signal and duration of 2.5V signal, from signal 4, depending upon traverse direction.

TOTAL TOP CONTACTS - Determined by counting the pulses of signal 5.

TOTAL TIME (TOP) - Determining by measuring and adding widths of pulses of signal 5.

TOTAL BOTTOM CONTACTS - Determined by counting the pulses of signal 7.

TOTAL TIME (BOTTOM) - Determined by measuring and adding widths of pulses of signal 7.

Approximately 1300 trials were recorded for the Precise Hand Movement Task

7.1.1.3 Precise Forces

Figure 7-1C shows the format used to record data for Precise Force Trials. Column 12 contains a redundant identifier indicating a Precise-type force. Column 13 is used to indicate the direction of the force according to the code of Table 7-3. The remaining data entries are determined from the traces of Figure 6-6:

PRECISE COMMAND - Determined from the amplitude of signal 2.

PRECISE FORCE AVERAGE - An average of six points taken every .5 seconds, over the last 2.5 seconds of the commanded direction force output.

PRECISE FORCE RANGE - The highest and lowest of the six points included in the Precise Force Average.

Approximately 650 Precise Force trials were recorded.

TABLE 7-3

FORCE/TORQUE TYPE AND DIRECTION CODES

Force/Torque Type (Column 12)	CODE
Impulse	1
Sustained	2
Precise	3

Force Direction (Column 13)	CODE
+X Pull	1
-X Push	2
+Y Right	3
-Y Left	4
+Z Up	5
-Z Down	6

Torque Direction (Column 13)	CODE
Clockwise	1
Counterclockwise	2

7.1.1.4 Sustained and Impulse Forces

Sustained and Impulse Forces were combined on one data sheet because of the similarity of computational techniques and because a computer and programming savings results from the combination. Figure 7-1D illustrates the format used. Columns 12 and 13 designate the force type and direction being recorded as described in Table 7-3. The remaining column entries are as follows:

MAX (I) - In the case of impulse forces, a time-slice is taken through the commanded direction and two error axes at a point in time when the maximum force in the commanded direction occurs. The commanded direction is scanned for four seconds to find the peak -- the 2-second command pulse plus an additional 2-seconds.

Forces are recorded, at this point, for three directions in columns 14-43.

FIN (S) - In the case of sustained forces, a slice is taken through the commanded direction and two error axes at the point in time when the cue-signal is extinguished. Forces are recorded, at this point, for three directions in columns 14-43. Note that the same columns are being used here as for MAX (I), but the code in column 12 will indicate whether the entries are for sustained or impulse forces.

RESPONSE TIME - For both sustained and impulse forces, the time from command signal "ON" until a 3 lb. force is exerted in the commanded direction is recorded as response time in columns 44-47.

MAX TIME - For impulse forces, the time from command signal "ON" until the maximum force occurs is recorded in columns 48-51.

MAX FORCE - For impulse forces, the value of the maximum force in the commanded direction is recorded in columns 52-56. (This value is actually already recorded somewhere in columns 14-43. Repeating it here provides a programming simplification).

MIN TIME - For sustained forces, the commanded direction force profile is scanned over the last 2 seconds of the 4-second command signal to find the minimum force which occurs during that time. The time (from command signal "ON") when that force occurs is recorded in columns 57-60.

MIN FORCE - For sustained forces, the minimum force which occurs during the last two seconds of the 4-second sustained force command signal is recorded in columns 61-65.

FIN FORCE - For sustained forces, the force in the commanded direction at command signal "OFF" is recorded in columns 66-70. (This value is actually already recorded somewhere in columns 14-43. Repeating it here provides a programming simplification.)

7.1.1.4 Sustained and Impulse Forces (Continued)

Approximately 1400 sustained and impulse force trials were recorded.

7.1.1.5 Precise, Sustained and Impulse Torques

Figure 7-1E illustrates the data format for the Torque Task. Because less information is recorded here than for the force task, all three types of torques can be recorded on one sheet. Columns 12 and 13 identify the torque type and direction via the code of Table 7-3. The interpretation of entries in the remaining columns is similar to the definitions given for the force task. Since only two directions are dealt with, no error data is recorded. Approximately 1400 Torque Trials were recorded.

7.1.1.6 Task-Time Data

Figure 7-1F illustrates the final data sheet which was utilized to record time data. This information was manually noted by the test director on the session protocols during performance of the experiment. The data was then transformed to the data sheet.

Columns 1-6 contain identification of experimental conditions in the same manner as all the data sheets. The remaining columns contain time data relevant to the tasks noted in the column headings.

Since the amount of data was relatively small, analysis of task-time data was performed manually.

7.2 COMPUTATION PROCEDURES

Conversion of the information contained on the data sheets to useful performance measures was accomplished by writing separate computer programs for each of the five data divisions, plus a sixth routine which is used to set input conditions for the analysis. The data was transferred to punched cards and then to permanent disc storage on the GE-605 Desk-Side Time-Sharing System. The programs provide the analyst with the capability to select the desired task and to average data points across different combinations of subjects or simulation modes or other experiment variables.

Regardless of the task being analyzed, the user is always first asked to set the condition for selection of data points. Table 7-4 illustrates a typical "conversation" between the 605 computer and the user. The system requests the necessary input and the user responds with a single code (responses are underlined in Table 7-4). This input is used to indicate to the program what data points are to be averaged together.

TABLE 7-4

ANALYSIS PROGRAM-INPUT ROUTINE

TASK NO., TASK NAME = 5, TORQTASK(R)

NO. MODES, MODES = 4,1,2,3,4(R)

NO. SUBJECTS, SUBJECTS = 2,1,2(R)

NO. SUITS, SUITS = 2,1,2,3(R)

NO. RESTRAINTS, RESTRAINTS = 3,1,2,3(R)

(R) - teletype carriage return

7.2 COMPUTATION PROCEDURES (Continued)

In the example shown, the user is requesting analysis of data collected in the Torque Emission Task. He has chosed to average all data for this task, combining across all four simulation modes, both subjects, all three suit conditions, and all three restraint conditions.

The program will continue by requesting additional input information pertinent only to the Torque Emission Task. The measures defined in Section 5.8.2 for this task will be computed and printed for study. The system then will permit the user to change any number of input conditions to new values and print the results. In this way, the analyst could for example, study differences in performance parameters as a function of different simulation modes, or suits, or some other condition.

The special input needed and the output provided for each task are discussed below.

7.2.1 TWO HAND TASK

The only additional parameter needed for analysis of Two Hand Task data is definition of the desired access condition -- free access or limited access. These choices are mutually exclusive in that data from one access condition cannot be averaged with data from the other condition. The user does have the option, however, of specifying that both access conditions be computed and printed, rather than specifying one condition, waiting, and then specifying the second condition.

A sample printout for this task is given in Figure 7-2. The first six lines indicate request for input. The output begins with a header identifying the conditions that describe the data presented. Measures are listed by test point type ("M", "F", or "S"), and include the means, ranges and number of data points found. "TRIAL TIMES" indicate the total time to perform three trials on

```
TASK NO.,TASKNAME=1,THDTASK

NO. MODES,MODES=1,1

NO. SUBJECTS,SUBJECTS=2,1,2

NO. SUITS, SUITS=1,2

NO. RESTRAINTS,RESTRAINTS=1,3

ACCESS CONDITION=0


MODE      : 1-G ,
SUBJECT   : 1,2,
SUIT      : A7L,
RESTRAINT: W&S,

 ACCESS CONDITION: FREE

         TRIAL TIMES              RESPONSE TIMES              SETTING ERRORS
   MEAN      RANGE       N    MEAN      RANGE       N    MEAN  RANGE     N  ZEROES
M 39.44 34.51-50.35     4    3.46   2.10- 5.15     7   0.53  0. -1.0    12     2
F 37.98 30.40-50.53     4    3.23   1.25- 6.65     9   0.52  0. -1.0    12     1
S 42.50 32.10-53.50     4    3.22   1.50- 5.35    12   0.54  0. -2.0    12     3


MODE      : 1-G ,
SUBJECT   : 1,2,
SUIT      : A7L,
RESTRAINT: W&S,

 ACCESS CONDITION: LIMITED

         TRIAL TIMES              RESPONSE TIMES              SETTING ERRORS
   MEAN      RANGE       N    MEAN      RANGE       N    MEAN  RANGE     N  ZEROES
M 39.02 36.80-40.60     3    3.88   2.20- 6.70     3   0.48  0. -1.5     9     3
F 44.73 38.53-51.95     5    4.41   2.60- 8.65    14   0.41  0. -1.0    15     4
S 44.21 38.28-55.25     3    3.53   2.05- 5.35     8   0.52  0. -1.5     9     2


 WISH TO CHANGE CONDITIONS? YES OR NO=NO
```

FIGURE 7-2 SAMPLE PRINTOUT - TWO HAND TASK

one test point, whereas "RESPONSE TIMES" are recorded individually by test point. All time values are in seconds. "SETTING ERRORS" computes the absolute value of the difference between the analog setting and the digital command. Means and ranges of these errors are computed and displayed. The column marked "ZEROES" indicates the number of times the subject exactly matched the command value.

If the analyst should desire to compute additional information, he may answer the request "WISH TO CHANGE CONDITIONS? YES OR NO=" with "YES". The program will then allow the user to change whatever input conditions he desires.

7.2.2 PRECISE HAND MOVEMENT TASK

Two additional inputs are required for computation of data collected from the Precise Hand Movement Task. As in the Two Hand Task, the access condition must be specified. In addition, the module orientation (springs left vs. springs right) must be dictated. It is not possible to average data across these variables. It is possible, however, to command the program to automatically cycle through all combinations of these conditions, thereby eliminating the need for supplying new input for every desired run.

Figure 7-3 presents typical output for this task. Data are listed by spring type and by direction of traversal. Direction 1 implies movement from the start of the trial to the far end of the path. Direction 2 implies movement from the far end back to the beginning of the path. Traverse times (in seconds) and contact data (absolute number of contacts and time spent in contact as a percentage of traverse time) are presented by spring direction and also for the total trial.

7.2.3 PRECISE FORCE TASK

When analyzing the Precise Force Task, the user must specify the desired position (center or upper right). Once again, the option of selecting <u>both</u> positions exists. Figure 7-4 illustrates typical output for this task where this option has been exercised.

Data consists of the mean absolute deviation from the command value, computed by comparing the average force emitted with the command value. The range of force values presents the lowest and highest force values that went into the computation of the average force. This range is <u>not</u> the range of average forces. All data are in pounds.

```
 TASK NO.,TASKNAME=2,PHMTASK

 NO. MODES,MODES=1,4

 NO. SUBJECTS,SUBJECTS=2,1,2

 NO. SUITS, SUITS=1,1

 NO. RESTRAINTS,RESTRAINTS=1,1

 ACCESS CONDITION=0

 ORIENTATION=0


MODE       : 6DOF,
SUBJECT    : 1,2,
SUIT       : SS ,
RESTRAINT: W  ,

 ACCESS CONDITION: FREE
 ORIENTATION     : SPRINGS LEFT
```

SPRING TENSION,LBS	DIRN	TRAVERSE TIME MEAN	RANGE	N	TOP CONTACTS MEAN NO. OF	% TIME IN CON.	BOT CONTACTS MEAN NO. OF	% TIME IN CON.
1.25	1	5.90	5.45- 6.35	2	1.50	6.36	1.00	3.98
1.25	2	4.95	4.75- 5.15	2	1.50	3.03	2.00	15.76
1.25	TOTAL	10.85		2	3.00	4.84	3.00	9.35
2.50	1	5.65	4.55- 6.75	2	0.50	1.77	3.00	8.76
2.50	2	4.69	4.24- 5.15	2	1.00	7.45	1.50	11.40
2.50	TOTAL	10.34		2	1.50	4.35	4.50	9.96
5.00	1	6.87	6.25- 7.50	2	1.00	1.45	2.50	4.73
5.00	2	5.20	5.00- 5.40	2	3.50	18.08	1.50	10.38
5.00	TOTAL	12.07		2	4.50	8.61	4.00	7.16

```
MODE       : 6DOF,
SUBJECT    : 1,2,
SUIT       : SS ,
RESTRAINT: W  ,

 ACCESS CONDITION: FREE
 ORIENTATION     : SPRINGS RIGHT
```

SPRING TENSION,LBS	DIRN	TRAVERSE TIME MEAN	RANGE	N	TOP CONTACTS MEAN NO. OF	% TIME IN CON.	BOT CONTACTS MEAN NO. OF	% TIME IN CON.
1.25	1	5.27	3.60- 6.95	2	0.50	0.57	3.50	9.67
1.25	2	4.72	4.55- 4.90	2	1.00	9.10	2.50	8.57
1.25	TOTAL	10.00		2	1.50	4.60	6.00	9.15
2.50	1	5.75	5.20- 6.30	2	1.50	3.39	1.50	1.13
2.50	2	4.45	4.40- 4.50	2	1.50	14.04	3.00	10.00
2.50	TOTAL	10.20		2	3.00	8.04	4.50	5.00
5.00	1	6.30	6.00- 6.60	2	2.00	2.70	2.00	4.05
5.00	2	4.90	4.75- 5.05	2	2.00	15.61	0.50	0.71
5.00	TOTAL	11.20		2	4.00	8.35	2.50	2.59

FIGURE 7-3 SAMPLE PRINTOUT - PRECISE HAND MOVEMENT TASK

```
TASK NO.,TASKNAME=3,PFTASK

NO. MODES,MODES=2,1,4

NO. SUBJECTS,SUBJECTS=2,1,2

NO. SUITS, SUITS=1,1

NO. RESTRAINTS,RESTRAINTS=1,3

POSITION NO.=0


MODE      : 1-G ,6DOF,
SUBJECT   : 1,2,
SUIT      : SS ,
RESTRAINT: W&S,

 FORCE RECEIVER POSITION: CENTER

                    MEAN ABS. DEV.          RANGE OF
       COMMAND        FROM CMD.     N     FORCE VALUES
PULL     18             4.90        6       4.6- 21.7
PUSH     18             2.15        6       7.1- 27.6
RT.      11             1.70        6      11.5- 15.2
LEFT     11             0.85        6       9.6- 14.0
UP       24             1.55        6      18.0- 25.4
DOWN     24             1.57        6      17.4- 29.4

MODE      : 1-G ,6DOF,
SUBJECT   : 1,2,
SUIT      : SS ,
RESTRAINT: W&S,

 FORCE RECEIVER POSITION: UPPER RIGHT

                    MEAN ABS. DEV.          RANGE OF
       COMMAND        FROM CMD.     N     FORCE VALUES
PULL     18             4.47        6       7.8- 18.6
PUSH     18             4.45        6       6.2- 21.1
RT.      11             3.32        6      10.2- 21.1
LEFT     11             0.77        6       9.9- 13.6
UP       24             1.48        6      15.5- 25.1
DOWN     24             1.47        6      18.6- 27.3

WISH TO CHANGE CONDITIONS? YES OR NO=YES
```

FIGURE 7-4 SAMPLE PRINTOUT - PRECISE FORCE TASK

7.2.3 PRECISE FORCE TASK (CONTINUED)

Although data from more than one restraint condition may be averaged together, the resulting printout may be very suspicious because different restraints had different command values associated with them. For example, if data from the shoe restraint and from the waist and shoe restraint conditions were averaged, the following result could occur for the Pull direction:

	COMMAND	MEAN ABS. DEV. FROM CMD.	N	RANGE OF FORCE VALUES
PULL	5	3.21	12	2.2-24.3

The high value of force (24.3 lbs.) appears highly unreasonable for a command of 5 lbs. The problem arises from the fact that 5 lbs. is the command value for the shoe restraint, whereas the command value for the waist and shoe combination is 18 lbs. The value "24.3" was associated with this higher command. As long as the analyst is aware of this problem, interpretation of the results is straightforward.

7.2.4 SUSTAINED AND IMPULSE FORCE TASK

The output for this task is illustrated in Figure 7-5. Data consists of the means and ranges of three force measures as defined in section 7.1.1.4. In addition, the time at which the maximum impulsive force occurs and the response time are presented.

All force data is in pounds, all time data in seconds.

7.2.5 TORQUE TASK

The Torque Emission Task requires two additional inputs: position of torque receiver module (center or lower left) and tool (L-handle or T-handle). The program will, on command, cycle through the four combinations of these conditions.

The data output (Figure 7-6) consists of the same measures computed for the Precise, Sustained and Impulse force emissions. All torque data is in in-lbs., all time data in seconds.

7.3 RESULTS AND CONCLUSIONS

The performance measures which resulted from the computation program were analyzed with three specific objectives. First, it was desired to analyze each task to determine whether or not it reliably and meaningfully differentiated between

```
 TASK NO.,TASKNAME=4,SIFTASK

 NO. MODES,MODES=1,1

 NO. SUBJECTS,SUBJECTS=2,1,2

 NO. SUITS, SUITS=1,3

 NO. RESTRAINTS,RESTRAINTS=1,3

 POSITION NO.=0


MODE      : 1-G ,
SUBJECT   : 1,2,
SUIT      : AES,
RESTRAINT: W&S,

 FORCE RECEIVER POSITION: CENTER
```

	SUSTAINED					IMPULSE		
	MIN		FIN			MAX		
	MEAN	RANGE	MEAN	RANGE	N	MEAN	RANGE	TIME N
PULL	28.5	7.8- 43.4	40.7	27.9- 55.8	5	123.5	81.2-167.4	1.39 4
PUSH	12.5	0. - 31.3	43.2	37.2- 49.6	3	82.0	70.7- 99.2	1.58 4
RT.	18.8	4.7- 32.6	46.3	40.3- 56.1	4	53.9	35.7- 83.4	1.94 4
LEFT	44.3	22.6- 57.4	60.0	44.0- 77.8	4	110.1	68.5-145.1	1.73 4
UP	54.0	35.0- 71.9	66.8	36.0- 87.8	4	97.3	82.2-114.7	1.54 4
DOWN	39.8	34.1- 49.9	72.1	41.5-105.4	4	103.9	83.4-127.4	1.88 4

	MEAN	RANGE	N
RESPONSE TIME:	1.34	0.60-2.60	48

```
MODE      : 1-G ,
SUBJECT   : 1,2,
SUIT      : AES,
RESTRAINT: W&S,

 FORCE RECEIVER POSITION: UPPER RIGHT
```

	SUSTAINED					IMPULSE		
	MIN		FIN			MAX		
	MEAN	RANGE	MEAN	RANGE	N	MEAN	RANGE	TIME N
PULL	7.0	0. - 18.3	11.5	3.1- 21.4	4	116.2	71.3-161.2	1.39 4
PUSH	8.4	0. - 15.2	25.9	22.0- 33.8	4	87.5	69.2-103.1	1.40 4
RT.	17.6	8.7- 26.4	29.9	26.4- 33.8	4	73.7	36.6-111.6	1.97 4
LEFT	36.3	23.9- 46.5	56.8	45.0- 69.4	4	124.5	95.8-145.7	1.70 4
UP	37.8	20.5- 47.3	46.8	35.3- 56.1	4	60.1	55.8- 69.4	1.70 4
DOWN	77.9	55.2- 99.2	95.2	55.5-133.3	4	112.7	83.1-143.8	1.79 4

	MEAN	RANGE	N
RESPONSE TIME:	1.47	0.70-2.50	48

```
 WISH TO CHANGE CONDITIONS? YES OR NO=NO
```

FIGURE 7-5 SAMPLE PRINTOUT - SUSTAINED & IMPULSE FORCE TASK

```
MODE      : 1-G ,KC  ,NBS ,6DOF,
SUBJECT   : 1,2,
SUIT      : SS ,A7L,AES,
RESTRAINT: S  ,

 FORCE RECEIVER POSITION: CENTER
 TOOL: L-HANDLE
```

	SUSTAINED					IMPULSE			
	MIN		FIN			MAX			
	MEAN	RANGE	MEAN	RANGE	N	MEAN	RANGE	TIME	N
CW	195.7	15.9-405.0	287.8	75.0-817.0	25	429.3	270.0-725.0	1.45	26
CCW	177.2	0. -356.0	276.0	117.5-500.0	25	310.6	95.0-515.0	1.55	25

	COMMAND	PRECISE MEAN ABS. DEV. FROM CMD.	N	RANGE OF TORQUE VALUES
CW	120	8.31	25	75.0-190.0
CCW	120	8.69	26	32.5-172.5

```
MODE      : 1-G ,KC  ,NBS ,6DOF,
SUBJECT   : 1,2,
SUIT      : SS ,A7L,AES,
RESTRAINT: S  ,

 FORCE RECEIVER POSITION: CENTER
 TOOL: T-HANDLE
```

	SUSTAINED					IMPULSE			
	MIN		FIN			MAX			
	MEAN	RANGE	MEAN	RANGE	N	MEAN	RANGE	TIME	N
CW	111.3	15.8-187.6	129.9	18.6-210.0	24	160.6	60.3-260.0	1.45	25
CCW	117.5	0. -207.5	131.6	0. -232.0	25	159.4	0. -248.0	1.26	25

	COMMAND	PRECISE MEAN ABS. DEV. FROM CMD.	N	RANGE OF TORQUE VALUES
CW	25	4.36	25	10.0- 50.0
CCW	25	8.74	22	22.5- 62.5

```
X
```

FIGURE 7-6 SAMPLE PRINTOUT - TORQUE EMISSION TASK

major experimental conditions. Second, performance measures were studied to discover any meaningful trends which, even without actual flight validation, provided useful information about the experimental conditions. Finally, performance measures were studied to discover design data suitable for inclusion in a handbook of human performance data.

To properly assess the significance of the results, the data were subjected to a statistical analysis. Non-parametric techniques were utilized for the analysis because of the small sample size involved, and because of the inability to make accurate predictions about the nature of the distributions underlying the data. The primary requirements for non-parametric analyses are that the observations be independent and that the variables have some underlying continuity. In such cases Siegel, 1956, recommends two tests of significance which were useful here. The Wilcoxon Matched Pairs Signed Ranks Test is applicable where observations corresponding to two levels of an independent variable have been collected (such as in testing whether there is a significant difference in performance between two subjects). The Friedman Two-Way Analysis of Variance is applicable where there are observations corresponding to three or more levels of an independent variable.

The main disadvantage of the above tests is that they are not influenced by the magnitude or the direction of different performances. They do not, for example, indicate whether subject 1 consistently performed "better" than subject 2, but only that the two subjects' performance was different. Subjective interpretation of performance means must therefore be used to determine the physical importance of performance differences.

Each task and its associated measures are analyzed below utilizing these techniques.

7.3.1 PRECISE HAND MOVEMENT TASK

Table 7-5 summarizes the results obtained for the Precise Hand Movement Task. The numerical entries in the table are mean scores across all experimental variables other than the variables of interest. Thus the entries under "MODES" represent averages for the different spring tensions, access conditions, orientations, subjects, and so forth.

The only measures listed in Table 7-5 are traverse time and number of contacts. Percentage time spent in contact did not provide any significant information in addition to the information provided by these two measures.

The significance of the results is summarized below for each variable:

MODES - Statistically significant different performances occurred across the four simulation modes for both the time measure (significant at the .005 level) and the accuracy measure (.01 level). The KC-135 simulation resulted in a much faster time than the other modes, a "hurry-up" phenomenon which occurred consistently across all tasks. Paradoxically, however,

TABLE 7-5

RESULTS SUMMARY - PRECISE HAND MOVEMENT

VARIABLE		TRAVERSE TIMES		NO. OF CONTACTS
MODES	1-G	14.2 Sec.		10.06
	NBS	12.5		*
	6 DOF	12.3		9.49
	KC-135	9.6		8.50
SUITS	SS	11.74		8.36
	A7L	13.34		10.56
	AES	14.36		10.38
RESTRAINTS	W	12.08		10.70
	S	13.05		9.00
	W&S	12.96		10.06
ACCESS	Free	12.59		6.84
	Lmtd.	12.94		9.86
ORIENTATION	Left	12.94		8.44
	Right	12.54		8.25
SPRINGS	1.25 Lb.	12.23		7.44
	2.50 Lb.	12.64		8.42
	5.00 Lb.	13.41		9.15
LOCATION OF CONTACTS			Top	3.67
			Bottom	4.68

* Data not recorded.

7.3.1 PRECISE HAND MOVEMENT TASK (Continued)

MODES(Continued) - the fewest number of contacts also occurred in the KC mode. This contradicts expectations, which imply that accuracy and traverse time should be inversely related. The results listed imply a direct relationship. The 1-g mode results were consistently slower and less accurate than the three 0-G simulation modes. This implies that the ability to exert precisely controlled hand movements is enhanced by the zero gravity environment when restrained at a worksite.

SUITS - Performance scores for both measures were statistically different at a .005 level of significance. Suited performance was 18% slower and 25% more inaccurate than shirtsleeve performance, representing a comparison of IVA vs. EVA performance of a dynamic, precision task. Differences in performance scores between the two suits were not large enough to be meaningful.

RESTRAINTS - Restraint differences were significant at a .05 level for traverse times and a .005 level for contacts. However, for both measures, the magnitude of the difference is less than 10%. This probably results from the fact that when the limited access panel is in place, subjects had to use the handhold for support. They were, therefore, instructed to use the handhold when the access condition was free(to permit comparison). As a result the restraints here are not really waist, shoes, and waist and shoes, but hand and waist, hand and shoes, and hand, waist and shoes.

ACCESS - Performance differences between the two access conditions were significant at the .05 level. For traverse time, the magnitude of the difference was less than 3%. But in terms of accuracy, a 43% degradation occurred when the access was restricted. This implies a serious problem in terms of precision when an astronaut is expected to work through a small access port.

ORIENTATION - Differences in performance for the two module orientations were small (less than 3%) and considered to be not meaningful.

SPRINGS - Although a statistically significant difference in performances occurred for the three springs, the differences seem completely attributable to the increase in spring tension. No particularly meaningful information is provided by these differences.

LOCATION OF CONTACTS - More contacts occurred on the bottom of the path than on the top. This is probably simply a result of the geometry of the situation - the subject's hand blocked his view of the bottom edge - and is not considered important.

In summary, the Precise Hand Movement Task differentiated significantly and importantly between different simulation modes and between shirtsleeve and suited conditions. In addition, an important problem associated with restricted access tasks was discovered.

7.3.1 PRECISE HAND MOVEMENT TASK (Continued)

Task Recommendations: The task procedure may be simplified by

- Using only one module orientation
- Using only one spring tension

The task telemetry may be reduced to only

- Total traverse time
- Total number of contacts

Contact location or duration need not be recorded.

7.3.2 TWO-HAND TASK

Table 7-6 summarizes the results obtained for the Two-Hand Task. Again, the table entries are mean scores across all variables other than the variable of interest. The significance of the results is summarized below for each variable:

MODES - All three performance measures exhibited statistically significant differences across modes at the .005 level. As in the Precise Hand Movement Task, trial times differed greatly in the different simulation modes. The KC-135 aircraft simulation total time was not the fastest, but it was about 20% faster than either the 1-g or 6 DOF results. The differences in response times and setting errors, though large in some instances, were not felt to be of any intrinsic value. The important conclusion is that a simulation effect upon performance does exist and this task, as measured by total trial time, will denote this effect.

SUITS - Performance differences across suit conditions were statistically significant at the .01 level for trial times and setting errors and the .005 level for response times. Moving from a shirtsleeve (IVA) to a suited (EVA) condition increased trial time 30% and response time 40%. In addition, this task indicated a 10% increase in trial time and a 15% increase in response time when wearing the AES suit as opposed to the A7L suit.*

The 65% increase in the magnitude of the setting errors between the AES and the two other suit conditions reflects an important visual problem noted by the subjects. Viewing through the AES suit helmet at the downward angle required to see the voltage meter, a small visual distortion was noted by both subjects and confirmed by this data. This problem is further substantiated if this data is broken out for the two access conditions: the difference is smaller in the limited access condition (where the subject looks through the opening and therefore at a more horizontal viewing angle) than in the free access condition (where the subject looks down at about a 30-45 degree angle).

*It is important to realize that these tasks, limited only to performance at a worksite, do not really constitute a suit evaluation. Nevertheless, important performance differences that were noted deserve special mention.

TABLE 7-6

RESULTS SUMMARY - TWO-HAND TASK

VARIABLE		TRIAL TIMES	RESPONSE TIMES	SETTING ERRORS*
MODES	1-G	36.7 Sec.	3.39 Sec.	.77
	NBS	21.9	2.32	1.09
	6 DOF	35.8	3.41	1.28
	KC-135	29.1	2.96	.65
SUITS	SS	28.6	2.56	.80
	A7L	35.6	3.32	.77
	AES	38.3	3.89	1.29
RESTRAINTS	W	32.7	3.21	1.11
	S	33.6	3.21	.93
	W&S	32.3	3.05	.83
ACCESS	Free	32.2	3.09	.97
	Lmtd.	33.4	3.21	.84
TEST POINTS	M	31.0	3.01	.88
	F	33.1	3.35	.90
	S	35.0	3.09	.95

*Mean absolute deviation from command.

7.3.2 TWO-HAND TASK (Continued)

RESTRAINTS - The three measures noted did not reveal any important differences regarding the three restraint conditions. Apparently, for a static task of this nature, any relatively stable, one-point restraint is satisfactory.

ACCESS - No important performance differences were noted for this variable. The limited access condition did not degrade performance for this static test of accuracy as it did in the dynamic accuracy required by the Precise Hand Movement Task.

TEST POINTS - Some minor performance differences can be noted for the three different test points, but they were not felt to be of any important value.

In summary, the Two-Hand Task differentiated significantly and importantly between different simulation modes and between shirtsleeve (IVA) and suited (EVA) conditions. In addition, for a precision, static task, it was discovered that a relatively stable one-point restraint of any type is satisfactory, and that the existence of a restricted access (similar to the restriction used in this experiment) does not degrade performance of such a task.

Task Recommendations: The experiment procedure may be simplified by:

- Using only one test point.

Although further simplification can be gained by using only one restraint condition and one access condition, it is recommended that these variables be retained. They are necessary for other tasks and therefore represent no real increase in complexity for this task. The time savings in their deletion would be small (only about 1 minute per session) and their retention would allow a chance to confirm the findings here concerning performance of static, precision tasks.

The task telemetry may be simplified by eliminating:

- Number of broken contacts.
- Duration of broken contacts.

These measures provided no meaningful information.

7.3.3 PRECISE FORCE TASK

Table 7-7 summarizes the results of the Precise Force Task. The table entries have the usual interpretation and represent the mean absolute deviation of the average force exerted from the commanded force.

There is a critical assumption that should be noted when data from different restraint conditions and different force directions are averaged together. Since the commanded value for these different conditions vary, it is assumed that the

TABLE 7-7

RESULTS SUMMARY - PRECISE FORCE TASK

VARIABLE		MEAN ABS. DEV. FROM CMD.
MODES	1-G	1.56 Lbs.
	NBS	3.40
	6 DOF	2.31
	KC-135	4.59
SUITS	SS	2.91
	A7L	2.50
	AES	2.88
RESTRAINTS	W	4.86
	S	2.03
	W&S	2.74
POSITIONS	Center	2.52
	Upper Rt.	3.08

7.3.3 PRECISE FORCE TASK (Continued)

three commands present about the same level of stress and complexity to the subjects. This is a reasonable assumption, since the values were selected from previously-collected force emission data using the same selection criteria for each combination of restraint and force direction. The assumption, of course, can not really be verified.

The results are summarized below for each major experimental condition:

MODES - Performance differences were statistically significant at a very high level (.005). There was a very large degradation (3 to 1) in precision force emission capability in the KC simulation compared to the 1-G simulation.

SUITS - No statistical or practical differences occurred across the different suit conditions.

RESTRAINTS - Restraint differences were significant at a .05 level. More importantly, this task indicated a phenomenon that occurred in all tasks where the restraint was critical to task performance. As expected, the waist restraint was not as good a restraint as either the shoe or waist and shoe combinations. But, perhaps surprisingly, the waist and the shoe combination restraint degraded performance. That is, the scores with the waist and shoe combination restraint deviated more from the commanded value than they did for the shoe only restraint. This is not an isolated effect, as it occurred in all force and torque tasks. The conclusion to be drawn is that a shoe-only restraint is more effective than when it is combined with this particular waist restraint, even though the latter represents a two-point body-anchoring system.

POSITIONS - A 20% performance degradation occurred when the force receiver was moved from the center to the upper right position. While this alone is not indicative of any problems with the major experimental variables, it does provide objective quantification of a useful performance parameter.

Interestingly, the performance degradation was well over 20% in the waist and waist and shoe restraint conditions, but almost negligible in the shoe restraint only condition.

In summary, the Precise Force Task differentiated significantly and meaningfully between the different simulation and restraint conditions. Once again, a simulation effect is definitely influencing performance. The inadequacy of the particular waist restraint used showed up clearly (as it will in other tasks).

Task Recommendations: No changes are recommended for this task.

7.3.4 SUSTAINED AND IMPULSE FORCE TASK

Table 7-8 summarizes the results of the sustained and impulse force task. Note that no data is reported for the KC simulation. During data analysis, the

TABLE 7-8

RESULTS SUMMARY - SUSTAINED, IMPULSE FORCE TASK

VARIABLE		SUSTAINED(FIN)	IMPULSE(MAX)
MODES	1-G	53.4 Lbs.	89.1 Lbs.
	NBS	26.0	86.4
	6 DOF	29.2	66.6
	KC-135	---	---
SUITS	SS	38.1	89.1
	A7L	42.8	88.9
	AES	38.8	84.1
RESTRAINTS	W	18.4	75.0
	S	41.3	91.8
	W&S	46.4	88.9
POSITIONS	Center	43.1	91.1
	Upper Rt.	36.0	84.8

7.3.4 SUSTAINED AND IMPULSE FORCE TASK (Continued)

average forces for this mode were discovered to be 50% higher than for the 1-G mode (inconsistent with the pattern displayed by the other modes) and almost twice as high as the average forces recorded in the other zero-g simulations. Although it could not be checked, the data were rejected on the assumption that the flight recorder was not functioning properly. It is entirely plausible to assume that this data is unreliable while still accepting the data for the precise force trials and for the torque trials (which were not at all consistent with the behavior of this data). In these cases, the force and torque emissions would correspond to the lower 1/3 of the 5-volt telemetry signal range. But in the sustained and impulse force trials the signals would correspond to the upper 1/3 of the telemetry range. If the difficulty in this task were associated with recorder malfunction at the higher voltages, it would be noticed only in this task. Most other telemetry consists of the "ON-OFF" type of signal where the height of the signal is of no concern.

Because of the value of force emission data to spacecraft designers and mission planners, the force data is presented in Figure 7-7.

The results are summarized below for each major experimental condition:

MODES - Performance differences across simulation modes were statistically significant at the .005 level for Sustained forces and the .01 level for Impulse forces. As should be expected, the degradation for sustained forces was much more serious than for impulse forces. The simulated zero-g modes(NBS and 6 DOF) displayed approximately a 50% reduction from the one-g sustained force emission capability. However, the degradation of impulsive force generating capability as a function of going from the one-g to the simulated zero-g mode was not nearly so severe. The almost 2-1/2 to 1 increased capability to exert impulse forces over sustained forces in the NBS and 6 DOF simulations is consistent with test results obtained from previous studies.

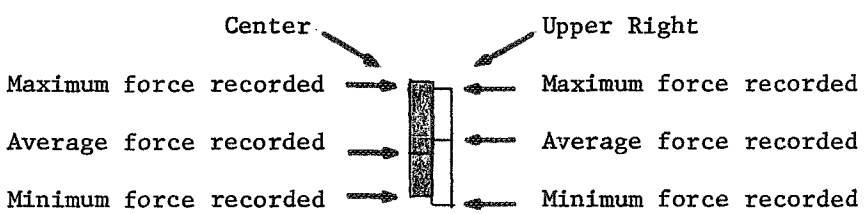
This task pointed out an interesting difficulty with 6 DOF simulation. Unlike other simulation modes, when the subject's body reacted to a force emission, not only was it necessary for him to regain control of his body, but he also had to stop the movement of the entire free-swinging 6 DOF rig. The momentum of this rig can make regaining control a difficult task. The potential result is that some part of the subject's body or the rig may collide with the supporting structure, either injuring the subject or damaging the equipment. The hypothesis here is that this potential is apparent to the subject and causes him to ease up in his task performance. Support for the hypothesis is found in a direction-by-direction comparison of impulse forces. In the right, left, up and down directions force emissions were much greater (20-50%) in NBS than in 6 DOF. In the Push-Pull directions(where body reaction is straight back and forth and where the waist restraint essentially stops backward reaction to a push force) the effect is not as noticeable. In sustained forces, where body reaction is not so violent, the effect is also not as noticeable.

INSTRUCTIONS FOR USE OF FIGURE 7-7

The next six pages contain summary data of the sustained and impulse force task. The data are presented for the one-g case and for a simulated 0-g case which consists of the average of data from the 6 DOF and Neutral Buoyancy simulations. It was deemed necessary to present average data for these two simulations since neither case alone is necessarily representative of the true 0-g situation.

The data are presented using a vertical bar-graph format, which is interpreted as follows:

FORCE RECEIVER POSITION



"Center" refers to a position where the force receiver handle is located directly in front of the subject's right nipple; "upper right" locates the handle about 15" above and 6" to the right of the center position. All other experimental conditions are clearly labeled on the chart.

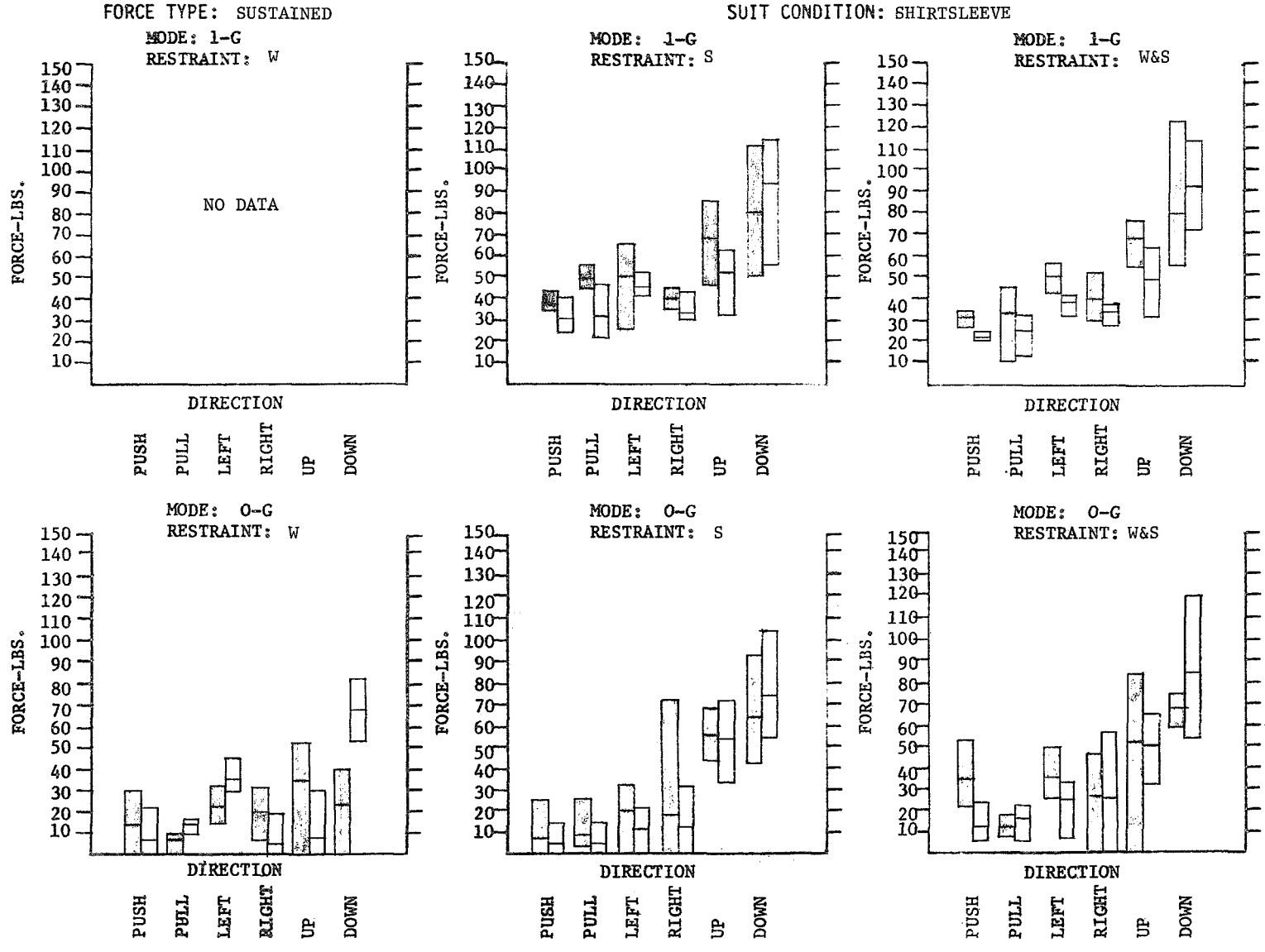


FIGURE 7-7 SUMMARY DATA CHART NO. 1

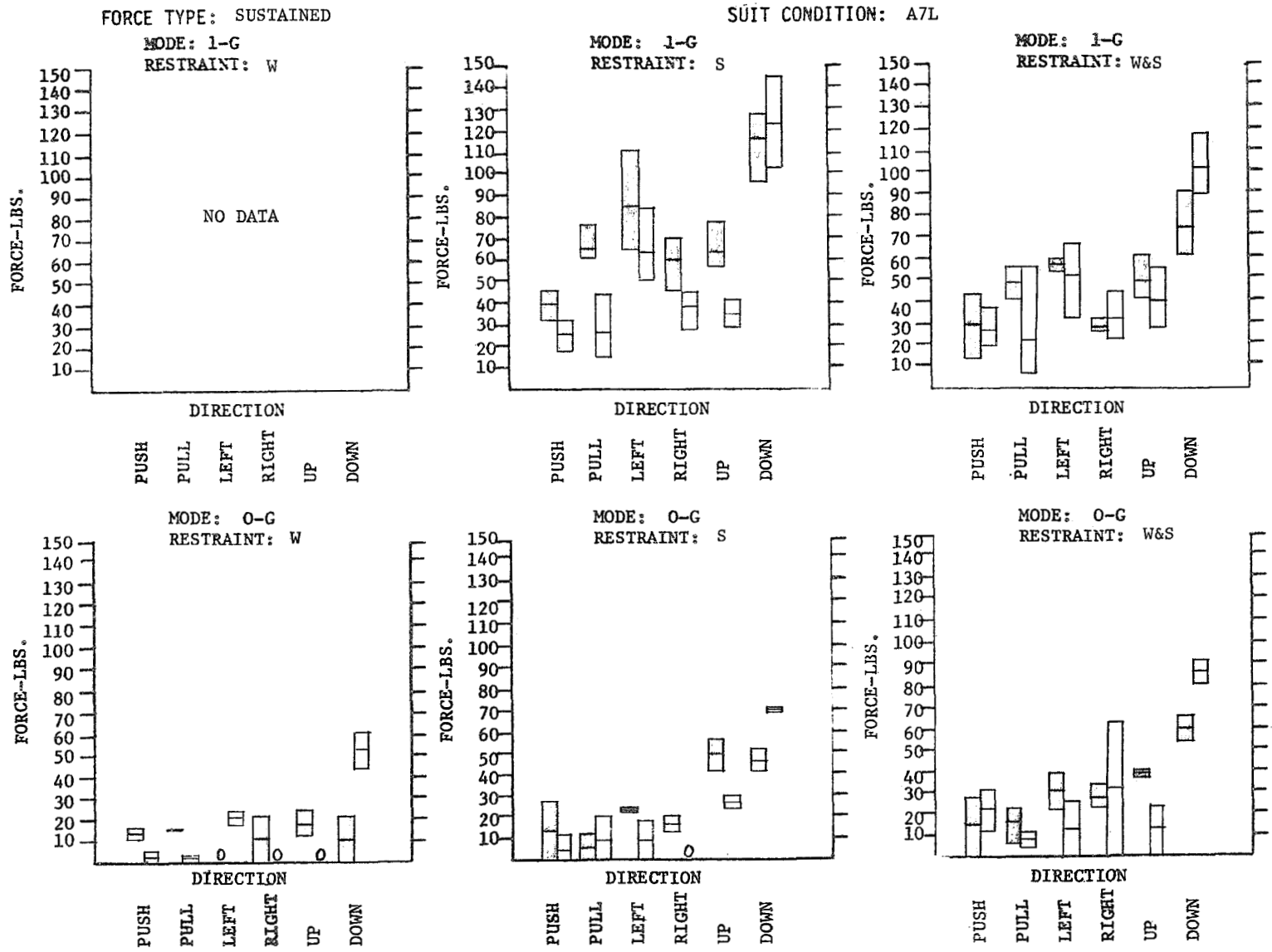


FIGURE 7-7 SUMMARY DATA CHART NO. 2

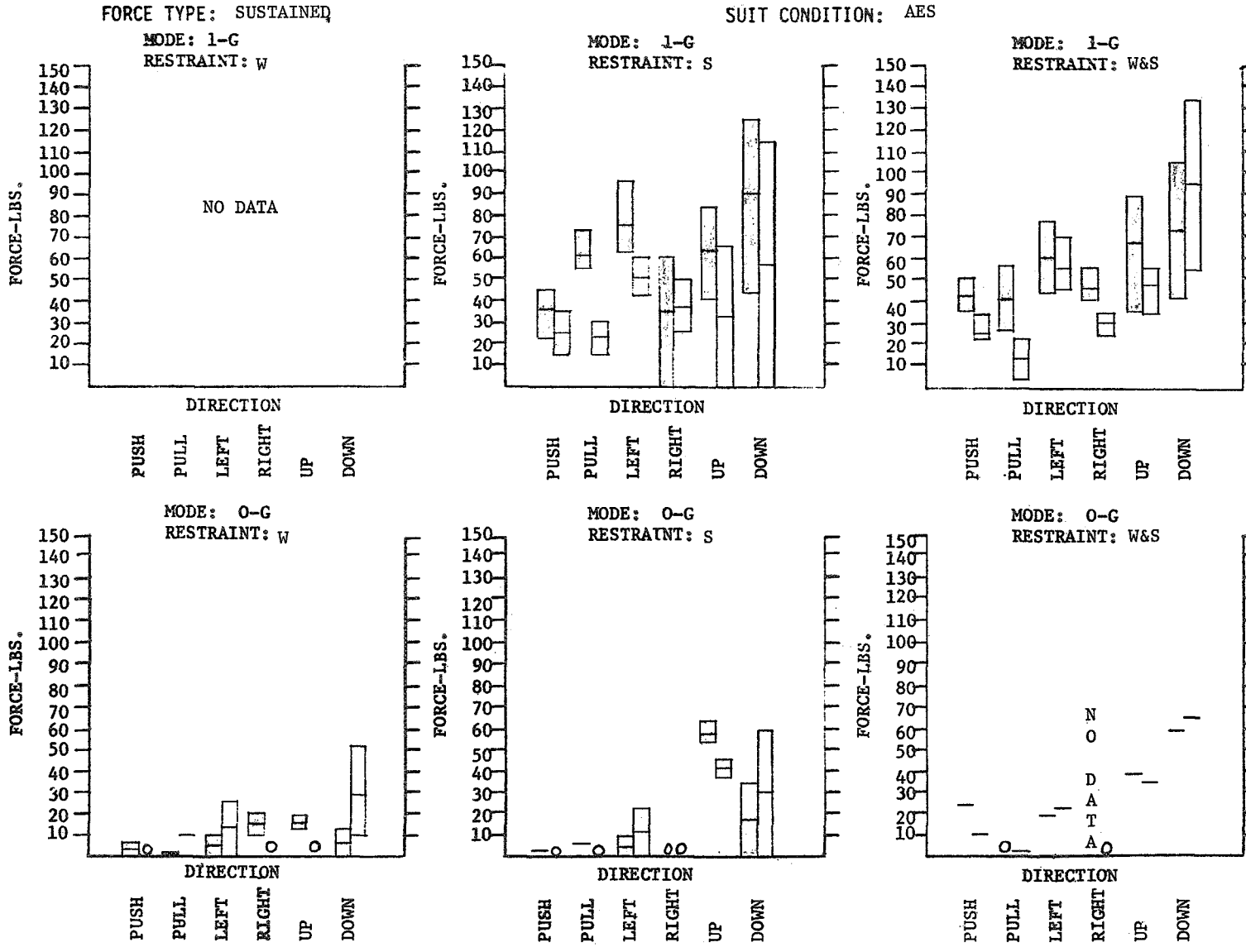


FIGURE 7-7 SUMMARY DATA CHART NO. 3

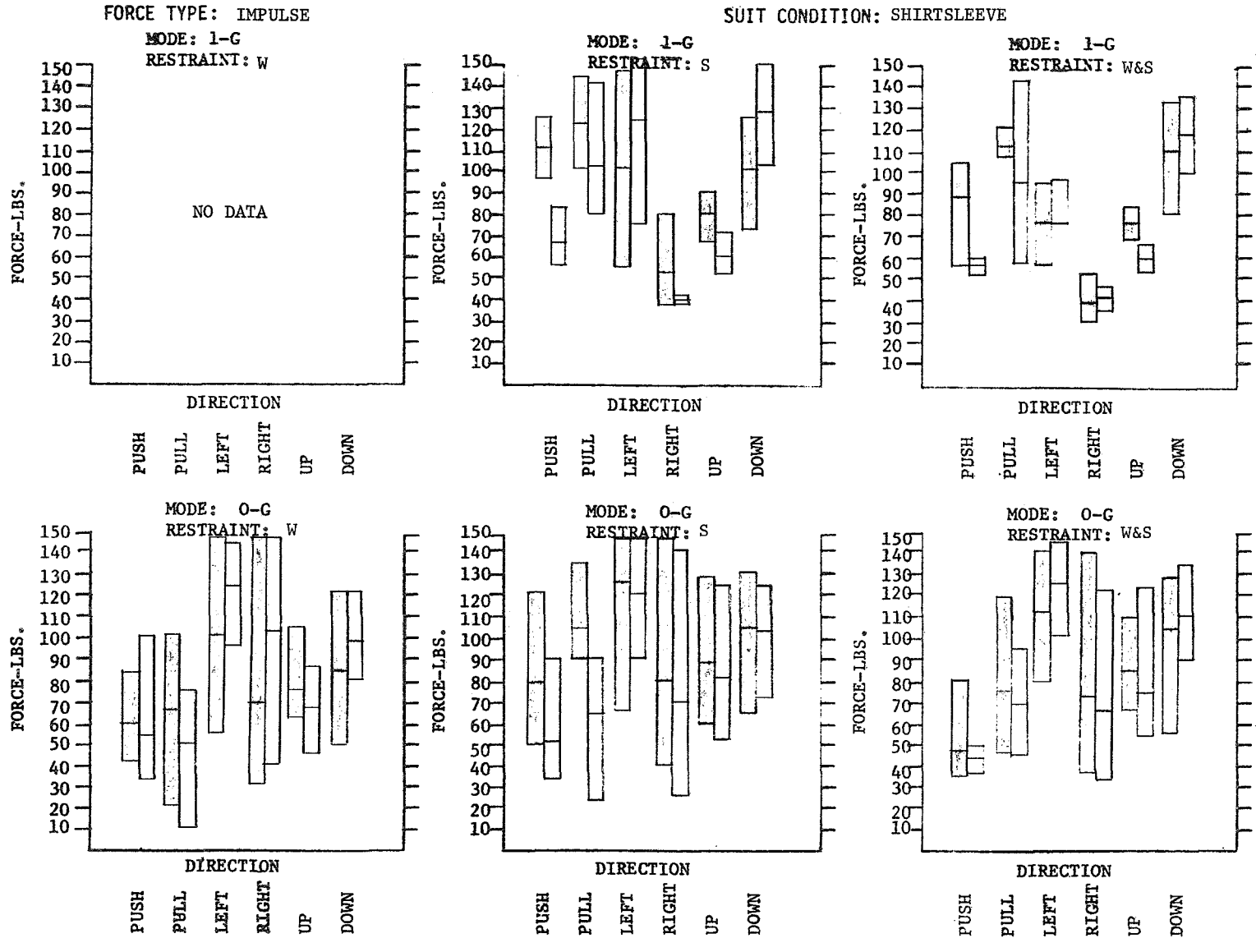


FIGURE 7-7 SUMMARY DATA CHART NO. 4

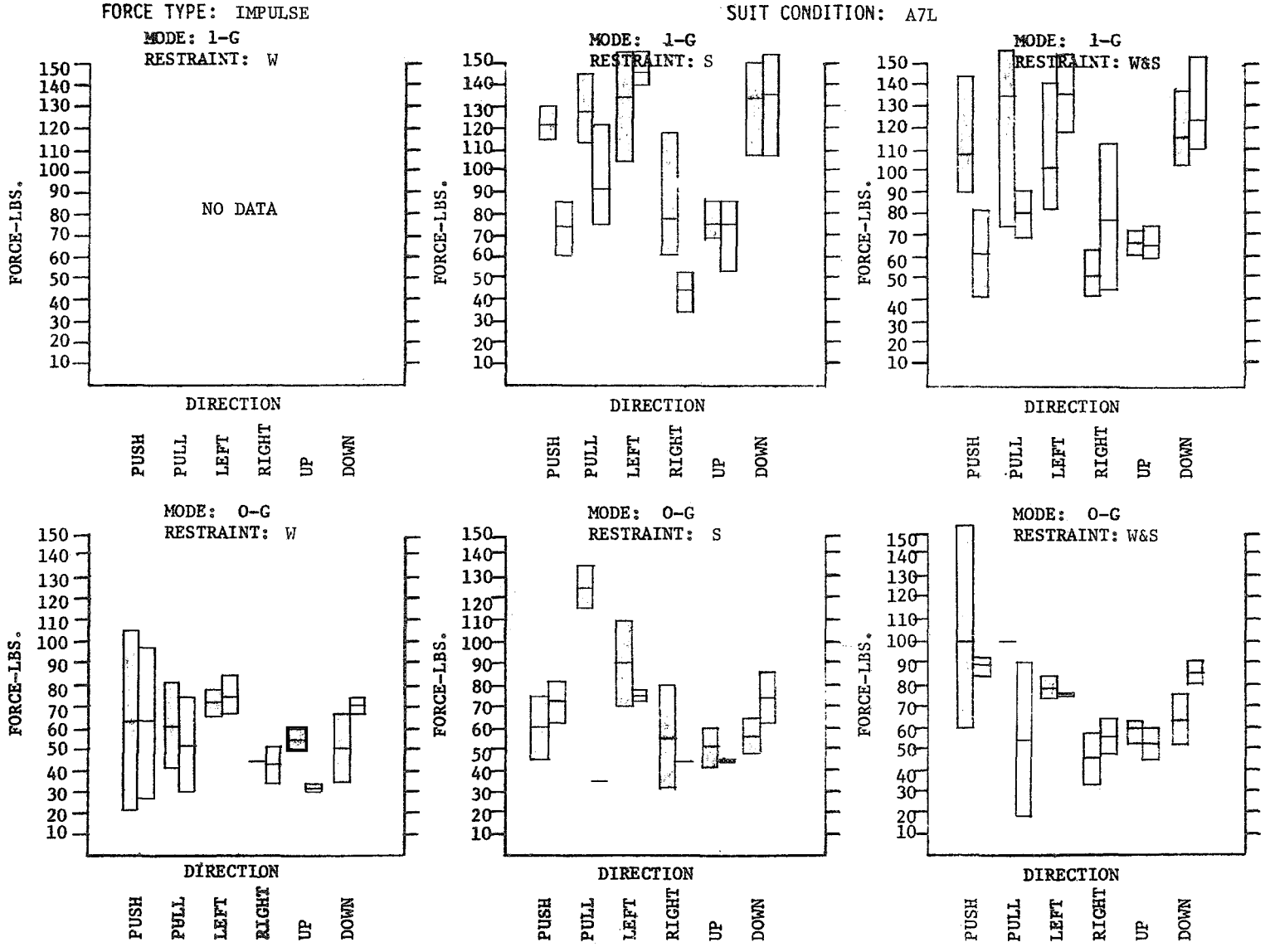


FIGURE 7-7 SUMMARY DATA CHART NO. 5

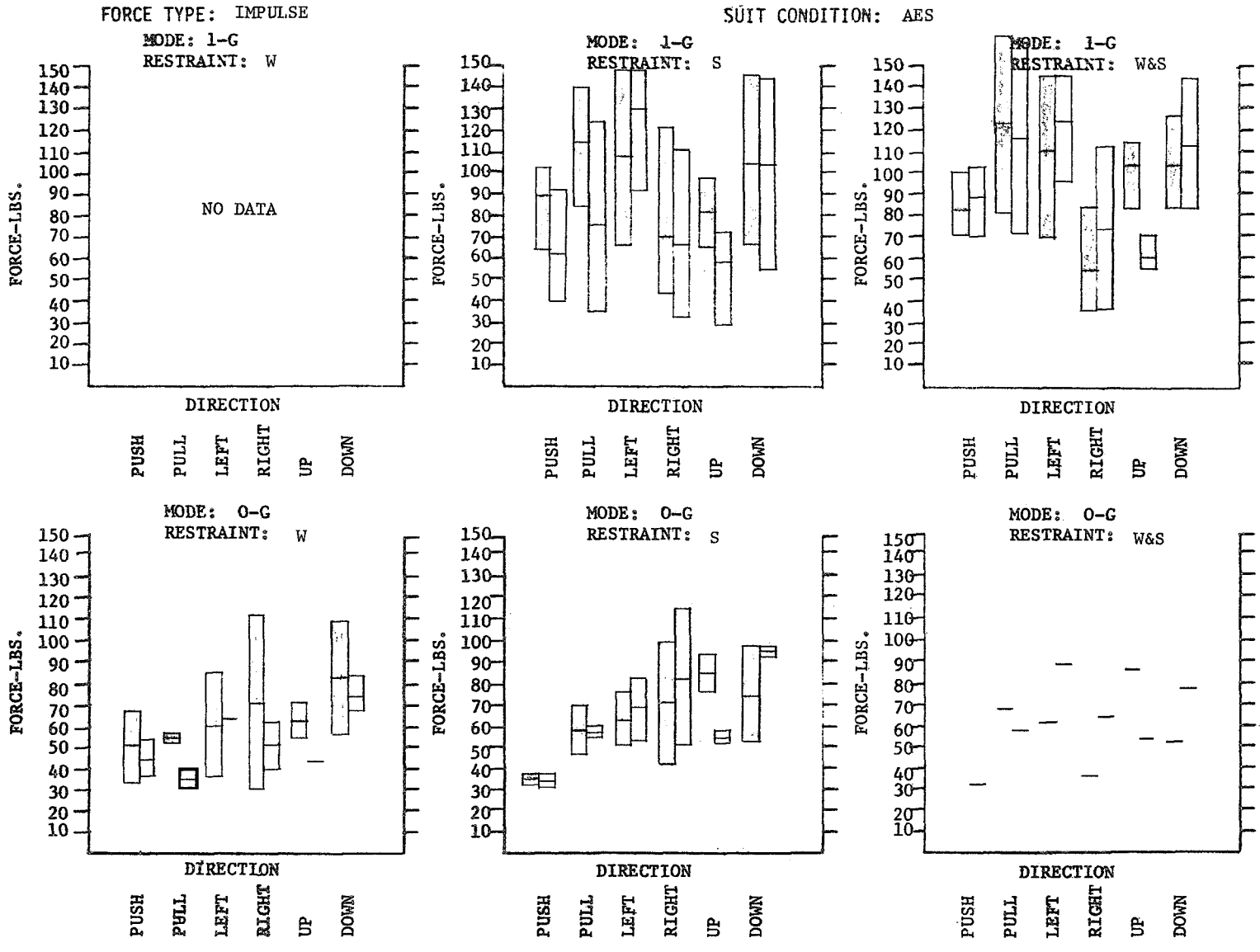


FIGURE 7-7 SUMMARY DATA CHART NO. 6

7.3.4 SUSTAINED AND IMPULSE FORCE TASK (Continued)

SUITS - Different suit conditions did not affect force emission capability.

RESTRAINTS - Performance differences were statistically significant at the .01 level for sustained forces, but not significant for impulse forces. The practical significance of these differences again indicated that the waist restraint combined with the shoe restraint results in a degradation of performance. This result did not appear in the impulse forces, where, as the statistical test shows, restraint conditions did not really affect performance.

POSITIONS - As in precise forces, a consistent performance degradation was noted when the force receiver was moved to the upper right position. These measures quantify this degradation as an astronaut works in a less-than-optimal position in the reach envelope.

In summary, this task presented further substantiation of simulation and restraint effects upon performance. An additional conclusion noted from this task was the existence of much slower (30%) response times in zero-g simulations than in the 1-g case.

Task Recommendations: No major changes are recommended for this task. It is suggested, however, that FIN (for sustained forces), MAX (for impulse forces), and response time are the only necessary measures, as other measures present only redundant or superfluous information.

7.3.5 PRECISE TORQUE TASK

The results for the Precise Torque Task are summarized in Table 7-9 and below:

MODES - Performance differences across modes were not statistically significant. However, large differences in magnitude were noted with 25 to 100% increase in deviations when going from the 1-G to the simulated zero-g modes.

SUITS - Performance differences across suits were statistically significant at the .05 level. The differences are large, but no strong conclusions can be drawn, particularly since the differences were not consistent with those found in the Precise Force Task. However, it should be noted that the mean deviations increased approximately 40% when going from the shirtsleeve to the suited conditions.

RESTRAINTS - Performance differences across restraint conditions were not statistically significant. However, once again, it is noted that the shoe restraint alone is better than the waist and shoe combination, both of which are better than the waist restraint only.

TABLE 7-9

RESULTS SUMMARY - PRECISE TORQUE TASK

	VARIABLE	MEAN ABS. DEV. FROM CMD.
MODES	1-G	7.5 In-Lbs.
	NBS	14.8
	6 DOF	9.4
	KC-135	10.3
SUITS	SS	7.8
	A7L	11.4
	AES	10.5
RESTRAINTS	W	11.0
	S	8.5
	W&S	9.9
POSITIONS	Center	8.6
	Lower Left	10.5
TOOLS	L-Handle	11.1
	T-Handle	8.0

7.3.5 PRECISE TORQUE TASK (Continued)

POSITIONS - A degradation in precise torquing performance is noted when the force receiver is moved from the center to the lower left position. This difference could not be tested statistically using the tests described previously. The large difference (approximately 20%) is probably due in part to the fact that the precise readout meter is no longer directly in front of the subject.

TOOLS - The different performance for the two tool conditions also could not be tested statistically. However, the results are not unlike what should be expected for these conditions and indicate a 40% degradation in exerting precisely controlled torques when going from a T-handle to an L-handle lever arm.

In summary, this task presented some meaningful results. However, these results add nothing to those already found in the Precise Force Task and in the other tasks. All of the experimental conditions evaluated here are evaluated elsewhere and with better reliability than this task offered.

Task Recommendations: As a result of this analysis, it is recommended that this task be dropped. This presents no hardware or telemetry savings. It reduces the experiment procedures and performance time-line by a slight amount.

7.3.6 SUSTAINED AND IMPULSE TORQUE TASK

The results of the Sustained and Impulse Torque emissions are summarized in Table 7-10. The comparative findings essentially confirm the results of the Sustained and Impulse Force Task. Data collected in both these tasks is valuable, however, first because it increases confidence in conclusions about the major experimental conditions, and second because both torque and force data are inherently valuable to spacecraft designers and mission planners. Because of this value, torque emission data is summarized in Figure 7-8.

The significance of the results for this task is discussed below:

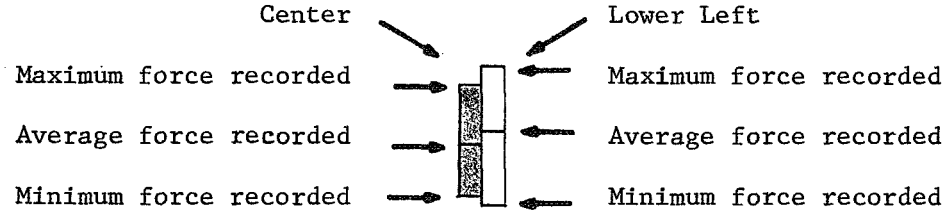
MODES - Performance differences across simulation modes were statistically significant at the .01 level for sustained torques and the .005 level for impulse torques. As in the force task, 6 DOF performance was consistently much lower than performance in the other 0-G simulation modes, lending further credence to the hypothesis that subjects tend to allow their performance to be affected by the potential dangers involved in 6 DOF simulation. It should also be noted that impulsive torquing capability is approximately 50% greater than sustained torquing capability. This finding is all the more interesting since previous studies and results have demonstrated almost a 2-1/2 to 1 ratio in favor of impulsive vs. sustained forces. Suggested here is the result that an astronaut can more closely sustain his maximum torquing capability than he can his maximum force producing capability. An additional finding is that sustained and impulsive torquing capability are relatively insensitive to different simulation modes(less than 15% variation from 1-g to the simulated 0-g modes when the 6 DOF simulation is ignored).

INSTRUCTIONS FOR USE OF FIGURE 7-8

The next six pages contain summary data of the sustained and impulse torque task. The data are presented for the one-g and for a simulated 0-g case which consists of the average of data from the KC-135, 6 DOF and Neutral Buoyancy simulations. It was deemed necessary to present average data for these three simulations since no single case is necessarily representative of the true 0-g situation.

The data are presented using a vertical bar-graph format, which is interpreted as follows:

FORCE RECEIVER POSITION



"Center" refers to a position where the force receiver handle is located directly in front of the subject's right nipple; "lower left" locates the handle about 12" below and 15" to the left of the center position. All other experimental conditions are clearly labeled on the chart.

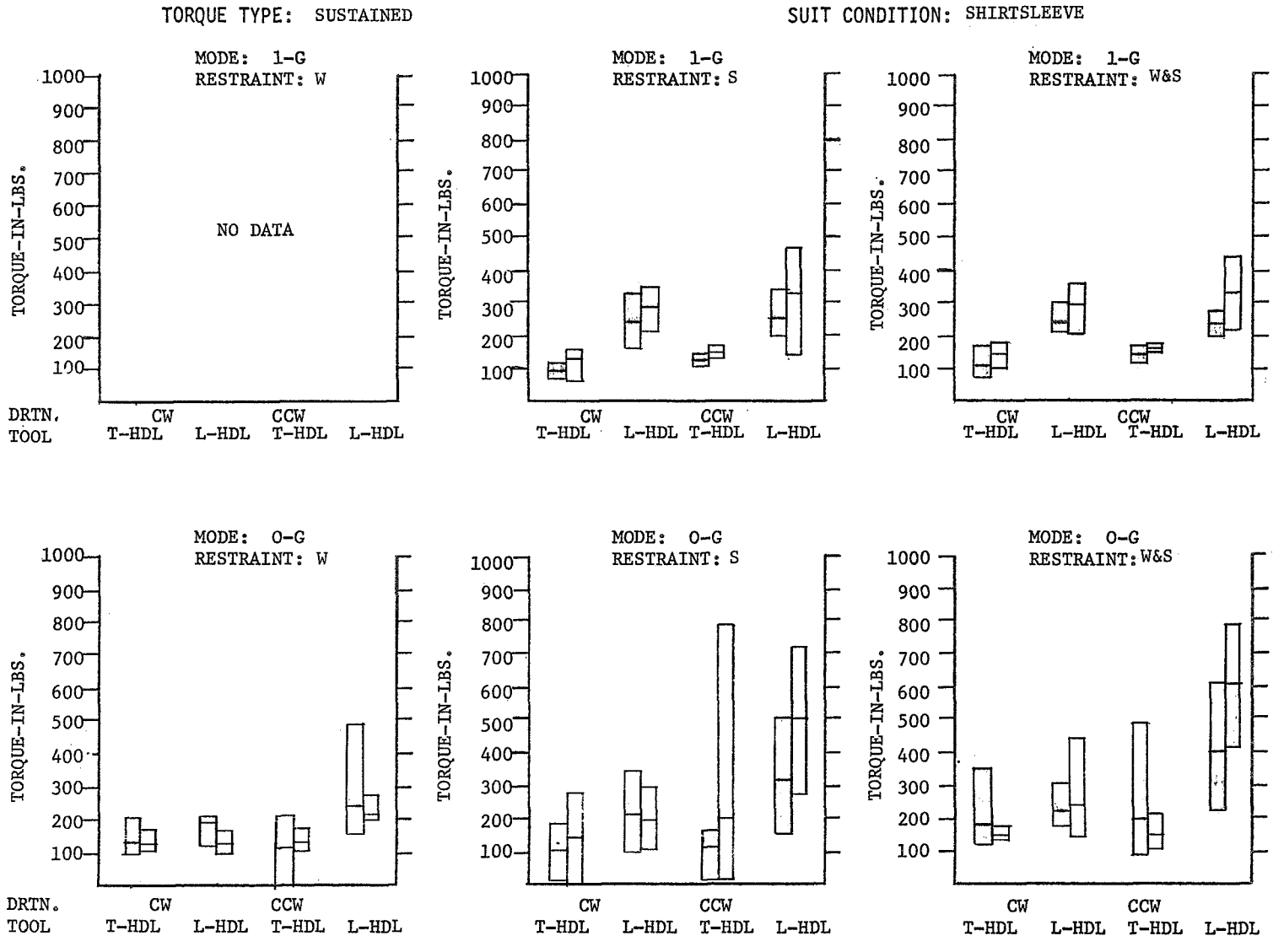


FIGURE 7-8 SUMMARY DATA CHART NO. 1

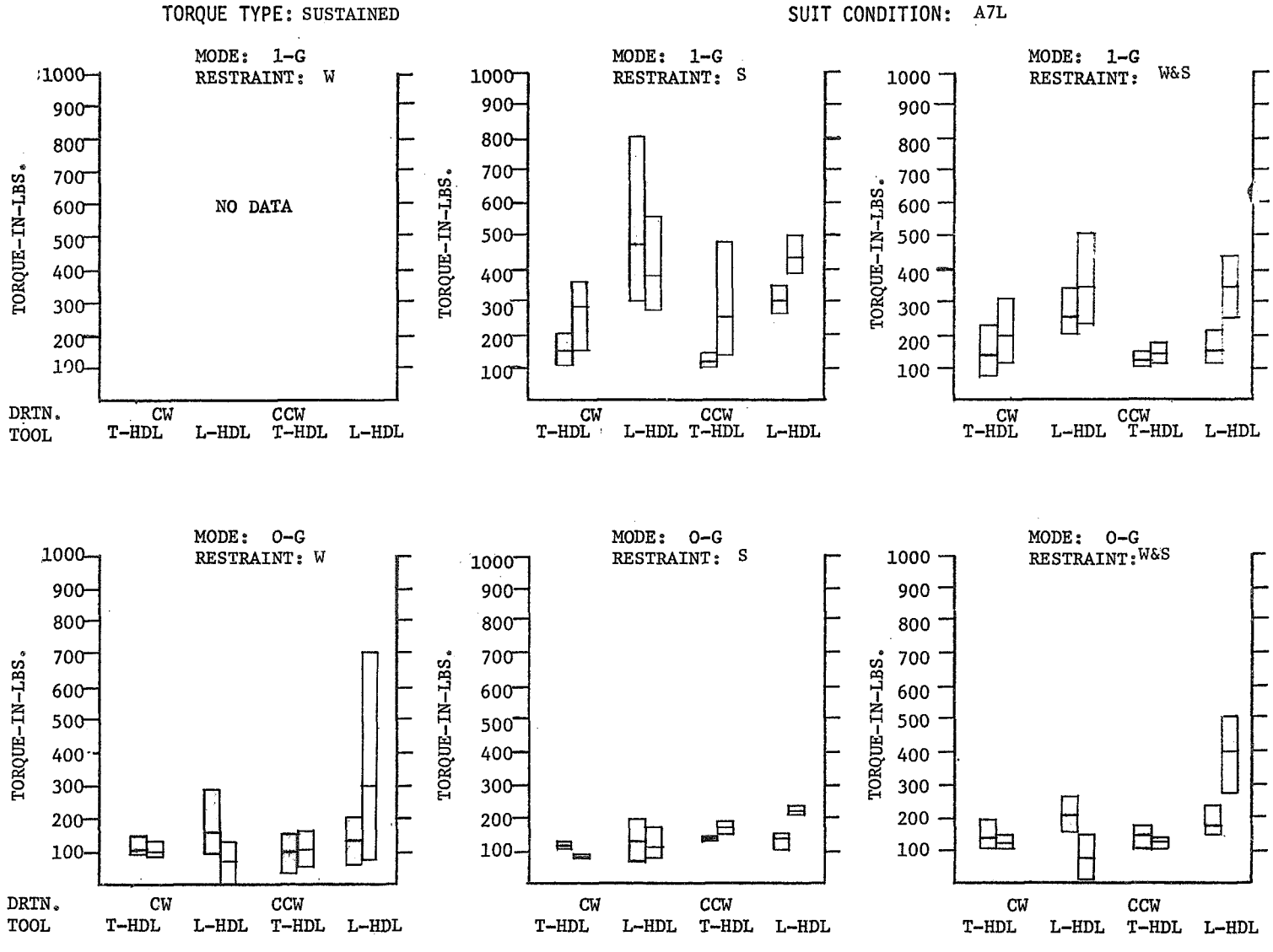


FIGURE 7-8 SUMMARY DATA CHART NO. 2

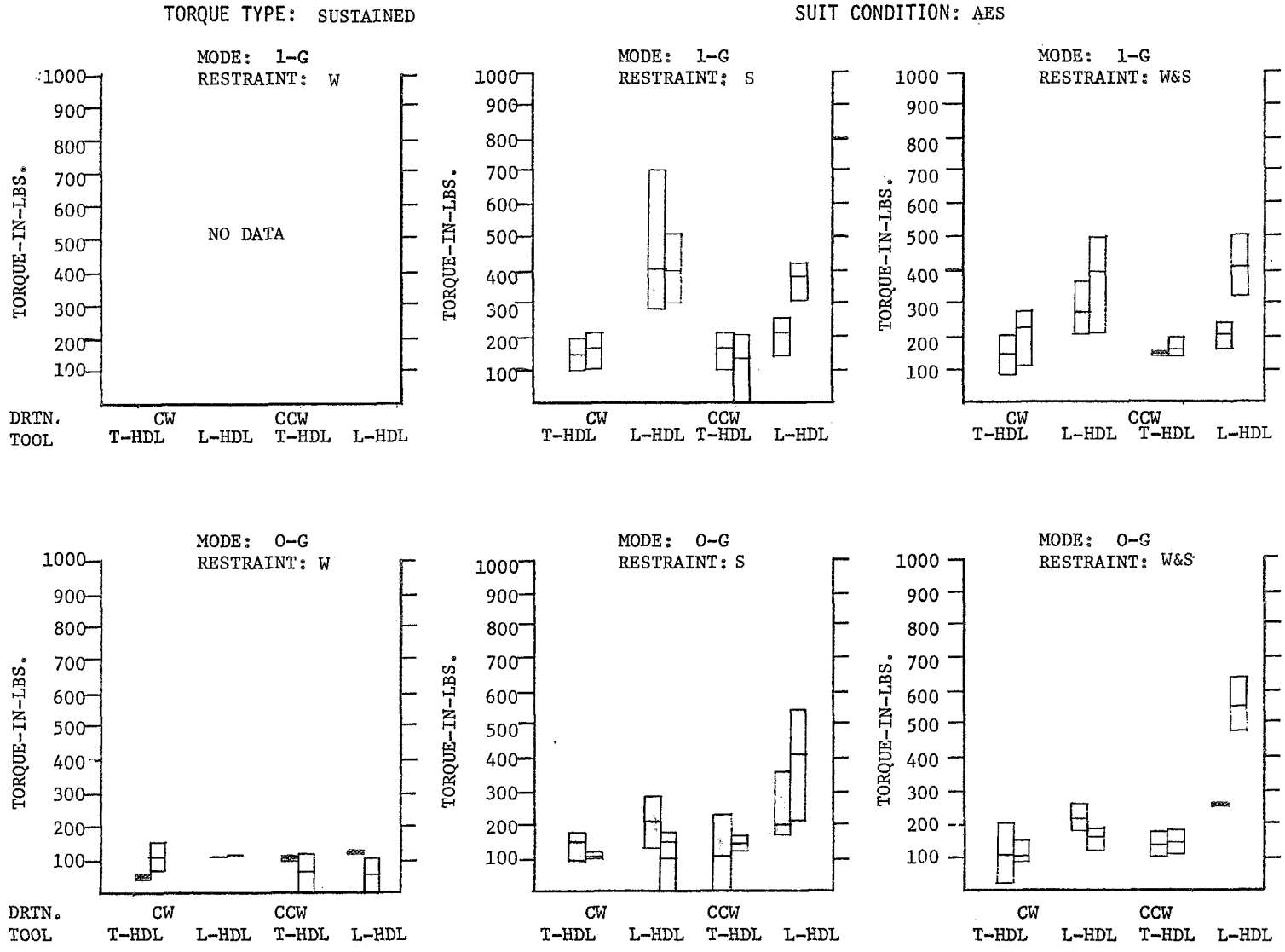


FIGURE 7-8 SUMMARY DATA CHART NO. 3

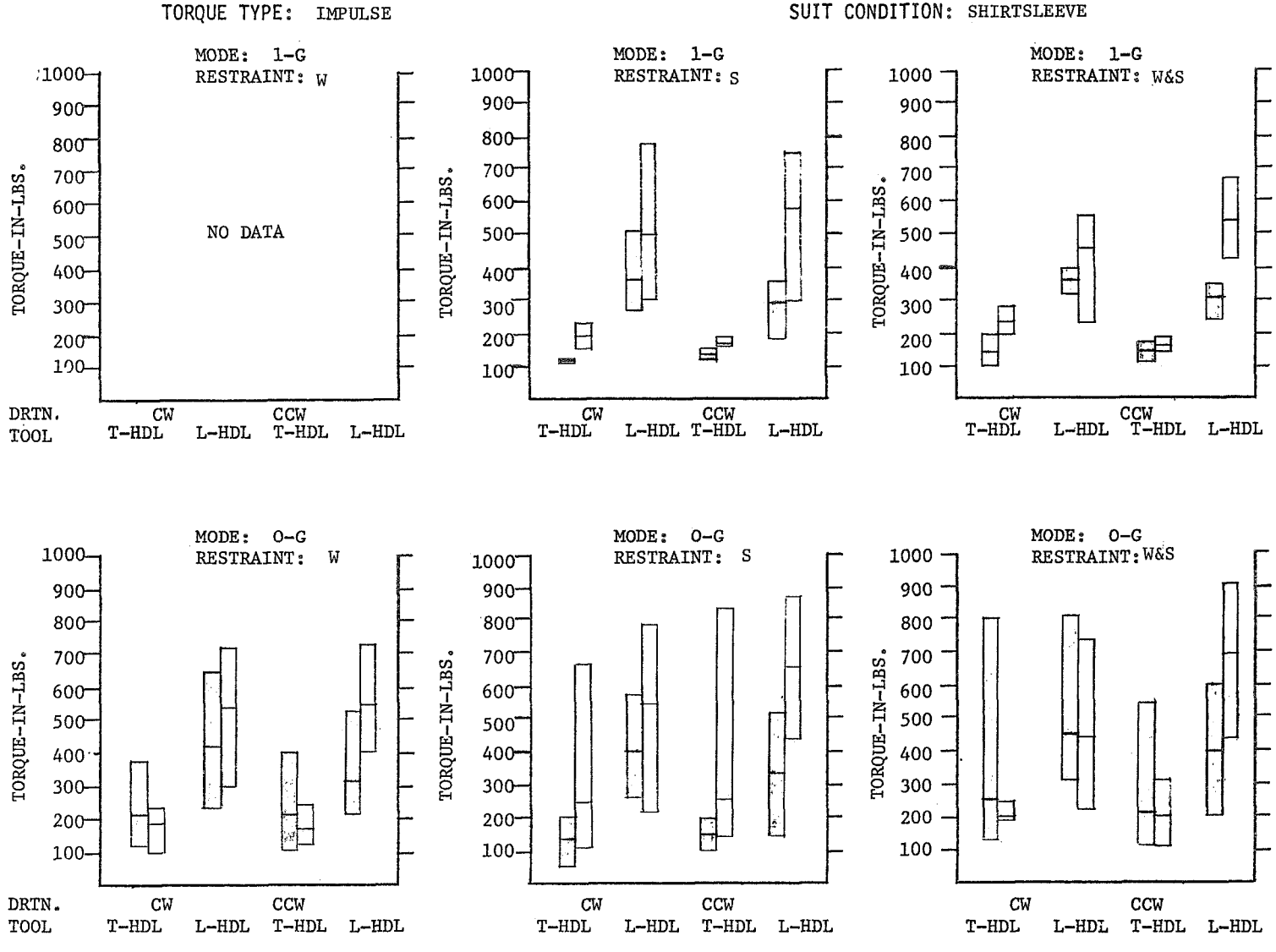


FIGURE 7-8 SUMMARY DATA CHART NO. 4

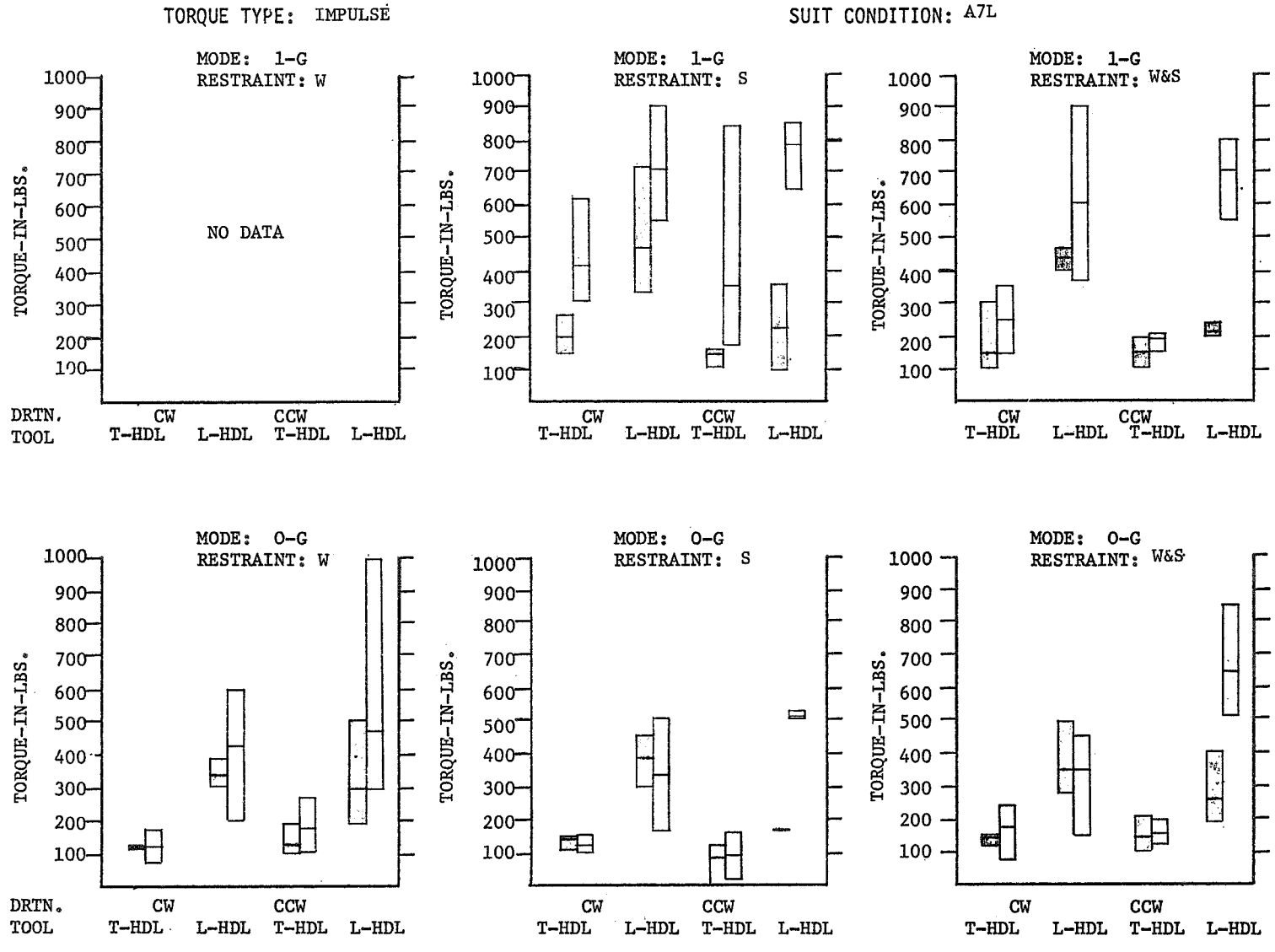


FIGURE 7-8 SUMMARY DATA CHART NO. 5

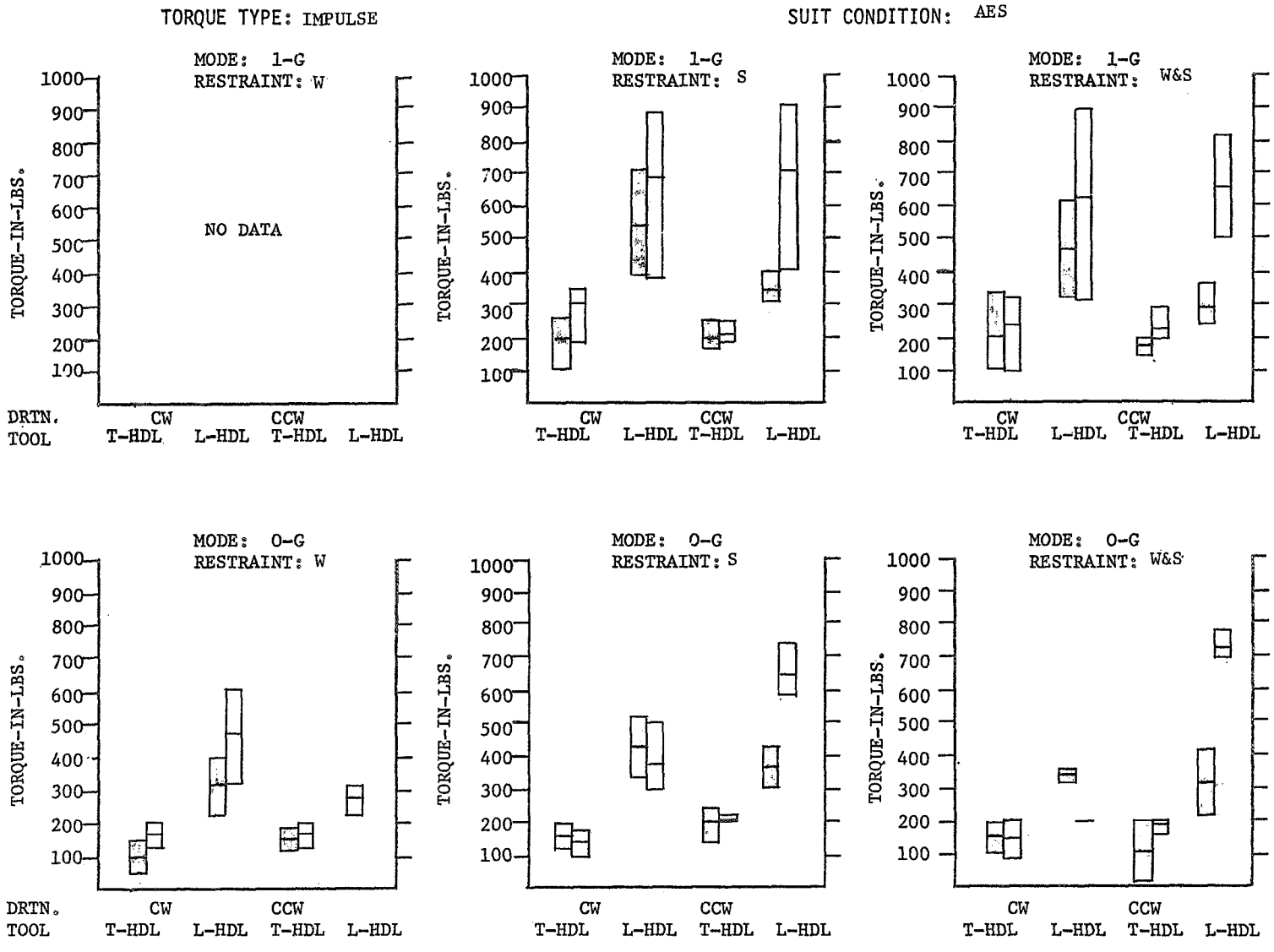


FIGURE 7-8 SUMMARY DATA CHART NO. 6

TABLE 7-10

RESULTS SUMMARY - SUSTAINED, IMPULSE TORQUE TASK

VARIABLE		SUSTAINED (FIN)	IMPULSE (MAX)
MODES	1-G	241.7 In-Lb.	352.5 In-Lb.
	NBS	212.5	369.3
	6 DOF	163.0	242.0
	KC-135	223.5	352.0
SUITS	SS	218.3	334.7
	A7L	208.7	319.1
	AES	220.3	344.6
RESTRAINTS	W	140.9	298.7
	S	231.4	347.0
	W&S	228.7	329.8
POSITIONS	Center	193.7	266.9
	Lower Left	238.3	398.9
TOOLS	L-Handle	283.9	470.9
	T-Handle	148.2	194.8

7.3.6 SUSTAINED AND IMPULSE TORQUE TASK (Continued)

SUITS - As with force emission capability, different suit conditions did not differentially affect torque emission capability. However, the 50% improvement in impulsive torquing ability over sustained torquing ability ability continued to be evident.

RESTRAINTS - The results of restraint conditions also duplicated force task results. Performance differences were significant at the .005 level for sustained torques but not significant for impulsive torques. The ineffectiveness of the waist restraint for sustained torque emission is again exemplified as well as the impulsive vs. sustained relationship noted above.

POSITIONS - The lower left position permitted much greater torque emission than the center position. This reflects that in the center position, only arm muscles can be used for torquing; with the receiver in the lower left position, all the back and shoulder muscles are brought into use.

TOOLS - The direction of the difference in torque emission capability as a function of tools is as expected. The task, however, provides objective quantification of the magnitude of this difference.

In summary, this task provided confirmation of the results of the force emission task. In addition, it provides useful design data relevent to the magnitude of the torques that can be generated and sustained under specific combinations of conditions.

Task Recommendations: No major recommendations are made for this task. The measures "MIN" and "MAX TIME" may be deleted, but this represents no changes for the telemetry list.

7.3.7 TIME DATA RESULTS

Several elements of the experimental sequence were evaluated only by the time required to perform them. The main significance of such results was related to suit and simulation conditions.

Removal of the Task Panel cover (Gain Access Task) took twice as long in the AES suit and three times as long in the A7L suit as did the shirtsleeve condition. Similarly, force receiver module removal/replacement took twice as long in the AES suit and 2.2 times as long in the A7L as did the shirtsleeve condition. The removal/replacement of the Precise Hand Movement module revealed no significant conclusions across any experimental variables.

No significant conclusions could be drawn from the restraint installation and removal tasks. Basically, this type of task is too dependent upon the specific nature of the equipment being used to permit extrapolation of any general conclusions.

7.3.7 TIME DATA RESULTS (Continued)

The time results of the Operational Maintenance Task indicated a two-to-one ratio between performance in a suited condition vs. a shirtsleeve condition. No differences, however, were noted between the two different suits. The only other important result from this task confirmed the existence of a simulation effect upon performance, with the KC simulation resulting in the fastest task time.

7.3.8 QUESTIONNAIRE DATA RESULTS

The questionnaires, presented in Table 5-1, were analyzed to discover any additional important results or conclusions. No statistically significant response differences were noted across simulation modes or across restraint conditions. However, a strong preference for the AES suit over the A7L suit (significant at the .01 level) was noted in the 1-G simulation. It cannot be inferred, of course, that this preference will carry over into the zero-g condition.

7.3.9 SUMMARY RESULTS

All of the tasks evaluated above were found to meaningfully differentiate between simulation modes. Generally, the KC-135 simulation caused subjects to hurry through their tasks. It was also found that 6 DOF simulation caused subjects to be conservative in their force and torque emissions. Without flight validation data, however, it is impossible to conclude which simulation mode (if any) best represents the true zero-g condition. The important conclusion here is that there is an effect upon performance due to the nature of the simulation technique and this experiment is capable of detecting that effect.

Suit differences were noted mainly from the Two-Hand Task and the Precise Hand Movement Task. Although some of these results were clearly important, it is apparent that a total suit evaluation objective cannot really be satisfied only by performing worksite-limited tasks. It is recommended that some non-worksite tasks be devised to improve this capability.

The force and torque emission tasks provided reliable and important conclusions regarding the restraint systems used. It is important to note that the waist restraint performed quite poorly, but the model used was a prototype and not the electrically operated unit originally intended for this experiment. Also, the Dutch Shoes should be redesigned to better accommodate the AES suit.

The Two-Hand Task indicated that, of the restraints evaluated, no important performance differences arose. Negative conclusions such as these are of value, since this indicates that the nature of the restraint is not a prime consideration for performance of a relatively static two-hand coordination task. Again, the important conclusion is that the tasks are capable of evaluating the effectiveness of alternative restraint systems.

In conclusion, the implementation of the recommendations contained throughout Section 7 will definitely result in an efficient and effective Experiment M508 which will indeed evaluate the selected pieces of EVA hardware (especially suits

7.3.9 SUMMARY RESULTS (Continued)

and restraints), satisfy the objectives of the Simulation Technique Evaluation Program, and provide useful design data on EVA/IVA performance capabilities in the zero-gravity environment.

SECTION 8

HANDBOOK OF HUMAN ENGINEERING DESIGN DATA FOR REDUCED GRAVITY CONDITIONS

The handbook contained in Volume III of this report was prepared as a "level of effort" development in conjunction with the experimental design and implementation phases of this study program. The primary purpose was to develop a handbook of human engineering data for the use of engineers, designers, and human factors specialists during the developmental and detail design phases of manned spacecraft programs. The following goals were selected to guide the development of the structure, presentation format, material selection and data content of the final product:

- To collect in a single volume the best "state-of-the-art" quantifiable data pertinent to Human Engineering Design for Reduced Gravity Conditions.
- To express this data in a format which could be readily utilized by the largest possible cross-section of various professional and lay specialties that have some role in designing for man in the extraterrestrial environment.
- To minimize descriptive prose to those areas where finite operational processes or definitions are involved rather than quantified data.

8.1 HANDBOOK DEVELOPMENT

In the process of defining the probable usage of this text, it was determined that the basic handbook would not only be used as an authoritative reference source for individual designers in respect to establishing specifications and requirements for physical man/machine interfaces, but could also provide the basis for standarization of operational protocol development. The publication and common use of authoritative absolute descriptors of the various needs, capabilities and tolerances of crewmen might also provide the basis for the establishment of standarized levels of capabilities for describing crew selection and training criteria in respect to the designation of specific maintainability tasks to individual crewman. With this in mind, it was decided to follow the precedents set by such documents as the Handbook of Chemistry and Physics, Biology Data Book, etc., i.e., the selected format for the document should consist of a repository of detailed, quantified data in tabular or graphic form whenever possible.

A secondary purpose was also identified, namely, a need to provide a single and comprehensive document for use in manned EVA design activities by the neophyte or newcomer to the field in order that he might be made aware of those areas where the presence of a human worker could and should influence the design of orbital hardware or processes. The final document, therefore, must provide readily accessible detailed data describing all pertinent functional or survival-critical interactions between man, his working environment, his vehicle and support hardwares.

While, as previously stated, it is hoped that widespread utilization of the text material will permit standarization of design practice in respect to vehicle,

8.1 HANDBOOK DEVELOPMENT (Continued)

equipment, and operations, the document must also be capable of providing custom-tailored specifications for unique mission/equipment/environment interactions.

8.2 DATA COLLECTION

Literature searches were requested from the National Aeronautics and Space Administration's Scientific and Technical Information Division as well as the Defense Documentation Center (DDC) regarding human performance in a reduced gravity environment. These searches were reviewed, and those items that appeared to contain required human performance data were ordered for review. The services of the Tufts University Human Engineering Information and Analysis Service (HEIAS) were also utilized during this effort. Volumes I and II of the HEIAS bibliographies were searched for space-related categories most relevant to the task. As a result of this search, a printout of approximately 500 references was developed. Items to be entered into the upcoming Volume III of the HEIAS Bibliography were also reviewed for relevancy. The NASA and DDC searches were arranged in ascending "AD" "STAR" accession numbers, respectively, when they were received. The basic HEIAS system carries the titles and abstracts of documents by accession number but cross-indexes the accession numbers of the documents by an alphabetical listing of primary categories relevant to human factors interests. In order to eliminate title duplication and facilitate the location of titles and abstracts, the HEIAS system was utilized as the basic collation system.

The fact that the DDC, NASA, and HEIAS information sources had different cutoff dates was considered, and an effort to complement the searches insofar as possible was made. This could not be accomplished until nearly all the major work of the search was completed and a three-way cross-reference system established between DDC, STAR and HEIAS accession numbers. An informal check from approximately a 50 percent sampling of STAR accession numbers indicated that routine acquisition of NASA reports was fairly complete and current for HEIAS. An item-by-item check against DDC search was undertaken, and items which were either missing from, or possibly not yet processed through, the HEIAS system were ordered and examined.

A basic review of currently available documentation was initiated, and basic data regarding human operator performance was collected. In this effort, the goal was to primarily gather empirical or experimental data generated in an actual or simulated reduced gravity environment.

8.3 DATA APPLICATION

It was felt that a document of this type should permit deliberate and detailed data to be available for four basic tasks that are currently deemed necessary when designing for maintainability in a manned orbiting system. For optimum maintainability potential, the following discrete tasks must be accomplished:

8.3 DATA APPLICATION (Continued)

Task A. The vehicle and all its subsystem housekeeping, structural, and mission-related hardwares must be deliberately analyzed in respect to the possibility of needing in-orbit maintenance. In those instances where maintenance during orbital operations is deemed both possible and feasible, specific efforts must be expended in order to ensure ease of diagnostics, access, institution of corrective procedures, and checkout capabilities. These hardware designs shall also consider packaging and general corrective processes involved in respect to minimizing "unique" technological skills, special tooling, instrumentation, facilities, and man-hours necessary to effect the repairs while maximizing the safety and efficiency of access to the work site.

Task B. The designer shall detail all crew support facilities and equipments necessary to accomplish the transport, restraint/tethering of the crewman and his materials at the work sites, as well as to provide an environment that is conducive to both work and survival.

Task C. The responsible system designers shall develop specifications necessary to describe the physical and functional characteristics of the maintenance interface including sizing, configuration, and information flows across the man/machine interfaces at the various potential work stations.

Task D. The designers must, as part of their maintainability tradeoffs, consider the capabilities of man in light of the constraints imposed by the system and the environment in the design and assignment of maintenance roles to the "orbital man".

To reiterate, the large preponderance of material selected for this document is expressed in graphic and/or tabular form with prose commentary limited to explanations of techniques utilized in the application of specific data. Prose is also utilized in "term definition" as indicated.

8.4 HANDBOOK ORGANIZATION

In selecting the basic generic headings for Human Engineering Handbook, heavy emphasis was placed on potential usage. Section 1 contains that information related to the description of human characteristics. Provisions are made for information which will permit allowances for man's physical and functional dimensional requirements as well as descriptors of his general motor, sensory, and cognitive performance capability. Information regarding his tolerance to various forms of physical, emotional, and environmental stressors are also provided in this section.

Section 2 has provisions for absolute value data which describes the composition and the various phenomena present in the orbital intravehicular and extravehicular environment. Data in this area involves discussions concerning the design

8.4 HANDBOOK ORGANIZATION (Continued)

requirements for the intravehicular environment related to atmospheric control, illumination levels, rotational dynamics and habitability. Extravehicular environmental considerations involve data on space hazards, effects of weightlessness, radiation levels, temperature extremes and illumination factors.

Section 3 has provisions for data which will describe the minimal and/or optimal physical and functional characteristics of hardware design where it might interface with man and modify his performance. Data in this area includes sizing, configurational, operational, and dynamic considerations for the vehicle and all its facilities including unique mission equipments, packaging and access.

Due to the "Level of Effort" nature necessitated by modified funding availability during mid-contract, it was decided to attempt to maximize the factual content of the document (in order to be truly representative of the literature available as of the cutoff date of June, 1969) rather than complete the glossary or index section. It is hoped that these shortcomings can be rectified during subsequent update efforts.

8.5 RESULTS AND RECOMMENDATIONS

The results of the effort to develop a Handbook of Human Engineering Design Data for Reduced Gravity Conditions are presented in Volume III of this report under the above title. This unique, 550 page document provides detailed and diverse quantified data on man's capabilities and tolerances for survival and productive effort in the extraterrestrial environment. It also provides quantified data and information on the space environment man will work and live in as well as the characteristics of the vehicular or residential environment he will need. A detailed, topical Table of Contents has been developed to provide easy and efficient access to the data to encourage the utilization of the document among technical and professional specialists involved in the design and construction of manned spacecraft.

Due to modifications to costs and funding levels, it was decided late in the program to sacrifice the development of an index and glossary rather than modify the depth and breadth of the data presented. At this time, it was also decided to increase the detailed structure and completeness of the Table of Contents to minimize the effect of the absence of an index.

Further savings in funding for use in data collection and presentation were made by minimizing publication costs via the use of secretarial typing time, direct reproduction of graphic and tabular material rather than redrafting for common format, and the common listing of references rather than the original contiguous foot note referencing originally contemplated.

Because of the above noted modifications and the significant amount of new and updated information published annually, it is recommended that a yearly addendum be published and distributed to document holders and a revised edition be considered every two(2) years.

SECTION 9

EXPERIMENT 84 A' & B

9.1 INTRODUCTION

This experiment was performed to provide one-g and zero-g shirtsleeve baselines for the force emission data collected during Experiment 84A which was performed at the Marshall Space Flight Center Neutral Buoyancy Facility in Huntsville, Alabama, under Contract NAS8-18117. In that experiment, "Force Application in Simulated Zero Gravity", the effects of restraint, force receiver angle, force receiver distance, and handle orientation on force emission capability in the pressure suited condition were evaluated. In order to increase the validity of extrapolation from 84A, two sampling experiments were performed during this contract in a format allowing statistical comparison with 84A. These experiments were called experiments 84A' and 84B. The experimental design of 84A was used as the baseline for the design of the follow-on studies.

The resultant data from the original experiment was of special importance to spacecraft designers since it provided the answers to two essential questions:

a. Given a force generation requirement, what are the accessibility and restraint criteria which must be imposed on the workspace envelope?

b. Given a specific workspace envelope and restraint, what are the force generation capabilities of an astronaut?

The two experiments in the current program were intended to provide the answer to two additional questions:

a. What is the effect on man's 1-g baseline force emission capability as a result of the zero gravity environment?

b. What is the effect on man's shirtsleeve baseline force emission capability as a result of a pressurized space suit.

9.2 OBJECTIVES

Measurement of the maximum impulsive and sustained force generation capability of man as a function of the systematic variation of restraint conditions will provide the spacecraft designer with comparative data on the relative values of specific types of restraint systems. By varying the orientation and location of the force receiver, it is also possible to provide comparative data to evaluate the relative effects of accessibility and variations of the work envelope on man's force application capabilities. While the restraint conditions selected for testing are not all applicable to present day spacecraft, these experiments were designed to generate sufficient information to assist the designer in specifying and designing new and better restraint systems than those presently available. The design of an optimum restraint when a desired force emission capability is required will be possible on a quantitative basis if the appropriate data are available. Also, since the astronaut will be provided with a restraint system which controls and/or limits his movements, the availability of force emission capability data as a function of force receiver location and

9.2 OBJECTIVES (Continued)

orientation will assist the designer in the solution of the man/machine interface problems. Therefore, the major objectives of these experiments are to:

a. Broaden the force emission capability baseline data to permit extrapolation from the shirtsleeve to the pressurized space suit environment.

b. Broaden the force emission capability baseline data to permit extrapolation from the 1-g to the 0-g environment.

9.2.1 EXPERIMENT 84A' NON-PRESSURE SUITED EXPERIMENT

The first of the new experiments, 84A', used the non-pressure suited or shirtsleeve zero gravity environment to provide a baseline with which to evaluate the force emission capability loss due to pressure suit restrictions. Also, since intravehicular activity (IVA) may be assumed to be more common than extravehicular activity (EVA), and since more difficult activities may be scheduled IVA because of the less restricting and less hostile environment, quantified data concerning force emission capability in the shirtsleeve zero gravity environment may be of greater use and application than the data collected already for EVA. The design of the shirtsleeve experiment was greatly simplified compared to the 84A experiment because the results from 84A have been used to delete variables or levels of variables which were found to be non-significant with respect to astronaut force producing capability. The conduct of the experiment and the data reduction are simplified by the use of techniques, computer programs, and scheduling criterion available from 84A.

9.2.2 EXPERIMENT 84B ONE-G BASELINE EXPERIMENT

The second of the experiments, 84B, was designed to study the effect of gravity on force producing capability. Performance of the same conditions used in 84A, where possible, in a 1-g environment will allow a quantified comparison which may result in a conversion factor or series of conversion factors for gathering zero gravity data in a one-gravity environment. A simplified version of the 84A protocol was used, dropping the variables found non-significant in 84A and also the variables which could not be simulated in 1-g (ex: no restraint).

9.3 EXPERIMENT DESCRIPTION

9.3.1 GENERAL DESCRIPTION

This experiment was concerned with determining the effects of zero-gravity on the force-producing capabilities of subjects as a function of the type of restraint and simulated conditions of accessibility. In this study, the

9.3.1 GENERAL DESCRIPTION (Continued)

restraints were varied in the number and location of the energy sinks provided to the subject. Additionally, the accessibility conditions were evaluated by changing the location and orientation of the force receiver with respect to the subject.

The subjects performed the tasks in one of two suit modes: Gemini G4C suit, pressurized to 3.5 psi or shirtsleeve. Zero gravity was simulated by the technique of neutral buoyancy submergence.

The experimental apparatus, Figure 9-1, was designed to provide efficient selection of the experimental condition combinations by an underwater technician. The experimental condition combinations consisted of eight types of restraint (including no restraint), two force receiver distances, and two force receiver angles. Maximum impulse and sustained forces were obtained from each of two subjects for each experimental condition. Impulsive forces were defined as the peak forces exerted during a 1.0 second interval, while sustained forces are defined as the minimum force maintained over a 4-second interval. The required forces were applied in push, pull, left, right, up, and down directions, at all force receiver locations.

Prior to each experimental run, the subject was attached to one of the restraint systems and stabilized in front of the force receiver handle. The handle had been previously set at one of the experimental distances and angles. When all personnel were ready, the test director initiated signals which displayed on the subject's cue panel the required direction and type of force to be exerted. After a 2-second cue time, a "go" signal was displayed to the subject, who was instructed to exert the appropriate force until the "go" signal extinguished. After a suitable rest period, new cue signals were displayed to the subject, and the above procedure repeated. After performing 12 trials of required force exertions (sustained and impulse forces in all six directions), the handle orientation and/or distance was changed, and a new sequence of 12 trials begun. An experimental session consisted of 96 trials and the experiment required 12 sessions to complete the data collection across all experimental conditions.

9.3.2 EXPERIMENT VARIABLES

The ability of an astronaut to exert forces in a zero-g environment is influenced by several factors, some of which are:

a. Type of restraint system

b. Location and number of restraint attachment points

c. Position and location of the body relative to the force receiver

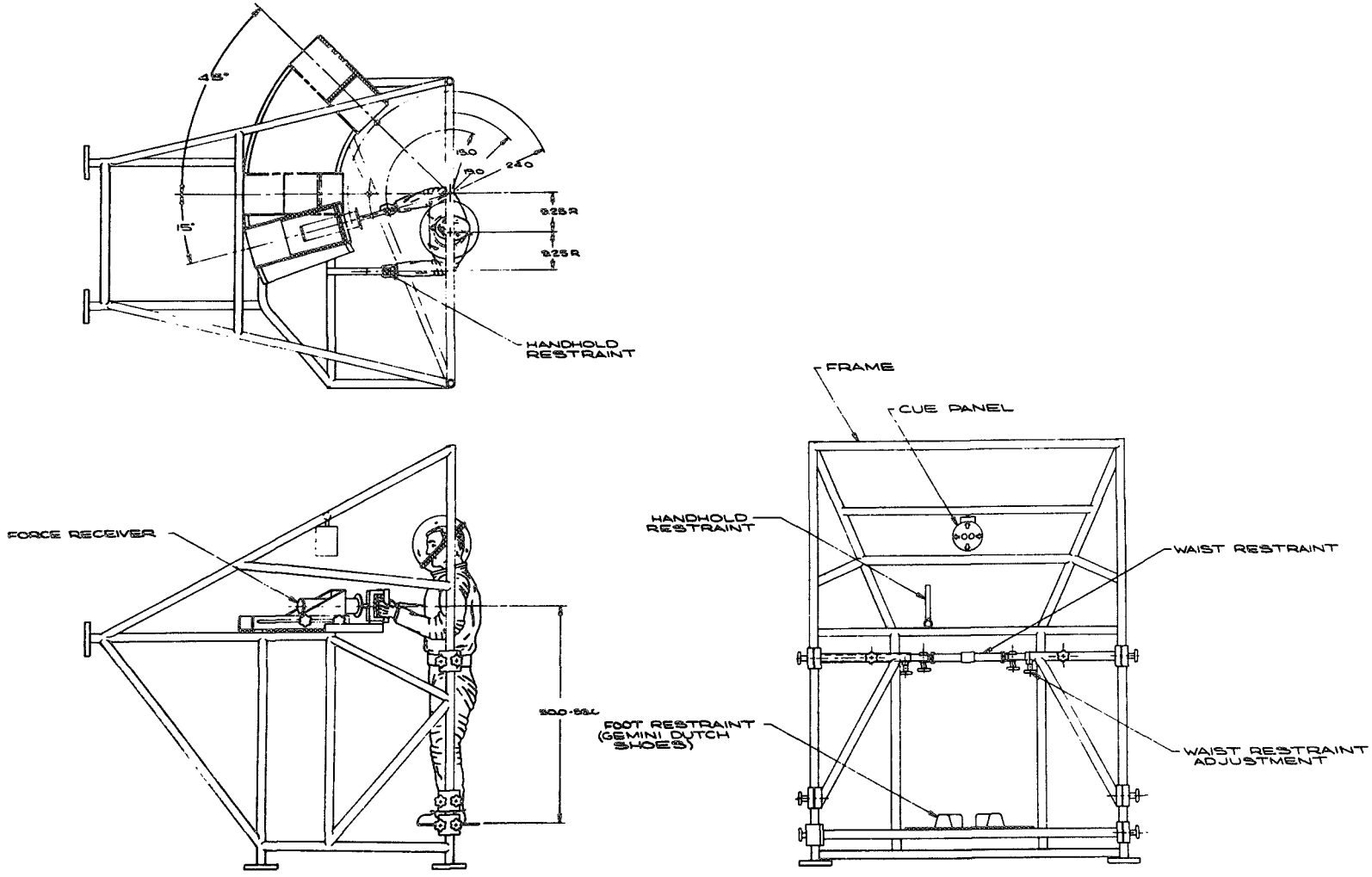


FIGURE 9-1 EXPERIMENT 84A UNDERWATER APPARATUS

9.3.2 EXPERIMENT VARIABLES (Continued)

d. Manual or tool assisted force requirements

e. Type of force required - impulse or sustained

f. Direction of force application

g. Location and orientation of force receiver

h. Type of spacesuit

i. Physical size of subjects

j. Suit pressurization method

However, evaluating the effects of all parameters of these variables was beyond the scope of this experiment. The variables selected for investigation in this experiment were:

a. Type of restraint system

b. Receiver angle

c. Receiver distance

d. Force direction

e. Force type

f. Subject differences

g. Suit condition

The ranges of the variables used in this experiment were selected with the intention of establishing the parameters of the principal factors affecting force-emission capability in zero-gravity. The same experimental conditions were used in these experiments as were used in 84A with certain exceptions as described below.

9.3.3 TYPE OF RESTRAINT SYSTEM

Restraint is perhaps the most important variable affecting force-emission capability in zero-gravity. The effectiveness of any given restraint is due to its efficiency as an energy sink and stabilizer in resisting the effects of the force emitted by the subject in any given direction. The restraints selected for this experiment were those which appear to be most representative of the current thinking on probable types and combinations, and include:

9.3.3 TYPE OF RESTRAINT SYSTEM (Continued)

	Use in 1-G
a. None (no restraint)	No
b. Handhold only	No
c. Waist only (2 point, rigid)	No
d. Gemini Dutch shoes only	Yes
e. Handhold and waist	No
f. Handhold and shoes	Yes
g. Waist and shoes	Yes
h. Handhold, waist, and shoes	Yes

Note that in the 1-G condition only those combinations of restraints involving the shoes were utilized. The implementation of each of the restraint conditions is described below.

9.3.3.1 No Restraint

In this condition, the subject used the left handhold and the force receiver handle to position himself properly in the apparatus. The proper position required that the subject stabilize himself vertically with his right nipple in the plane of the vertical restraint support members facing forward toward the cue panel, level with the center of the force receiver handle. Immediately prior to the application of force (during the 2-second cue time), the subject released the left handhold and maintained contact with the force receiver with only the right hand. The safetymen were positioned so that they could prevent the subject from colliding with the apparatus and helped the subject get back into position for the next force application. This assistance from safety personnel in preventing injury to the subject is an integral part of this test condition, since without such aid, the reaction to the forces exerted could have caused injury to the subject or damage to the space suit.

9.3.3.2 Handhold Only

In the handhold-only restraint condition, as in the no-restraint condition, protection by safetymen was required. The handhold restraint was located 19 inches forward of the subject's left shoulder, and its center was at the same height as the center of the force receiver handle.

9.3.3.3 Waist Only

The waist restraint consisted of a wide fabric belt attached to telescoping metal bars extending from the sides of the support structure. The telescoping bars permitted the positioning of the swivel plates against the side of the pressure suit to prevent rotation around the sagittal axis (yaw). The swivel plates permitted the subject to pitch freely, fore and aft, around the axis formed by the support bars. In the case of "pull" forces which pitched the subject toward the apparatus, the safetymen prevented him from colliding with the apparatus. The height of the waist restraint was adjusted for each subject such that the center of the force receiver handle was level with his right nipple. The waist restraint is shown in Figure 9-1.

9.3.3.4 Gemini Dutch Shoes Only

The shoe restraint used in this study was the Gemini Dutch Shoes, shown in Figure 9-1. The shoes effectively immobilized the subject against up and down movements and provided a pivot point for left, right, push and pull forces. The height of the shoe restraint was varied such that the center of the force receiver handle was at the level of the subject's right nipple.

9.3.3.5 Handhold and Waist

This restraint was a combination of the handhold and waist restraints and represented a two-point energy sink.

9.3.3.6 Handhold and Shoes

This restraint was a combination of the handhold and Dutch Shoe restraints and represented a two-point energy sink.

9.3.3.7 Waist and Shoes

This restraint was a combination of the waist and shoe restraints and represented a two-point energy sink that freed both hands for use at a work site.

9.3.3.8 Handhold, Waist, and Shoes

This restraint was a combination of the handhold, waist, and shoe restraints and represented a three-point energy sink.

9.3.4 RECEIVER ANGLE

The location of the force receiver in the subject's reach envelope is a major determinant of force emission capability. However, the extremely high number of possible locations prohibits an all-inclusive study of the effects of location. One aspect of location selected for investigation was the horizontal angle subtended by the location of the force receiver with respect to a fixed point on the subject's frontal plane, assuming the subject to be oriented vertically. The origin in this case uses the reference point of the right shoulder, with the arm held straight out being zero degrees. All of the angles used were in the plane which was perpendicular to the sagittal axis and intersect the subject's right nipple. The statistical analysis of the 84A data indicated that there was no significant difference between the 0^{o} and the -15^{o} receiver angles. Closer inspection of the data revealed some small trends associated with particular experimental condition combinations, however, these were not deemed to be of sufficient intensity to warrant further investigation at this time. It was decided to use only the -15^{o} and the 45^{o} receiver angles in this experiment. The -15^{o} was chosen over 0^{o} because the -15^{o} to 45^{o} allows a test over a greater experimental range, encompasses the 0^{o} point and therefore, permits greater generalization of the data.

9.3.5 RECEIVER DISTANCE

Another aspect of accessibility investigated in this experiment was the distance from the subject to the force receiver. The intent to bracket the range of possible distances can be seen in the theoretical definitions of the three receiver distances chosen for inclusion in the original 84A experiment. The distances, called near, medium, and far, were determined to sample the reach envelope.

In the statistical analysis, receiver distance was not found to be significant, but "near" and "far" had individual advantages in certain force directions. "Near" was determined to be 15 inches forward of the shoulder reference point and, was defined as the closest position that could practically be reached while wearing a pressurized space suit. This distance resulted in an elbow angle of approximately 90 degrees. "Far" was determined to be 24 inches forward of the shoulder reference point, and was defined as the farthest position that could practically be reached, resulting in an elbow angle of approximately 180 degrees. The actual distance in inches varies slightly between subjects and was restricted slightly by equipment limitations.

9.3.6 HANDLE ORIENTATION

Statistical analysis of the 84A data also showed no significant difference between vertical and horizontal handle orientations; however, the vertical orientation appeared to be slightly better. For this reason the horizontal orientation was dropped and only the vertical handle orientation was used in this experiment.

9.3.7 FORCE DIRECTION

Since force-producing capability varies greatly with the intended direction of force application, subjects in this experiment were asked to generate forces in both directions of the three orthogonal axes defining the location of the force receiver. The directions of force application were:

a. Push

b. Pull

c. Left

d. Right

e. Up

f. Down

9.3.8 FORCE TYPE

Two types of data concerning force-emission capability are especially useful to the designer of advanced space systems. These are impulse and sustained forces, with the former defined as the peak force that is exerted during a 1-second interval, and the latter defined as the maximum force capable of being maintained during a 4-second interval. Quantitative data for these two types of emission will allow the equipment designer to answer the questions:

a. What is the peak force which the astronaut can be depended on to produce in a given condition combination?

b. What force can the astronaut maintain for a reasonable amount of time?

In this experiment, the subject was instructed to exert maximum force in the direction indicated on the cue panel, and to hold this force as long as possible, or until the "go" signal extinguished. The cue panel communicated the force type by presenting either the word "impulse" or "sustained" at the same time the instruction for force direction was presented. After the 2-second illuminated cue period, the "go" signal appeared and was maintained one second for impulse trials and 4 seconds for sustained trials. The instruction or cue signal also remained on until the termination of the "go" signal.

9.3.9 SUBJECT DIFFERENCES

One of the primary questions requiring an answer early in the analysis of the data is concerned with the "sameness" or difference between the subjects used in the original 84A and the current 84A' and 84B experiments. If the subjects

9.3.9 SUBJECT DIFFERENCES (Continued)

used in the two experiments differ significantly with respect to their force emission capability, then the ability to extrapolate from the 84A data will be questionable at best.

9.3.10 SUIT CONDITION

Two parameters of the suit condition variable were evaluated in this experiment. The shirtsleeve mode (not wearing a pressure suit) was used in both the 1-g and 0-g simulation. The pressurized suit (Gemini G4C spacesuit) was utilized in the 1-g and 0-g simulation. The Gemini G4C suit was selected as being most comparable to the Apollo State-of-the-Art suits used in the original experiment and available for use in the current program. The suit was water pressurized to 3.5 psia by a system developed by GE and described in detail in the study report on Contract NAS8-18117.

9.4 EXPERIMENT SET-UP

The 84A' and 84B experiments were performed at General Electric's Controlled Buoyancy Facility at Valley Forge, Penna. The hardware is described in detail in the study report on Contract NAS8-18117 and need not be repeated here.

During the conduct of the experimental sessions two-way voice communication was maintained between the test director and the subject. Closed-circuit TV provided video observation of the subject during neutral buoyancy testing. Force receiver signal outputs were recorded on a Brush Mark 200 oscillographic recorder. Four channels were recorded-three containing the positive and negative deflections for each particular axis and one to depict the various commands being given to the subject.

9.5 DATA ANALYSIS AND RESULTS

9.5.1 DATA REDUCTION

All data collected from this experiment were manually transformed to a coded sheet, illustrated in Figure 9-2. The coding system identified each data point according to the variables in effect when it was collected. The computations performed with this data were similar to those performed on the M508 data. A time-shared computer program permits various combinations of data to be averaged and printed out in a format compatible with the 84A data formats for comparison. A sample printout is shown in Figure 9-3.

The measures computed are similar to those computed for the 84A experiment and are as follows:

87 DATA

IBM

FORTRAN Coding Form

X28-7327-6 U/M 025
Printed in U. S. A.

TRIAL ID

DATA →

DATE

PUNCHING INSTRUCTIONS

GRAPHIC

PUNCH

PAGE OF

CARD ELECTRO NUMBER*

1	2 3 4 5	6	7 8 9 10 11	12 13	14 15 16 17 18	19 20	21 22 23 24 25	26 27	28 29 30 31 32	33 34	35 36 37 38 39	40 41	42 43 44 45 46	47 48	49 50 51 52 53	54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80
				TYPE	FORCE	TYPE	FORCE	TYPE	FORCE	TYPE	FORCE	TYPE	FORCE	TYPE	FORCE		IDENTIFICATION SEQUENCE
				DIRT		DIRT		DIRT		DIRT		DIRT		DIRT			
					*		*		*		*		*		*		

*A standard card form, IBM electro 888157, is available for punching statements from this form

FIGURE 9-2 DATA CODING SHEET

```
MODE                :1-G,NBS,
SUBJECT             :1,2,
SUIT                :SS ,G4C,
RESTRAINT           :N   ,H   ,S   ,W   ,H&S ,W&S ,H&W ,HW&S,
RECEIVER ANGLE      :-15, 45,
RECEIVER DISTANCE:NEAR,FAR ,
```

	SUSTAINED MIN			IMPULSE MAX		
	MEAN	RANGE	N	MEAN	RANGE	N
PULL	53.0	0. -175.0	127	89.5	0. -175.0	127
PUSH	30.9	0. - 75.0	124	35.9	10.0- 78.0	128
UP	32.7	0. -125.0	126	48.4	5.0-103.0	127
DOWN	29.3	0. - 70.0	125	36.9	2.0- 68.0	128
RT.	28.7	0. -125.0	123	44.4	5.0-120.0	127
LEFT	22.5	0. - 70.0	127	29.7	14.0- 50.0	125

```
WISH TO CHANGE CONDITIONS? YES OR NO=NO
```

FIGURE 9-3 EXPERIMENT 84A' & B DATA SAMPLE PRINTOUT

9.5.1 DATA REDUCTION (Continued)

MIN - The minimum force that occurs in the commanded direction during the last 3 seconds of the 4-second command for sustained forces.

MAX - The maximum impulsive force that occurs during the 1-second the GO-light is on and the 1 second afterwards.

The mean, range and number of points found for these measures were computed and displayed for subsequent data analysis.

9.5.2 RESULTS

Figure 9-3, which contains the sample computer program printout, represents averaging of all data points collected in this program. When compared with the 84A data a rather unfortunate result was noted. A difference in magnitude of approximately 2:1 exists for each of the paired directions of a given axis. The effect is most obvious in the range of MAX forces. The largest force in the PULL direction is 175.0 lb; in the PUSH direction it is only 78.0 lb. The other two axes exhibit similar behavior.

This effect was not at all noticeable in the 84A data and there is no plausible reason to suspect such an effect here. A study was made of the distribution of data collected here and ultimately it was decided that, for the PUSH, LEFT and DOWN directions (all of which were characterised by negative voltage outputs), the recorder was being operated near saturation in the 50-70 lb. region. Thus the problem could not be spotted during experiment operations. The daily calibration procedure utilized a fish scale to exert known forces. Using this technique only forces up to about 50 or 60 pounds could be reliably maintained. Thus, it went completely unnoticed that forces of perhaps 100 or 120 lbs. were being damped at 60 or 70 lbs. The magni ude of linear deviation on the recorder was such that this damping would not readily be noticeable. As a result of this problem, it was deemed necessary to eliminate the LEFT, PUSH and DOWN direction from consideration and utilize only the RIGHT, PULL and UP directions for comparison with 84A.

The following paragraphs describe the results of the data analysis and comparisons conducted to evaluate the capability of extrapolating from the original Experiment 84A 0-g pressure suited data to the 1-g and 0-g shirtsleeve conditions. The statistical analysis performed on the data was the same as described in detail in the Contract NAS8-18117 Final Report. The two non-parametric statistics used were the Wilcoxon Matched-Pairs, Signed Ranks Test and the Friedman Two-Way Analysis of Variance.

9.5.2.1 Mean Forces Across Subjects

The first comparison evaluated the subjects utilized in the current experimental program against those utilized in the original Experiment 84A. The

9.5.2.1 Mean Forces Across Subjects (Continued)

comparisons involved the mean of the MINS and the mean of the MAXS for the neutral buoyancy simulation case in the new data (84A') and the old (84A) data. The results indicated there were no significant differences between the current subjects and the original subjects in terms of their ability to exert sustained or impulsive forces.

9.5.2.2 1-G Versus 0-G Force Emission Means

The next analysis compared the mean force emission capability in a 1-g environment with the mean force emission capability in the neutral buoyancy simulated zero-g environment. Results of this analysis indicated that sustained force emission capability differed significantly at the .05 level across the 0-g and 1-g environments. The same result (a significant difference at the .05 level) was found when comparing the mean impulsive force emission capability across the 2 gravity conditions. In spite of the statistical significance of the difference in impulsive force emission capability, it appears that the magnitude of the real difference is not very important. The zero-g means differed from the 1-g means by only 2 to 12 lbs. representing a 3 to 20 percent variation. In all cases, the 1-g mean fell within the range of the zero-g means. The 20% difference in the means was found in the Up direction only and indicated a difference that is later confirmed by the suited vs. shirtsleeve analysis in which there appears to be a suit restriction in the capability to exert Up forces. In the case of sustained forces, there appears to be an increased force emitting capability in the 1-g mode that is 2.4 to 2.8 times as great as the zero-g force emission capability. These results indicated that impulsive force emission is relatively uneffected by changes in gravity conditions and that sustained force emission capability is approximately 2-1/2 times as great in the 1-g environment than in the zero-g.

9.5.2.3 Shirtsleeve Vs. Pressure Suited Force Emission Means

Results of the statistical analysis of the mean force emission capability between shirtsleeve and pressure suited conditions indicated no significant difference between impulsive or sustained force emission capability. However, in both the impulsive and sustained forces in the Up direction, the shirtsleeve mean force capability was approximately 40% greater than the pressure suited force emission capability. This was especially evident since all other directions indicated approximate equality in mean force producing capability between the suited and shirtsleeve modes.

9.5.2.4 Mean Forces Across Receiver Angles

Results of the statistical analysis of the mean force capability across different receiver angles indicated no significant difference in either the impulsive or sustained force cases. This finding is consistent with the results of the analysis of the original 84A Experiment and visual inspection of the data

9.5.2.4 Mean Forces Across Receiver Angles (Continued)

indicate relatively the same trend with respect to receiver angle and direction interactions. The capability to exert sustained and impulsive Push/Pull forces tends to increase as the force receiver is moved away from directly in front of the subject. However, this tendency appears to reverse for the other directions. That is, the Up/Down and Left/Right force emission capability tends to decrease as the force receiver is moved laterally from in front of the subject.

9.5.2.5 Mean Forces Across Receiver Distances

Results of the statistical analysis across the receiver distances indicated no significant differences for either the impulsive or sustained force emission capabilities. It appears from the data that the ability to exert pull forces is slightly enhanced as the force receiver distance is increased, and that the ability to exert up and right forces is diminished as the force receiver distance increases.

9.5.2.6 Mean Forces Across Restraints

A statistical analysis of the mean force emission capability across various restraint conditions indicated a significant difference at the .005 level for both sustained and impulsive forces. This finding is also consistent with the previous study results.

9.5.3 CONCLUSIONS

The conclusions that can be drawn from the above data analysis and results are as follows:

a. The force emission capabilities of the subjects used in the original Experiment 84A and the current Experiment 84A' and 84B did not differ significantly.

b. Impulsive force emission capability is not significantly affected by varying the gravitational field from zero to 1-g.

c. Sustained force emission capabilities in the 1-g environment appear to be approximately 2-1/2 times as great as sustained force emission capabilities in the simulated zero-g environment.

d. Sustained and impulsive force emission capabilities are relatively unaffected by the pressurized space suit except in the Up direction for the suits used in this program (Gemini G4C).

e. The data graphs summarizing the pressure suited force emission capability data collected in the original Experiment 84A are

9.5.3 CONCLUSIONS (Continued)

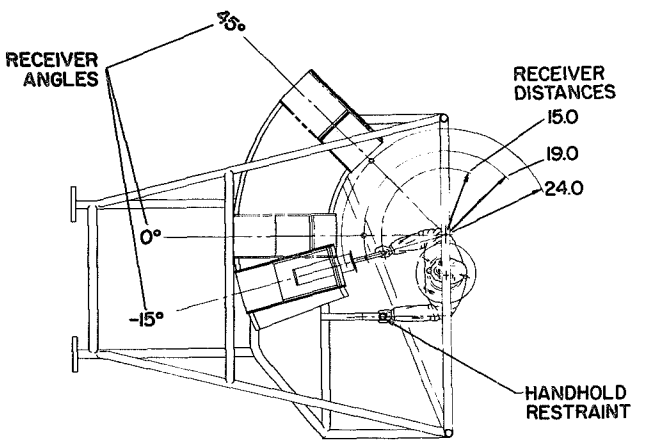
e. presented in Figure 9-4, Charts 1 through 12, and can be used in the following manner:

- The mean impulsive forces can be used to represent the 1-g and zero-g, shirtsleeve and pressure suited impulsive force emission capability.

- The mean sustained force graphs can be used to represent the 1-g shirtsleeve and pressurized suited force emission capability by multiplying the means by a factor of 2-1/2.

FIGURE 9-4 FORCE EMISSION SUMMARY DATA CHARTS

The following graphs present the means and ranges of forces resulting from the investigation of force producing capability under various conditions of gravity, restraint and worksite geometry. The Sustained mean forces presented on the graphs represent the simulated zero gravity, shirtsleeve and pressure suited capabilities. To obtain a close approximation of the one-g shirtsleeve and pressure suited Sustained mean force capability, multiply the Sustain means by 2.5. The Impulse mean forces presented on the graphs represent the one-g and simulated zero gravity, shirtsleeve and pressure suited capabilities.



FORCE TYPE

SUSTAINED = FORCE MAINTAINED FOR 4 SECONDS
IMPULSE = PEAK FORCE OBTAINED IN 1 SECOND

RECEIVER DISTANCES

15" ≃ 90° ELBOW ANGLE
19" ≃ 135° ELBOW ANGLE
24" ≃ 180° ELBOW ANGLE

HANDLE ORIENTATION

LOCAL VERTICAL
LOCAL HORIZONTAL

RANGE – MAX = LARGEST FORCE
MEAN = AVERAGE OF ALL FORCES
RANGE – MIN = SMALLEST FORCE

The data on this chart represents the sustained force emission capability for shirtsleeve and pressure suited zero gravity conditions. To determine the approximate sustained force emission capability for the shirtsleeve and pressure suited one-g conditions, multiply the 0-g mean values by 2.5.

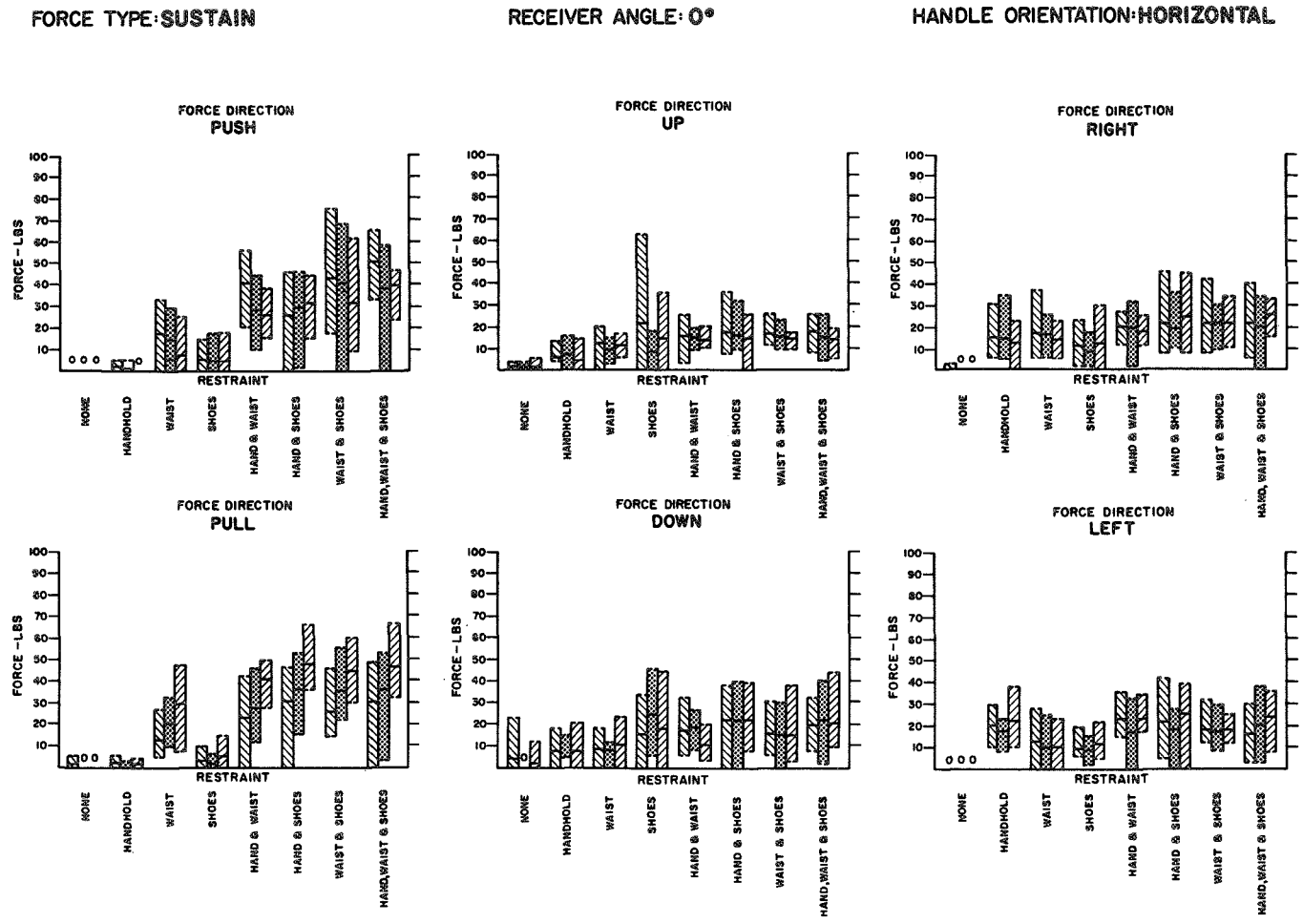


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #1

The data on this chart represents the sustained force emission capability for shirtsleeve and pressure suited zero gravity conditions. To determine the approximate sustained force emission capability for the shirtsleeve and pressure suited one-g conditions, multiply the 0-g mean values by 2.5.

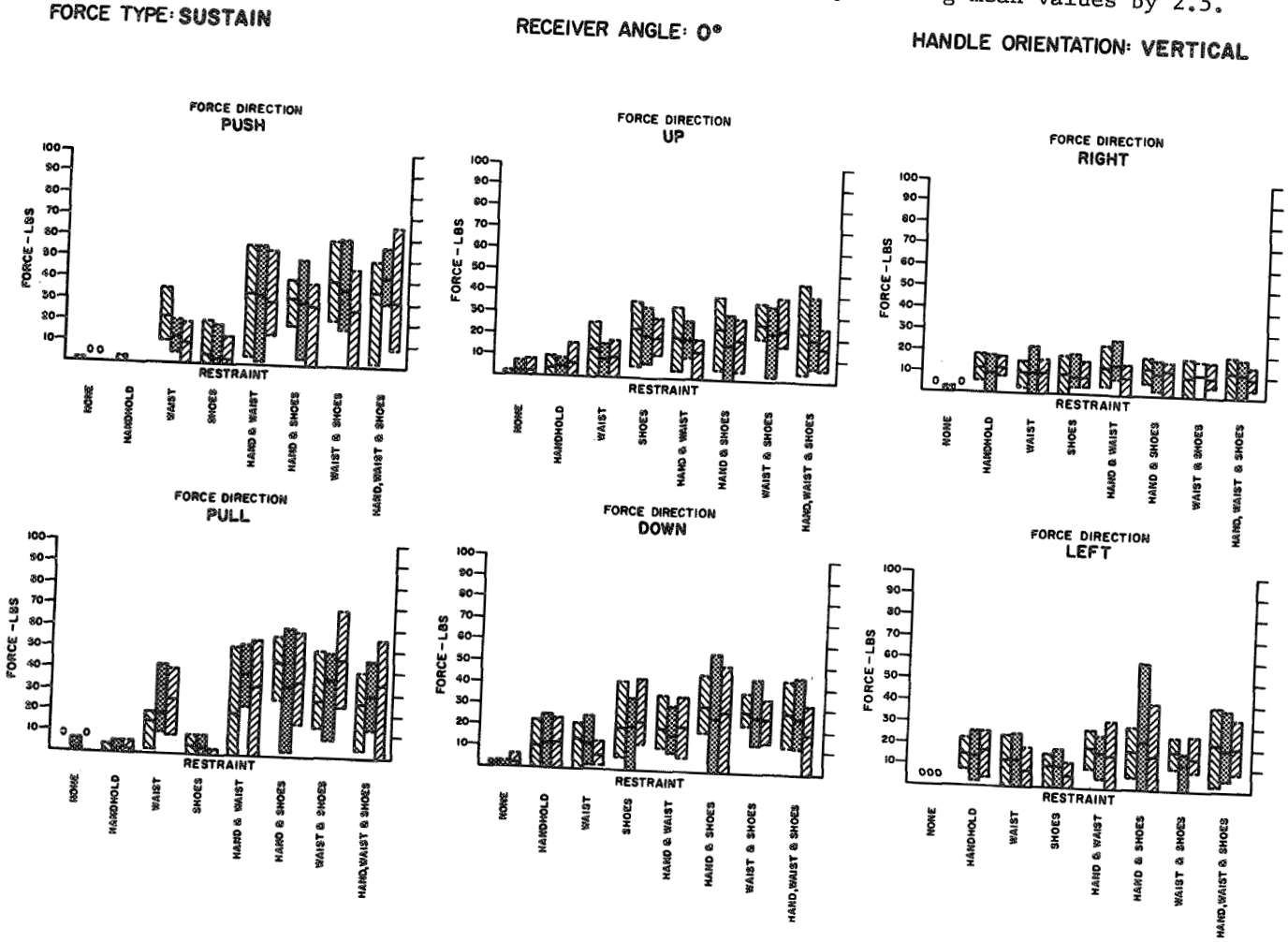


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #2

The data on this chart represents the sustained force emission capability for shirtsleeve and pressure suited zero gravity conditions. To determine the approximate sustained force emission capability for the shirtsleeve and pressure suited one-g conditions, multiply the 0-g mean values by 2.5.

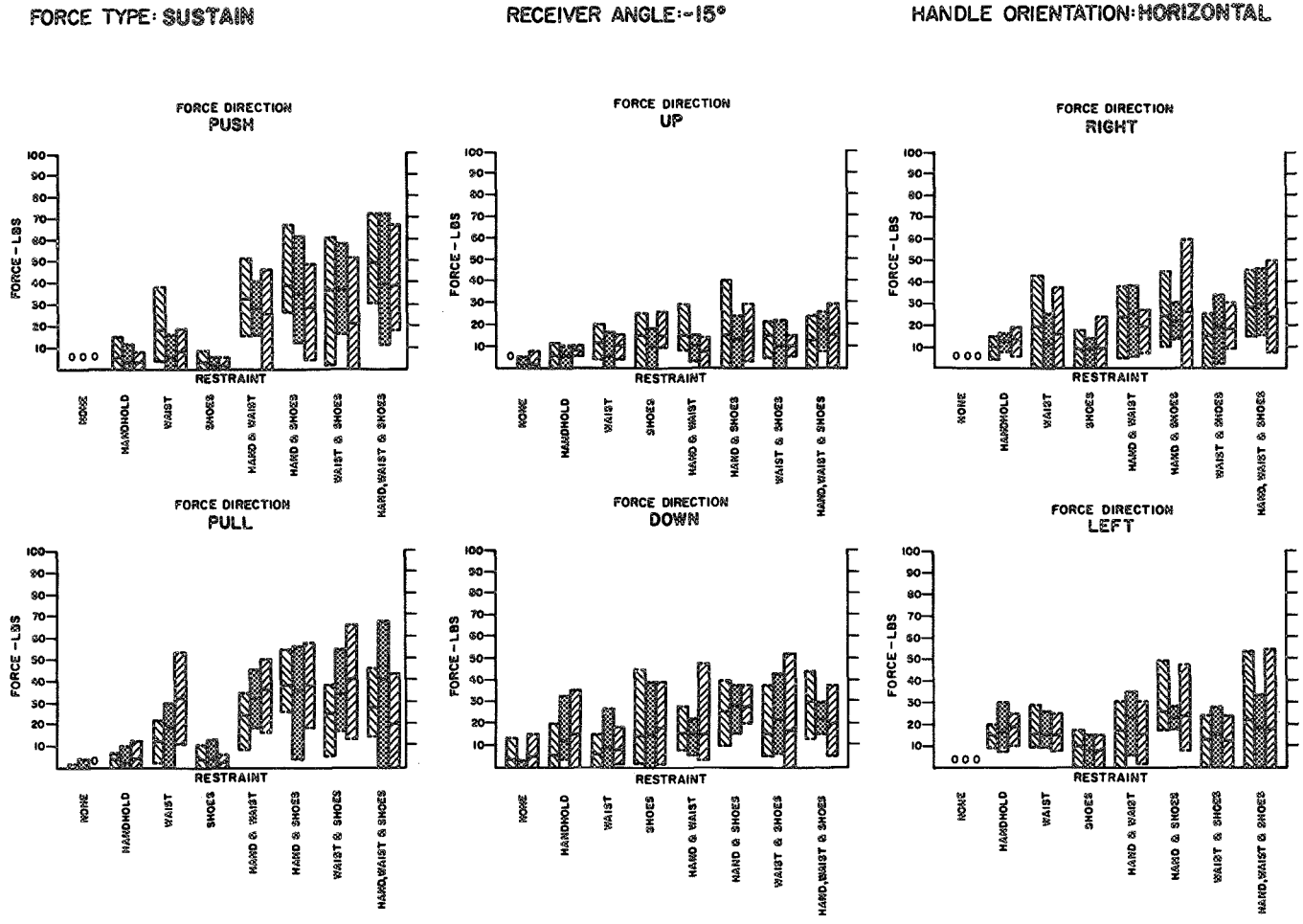


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #3

The data on this chart represents the sustained force emission capability for shirtsleeve and pressure suited zero gravity conditions. To determine the approximate sustained force emission capability for the shirtsleeve and pressure suited one-g conditions, multiply the 0-g mean values by 2.5.

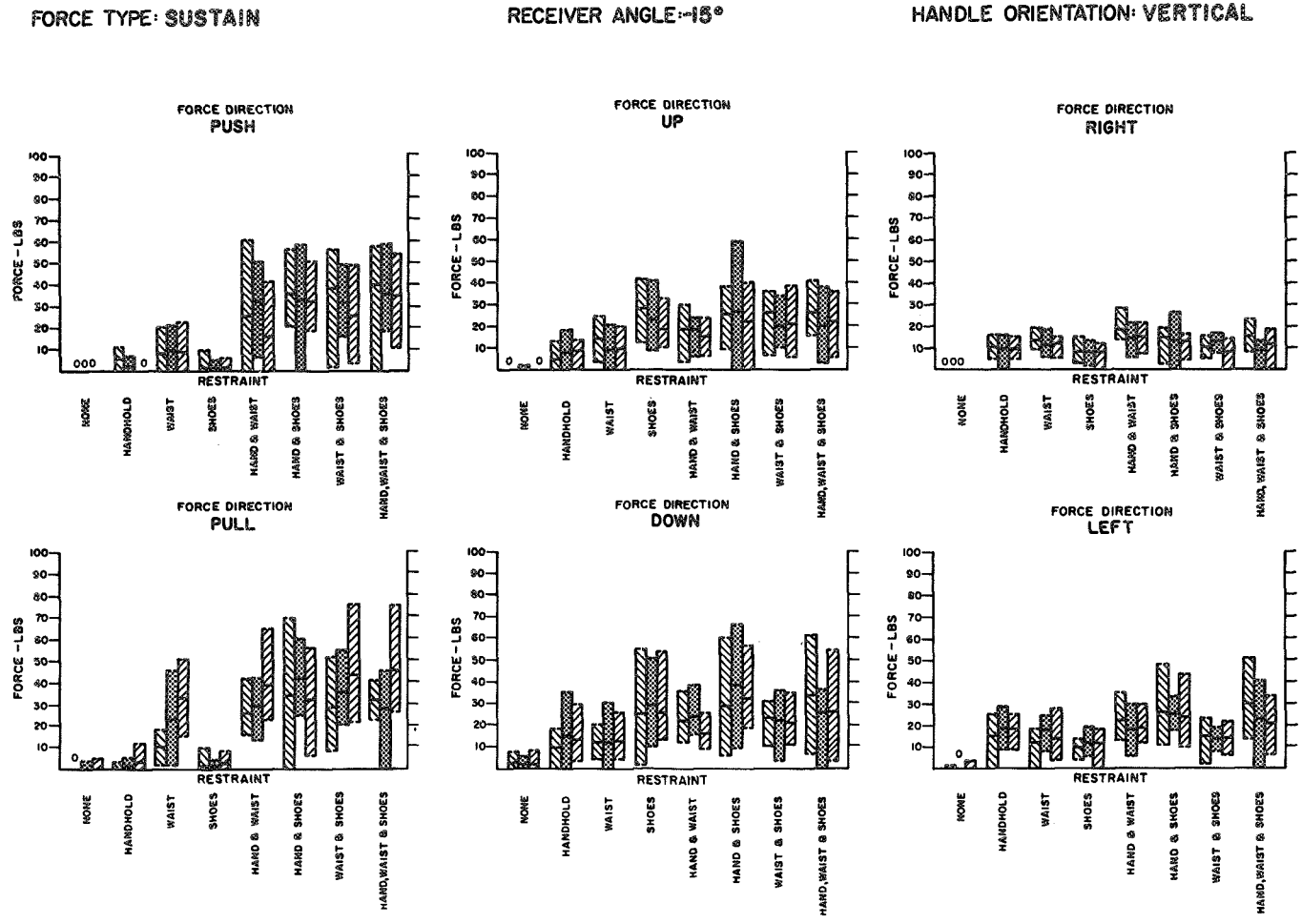


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #4

The data on this chart represents the sustained force emission capability for shirtsleeve and pressure suited zero gravity conditions. To determine the approximate sustained force emission capability for the shirtsleeve and pressure suited one-g conditions, multiply the 0-g mean values by 2.5.

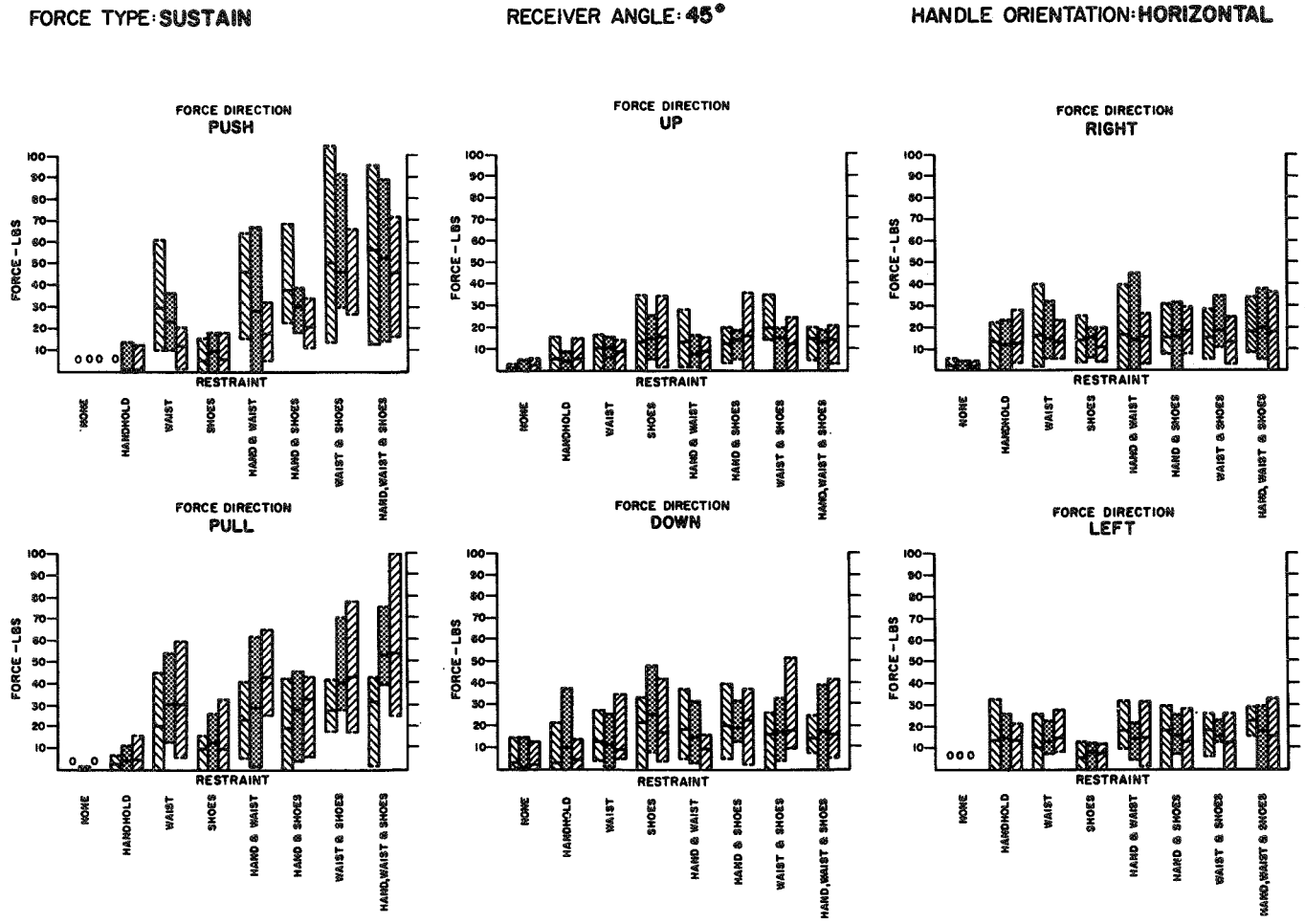


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #5

The data on this chart represents the sustained force emission capability for shirtsleeve and pressure suited zero gravity conditions. To determine the approximate sustained force emission capability for the shirtsleeve and pressure suited one-g conditions, multiply the 0-g mean values by 2.5.

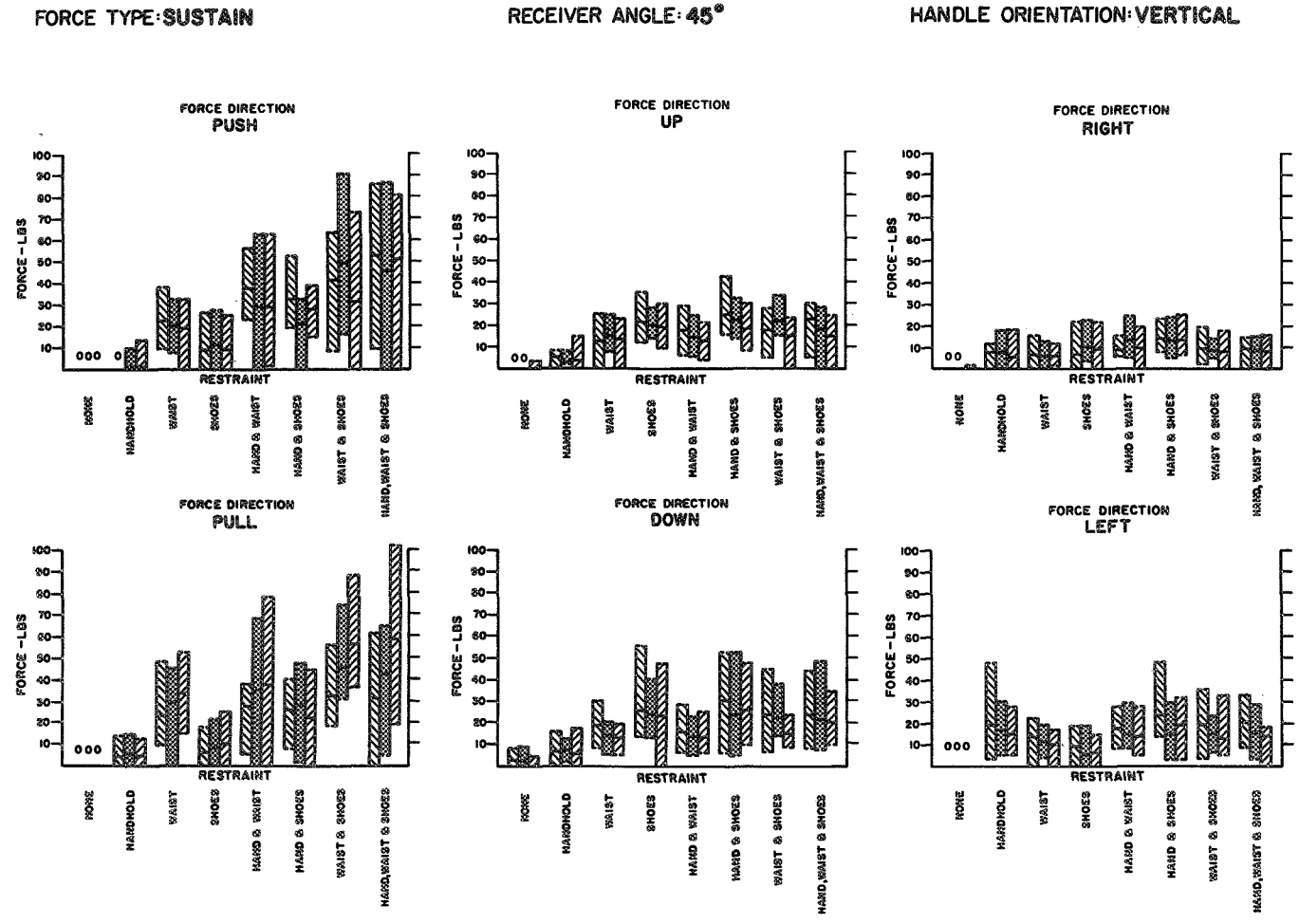


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #6

The mean impulsive force emission data on this chart should be used as the best approximation of impulsive force producing capability in a zero or one gravity environment under shirtsleeve or pressure suited conditions.

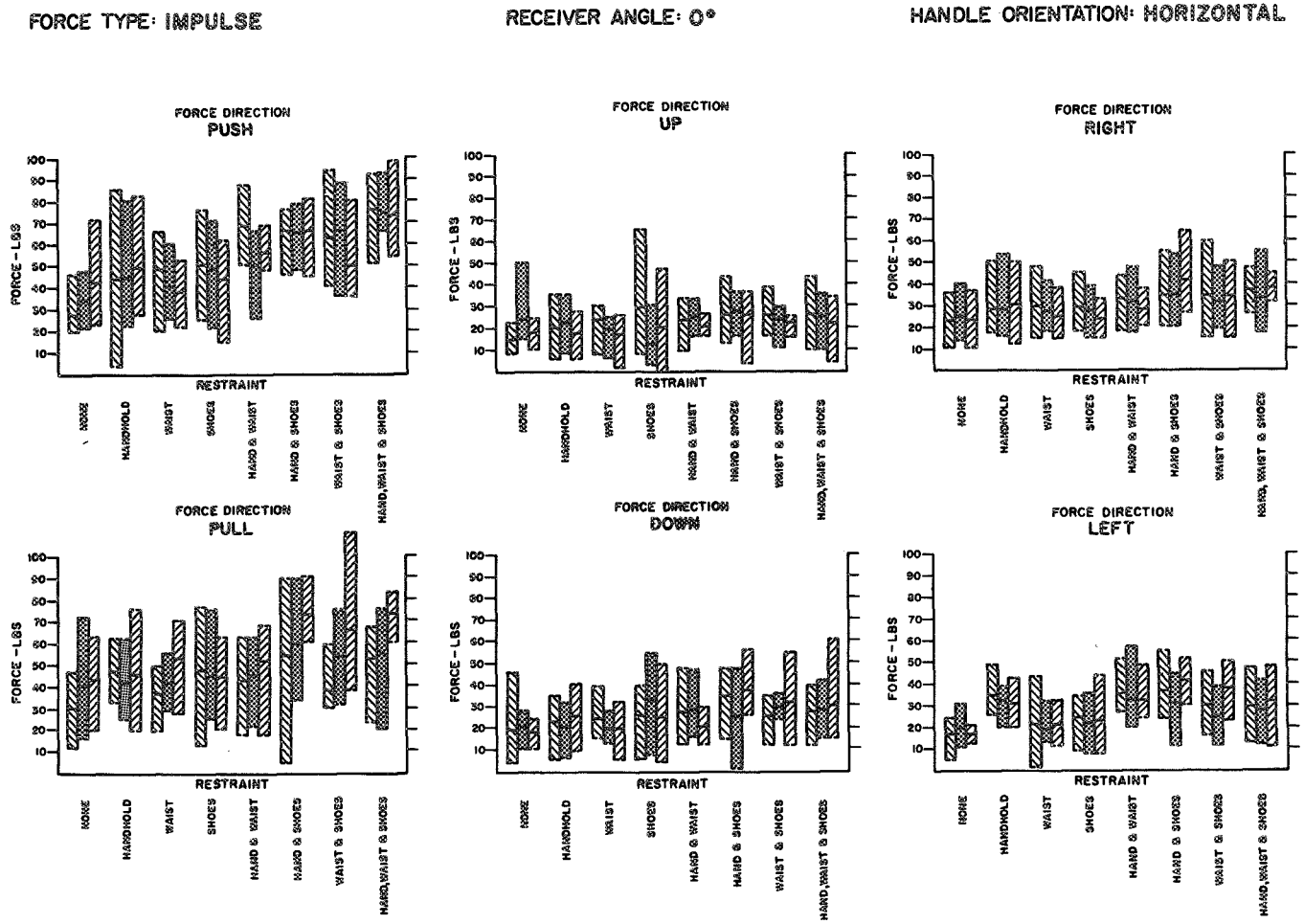


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #7

The mean impulsive force emission data on this chart should be used as the best approximation of impulsive force producing capability in a zero or one gravity environment under shirtsleeve or pressure suited conditions.

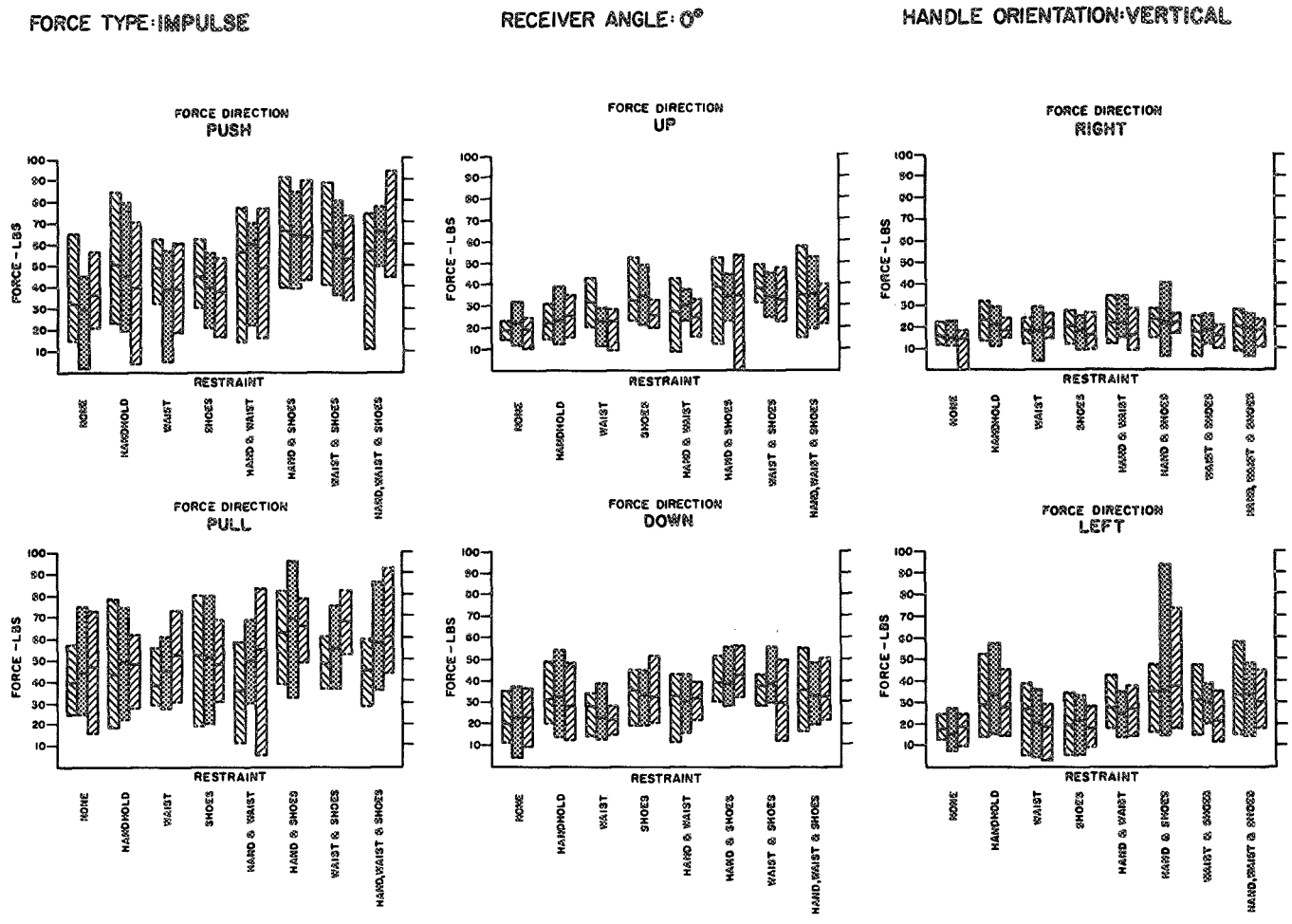


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #8

The mean impulsive force emission data on this chart should be used as the best approximation of impulsive force producing capability in a zero or one gravity environment under shirtsleeve or pressure suited conditions.

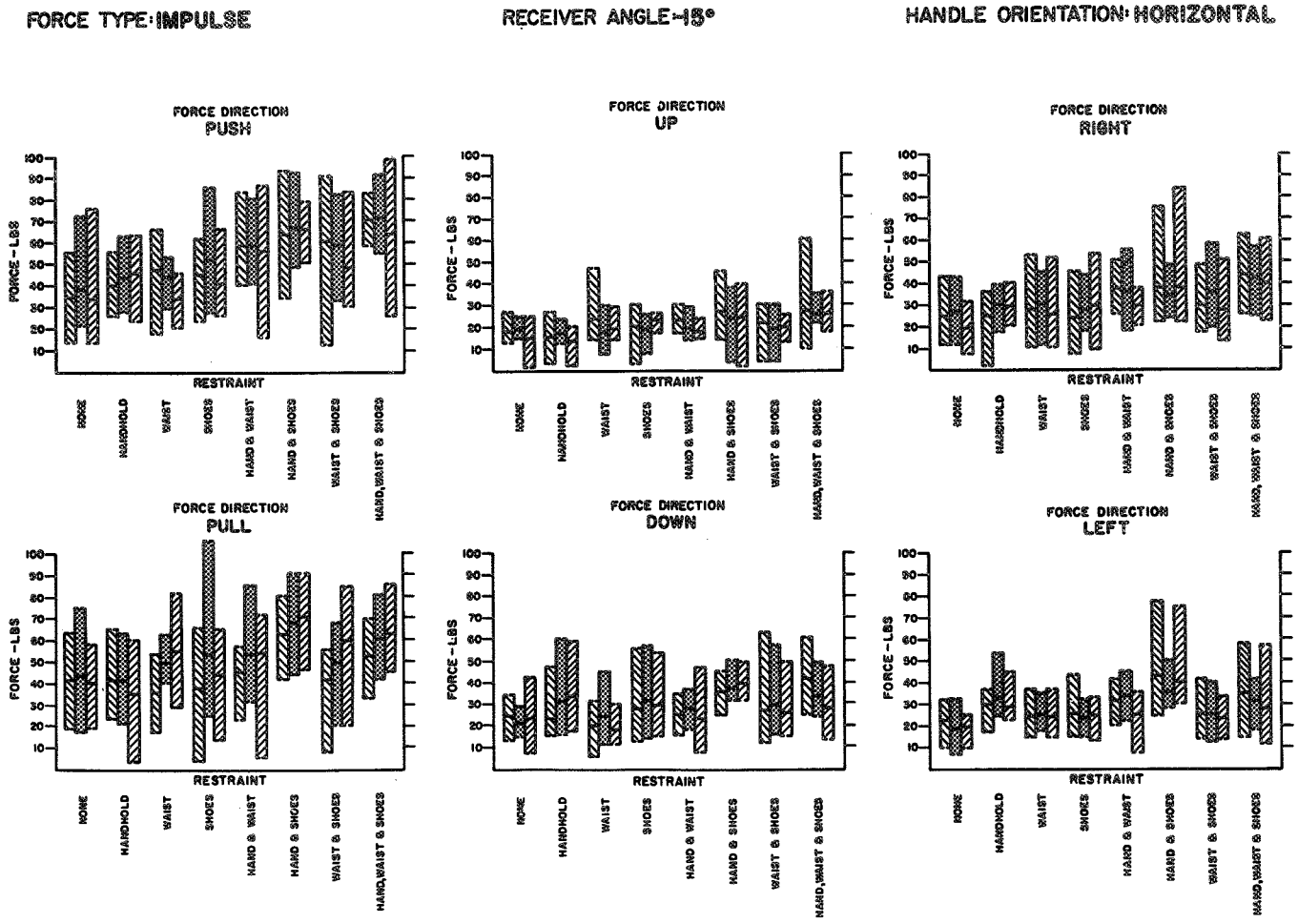


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #9

The mean impulsive force emission data on this chart should be used as the best approximation of impulsive force producing capability in a zero or one gravity environment under shirtsleeve or pressure suited conditions.

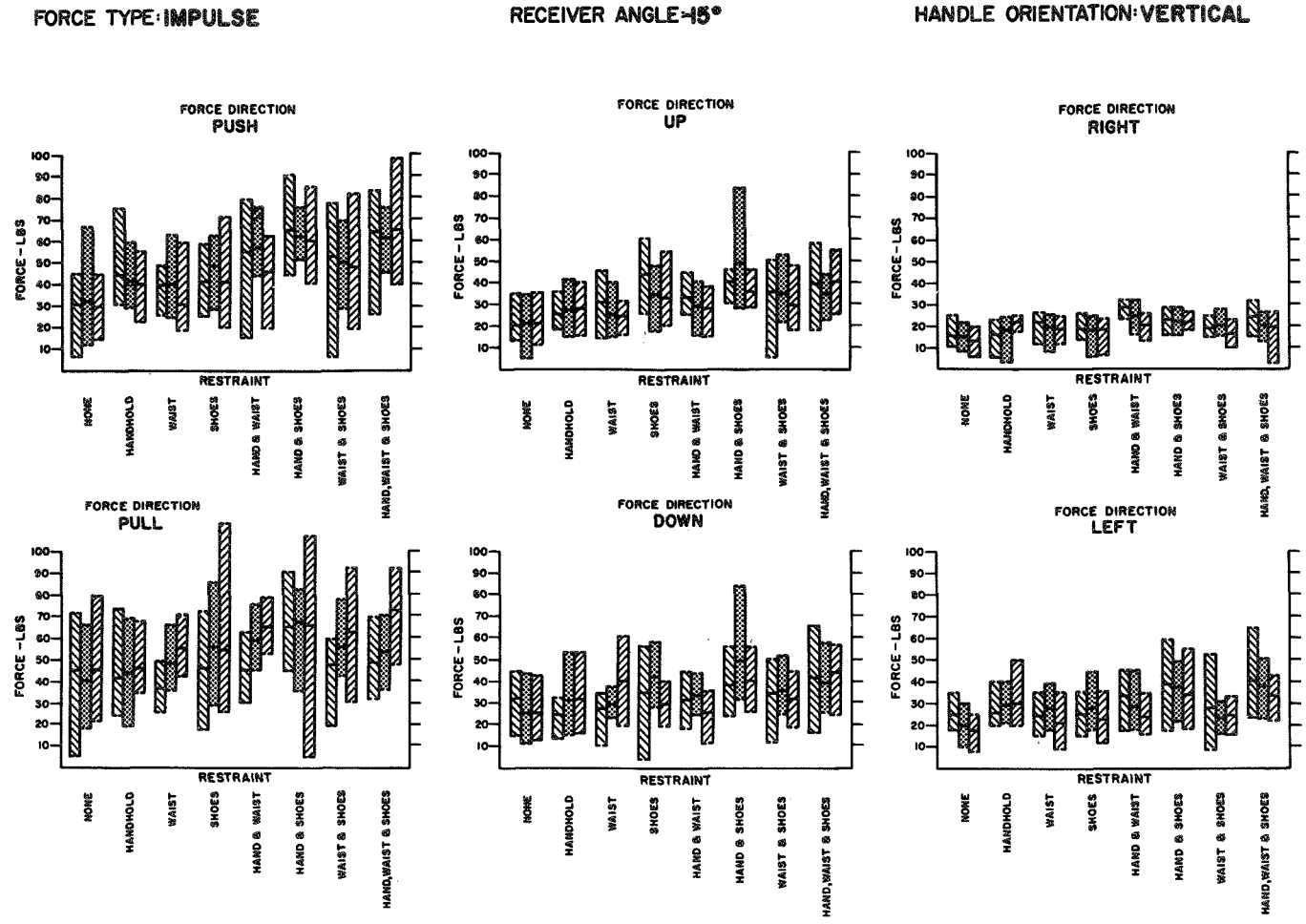


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #10

The mean impulsive force emission data on this chart should be used as the best approximation of impulsive force producing capability in a zero or one gravity environment under shirtsleeve or pressure suited conditions.

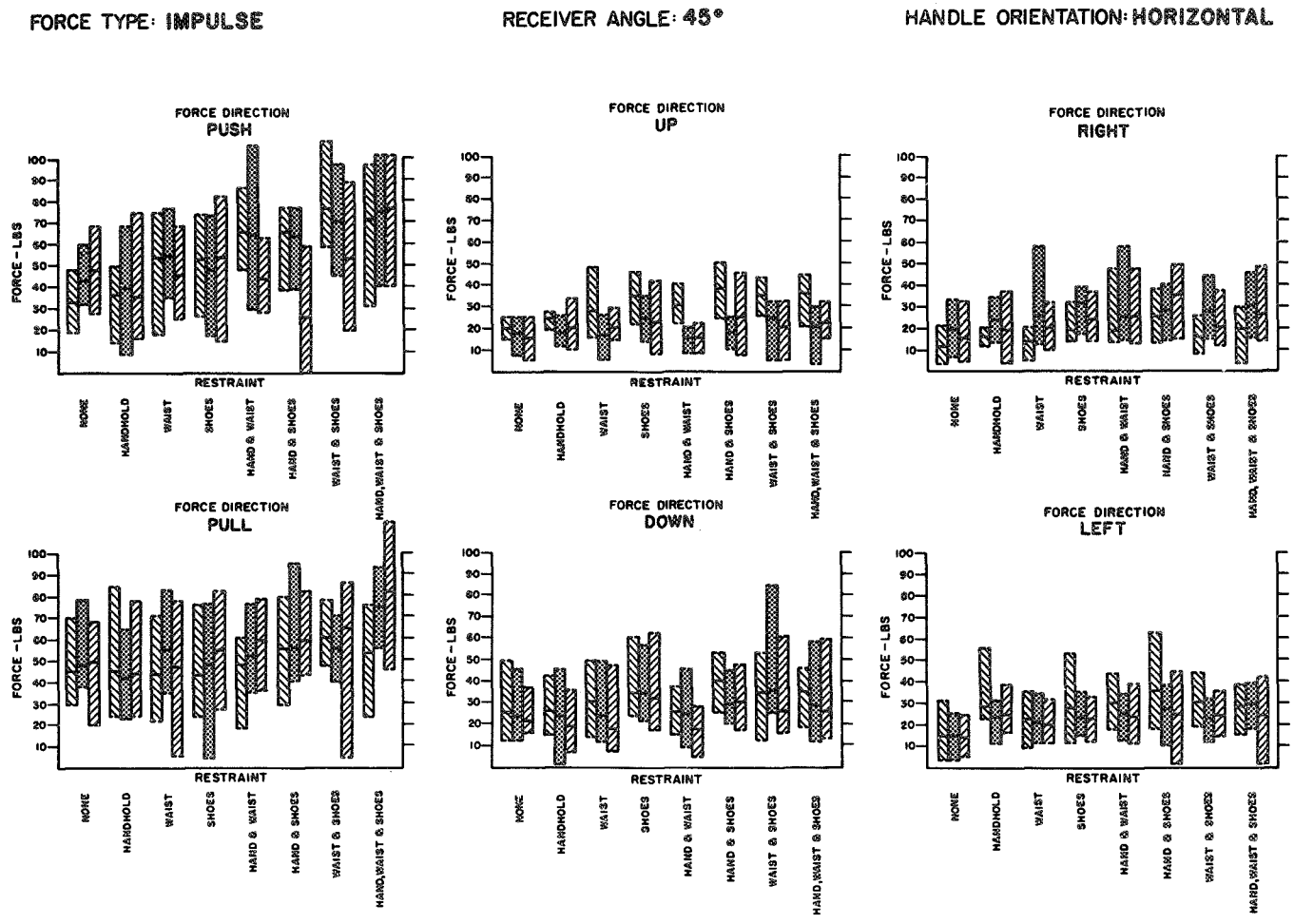


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #11

The mean impulsive force emission data on this chart should be used as the best approximation of impulsive force producing capability in a zero or one gravity environment under shirtsleeve or pressure suited conditions.

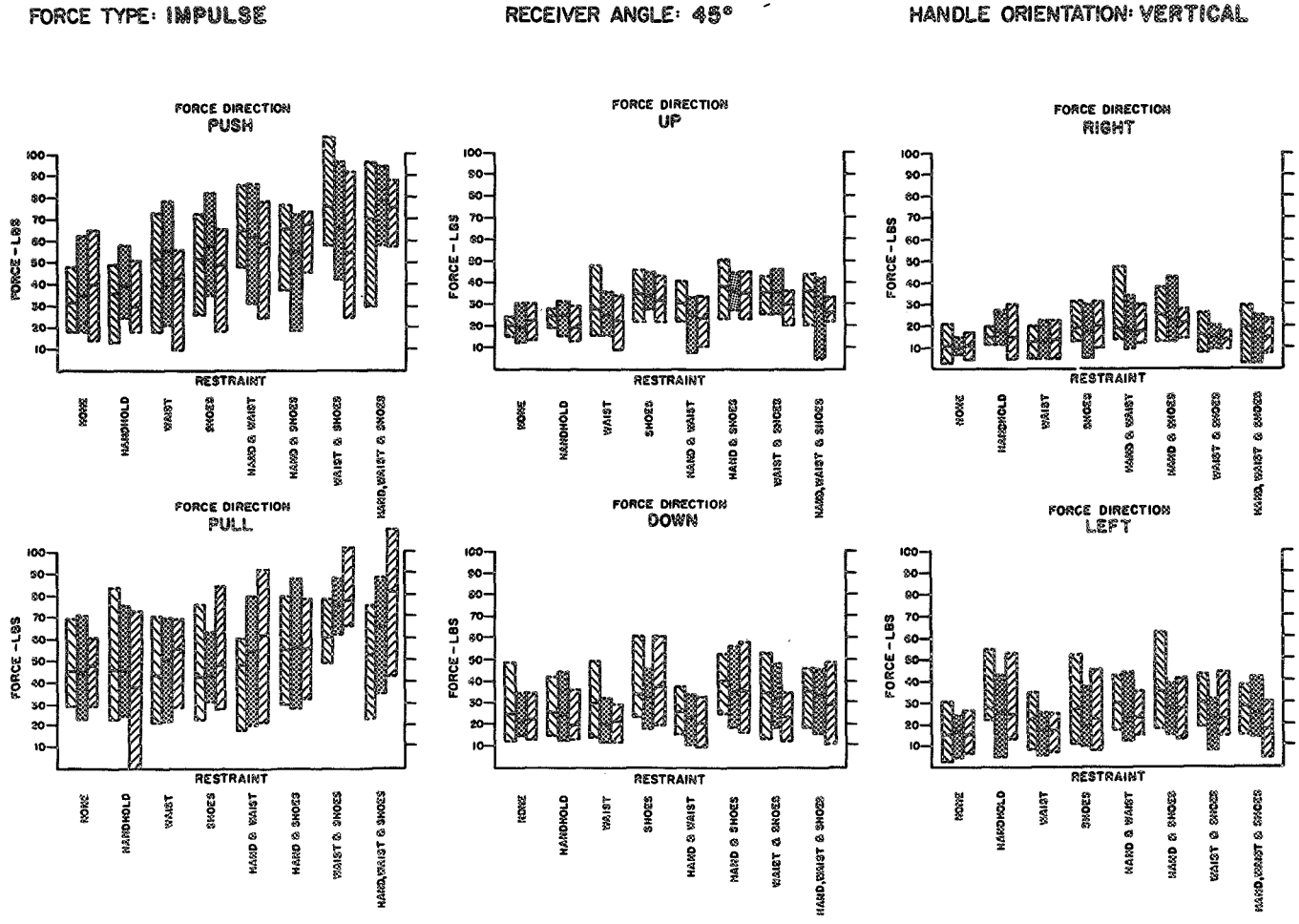


FIGURE 9-4 EXPERIMENT 84A SUMMARY DATA CHART #12

SECTION 10

PROGRAM CONCLUSIONS AND RECOMMENDATIONS

10.1 INTRODUCTION

This section provides a brief review and summary of the major accomplishments, conclusions and recommendations that resulted from the conduct of the Astronaut Zero Gravity Performance Evaluation Program.

10.2 CONCLUSIONS

Experiment M508 was initially conceived to provide information relative to the performance of selected pieces of EVA hardware. At a later date, it was realized that the experiment could serve as a means of evaluating the various ground-based zero-g simulations currently used for astronaut training as well as for physiological and psychomotor performance studies. Finally, it was also realized that the experiment could provide valuable zero-gravity human performance design data. The most important conclusion to be drawn from the work reported here is that all of these objectives are well satisfied by the experiment which was designed and performed for this contract.

Given that the program objectives remain as EVA hardware evaluation, simulation technique evaluation and the generation of design data, the importance of utilizing the experiment which results from execution of the individual task recommendations in Section 7 cannot be overstressed. It is worthwhile to review here the results which dictate the inclusion or deletion of certain tasks and/or experiment variables.

The Precise Hand Movement Task indicated important performance differences across simulation modes and between suited (EVA) and shirtsleeve (IVA) conditions. In addition, it was noted that the existence of a limiting access port seriously degrades one's ability to accurately perform a dynamic task. This type of information is directly relatable, for example, to the removal and replacement of small film cassettes, where precision alignment is required.

In the Two-Hand Task (a static test of accuracy) it was found that the access condition did not affect the accuracy of performance. It was also found that any relatively stable one-point restraint is suitable for such a task. This type of information would be useful in designing an astronaut function involving a task such as sensor alignment. This task also proved capable of differentiating between simulation modes and between suited and shirtsleeve conditions.

The Precise Force Task provided important results concerning simulation modes and restraints. The Precise Torque Task tended to confirm these results, but because it did not provide any conclusions or results that were new or different, this task was recommended for deletion.

The Sustained and Impulse Force and Torque Tasks also tended to confirm each other. But each of these tasks provides inherently valuable design data on a basic human performance capability and should therefore be retained. Two of the most important results found in these tasks were the existence of inhibited performance in the 6 DOF simulation and the ineffectiveness of the variable-flexibility waist tether utilized in this experiment. Design data was enhanced by being collected at various reach envelope locations, using different tools, etc.

10.2 CONCLUSIONS (Continued)

The Operational Maintenance Task, Restraint Installation Task and the Gain Access Task were all found to be too specific in nature to provide meaningful results. These tasks were recommended for deletion, resulting in a time savings to the experiment of approximately one-fourth the total experiment time.

It was stated in Section 7 that the experiment did note several important differences in performance resulting from the nature of the A7L and the AES suits. The experiment was more effective, however, for quantifying differences in an IVA (shirtsleeve) condition vs. an EVA (suited) condition. It is therefore recommended that only one suit be kept for the flight experiment. As an alternative, the "worksite only" restriction can be removed, allowing additional experimental tasks which would provide a more complete suit evaluation.

With regard to the other major experimental condition - restraints - it is recommended that the experiment utilize at least two different restraint conditions. The manually operated waist tether, however, should either be greatly improved or replaced prior to inclusion in the flight program. The Dutch Shoes must also be modified to fit the AES suit boots (if that suit is retained in the program). The important point to bear in mind, of course, is that the experiment can and will denote performance differences which result from the utilization of any restraints.

One of the most significant conclusions from this program has been the demonstrated value of utilizing representative tasks to provide objective, quantifiable data rather than real operational tasks that provide only subjective or qualitative data of a "Go-No Go" nature. The technique which resulted in the design of these tasks (Section 3.0) is a sound one. To some, they have seemed irrelevant and inappropriate. The technique and resultant experimental tasks are based upon consideration of the psychomotor capabilities required of astronauts to perform the experiments planned for the next decade of manned space flight. In addition, the experiment program reported here illustrates well how the representative tasks do in fact satisfy the objectives of the M508 Experiment.

10.3 RECOMMENDATIONS

The most important recommendation that can be made to NASA is that the flight validation data on this experiment be collected consistent with the experiment design as it now exists. The result of the flight experiment will literally be a human performance data bank providing evaluations and comparisons never before available. These evaluations could utilize computer programs and techniques already existing from this contract with virtually no changes. For the first time, analysts could objectively determine the most effective means for simulating zero-gravity for different tasks. It is not extreme to conceive of a situation in the future where a spacecraft designer or mission planner requires the performance of a particular task; with suitable reflection, he decides (for example) that force emission is not important to performance of the task, but an ability to accurately perform a dynamic manipulation is. Consulting the Precise Hand

10.3 RECOMMENDATIONS (Continued)

Movement Task data bank, he could determine the proper restraint to recommend for task performance, the proper simulation technique to use for astronaut training, etc. He could even trade-off the time savings that might result from modifying an EVA task design to permit its performance in an IVA mode vs. the potential equipment ramifications of such a redesign.

The work reported in this document confirms the existence of a potential to satisfy the M508 program objectives. Flight performance of this experiment in the near future will capitalize on this potential and provide significant knowledge on the problems of human performance in zero-gravity.

APPENDIX A

ASTRONAUT PERFORMANCE PROGRAM DESIGN VERIFICATION TEST PROTOCOLS

			PAGE
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API-11 (III)	-	EXPERIMENT SCHEDULES AND PROCEDURES (MODIFIED)	A-15
API-11 (IV)	-	REQUIREMENTS SPECIFICATIONS FOR EXPERIMENTAL PERSONNEL	A-36
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I. EXPERIMENT DESCRIPTION

Because of the length of the original experiment description and because the information is included in the body of the Detailed Technical Report, the reader is directed to Sections 3 and 5 of Volume II for answers to specific experiment description questions.

II. FACILITIES AND SUPPORT EQUIPMENT REQUIREMENTS SPECIFICATION

1.0 INTRODUCTION

This specification defines the requirements for the facilities and support operations required for the Astronaut Performance Program (M508) Design Verification Tests. These tests are to be conducted under simulated zero-gravity conditions, including neutral buoyancy, Keplerian flights and 6 Degree-of-Freedom mechanical simulations and a 1-g walkthrough.

The 1-g walkthrough and neutral buoyancy simulations are to be conducted in General Electric facilities, the Keplerian flight is to be conducted on a KC-135 aircraft based at Wright-Patterson AFB, and the 6 Degree-of-Freedom mechanical simulation will use the facility located at the MSFC, Huntsville, Alabama.

Also defined in this specification are the interface requirements for the simulation facility/M508 equipments and the operations necessary for the conduct of the test programs.

2.0 NEUTRAL BUOYANCY SIMULATIONS

The neutral buoyancy simulation phase of the Design Verification Tests will be conducted in the General Electric facility at Valley Forge, Pa. (See Figure 1).

2.1 ENVIRONMENTAL CONDITIONS

2.1.1 Water

The water temperature in the facility shall be controlled to 85° $\pm$ 5°F.

The water shall be kept clean and free of all debris and measurable bacteria. Visibility in the water shall be such that a person underwater at the side of the pool can see clearly across to the opposite side. A person standing on the walkway shall be able to see the bottom clearly.

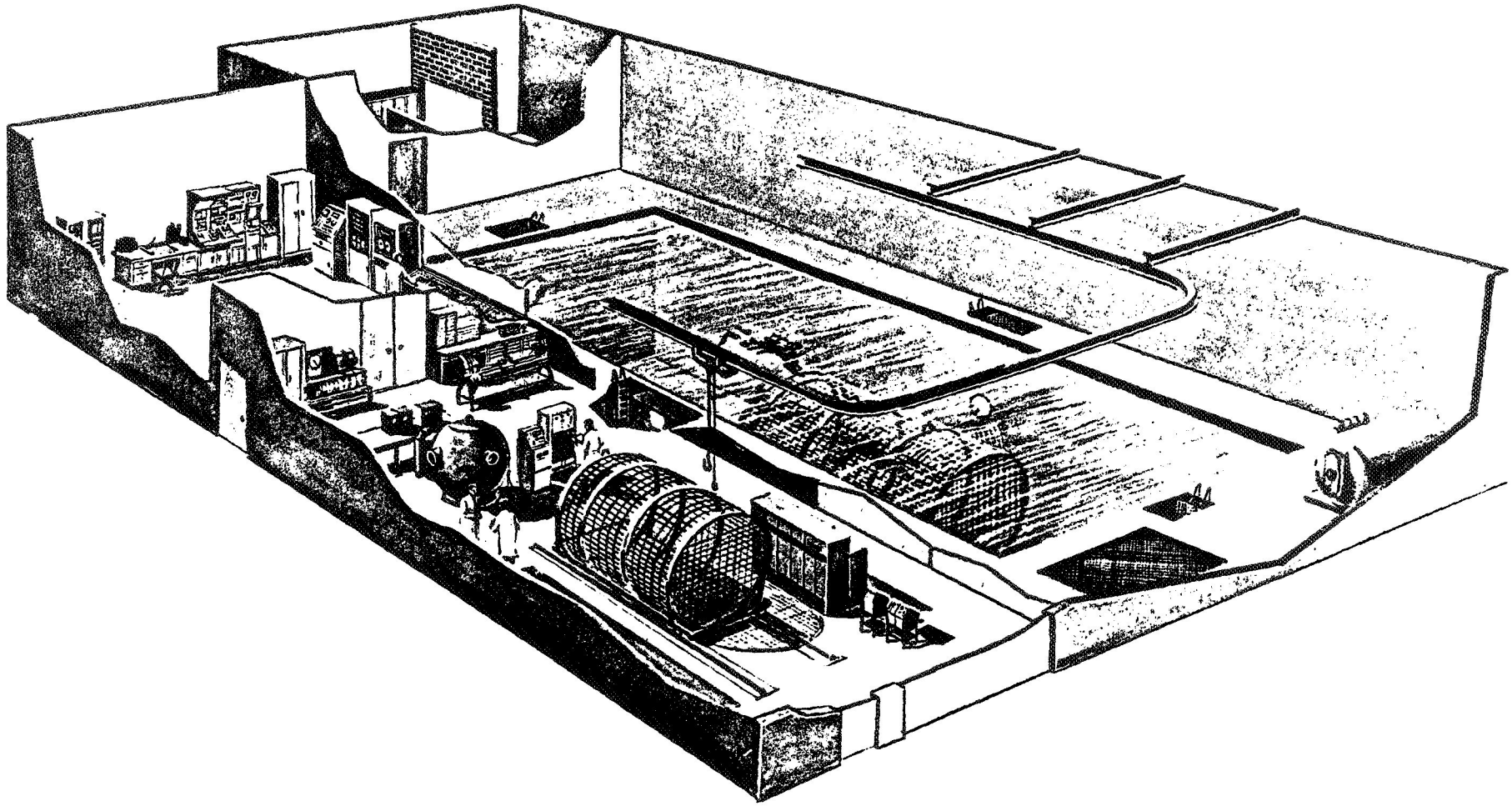


FIGURE 1 GE CONTROLLED BUOYANCY FACILITY

2.1.2 Water Surroundings

The pool enclosure shall be maintained within 5°F of the water temperature and shall be free from drafts. All entrances to the pool area shall be protected with curtains or double doors so that there will be no drafts when outside doors are opened.

2.2 PERSONNEL ACCOMMODATIONS

A dressing room shall be provided for those persons participating in water operations. This room will also provide lockers for storing clothing and other personal belongings. The dressing room should also provide a shower for the personnel. As personal SCUBA gear shall also be stored here, wash down facilities for these equipments will be required. The dressing room shall be maintained at the same temperature as the pool area.

2.3 INSTRUMENTATION AND DATA RECORDING

2.3.1 Underwater Photography

There shall be two cameras for underwater use each having remote focus and zoom controls. The cameras shall be mounted on remotely controlled tilt and pan units. A separate monitor will be required for each camera.

Adequate underwater lighting shall be provided to the extent that the data films are of the highest quality attainable with the particular equipment used.

2.3.2 Audio Recording

A means shall be provided for recording voice comments during the conduct of each experimental session. The voice channel/recorder shall be capable of at least one hour of continuous operation.

2.3.3 Control Station

All experiment controls, communications and photographic equipment will be operated from a single control station located in the vicinity of the pool. The control station shall be designed and constructed in a manner such that one person (the test director) can operate the required switching circuits and controls during the conduct of the experiment.

The control station shall contain, as a minimum, the following:

- o TV Controls and Monitors
- o Experiment Cue Controls
- o Data Recording Controls
- o Communication Links
- o Table Space

2.3.4 Backup Equipment

There shall be sufficient backup equipment available so that a failure in any experimental equipment will not cause excessive delays in the experimental operations.

2.4 ELECTRICAL POWER REQUIREMENTS

The power required to operate the experiment equipment is 28VDC (unregulated), 40 watts continuous.

2.5 SUPPORT EQUIPMENT

2.5.1 Backpack & Helmet

The suit pressurization system and special underwater helmet shall be supplied for the duration of the test program. Electrical power and breathing air for the backpack and subject shall be supplied by the facility.

2.5.2 SCUBA Equipment

SCUBA equipment shall be provided for all personnel participating in underwater activities. The amount of equipment to be provided is as follows:

- Experiment Installation, Set-Up and Checkout Operations
  - 5 regulators, masks, fins, etc.
  - 20 tanks per day
- Training Operations
  - 8 regulators, masks, fins, etc.
  - 20 tanks per day
- Experiment Conduct
  - 6 regulators, masks, fins, etc.
  - 20 tanks per day

The tanks should be filled overnight and be ready for operations at 7:30 A.M. each morning. Provisions shall be available to allow the SCUBA equipment to be washed at the end of each day's use and stored in the dressing room.

2.5.3 Hookah Equipment

Four operating Hookah lines will be supplied in the water at all times. These will be considered as the prime breathing apparatus for the safety man and experiment technician while they are underwater.

The remainder will be available to the subject and topside safety man for emergencies.

2.5.4 Communications

Communications shall be provided in the following modes:

- Test director to all persons in pool and surrounding area
- Safety man to test director
- Subject to safety man and test director

2.6 EXPERIMENT EQUIPMENT/FACILITY INTERFACE

2.6.1 Mounting Interface

The experiment equipment shall be mounted to a support structure which in turn will be attached to the wall of the facility. This attachment shall be through existing mounting points. The location and dimensions of the support structure mounting points shall be supplied at a later date.

2.6.2 Electrical Interface

The following electrical signals shall interface with the underwater experiment equipment.

- o 28 VDC supply, unregulated, 40 watts
- o DC return
- o Data Outputs
  - Analog signals 0-5 VDC
  - Bilevel (Digital) Signals 15 VDC

2.7 REPAIR AND MAINTENANCE

Facilities shall be provided for maintenance and repair of the experimental equipment and instrumentation. This facility shall be equipped with standard hand tools and the following test equipment as a minimum:

- o Oscilloscope
- o DC Power Supply: 0 to 25 v
- o Vacuum Tube Voltmeter

3.0 KEPLERIAN FLIGHT SIMULATIONS

The Keplerian Flight simulation test will utilize a KC-135 aircraft based at Wright-Patterson AFB.

Two basic facilities are required for the Design Verification Tests. These are the KC-135 aircraft and a ground facility. The KC-135 aircraft as defined herein includes the flight crew and all other equipment and personnel required to make the aircraft an operational testbed.

The ground facility shall consist of a laboratory/workshop type room with work benches, desks and power source (110V, 60 hz) to be utilized as a storage and maintenance area for the General Electric experimental equipment.

3.1 TEST EQUIPMENT IDENTIFICATION

General Electric shall supply the following equipment required to perform the test operations in the KC-135 aircraft other than described above in Paragraph 3.0. This equipment shall include:

a. Task Panel

b. Restraints

c. Task Panel Support Structure

d. Ancillary Equipment Support Structure

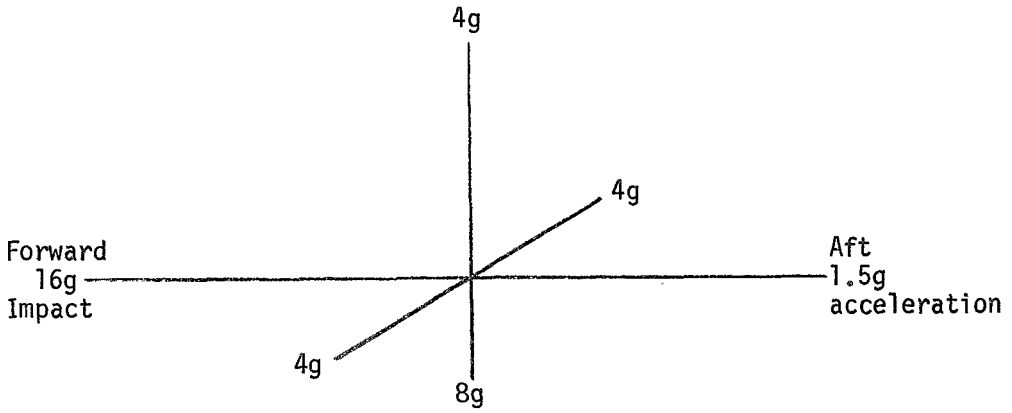
e. Cables

f. Miscellaneous Tools, spare parts and test equipment necessary for the maintenance of the test setup.

3.2 ENVIRONMENTAL CONDITIONS

3.2.1 Acceleration (Shock) Loads

The equipment (mounted) shall be capable of withstanding the loads shown in the diagram below.



3.2.2 Vibration

The experiment equipment shall be capable of withstanding the vibration environment shown below.

.036 DA	5 - 10 Hz
.02 DA	10 - 45 Hz
± 2g	45 - 500 Hz

3.3 PERSONNEL REQUIREMENTS & ACCOMMODATION

3.3.1 Personnel Requirements

All General Electric personnel engaged in the test flights shall meet the following qualifications:

1. Establish the proper security clearance at Wright-Patterson AFB.
2. Successfully pass a Class III flight physical.

3. Complete physiological training which consists of -

   a. Altitude chamber indoctrination.
   b. Explosive decompression.

4. Complete survival training.

3.3.2 Test Subject Dressing Room

The ground laboratory shall serve as the dressing room for the test subject.

3.4 ELECTRICAL POWER

3.4.1 KC-135 Aircraft

The aircraft shall supply.

a. 28 VDC (unregulated) 40 watts

b. 3o 400 hz (Power to be supplied later)

The aircraft shall supply mating pairs of all connectors. The experiment and test equipment shall supply unended cables 20 ft. long.

3.4.2 Ground Facility

The ground facility shall supply -

110V, 60 hz (Power to be supplied later)

3.5 SUIT PRESSURIZATION

The aircraft shall supply air for suit pressurization and umbilicals sufficiently long to reach the work area. Suit-umbilical connectors shall be supplied by General Electric.

3.6 EXPERIMENT EQUIPMENT/KC-135 INTERFACE

3.6.1 Mounting Interface

All equipment support structures will be mounted to the floor of the aircraft. Tie-down points are arranged on a 20-inch grid pattern on the aircraft floor. The grid pattern straddles the aircraft centerline. The tie-down points will accept a 3/8 dia. bolt.

3.6.2 Electrical Interface

The power connections described in Paragraph 3.4 above represent the total electrical interface with the aircraft.

4.0 6 DEGREE-OF-FREEDOM MECHANICAL SIMULATION

The 6 Degree-of-Freedom Mechanical simulation shall utilize the facility at the Marshall Space Flight Center, Huntsville, Ala.

Two basic facilities are required for the Design Verification Tests. These are the mechanical simulator and a maintenance laboratory facility. The mechanical simulator as defined herein includes all other equipment and personnel required to make the simulator an operational testbed.

The laboratory facility shall consist of a laboratory/workshop type room with workbenches, desks and power source (110V, 60 hz) to be utilized as a storage and maintenance area for the General Electric experiment support equipments.

4.1 TEST EQUIPMENT IDENTIFICATION

General Electric shall supply all equipment required to perform the test operations other than described above in Paragraph 4.0. This equipment shall include:

a. Task Panel

b. Restraints

c. Task Panel Support Structure

d. Ancillary Equipment Support Structure

e. Cables

f. Miscellaneous tools, spare parts and test equipment necessary for the maintenance of the test setup.

4.2 ENVIRONMENTAL CONDITIONS

Since the test facility is located in an environmentally controlled building, no special environmental considerations or provisions need be made.

4.3 PERSONNEL REQUIREMENTS AND ACCOMMODATIONS

4.3.1 Personnel Requirements - To be determined.

4.3.2 Test Subject Dressing Room

The laboratory shall serve as the dressing room for the test subject.

4.4 ELECTRICAL POWER

The facility shall supply

110V, 60 hz (Power to be supplied later)

4.5 SUIT PRESSURIZATION

The MSFC facility shall supply air for suit pressurization and umbilicals sufficiently long to reach the work area. Suit-umbilical connectors shall be supplied by General Electric.

4.6 EXPERIMENT EQUIPMENT/SIMULATOR INTERFACE

4.6.1 Mounting Interface - To be determined.

4.6.2 Electrical Interface

The interfaces/requirements described in Paragraph 2.6.2 above represent the total electrical interface with the MSFC facility.

5.0 1-G WALKTHROUGH

The 1-g walkthrough test shall use the area immediately adjacent to the neutral buoyancy facility described in Section 2. Therefore, all requirements of that section apply here with the exception of those items directly relating to the underwater operations.

III. EXPERIMENT SCHEDULES AND PROCEDURES

1.0 SCHEDULES

1.1 Program Schedules

This section presents the program-level and daily schedules for conduct of the Design Verification Tests.

Figure 1.1 contains the phasing of the various simulations for DVT and is predicated on a follow-on contract go-ahead of 1 March 1969. The main portion of testing will be conducted beginning 5 May 1969. The one-g walkthrough will be performed first in order to simplify simulation-inherent complexities while procedures and hardware are still in the early phases of operation. At the conclusion of one-g testing, a week has been allocated for any procedural or design modifications that may be required.

The one-g simulation effort will be followed in turn by neutral buoyancy, 6 DOF air-bearing, and KC-135 simulations. An additional week of KC-135 testing is scheduled to begin on 28 April 1969 to permit initial checkout of all test equipment and personnel.

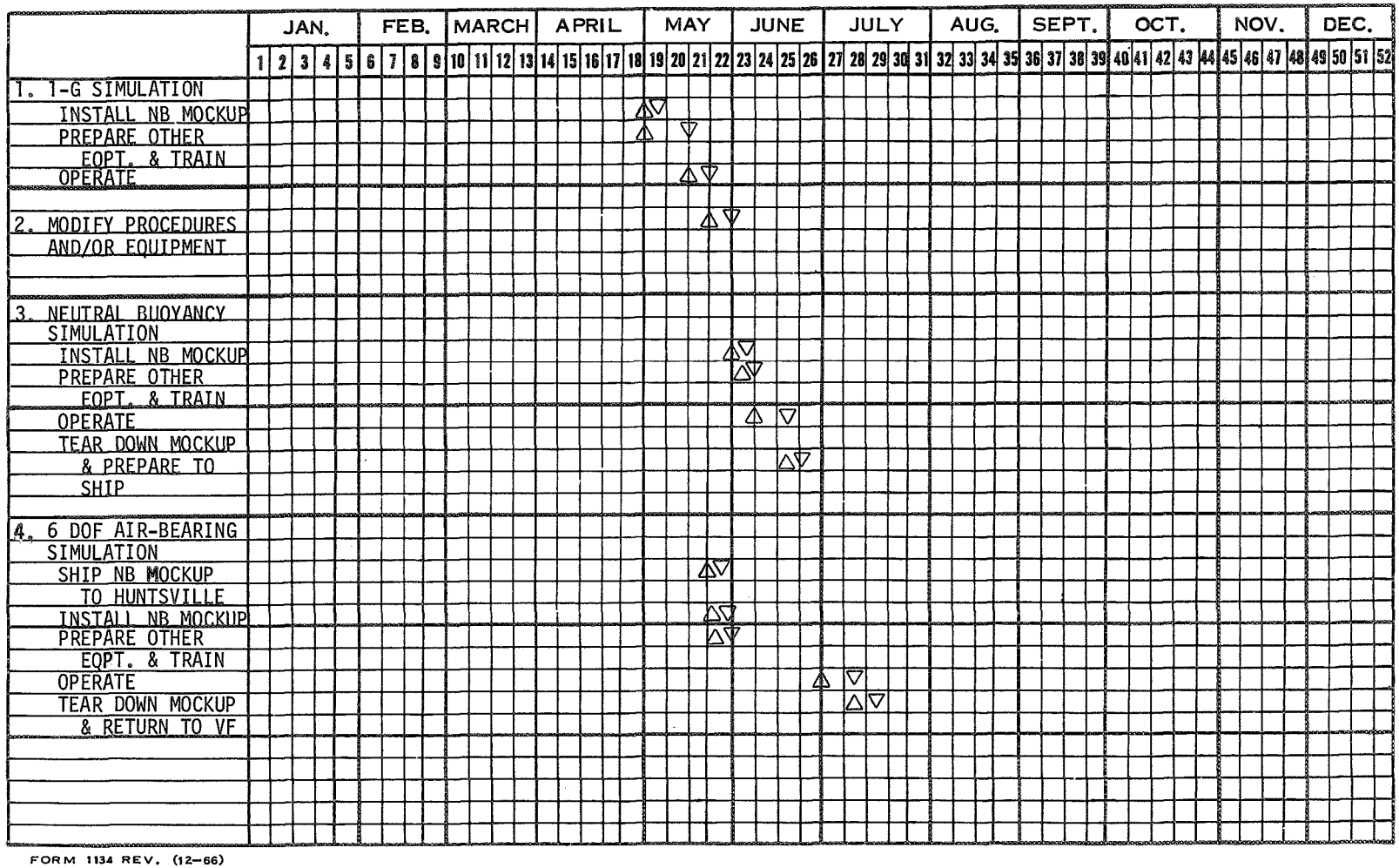
The schedules of Figure 1.1 have been prepared to allow use of the same subjects throughout the program.

1.2 Daily Schedules

Daily schedules for each phase of simulation testing are presented in Figures 1.2 through 1.5. The daily schedules are based on the following:

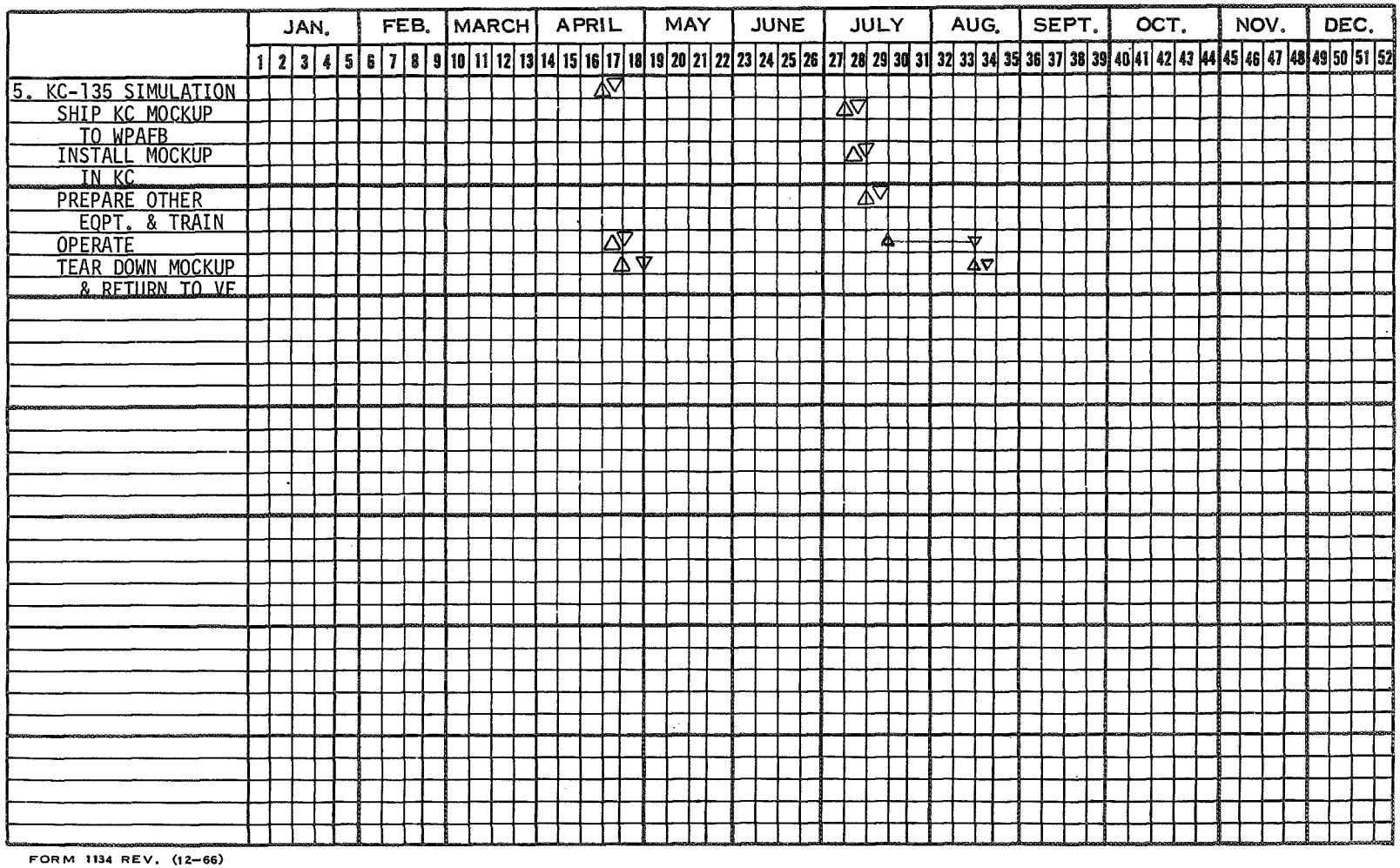
One-G Walkthrough	- 36 sessions total - 6 sessions per day - each subject performs 3 sessions per day
6 DOF	- 36 sessions total - 4 sessions per day - each subject performs 2 sessions per day
NBS	- 36 sessions total - 4 sessions per day - each subject performs 2 sessions per day
KC-135	- 18 sessions total - 1 session per day (requiring two flights per day) - each subjects performs 1/2 session per day
SESSION TIME:	Approximately 45 minutes

FIGURE 1.1 DESIGN VERIFICATION TESTING SCHEDULE (FOLLOW-ON CONTRACT - 1 MARCH 1969)



FORM 1134 REV. (12-66)

FIGURE 1.1 DESIGN VERIFICATION TESTING SCHEDULE (Cont'd.)



FORM 1134 REV. (12-66)

FIGURE 1.2 DAILY SCHEDULE

ONE-G WALKTHROUGH SIMULATION

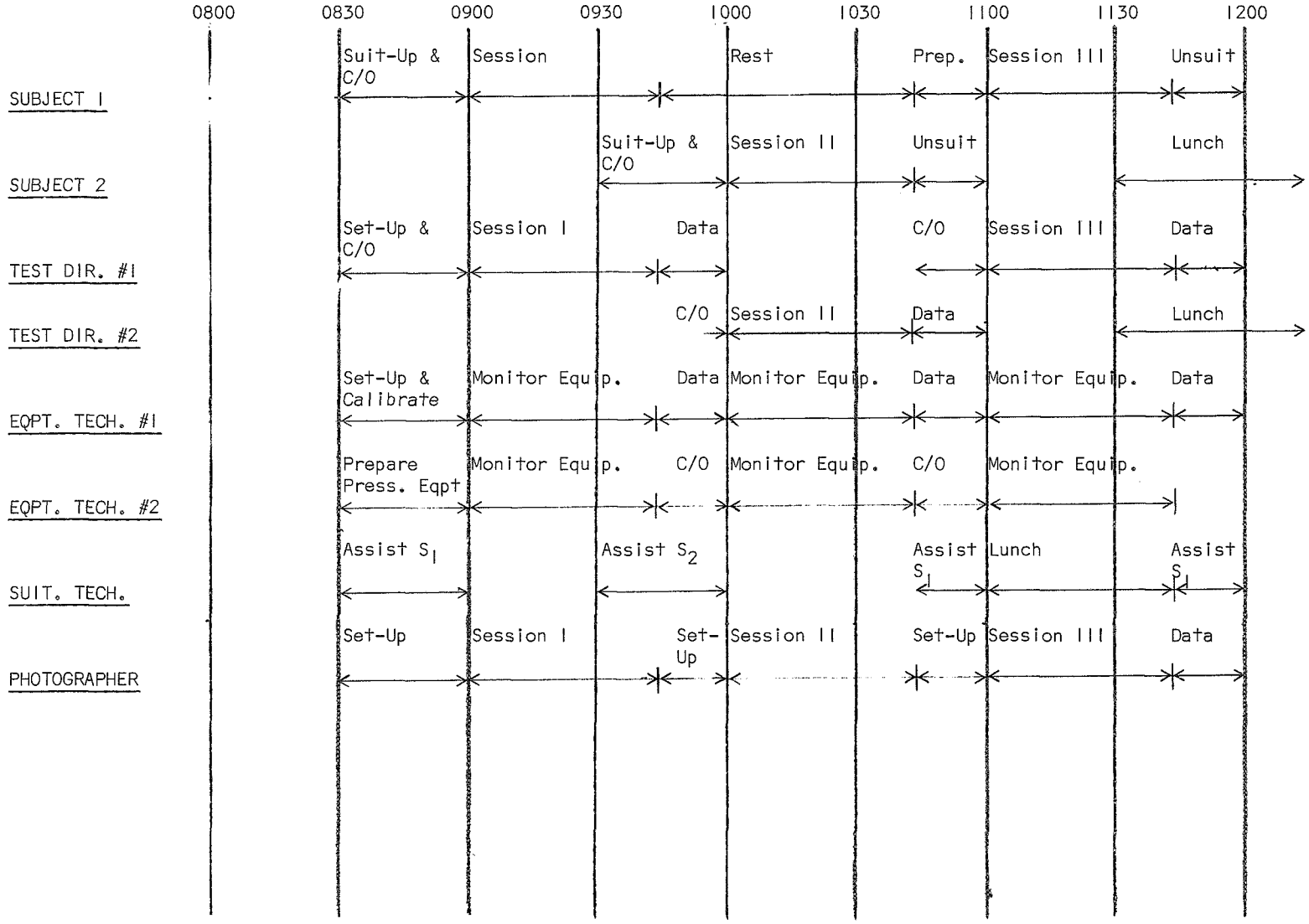


FIGURE I.2 DAILY SCHEDULE(Cont'd.)

ONE-G WALKTHROUGH SIMULATION

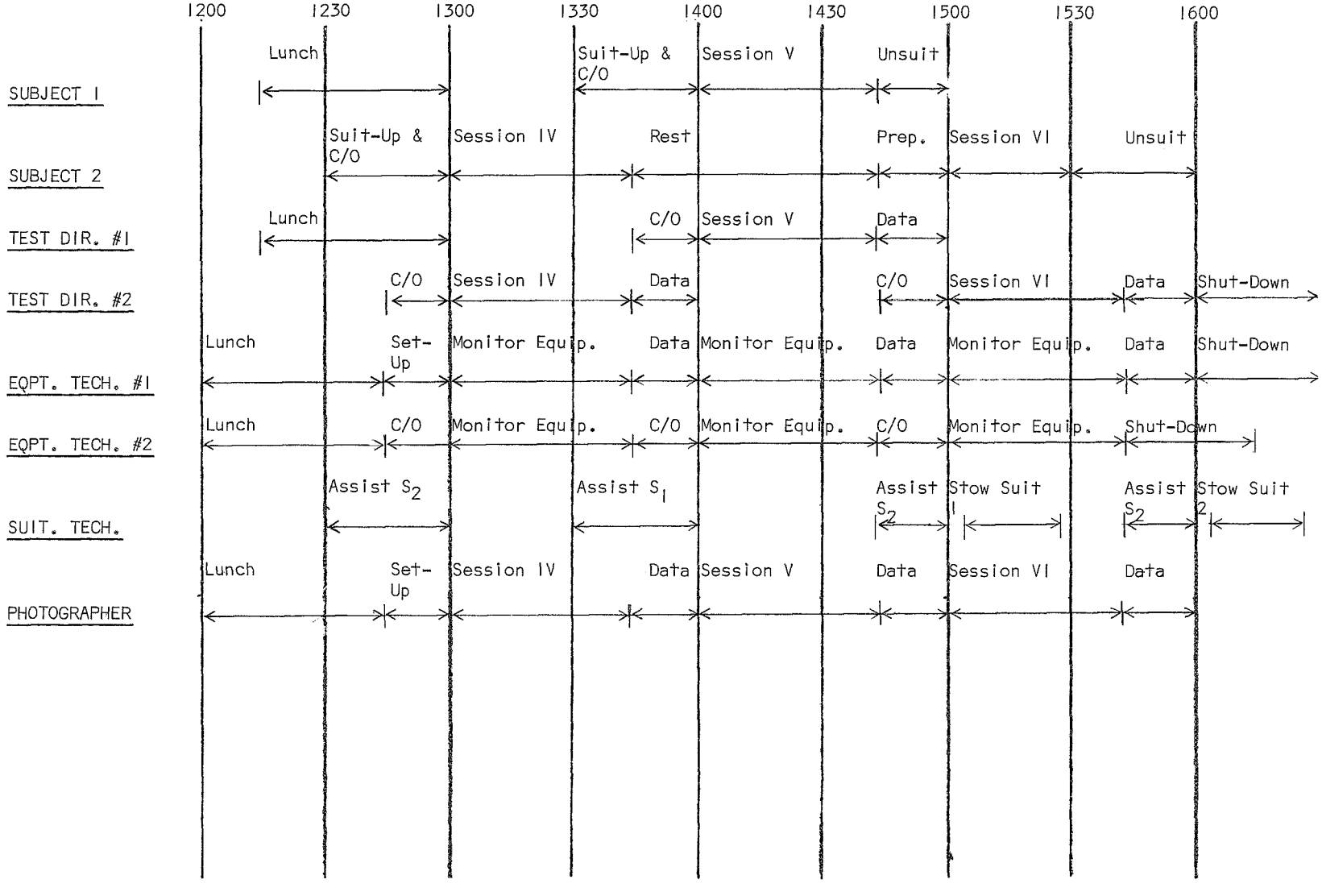


FIGURE I.3 DAILY SCHEDULE

NEUTRAL BUOYANCY SIMULATION

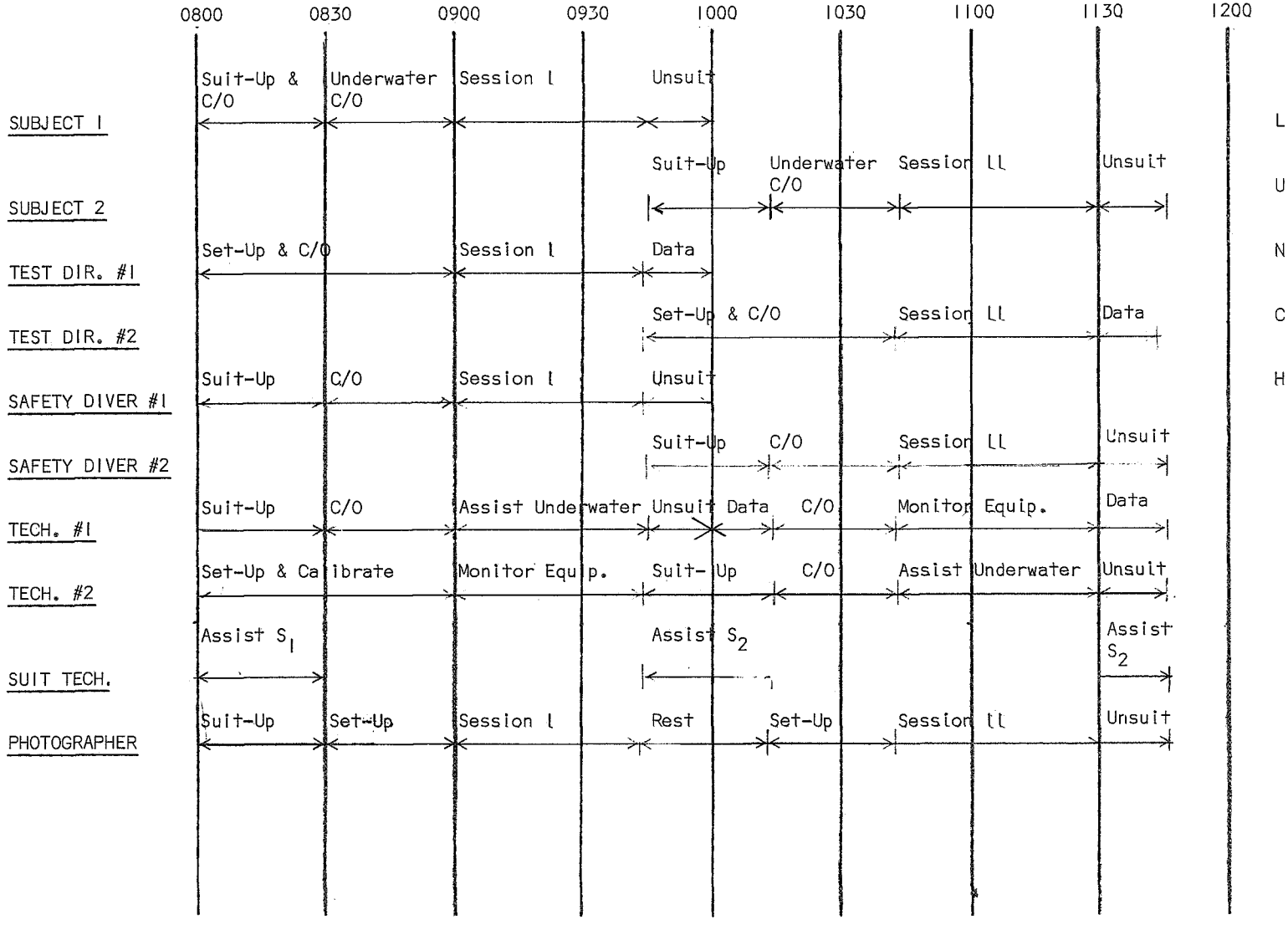


FIGURE I.3 DAILY SCHEDULE (Cont'd.)

NEUTRAL BUOYANCY SIMULATION

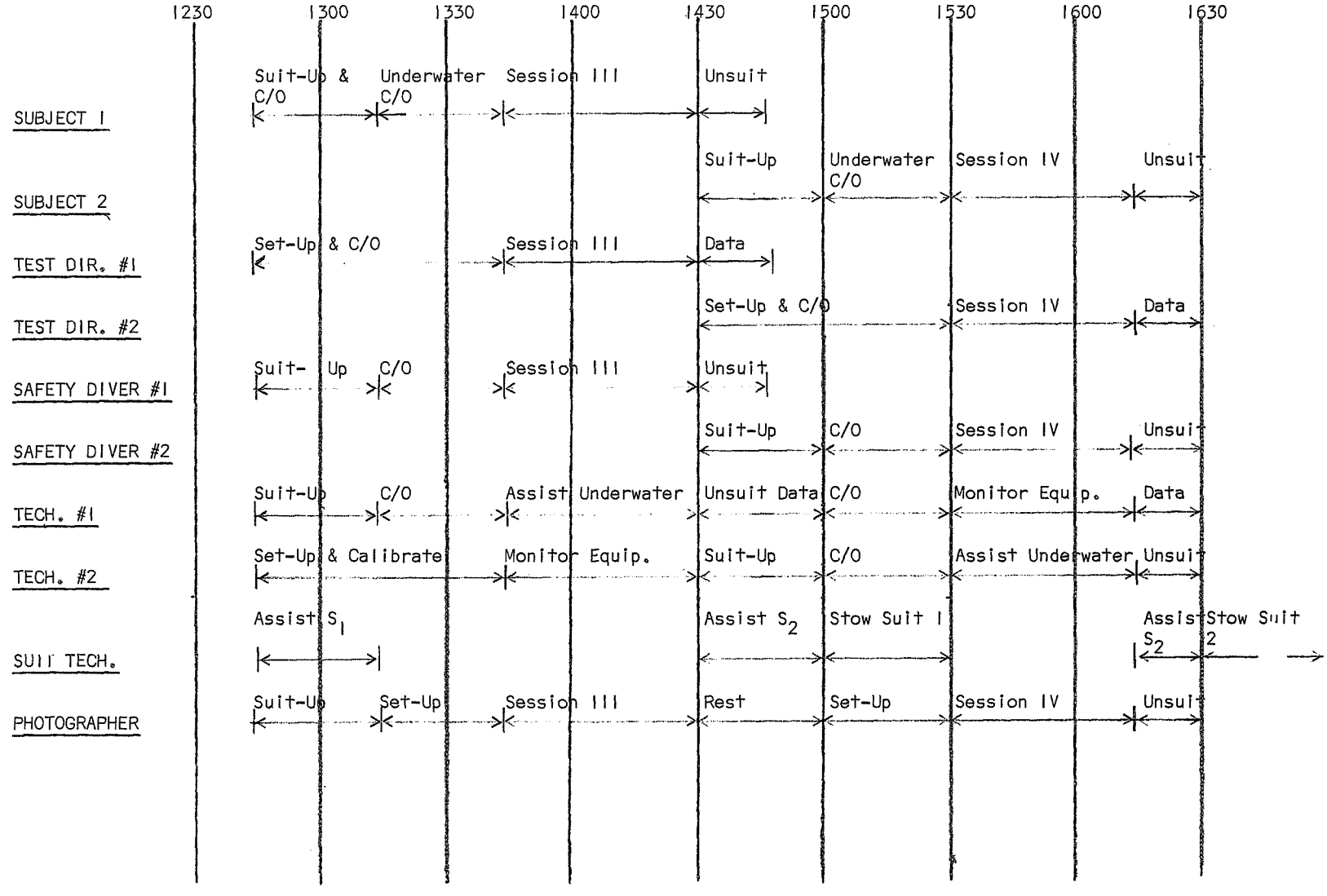


FIGURE I.4 DAILY SCHEDULE

6 DOF AIR-BEARING SIMULATION

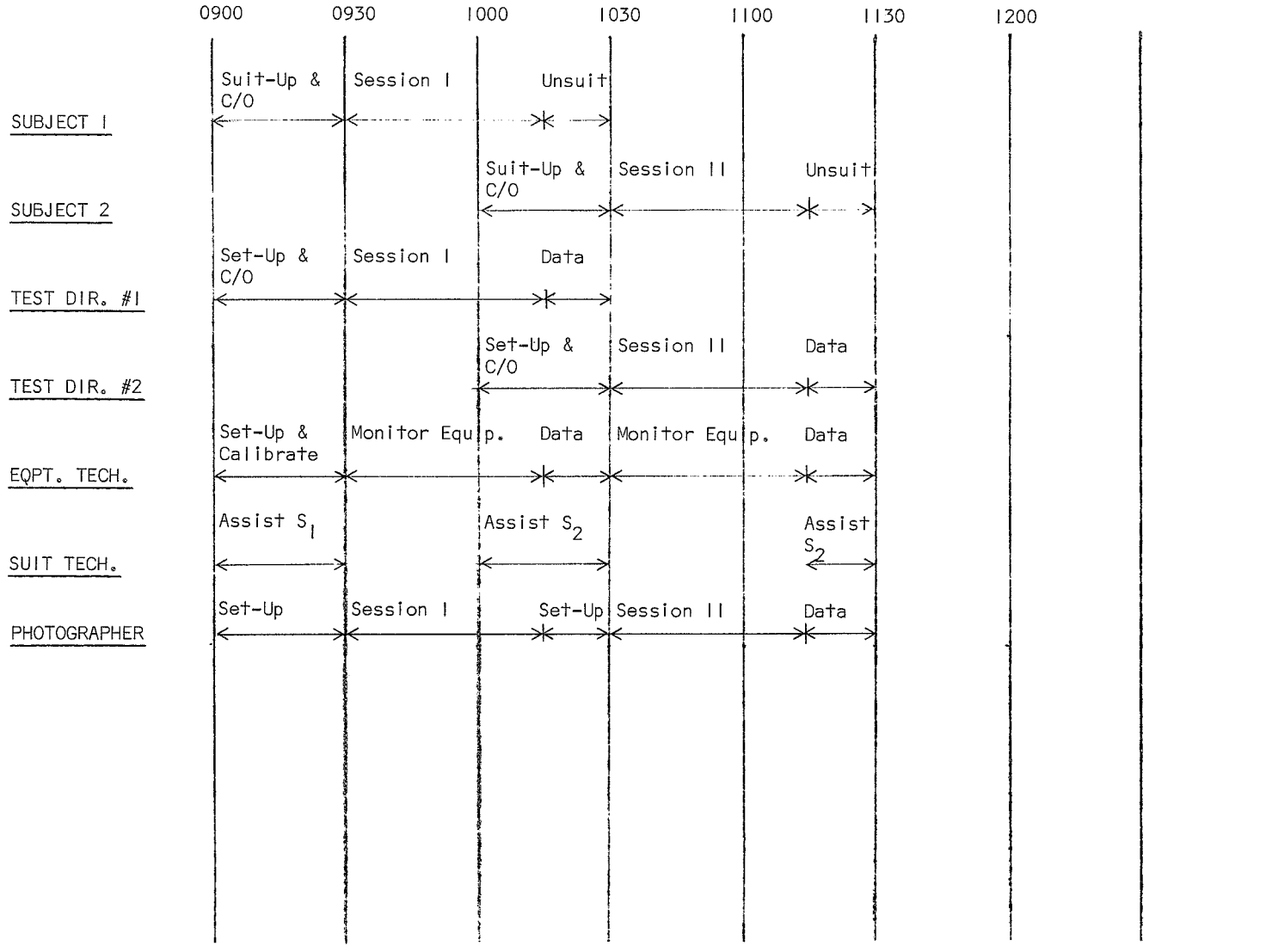


FIGURE I.4 DAILY SCHEDULE(Cont'd.)

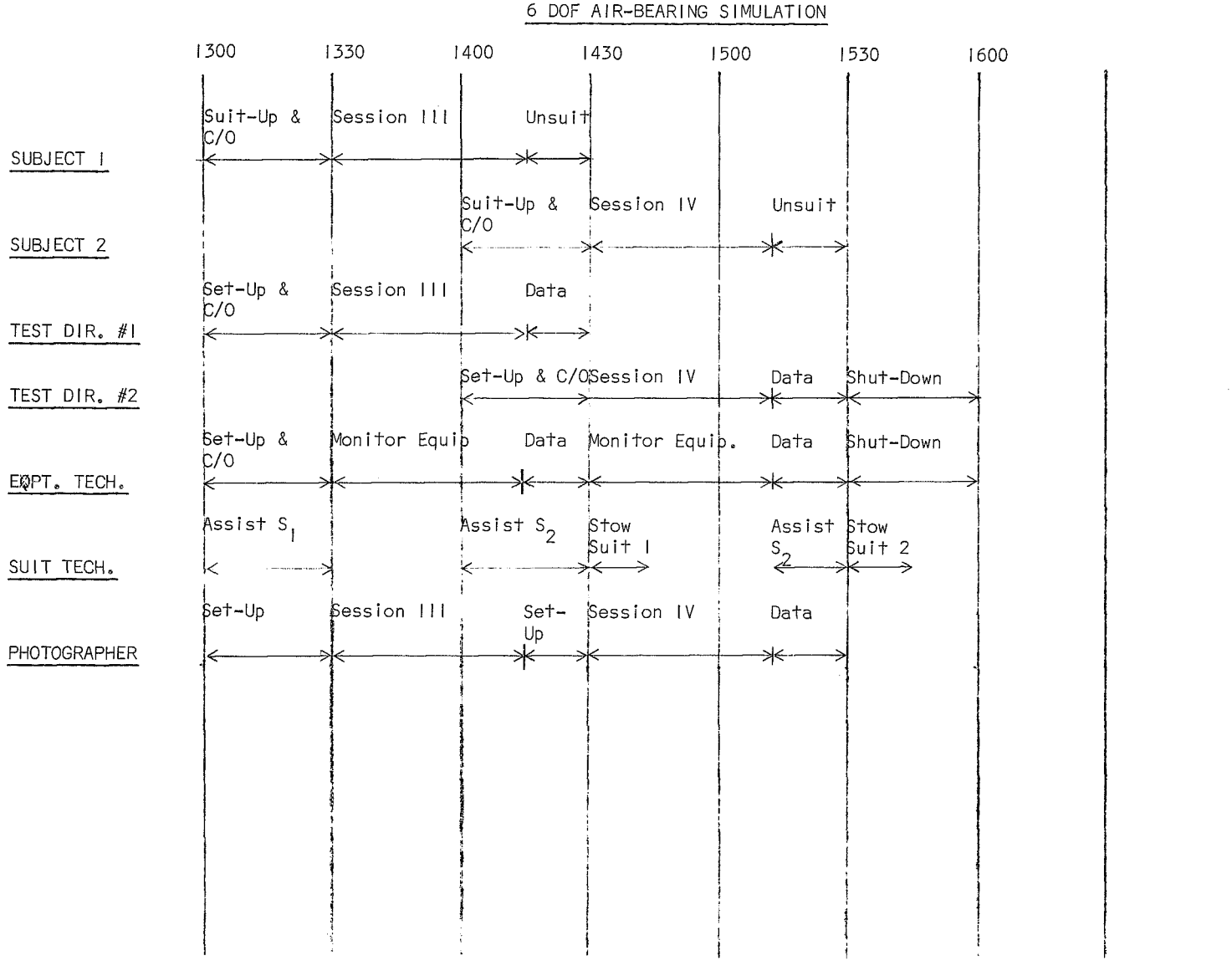


FIGURE 1.5 DAILY SCHEDULE

KC-135 SIMULATION

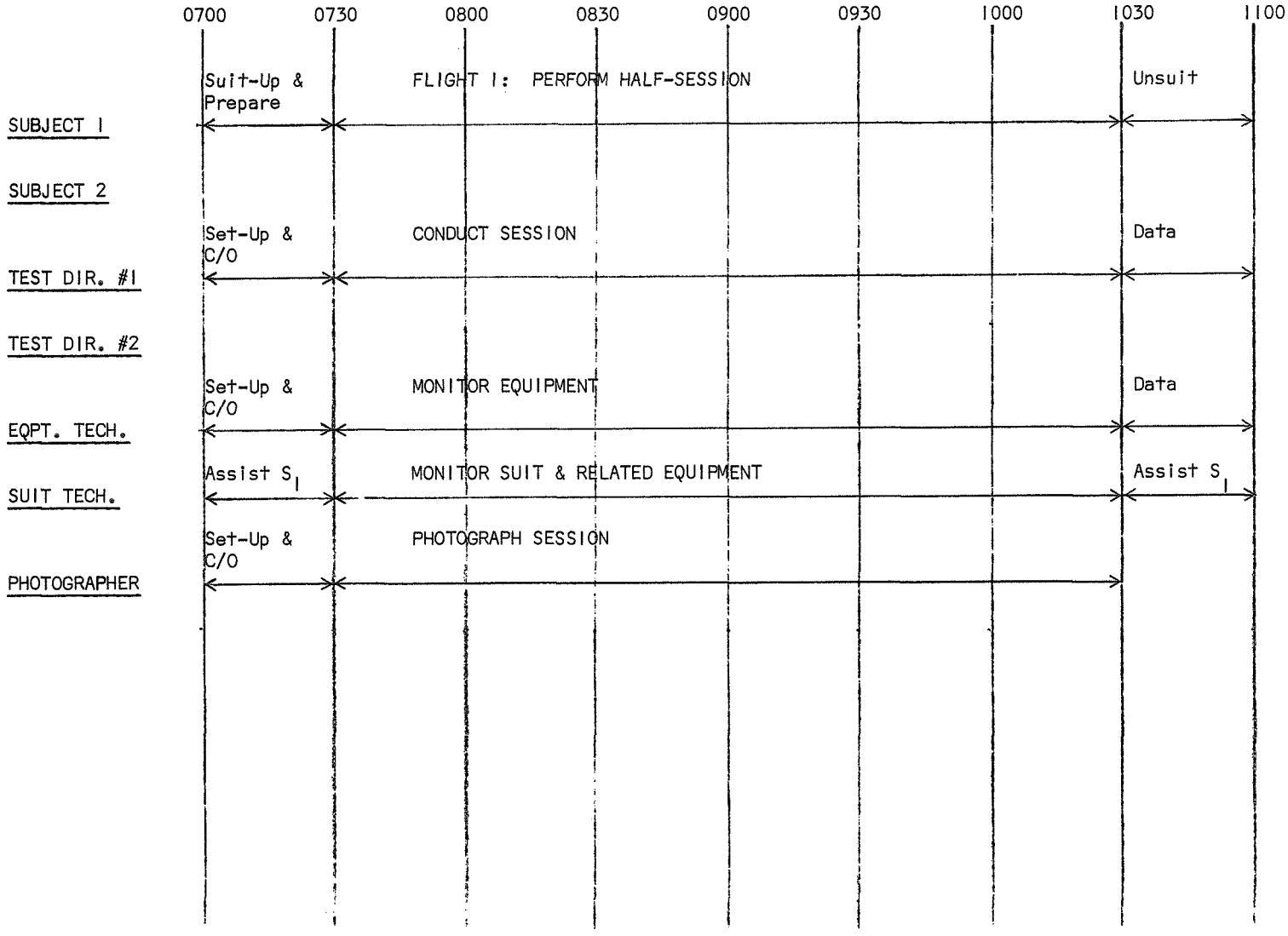
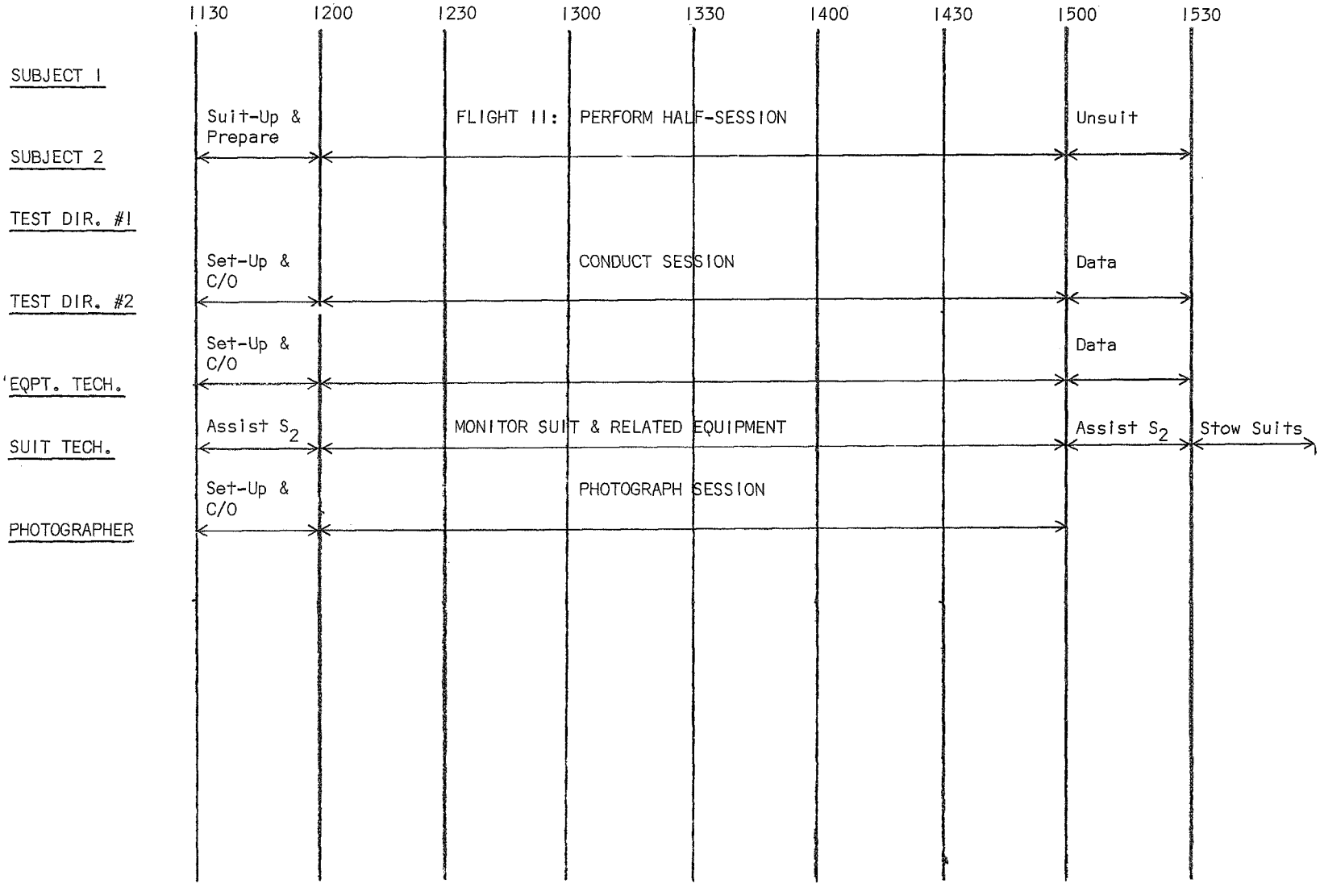


FIGURE 1.5 DAILY SCHEDULE (Cont'd.)

KC-135 SIMULATION



2.0 EXPERIMENT PROCEDURES

A sample of the abbreviated experimental session document follows. Subject and Observer(Test Director) tasks are listed and are correlated with the task sequence items shown in Section 3 of Volume II, Detailed Technical Report. A timeline, showing session times for each major task is also included, as well as a Remarks column for Observer comments.

A total of 126 abbreviated session documents (36 each for one-g walk-through, NBS, and 6 DOF, and 18 for KC-135) will be provided, in a computerized format, for conducting all sessions.

3.0 DATA HANDLING PROCEDURES

Special care must be taken to clearly indicate the contents of data containers collected during a session. Each session will generate the following:

- o One-400 ft. roll of color film
- o One roll of multi-channel magnetic tape, containing voice and other data
- o Experiment Procedures document containing written comments
- o Subjective questionnaires

All magnetic tape will be processed by the General Electric Co. at Valley Forge, Pa. All film will be processed at NASA's Manned Spacecraft Center in Houston, Texas. During one-g and neutral buoyancy testing, it shall be the responsibility of the test director to see that the above four items generated during a session are properly delivered for processing. During the other tests, which are conducted at field locations, these four items will either be mailed to Valley Forge for processing or hand-carried back at the conclusion of a period of tests. The choice is left to the discretion of the test director and should depend on the expected duration of a test period.

The experiment procedures documents and subjective questionnaires will include spaces for the identification of session number and the experimental conditions. Rolls of film and magnetic tape shall be stored in individual containers and labeled as follows:

EXPERIMENT M508

DESIGN VERIFICATION TESTS

SIMULATION MODE: _____ DATE: _____

SESSION NUMBER: (1-36 for 1-g, NBS, and 6 DOF; 1-18 for KC-135)

SUBJECT (1 or 2)

SUIT (SS, Apollo Block II, or EV Constant Volume)

RESTRAINT (Shoes, Waist or Waist and Shoes)

LOCATION: _____

_____
TEST DIRECTOR'S SIGNATURE

EXPERIMENT SESSION PROCEDURES

SIMULATION MODE: DATE:

SESSION NUMBER: 1

SUBJECT: 2

SUIT: Shirtsleeve

RESTRAINT: Shoes

REPLICATION: 1 TEST DIRECTOR:

** = TIME MARKS

TASK ITEM	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN SEC	REMARKS
PREPARATION	SUIT-UP ASSUME POSITION STAND-BY	RECORDER READY ____ CAMERA READY ____ CUE PANEL READY ____ TIMER SET ____ COMM. CHECK ____ TAPE ENTRY: MODE ____ SUBJECT ____ SUIT ____ RESTRAINT ____ REPLICATION ____ DATE ____ REAL TIME ____ MOD. PWR SW'S OFF ____ "STAND-BY" RECORDER ON ____ CAMERA ON ____		REAL TIME: ____ ____ HRS. MIN.
1.0 INSTALL REST.		"START"**	____	
1.1 INSTALL HDHD.	LANYARD RELEASED	**	____	
1.6 INS. FT. REST.	LANYARD RELEASED	**	____	
1.7 DON FT. REST.	RELEASE HANDHOLD	**	____	
1.10 ING. EQ. REST.	2nd TETHER INST.	**	____	
1.11 REST. EQ.	RIGHT TETHER RIGID	**	____	
REST		"REST" 30 SEC. CAMERA OFF ____ RECORDER OFF ____		DUMP SUIT PRESS. REAL TIME: ____ ____ HRS. MIN.
2.0 GAIN ACCESS		"STAND-BY" RECORDER ON ____ CAMERA ON ____ "START"**	____	PRESSURIZE SUIT
2.1 ATTACH TETHER TO COVER				
2.2 RELEASE COVER FASTENERS	ATTACH LANYARD TO RATCHET	**	____	
	RELEASE LANYARD FROM RATCHET	**	____	
	ATTACH LANYARD TO T-HANDLE	**	____	
	RELEASE LANYARD FROM T-HANDLE	**	____	
2.3 REMOVE COVER	RELEASE LANYARD FROM HDHD.	**	____	
REST		"REST" 30 SEC CAMERA OFF ____ RECORDER OFF ____		DUMP SUIT PRESS. REAL TIME: ____ ____ HRS. MIN.

TASK ITEM	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN. SEC.	REMARKS
PERFORM SPECIFIC TASK		"STAND-BY" RECORDER ON_____ CAMERA ON _____		PRESSURIZE SUIT
4.1 INSPECTION & C/O 4.1.1 VISUAL INSPEC.		"START"**	____	
	FR IN POS. #L TENSION RINGS LEFT OP. MAINT. SW. UP OP MAINT. PRES. VERNIER METER DIALS SET TO ZERO ELECTRONIC PROBE READY STYLUS READY			
4.1.2 C/O FR	INSTALL CALIB. DEV.	FR POWER ON_____ FT. FD. DL		
	"READY"	P +Z 2.0		0.0 LBS. CHECK
	"READY"	P +Z 2.0		25.0 LBS. CHECK
	"READY"	P +Z 2.0		60.0 LBS. CHECK
	"READY"	P -Z 2.0		0.0 LBS. CHECK
	"READY"	P -Z 2.0		25.0 LBS. CHECK
	"READY"	P -Z 2.0		60.0 LBS. CHECK
	"READY"	P +Y 2.0		0.0 LBS. CHECK
	"READY"	P +Y 2.0		25.0 LBS. CHECK
	"READY"	P +Y 2.0		60.0 LBS. CHECK
	"READY"	P -Y 2.0		0.0 LBS. CHECK
	"READY"	P -Y 2.0		25.0 LBS. CHECK
	"READY"	P -Y 2.0		60.0 LBS. CHECK
	"READY"	P +X 2.0		0.0 LBS. CHECK
	"READY"	P +X 2.0		25.0 LBS. CHECK
	"READY"	P +X 2.0		60.0 LBS. CHECK
	"READY"	P CW 2.0		
	"READY"	P CW 2.0		
	"READY"	P CW 2.0		
	"READY"	P CCW 2.0		
	"READY"	P CCW 2.0		
	"READY"	P CCW 2.0		
		FR POWER OFF_____		
	ALL LANYARDS RELEASED	**	____	
REST		"REST" 30 SEC CAMERA OFF_____ RECORDER OFF_____		DUMP SUIT PRESSURE REAL TIME: ____ ____ HRS. MIN.

TASK ITEM	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN.	SESSION TIME SEC.	REMARKS
MTP TASKS		"STAND-BY"			PRESSURIZE SUIT
RESTRICTED ACCESS		RCDR ON ____ CAMERA ON ____			
INSTALL ACCESS PANEL	TURNBUCKLES TIGHTENED	"START"** **		____	
TWO-HAND TASK	OBTAIN PROBE	MOD PWR ON ____ CHECK RCDR		____	
	ASSUME READY POS.	PROGRAM: CONTACT TYPE DIGITAL VALUE START			3-SEC REST BETWEEN TRIALS
	M M F S F S M S F 49 37 47 67 29 57 63 25 73				S MUST RETURN TO ZERO
	RETURN PROBE	MOD PWR OFF ____ **			
HAND-MVT TASK	OBTAIN STYLUS	MOD POWR ON ____ CHECK RCDR		____	
		SEQUENCE: 3 1 2			5-SEC REST BETWEEN TRIALS
REVERSE MODULE	FASTENERS OPEN	MOD PWR OFF ____ **		____	
	FASTENERS LOCKED	**		____	
HAND-MVT TASK	OBTAIN STYLUS	MOD PWR ON ____ CHECK RCDR			
		SEQUENCE: 2 1 3			5-SEC REST BETWEEN TRIALS
REVERSE MODULE	FASTENERS OPEN	MOD PWR OFF ____ **		____	
	FASTENERS LOCKED	**		____	
FREE ACCESS					
REMOVE PANEL	LANYARD ATTACHED	**		____	
	RODS STOWED	**		____	

TASK ITEM	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN. SEC.	REMARKS
4.* OPERATIONAL MAINT. TASK				
NOTE:	IF STILL IN A "REST" PERIOD, PERFORM THE FOLLOWING STEPS:			PRESSURIZE SUIT.
		"STAND-BY"____ RECORDER ON CAMERA ON ____		
		DEPRESS FAILURE ACTIVATOR**	____	
	RELEASE FAILURE ALARM	**	____	
	RELEASE LANYARD FROM TOOL	**	____	

TASK ITEM	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN. SEC.	REMARKS
TWO-HAND TASK	OBTAIN PROBE	MOD PWR ON ____ CHECK RCRD.		
	ASSUME READY POSITION	PROGRAM: CONTACT TYPE DIGITAL VALUE START		3-SEC REST BETWEEN TRIALS
	F S F S F S M M M 71 47 13 21 65 81 53 53 43			S MUST RETURN TO ZERO
	RETURN PROBE	MOD PWR OFF ____ **	____	
HAND-MVT TASK	OBTAIN STYLUS	MOD PWR ON ____ CHECK RCRD.		
		SEQUENCE: 2 1 3		5-SEC REST BETWEEN TRIALS
		MOD PWR OFF ____		
REVERSE MODULE	FASTENERS OPEN	**	____	
	FASTENERS LOCKED	**	____	
HAND-MVT TASK	OBTAIN STYLUS	MOD PWR ON ____ CHECK RCDR		
		SEQUENCE: 2 3 1		5-SEC REST BETWEEN TRIALS
		MOD PWR OFF ____		
REVERSE MODULE	FASTENERS OPEN	**	____	
	FASTENERS LOCKED	**	____	
REST		"REST" 60 SEC CAMERA OFF ____ RCDR OFF ____		DUMP SUIT PRESSURE REAL TIME: HRS. MIN.

TASK ITEM	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN	SESSION TIME SEC	REMARKS
3.3&3.4 FORCE/TORQUE EMISSION		STAND-BY			PRESS. SUIT
		RCDR ON	---.		
		LIGHTS ON	---.		
		CAMERA ON	---.		
	INSTALL D-HANDLE OR TOOL AS RQRD				INFORM S OF TYPE OF TRIALS TO BEGIN
		FR PWR ON	---.		
		START **	.	-----	

2
1
3

FOR USE WITH SHOE RESTRAINT

TORQUES POS 1 W	T	D	DL	FORCES POS 1 T	D	DL
				*P	-X	5.LB
				*P	+Z	20.LB
				*P	-Y	11.LB
				*P	+X	5.LB
				*P	+Y	11.LB
				*P	-Z	20.LB
REST 30 SECONDS						
T	I	CCW	2.0	S	-X	2.0
T	S	CW	2.0	I	-Z	2.5
T	S	CCW	2.0	S	-Z	2.0
T	*P	CW	2.0	I	+Z	2.0
T	*P	CCW	2.0	S	+Y	3.5
T	I	CW	2.0	I	-X	2.5
*P TORQUE= 25.IN-LB						
REST 30 SECONDS						
R	I	CCW	2.0	I	+X	3.5
R	I	CW	2.0	S	-Y	4.0
R	S	CCW	2.0	S	+Z	3.5
R	S	CW	2.0	I	+Y	2.0
R	*P	CW	2.0	S	+X	2.5
R	*P	CCW	2.0	I	-Y	3.5
*P TORQUE=120.IN-LB						
REST 30 SECONDS						

TORQUES POS 3 W	T	D	DL	FORCES POS 2 T	D	DL
				*P	+X	5.LB
				*P	-Y	11.LB
				*P	-Z	20.LB
				*P	+Z	20.LB
				*P	-X	5.LB
				*P	+Y	11.LB
REST 30 SECONDS						
R	I	CCW	2.0	I	+X	2.0
R	*P	CW	2.0	S	+X	2.0
R	S	CCW	2.0	I	-Y	2.0
R	S	CW	2.0	I	-X	2.0
R	*P	CCW	2.0	S	-X	3.5
R	I	CW	2.0	S	+Z	3.0
*P TORQUE=120.IN-LB						
REST 30 SECONDS						
T	S	CCW	2.0	I	+Z	3.0
T	I	CCW	2.0	S	-Y	2.5
T	S	CW	2.0	I	-Z	3.5
T	I	CW	2.0	S	-Z	2.0
T	*P	CW	2.0	S	+Y	4.0
T	*P	CCW	2.0	I	+Y	2.0
*P TORQUE= 25.IN-LB						
REST 30 SECONDS						

REMOVE D-HDLE OR TOOL ADAPTER

FIRST TWO MODULE REPLACEMENTS	PWR OFF	FR PWR OFF **---.	-----		
	PWR ON	FR PWR ON **---.	-----		
THIRD MODULE REPLACEMENT	PWR OFF	FR PWR OFF **---.	-----		
	BOLTS TIGHTENED	**	-----		
REST		REST 60 SEC			DUMP SUIT PR.
		CAMERA OFF ---.			REAL TIME:
		LIGHTS OFF ---.			---. ---.
		RCDR OFF ---.			HRS MIN

TASK LIST	SUBJECT ACTION	OBSERVER ACTION	SESSION TIME MIN.	SEC.	REMARKS
3.6 RETRIEVE COVER		"STAND-BY" RECORDER ON____ CAMERA ON ____			PRESSURIZE SUIT
	RETURN HOLD.	"START"**	____		
	POSITION COVER TO TASKBOARD				
	ATTACH LANYARD TO RATCHET	**	____		
	RELEASE LANYARD FROM RATCHET	**	____		
	ATTACH LANYARD TO T-HOLE.	**	____		
	RELEASE LANYARD FROM T-HOLE.	**	____		
	RELEASE LANYARD FROM HOLD.	**	____		
4.0 RELEASE RESTRAINTS					
4.1 REMOVE EQUIP. FROM RESTRAINTS	LANYARD REL'D. FROM TOOL KIT	**	____		
4.2 REMOVE EQUIP. RESTRAINTS	2nd TETHER TIED-DOWN	**	____		
4.9 REL. FT. RESTRAINT					
4.10 REMOVE FT. RE-STRAINT	FT. RESTRAINT TIED-DOWN	**	____		
4.11 REMOVE HANDHOLD	HANDHOLD TIED-DOWN	**	____		DUMP SUIT PRESS. REAL TIMES: ____ ____ HRS. MIN.

IV. REQUIREMENTS SPECIFICATIONS FOR EXPERIMENTAL PERSONNEL

1.0 SCOPE

This specification delineates the qualifications and skills required of the experimental test subjects and support personnel for the conduct of the Design Verification Tests. It is to be utilized for personnel selection and does not include any information, qualifications, or procedures that will be covered during the experiment training program. The qualifications specified in this document must first be demonstrated by the appropriate personnel prior to the initiation of the experiment training program. The roles or areas of qualification are:

Subjects

Test Directors

Data Recording Equipment Technician

Suit Technician

Photographer

Experiment Technician/Safety Man

Medical Personnel

1.1 EXPERIMENTAL SUBJECT REQUIREMENTS

1.1.1 Physical Qualifications

Age: The experimental subjects will be between 21 and 40 years of age. This requirement may be waived at the discretion of the test director.

General Physical Condition: Each subject will have (or be able to pass) an FAA Class III physical rating or equivalent. Special attention will be given to ensure that no subject be selected with a history of diabetes, inner ear malfunctioning, cardiovascular anomaly, or severe airsickness.

Vision: All subjects will have vision correctable to 20/20 and no worse than 20/30 uncorrected.

Hearing: All subjects will have normal hearing ability. For this experimental program, normal hearing is defined as hearing ability sufficient to carry on normal listening functions without noticeable loss of comprehension.

1.1.2 Experimental Qualifications

Swimming: All subjects will exhibit ease and proficiency in the water. They will be capable of swimming 150 meters on the surface, 25 meters underwater, and of treading water for 5 minutes.

Skin Diving: All subjects will have exhibited proficiency in the use of skin diving equipment including face mask, snorkel and fins.

Pressure Suit/Chamber Indoctrination: All subjects will have successfully completed a pressure suit indoctrination course to familiarize them with the operational characteristics of pressure suits. Additionally, it is desirable that all subjects be given exposure to high altitude chamber operation and explosive decompression.

General Educational and Vocational Background: All test subjects will be high school graduates (or equivalent) and be presently working in the aerospace field. This requirement may be waived if candidates exhibit high motivational qualities and general background and experience necessary to understand the purposes of the research and be able to comment adequately on the test results.

1.2 TEST DIRECTIONS

1.2.1 General Physical Condition

All underwater support personnel will have a current FAA Class III physical rating or equivalent. Special attention will be given to ensure that no persons be selected with a history of diabetes, inner ear malfunction, cardiovascular anomaly, or severe airsickness.

1.2.2 Experimental Qualifications

Underwater Experience: All test directors will have demonstrated proficiency in the use of skin diving and SCUBA diving equipment.

General Educational and Vocational Background: All test directors will have college degrees and have had experience in the design, conduct and analysis of human engineering experiments.

1.3 DATA RECORDING EQUIPMENT TECHNICIAN

1.3.1 General Physical Condition

All technicians will have passed a current employee physical examination.

1.3.2 Experimental Qualifications

General Educational and Vocational Background: The technician will have extensive training and experience in electrical technology with some background in data reduction of analog recordings.

1.4 SUIT TECHNICIAN

1.4.1 General Physical Condition

Same as Paragraph 1.2.1 above.

1.4.2 General Educational and Vocational Background

The suit technician will be thoroughly familiar with the use, care, maintenance and repair of the Apollo Block II suit and EV Constant Volume suit.

1.5 PHOTOGRAPHER

1.5.1 General Physical Condition

Same as Paragraph 1.2.1 above.

1.5.2 Experimental Qualifications

SCUBA Diving: The photographer will have demonstrated proficiency in the use of skin and SCUBA diving equipment to the satisfaction of the test director.

Photography Experience: The photographer will have had training and experience in all areas of photography including underwater photography.

1.6 EXPERIMENT TECHNICIAN/SAFETY MAN

1.6.1 General Physical Condition

Same as Paragraph 1.2.1 above.

1.6.2 Experimental Qualifications

Swimming: All underwater support personnel will exhibit ease and proficiency in the water. They will be capable of swimming 150 meters on the surface and 25 meters underwater, and treading water for 5 minutes. In addition, the safety men and underwater experiment technicians will be qualified safety instructors or life savers, or will demonstrate equivalent ability.

Skin Diving: All underwater support personnel will have passed a course in skin diving and will have exhibited proficiency in the use of skin diving equipment. Proficiency will be demonstrated to the satisfaction of the test director.

SCUBA Diving: All underwater support personnel will have passed a course in SCUBA diving and will have demonstrated proficiency in the use of a SCUBA tank regulator and hookah. Proficiency will be demonstrated to the satisfaction of the test director.

1.7 MEDICAL PERSONNEL

1.7.1 General Physical Conditions

Same as Paragraph 1.3.1 above.

1.7.2 General Educational and Vocational Background

All medical personnel will have received at least a Registered Nurse qualification and will have background knowledge and experience in the medical hazards of pressurized suit and underwater operations.

1.8 GENERAL

It is highly desirable that individuals selected for the qualifications defined above be capable of serving in more than one capacity. Thus, personnel selection will be conducted with the intention of finding Test Directors who could serve as Suit Technicians, Data Recording Technicians with diving capabilities, etc.

V. EXPERIMENT TRAINING PROGRAM

1.0 INTRODUCTION

The basic experiment training program for the Astronaut Performance Program Design Verification Testing will consist of comprehensive training in: (a) the various simulation techniques to be utilized; (b) the experimental equipment to be used; and (c) the experimental procedures. The training will consist of both classroom instruction and operational training on the test equipment where applicable. Insofar as possible, the same individuals will be used for each respective operational responsibility throughout the phases of the Design Verification testing. The personnel trained will include at least one back-up person for each critical test position.

Subjects to be used for each simulation will be the same individuals unless unforeseen events preclude this possibility. At least one back-up subject will be trained. Training of the subjects on each of the specific Design Verification Tests will be continued until the subject has achieved asymptotic performance. Asymptotic performance will be determined by the test director when the subject has passed the interior level and no longer shows noticeable improvement in performance.

Training sessions for each of the simulations will be conducted using the "shirtsleeve" condition, the Apollo Block II suit and the EV Constant Volume Joint suit. Training in each suit and restraint combination will be performed for the specific simulation operations and experiment procedures.

2.0 SIMULATION OPERATIONS

2.1 Normal Gravity Test Training

All of the procedures indicated in the Functional Flow Block Diagram (FFBD) in Volume I, Section 2.0 will be initially trained in 1 "G". The measures to be taken as performance indicators are the same as those delineated in Volume I, Sections 3.1, 3.3 and 3.4. The 1 "G" training will be performed at the General Electric Company Facility at Valley Forge. Trained safety and medical personnel will be present during all training sessions in addition to the required experimental test and support personnel. In addition, all test subjects will be experienced in the specific pressure suits and pressure suit conditions to be used for design verification testing. It is envisioned that

the training period will be quite extensive in order to familiarize all personnel involved in the experiment. This first training operation will not only acquaint subjects and procedures, but will also provide the initial exposure of prime and support equipment to technicians and other support personnel. Subsequent training periods, assuming consistent utilization of personnel, should require significantly less training time.

2.2 NEUTRAL BUOYANCY UNDERWATER SIMULATION

The procedures for neutral buoyancy underwater simulation for the design verification testing are provided in Volume III, Section 2.0. As indicated previously, training of subjects will be performed to asymptotic performance for the underwater neutral buoyancy simulation. The measures to be taken as performance indicators are the same as those delineated in Volume I, Sections 3.1, 3.3 and 3.4.

The neutral buoyancy training will be performed at the Controlled Buoyancy Facility of the General Electric Company at Valley Forge. Safety personnel, specially trained in neutral buoyancy pressure suit operations, and medical personnel will be present during all neutral buoyancy operations in addition to the required experiment support personnel.

Training in the neutral buoyancy techniques, both in suited and unsuited modes will be minimal since all test personnel to be used will be experienced in the underwater operational and safety procedures.

2.3 SIX DEGREE-OF-FREEDOM MECHANICAL SIMULATION

Test subjects will be trained in the procedures indicated in the FFBD in Volume I, Section 2.0 on the MSFC Six Degree-of-Freedom Mechanical Simulator. The measures to be taken as performance indicators are the same as those delineated in Volume I, Sections 3.1, 3.3 and 3.4. Trained safety and medical personnel provided by MSFC will be present during all simulation operations in addition to the required GE experiment support personnel.

Classroom instruction with demonstrations will be provided for the MSFC personnel to familiarize them with the experiment equipment, sequences and operations.

2.4 KEPLERIAN FLIGHT ZERO GRAVITY SIMULATIONS

Test subjects will be trained in the test procedures indicated in the FFBD in Volume I, Section 2.0 during Keplerian Zero Gravity Simulation. Training will be conducted on Keplerian Flights at Wright-Patterson Air Force Base. The performance measures to be taken are delineated in Volume I, Sections 3.1, 3.3 and 3.4. Trained safety and medical personnel from Wright-Patterson, experienced in Keplerian Flights, will be present during all simulation operation in addition to the required GE experiment support personnel.

Classroom instruction with demonstrations will be provided for the Wright-Patterson personnel to familiarize them with the experiment equipment, sequences and operations.

3.0 EXPERIMENT PROCEDURE TRAINING

Subjects to be used for the Design Verification Testing will be provided by GE. These subjects will be personnel who have been closely associated with the M508 program and therefore will be familiar with the experiment equipment.

The test subjects will be given brief classroom instructions and be thoroughly trained in all experiment operations given in detail in Volume I, Section 3.1 and Volume III, Section 2.0. Training in the specific tasks such as precise hand movement, the eye-hand coordination task, the operational maintenance task and the force emission tasks will be intensive. Asymptotic performance, as determined by statistical methods, will be required on each specific task and each simulation mode prior to testing.

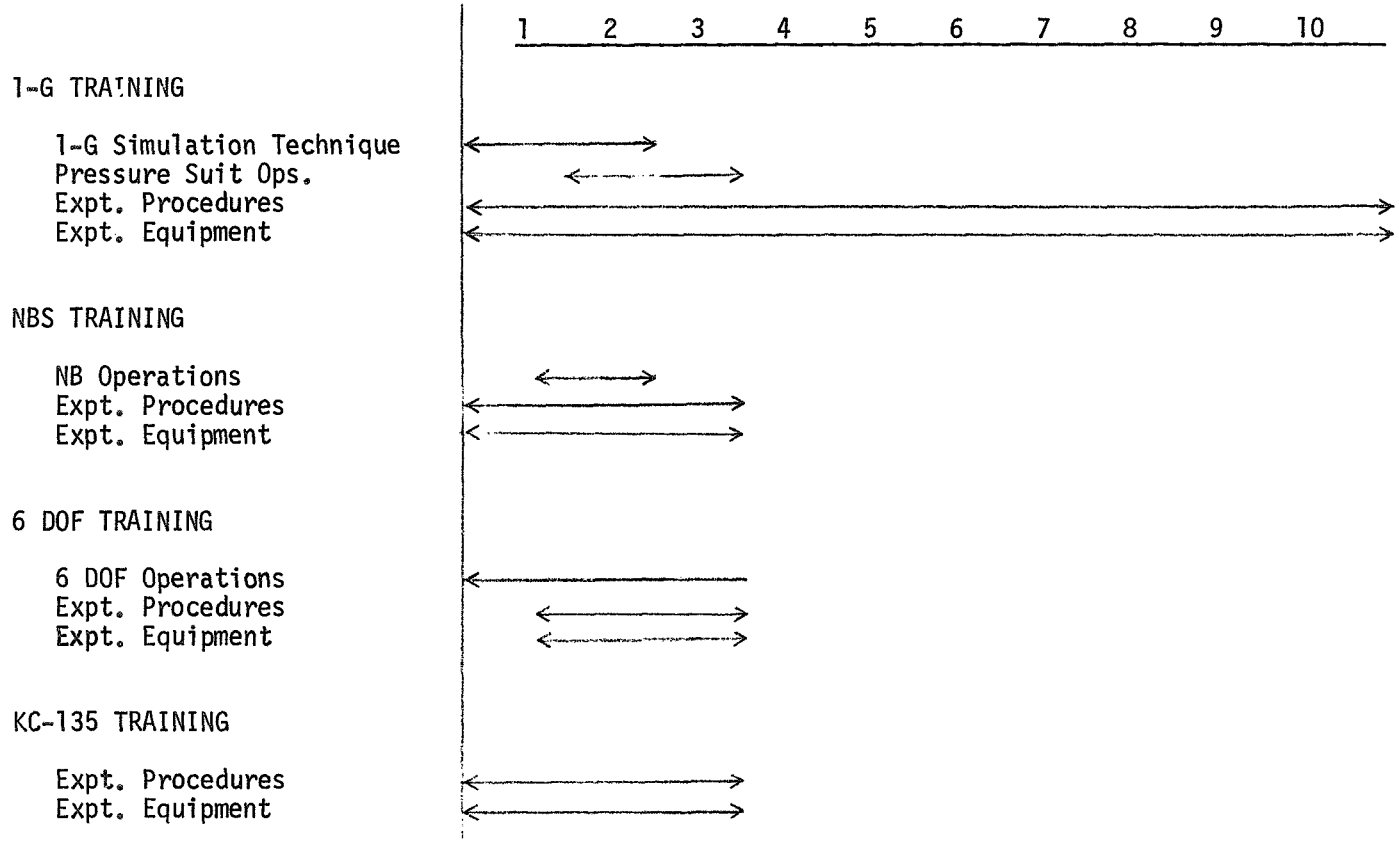
The test director and observers will also be intensively trained in the experiment procedures. Practice sessions for the director and observers will be conducted to insure that data collection, reduction and evaluation techniques are efficient and adequate.

4.0 SCHEDULE/PHASING

Figure 1 indicates the number of days allotted to training for the various simulation modes. One-g training, which initiates exposure of the experiment to all personnel, will require 10 days. Neutral buoyancy training will only require 3 days, since all personnel involved are experienced in neutral buoyancy operations and will, at that point, be experienced in experiment procedures. Six DOF simulation training will be primarily devoted to familiarization with the air-bearing simulator. Finally, KC-135 training

will simply involve practice in experiment procedures in the part-task mode imposed by Keplerian flight simulation. Not shown on the KC-135 training schedule is an orientation flight for all General Electric experiment personnel prior to the actual training program.

FIGURE 1. TRAINING SCHEDULE (DAYS)



VI. EXPERIMENT EQUIPMENT LIST

1.0 INTRODUCTION

This document provides a listing of the equipments required to support the Design Verification Tests to be performed on the Astronaut Performance Program.

1.1 EXPERIMENT HARDWARE

1	Task Board: Cover Access Panel Cue Panel Force/Torque Module Precise Hand Movement Module Operational Maintenance Module Electronics C/O Module
1	Observer's Panel
1	Handhold Restraint
1	Gemini Dutch Shoes Restraint (GFE)
1	Variable Flexibility Waist Restraint (GFE)
4	Lanyards and Take-Up Reels
	Apollo Block II Space Suit and Helmet (GFE)
	EV Constant Volume Spacesuit and Helmet (GFE)
2	Variable Flexibility Equipment Tethers

1	Tool Kit:
1	Ratchet Wrench
1	3/8" Socket for Ratchet Wrench
1	5/32" Hex-Drive on T-Handle
1	Open-end wrench
Set	Force Module Calibration Equipment
1	Precise Hand Movement Tension-Check Device
1	Plumbing Component Spare
1	Mobility Aid
AR	Power Supplies
AR	Suit Pressurization System & Suit Interfaces
AR	Support Structure
AR	Electrical Cables

2.0 DATA RECORDING EQUIPMENT

1	Motion Picture Camera (6 frames/sec) (GFE)
AR	Film for Above (GFE)
1	14 Ch. (Estimated) Magnetic Tape Recorder (GFE)
AR	Tape for Above
1	8 Ch. Oscillographic Recorder (GFE)
AR	Paper for Above
1	Bio-medical Recorder (GFE)
AR	Tape for Above
AR	Amplifiers
	Power Supplies

3.0 SIMULATION SUPPORT EQUIPMENT

3.1 GENERAL

Supplemental Lighting

Communications: Two-Way - Subject/Test Director (with recording capability)

Test Director to Simulation Facility Work Area

Repair and Maintenance Equipment:

Electrical Test and Diagnostic Instruments

Tools

Spare Parts

3.2 KC-135

Power Conversion Equipment

3.3 NEUTRAL BUOYANCY SIMULATION

2 TV Cameras

2 Monitors

Subject's Hookah

SCUBA Equipment:

- Fins
- Masks
- Snorkels
- Air Bottles
- Regulators
- Wet Suits

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