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STUDY FOR THE COLLECTION OF HUMAN ENGINEERING DATA FOR MAINTENANCE AND REPAIR OF ADVANCED SPACE SYSTEMS

FINAL STUDY REPORT

VOLUME I

SUMMARY TECHNICAL REPORT

PREPARED UNDER
CONTRACT NO. NAS8-18117

FOR

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA 35812

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
Valley Forge Space Technology Center
P.O. Box 8555 • Philadelphia, Penna. 19101

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PREFACE

The final report for the study directed towards obtaining human engineering data for the maintenance and repair of advanced space systems is presented in three volumes. The volume designations are as follows:

Volume	Title
I	Summary Technical Report
II	Detailed Technical Report
III	Preliminary Handbook of Human Engineering Design Data for Reduced Gravity Conditions

The analytical and operational portions of the study program were performed and directed by the Advanced Manned Systems Engineering Operation of the General Electric Company Missile and Space Division with test operations and handbook development support from other components of the Division.

In addition, considerable support was provided at the Marshall Space Flight Center for the fabrication, installation, and maintenance of the test equipment and instrumentation during the study experiment operations. We would like to acknowledge those NASA and Hayes Engineering personnel who provided this support, plus those who volunteered to act as test subjects and underwater technicians.

Test Subjects

NASA-MSFC	Hayes Engineering
H. L. Brink, Test Lab	J. Stephenson
R.C. McCaffrey, TS-MP	W. Hunter
B.S. Cain, Test Lab	C. Williams

Operational Support

NASA	Hayes Engineering
D. L. Hammer, Test Lab	W. Meeks
	D. Perryman
	R. Brye
	H. Canier
	D. Trosper
	W. McBride

Engineering Support

P&VE	ME Lab	Comp Lab
Dr. J. Rogers	P.H. Schuerer	J. Means
H.Y. Grubbs	W.B. Cruise	B.R. Pace
R.D. Hall	C.R. Cooper	R. Rogers
R.T. Heckman	D.C. Neville	
E.C. Pruett	R.L. Nichols	
R.B. Sims	C.A. Torstenson	
J. Peebles	A. Bienert (Hayes)	

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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 NAS8-18117,"Study for the Collection of Human Engineering Data for the Maintenance and Repair of Advanced Space Systems." The study was performed during the period 26 August 1966 through 31 December 1967 and encompassed:

a. The preliminary planning and experimental definition of eight contractually specified experiments

b. The development of a program plan for the implementation of these experiments, utilizing reduced gravity simulation techniques

c. The final design and implementation of one composite experiment, using neutral buoyancy submergence techniques for the simulation mdeia

d. The preparation of the protocol and design for a second experiment

e. The preparation of a Preliminary Handbook of Human Engineering Design Data for Reduced Gravity Conditions. This primarily consisted of the development of the format for the handbook and the initial collection of applicable content material.

In contrast with the relatively simple extravehicular tasks required in the Gemini missions, future space systems will require extensive manned operations of all kinds. The experiments developed and implemented during this study were, therefore, designed to fill a portion of the gap in our knowledge of man's capabilities to perform complex tasks in the zero-gravity environment. The content and depth of detail in the initial experimental definition was limited to that necessary for the evaluation and subsequent selection of the experiments for both immediate and future implementation. The composite experiment selected for implementation during this study program was designed for an objective evaluation of the specific behavioral characteristics, in this case force emission, and a rather sophisticated data gathering and reduction system was utilized in order to maximize the data return.

As this study was designed to provide selected human engineering data of the type which will be required by space vehicle designers during the post-Apollo period, no attempt was made to provide applications research as part of the experimental program. However, the parametric boundr considered for the inidvidual experiments were realistically set by consideration of the known and predicted requirements for the maintenance and repair of future spacecraft systems.

SECTION 2

PROGRAM SCOPE

It was the purpose of this research program to begin the accumulation, evaluation, and publication of human engineering data, principles, and criteria related to man's maintaining and repairing advanced space systems in a form useful to the designer. Although past and other current studies-in-depth on the attributes and capabilities of the space-suited man provide some of the required information, much experimental work remains to be done. In that conceptual design of advanced space systems has already begun, it is necessary to develop rapidly, a supporting human engineering technology to facilitate these design efforts.

The scope of this study program included a literature review to obtain and collate available human factors data relative to maintenance and repair activities in zero-g. At the same time, an experimental program was developed to provide, through the use of zero-g simulation techniques, missing information in certain critical behavioral areas.

As is so often the case in research programs, it was necessary to modify the scope of the study somewhat during the course of the program, as a result of such things as the expanded scope of combined experiments after completion of the preliminary design, operational problems during testing, and the limited resources available for the study.

The scope of the program at the time of inception included:

a. A literature search to obtain and collate available information on zero and 1/6th g pertinent to human factors, with emphasis on maintenance and repair.

b. Preliminary definition and planning of eight experiments.

c. Initiation of research on three experiments selected by NASA

d. Preparation of detailed experiment plans and equipment designs for the additional maintenance and repair experiments not selected in c.

e. Identification and justification of critical maintenance and repair human engineering experiments requiring manned space-flight for their implementation.

The preliminary handbook contained as Volume III of this final report is a direct result of a, above. A summary of the contents and other pertinent information are contained in Section 8 of this volume.

Upon completion of the preliminary definition for the experiments identified in b, above, a meeting of the NASA inter-center Ad Hoc Committee on In-Space Maintenance was called to review the program and recommend an order of implementation as specified in c. The experiments selected, in suggested order of implementation, are Experiment No. 8 (modified), Experiment No. 1, and Experiment No. 2. The modifications to Experiment No. 8 included its combination with Experiment No. 4, and the elimination of some variable combinations in the combined experiment. The new experiment is referred to as Experiment 84.

Prior to the start of actual test operations on Experiment 84, further program changes were made which considerably expanded its scope, hence, the designation Experiment 84A. The scope changes included the expansion of the number of force receiver locations, the inclusion of both water and air as space suit pressurization media in the neutral buoyancy operations, and the addition of 1-g comparative data requirements. (See Section 6 for details.) In addition, Experiment Nos. 1 and 2, as such, were deleted, and a modified Experiment No. 1 substituted, hence, the designation Experiment 1A. In addition, scope items d and e were deleted.

During the conduct of test operations for Experiment 84A, it became apparent that the greatly expanded scope of the revised experiment (requiring over 27,000 force application trials) would require the full time commitment of test personnel and facilities greatly in excess of the resources of this study. It was therefore decided to limit the experimental program to Experiment 84A and the design, but not implementation, of Experiment 1A. The results of these efforts are reported in this document.

SECTION 3

EXPERIMENT DEFINITION AND SELECTION

The effort during the initial study period consisted of defining the requirements for eight specified experiments. These were identified by NASA as a function of the type of data required by design engineers. The types and variations of the experimental variables were selected to assure broad applicability of the data to many potential space missions. While this generic approach tends to limit the precision of application to specific missions and hardware, the net result is a reduction in the amount of applied research and/or simulation required for as yet unidentified missions in the post-Apollo period. The resultant data will serve sufficiently in those cases where a preliminary estimate is all that is required and when highly accurate forecasting of performance variables is required. Also, the data resulting from these experiments will serve to bound the problem and focus applications research on the appropriate area for investigation. The eight specified experiments are entitled:

a. "Experiment No. 1-Manipulation, Transport and Maneuvering of Free Masses in Zero-G as a Function of Object Volume and Path Configuration."

b. "Experiment No. 2-Manipulation, Transport and Maneuvering of Free Masses in Zero-G as a Function of Mobility Aids and Path Configuration."

c. "Experiment No. 3-Modular Replacement in Zero-G as a Function of Module Receptacle Size."

d. "Experiment No. 4-Torque Generation in Zero-G as a Function of Accessibility."

e. "Experiment No. 5-Modular Replacement in Zero-G as a Function of Accessibility and Visual Feedback."

f. "Experiment No. 6-Component Part Replacement in Zero-G as a Function of Component Shape and Accessibility."

g. "Experiment No. 7-Investigation of the Use of Wrench and Torsion Type Conventional Tools in Zero-G."

h. "Experiment No. 8-Push-Pull Force Generation in Zero-G as a Function of Restraint Conditions."

In this preliminary definition phase the specified experiments were defined only to the level necessary for evaluation and implementation selection by NASA. The definition phase included a preliminary description of experimental protocol and procedures, a proposed listing of experiment equipment requirements, and an evaluative and comparative listing of estimated costs and schedules. The following sections present brief descriptions of the experimental conditions for the eight experiments and proposed implementation plans. As shown in a later section, the actual experiment which was implemented during this study is a composite of selected variables from two of these eight experiments.

The initial study effort required the consideration of 1/6 g as well as zero-g. It became evident early in the study that for most of the selected experiments, the simulation of multiple reduced gravity conditions required rather extensive modifications of both the experiment protocol and the equipment design. In addition, the considerable increase in test time (which would be necessary because of the replication of experimental procedures at various g-levels) put further consideration of multiple reduced gravity conditions beyond the scope of this study. Therefore, with the concurrence of NASA, the study effort was limited to the zero gravity condition only.

SECTION 4
EXPERIMENTAL TECHNIQUES

The development of a multi-experiment program within the bounds of the specified contract scope naturally leads to the attainment of a high degree of commonality in experimental techniques as well as in support and operational requirements. For this program these include the neutral buoyancy zero-g simulation procedures, equipment design techniques, the underwater facility, and the use of the General Electric self-contained backpack.

4.1 NEUTRAL BUOYANCY SIMULATION

The experiment program was based upon the utilization of neutral buoyancy submergence techniques for the simulation of zero gravity. This technique provides a relatively simple way of attaining a 6-degree-of-freedom motion and overcomes some of the fundamental limitations of other simulation techniques. Zero-g can be simulated by making the buoyant force equal to the object weight with the center of buoyancy coinciding with the center of gravity in order to avoid introducing an orientation bias. Also, gravitational fields between zero and 1-g can be simulated by providing buoyant forces which are less than the object weight.

In general the advantages of the underwater simulation techniques are:

a. Added system inertia, such as that caused by mechanical simulation devices, is not imposed.

b. Every part of the body can be buoyed to null gravity; consequently, body motions do not cause gravitational imbalances.

c. The test subject is not strapped down or inhibited from free total body motions.

d. The test subject will require the same type of torsional and fixational restraints as he would in the zero-gravity environment.

e. Three dimensional movement through realistic volumes is possible.

A valid simulation must provide the subject with the proper visual and kinesthetic cues. When he impresses a specific force history on an object, that object should respond with a motion history approaching that which would occur in space. This can be accomplished to the degree that the following conditions are satisfied.

a. Six-degree-of-freedom motion must be provided.

b. The gravitational attractive force of the environment being simulated must be duplicated.

c. The model mass and moment of inertia must duplicate that of the space object.

d. The model must approximate the size and shape of the space object.

e. Extraneous effects, which are introduced by the simulation but which are not present in space, such as hydrodynamic forces and moments, must either be reduced to an acceptable level or analytical methods for accounting for these effects must be developed.

Underwater simulations employing neutral buoyancy for simulating activities in orbital operations satisfy conditions a and b above. Less obvious is how to satisfy conditions c, d, and e, simultaneously, i.e., make the model neutrally or partially buoyant, minimize hydrodynamic forces and moments, and at the same time simulate the mass, moment of inertia, and shape of specific space objects. However, by a thorough understanding of the cause and effects of the two main extraneous influences, hydrodynamic mass and drag, we can develop techniques which will satisfy these requirements to the maximum extent possible, thereby providing a high-fidelity simulation.

Hydrodynamic mass manifests itself as an apparent increase in the true mass of a submerged body. It derives from the acceleration of water that accompanies the acceleration of a rigid body in water. The hydrodynamic mass should not be confused with drag as the latter is a function of velocity only, for a given body and fluid medium, and is present only as long as there is a relative velocity. Hydrodynamic mass is a variable function of acceleration and vanishes at constant velocity. Drag and hydrodynamic mass are similar only in that both are functions of body geometry, size, and the mechanical properties of the fluid medium. While drag resists the velocity, hydrodynamic mass resists the change of velocity.

The problem that faces the neutral buoyancy simulation designer is to design both the simulation and the equipment so that the hydrodynamic mass and drag effects are either reduced to an acceptable level or are used to advantage. While the actual objects to be moved in space may be more or less dense than water and may be expected to have wide ranges of inertial characteristics, their neutral buoyancy counterparts are constrained to be the same density as water. Analyses have shown that by judicious selection of model shape and size, a neutrally buoyant model can be made to exhibit the mass and inertial characteristics of the actual equipment in space. This is accomplished by designing so that the hydrodynamic mass is employed to make up the difference between the actual equipment mass and the model mass. Note that a neutrally buoyant body accelerated in water can exhibit considerable hydrodynamic mass. For instance, a neutrally buoyant sphere has an additional hydrodynamic mass approximately equal to 50 percent of the mass of the sphere itself. Consequently, a 2-slug neutrally buoyant sphere will accelerate in response to an impressed force as though it were 3 slugs.

A derivation of the neutral buoyancy scaling laws, the model design equations, and a discussion of the experimental verification for this approach will be found in Volume II Appendix A, of this report.

4.2 PERSONNEL SUPPORT

4.2.1 PRESSURE SUITS

Apollo State-of-the Art pressure suits were used throughout the entire experiment program. (See Figure 4.2-1.) Although the state-of-the-art suit differs from the Block II suit now in use for the Apollo program, they are generically similar and the data obtained is considered valid.

During the course of the experiment operations for Experiment 84A, significant delays were encountered due to suit failures. Elbow and shoulder joint cables caused the most trouble--with an occasional broken neck ring, or blown elbow, or knee bellows. When a cable broke, the experiment session was aborted and the suit was repaired. Also encountered, but to a lesser extent, were suit leakage problems. However, in this case, the experiment session was not stopped unless the leak was such that the suit would not hold pressure.

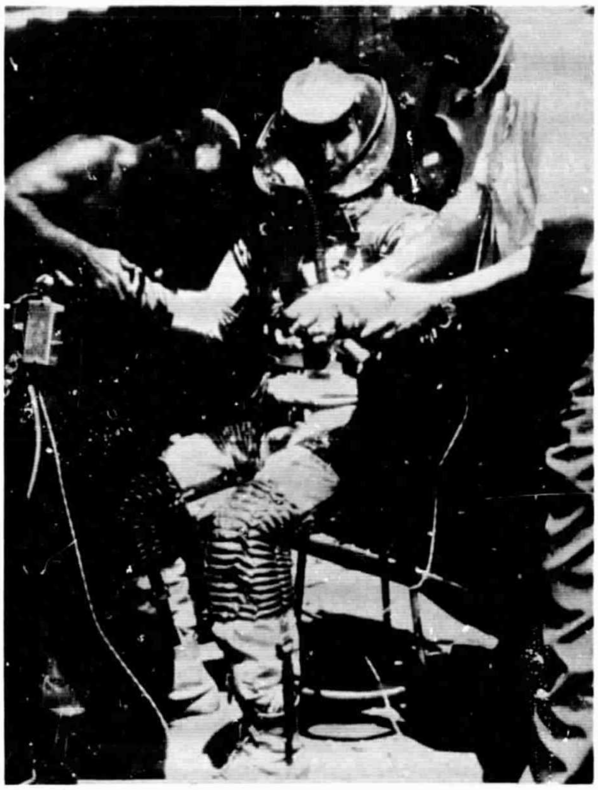


Figure 4.2-1. Apollo State-of-the-Art Pressure Suit

4.2.2 PRESSURIZATION/BREATHING SUPPLY

During the experiment suit pressure was maintained at 3.7 ± 0.2 psig. This pressure was imposed as the NASA requirement for the operating design pressure for the State-of-the-Art suits. However, some question exists as to the most desirable method of pressurizing a spacesuit for neutral buoyancy operations. One point of view is that the suit should be pressurized with air, since it represents the most natural condition for the astronaut in an actual space flight. The other point of view is that the suit should be pressurized with water, since this will provide the most realistic simulation with regard to suit dynamics.

At the conclusion of the preliminary definition phase of this study, it was decided to implement the experimental program utilizing both methods. Experiment 84A would provide comparative information on relatively static force applications, and Experiment 1A would allow a comparison of the two pressurization media under translational and manipulative conditions.

4.2.2.1 Water Pressurization

In practice the water pressurization technique requires the use of a SCUBA mask worn under the spacesuit helmet and a SCUBA mouthpiece to supply air, since water fills the helmet as well as the suit. The helmet which is provided as part of the State-of-the-Art suit does not allow sufficient space for the mask and mouthpiece. In addition, it is so designed that access to the subject's mouth, either by opening the visor or by removing the helmet entirely, is fairly difficult and unreliable. Therefore, a new helmet, shown in Figure 4.2-2, was designed and built by GE for this study. This helmet mates with the suit neck ring and requires no modifications to the suit. Its main features are the split hemisphere design which is held with a specially adapted quick-release Marmon clamp, and its size and shape, which allows the inclusion of under-water 2-way communications equipment.

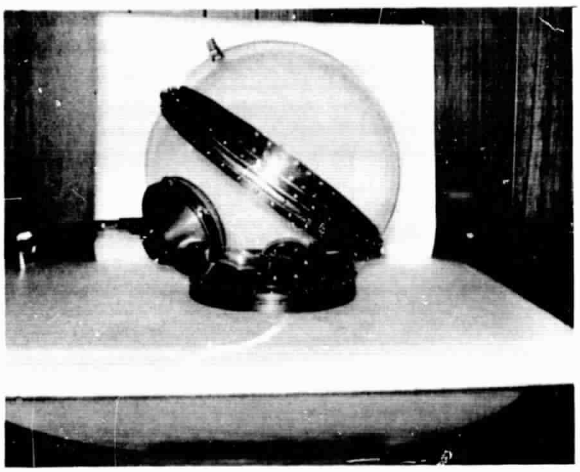


Figure 4.2-2. Underwater Helmet

The quick-release clamp, operable by either the test subject or a safety man, enables safety personnel to provide a rapid supply of breathing air in the event of an emergency.

The helmet also contains a specially designed second-stage demand regulator. Breathing air at 100 psi was supplied from the surface control station through a hookah. The control station acts as the first stage regulator in a standard SCUBA system, allowing the second-stage demand regulator to function in accordance with the man's breathing rate and depth. Water pressure is supplied through a pump and maintained at a preset value by redundant regulators located in the backpack shown in Figure 4.2-3 and schematically depicted in Figure 4.2-4.

The pump is a constant-flow device which continually pumps water from the surroundings into the suit. The regulators were preset to open at a pressure of 3.7 psig. This constant-flow system also eliminates problems associated with suit leaks as the pump is capable of providing 12 cfm of water into the system.

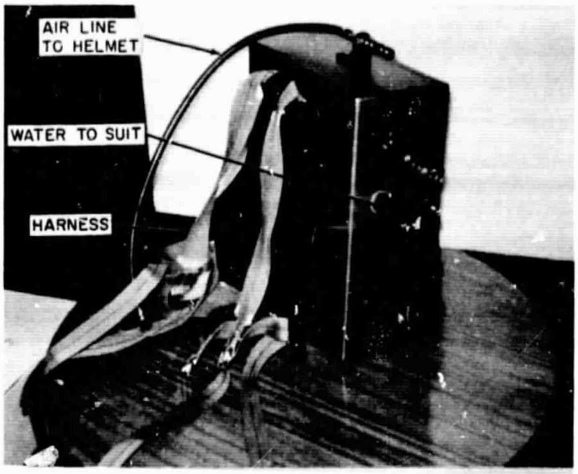


Figure 4.2-3. Underwater Backpack

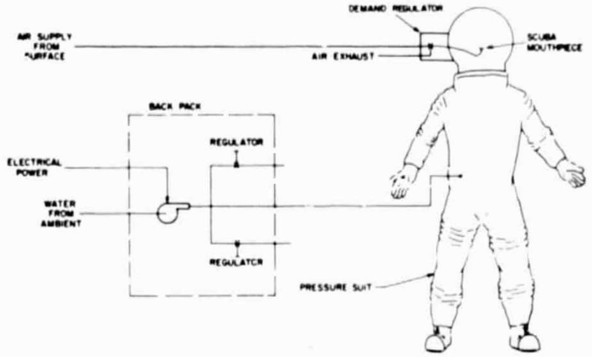


Figure 4.2-4. Water Pressurization/Air Breathing System

4.2.3 ATTAINMENT OF NEUTRAL BUOYANCY

During the experiment, familiarization, and training activities a gross neutrally-buoyant state, in an upright position, was determined for each test subject in both the air and water pressurized conditions. For the water-pressurized conditions approximately 50 to 80 cubic inches of styrofoam flotation material, providing about 3 pounds of buoyancy, was required to attain neutral buoyancy. This buoyant material was located at the test subject's stomach. In order to account for slight daily changes in the subject's weight, the buoyancy was adjusted by adding or removing small amounts of floatation material each time the subject entered the water.

For the air-pressurized condition, approximately 130 pounds of weight was required to stabilize in a neutral condition. This was obtained by placing a large harness over the shoulders of the subject with weights distributed in front and back, with additional weights attached to the arms and ankles. Again, each subject was trimmed to the neutrally buoyant state each time he entered the water, to account for daily weight changes.

4.2.2.2 Air Pressurization

In order to provide the same subject/backpack mass and geometry as in the water pressurization case, the subject wore the same helmet and backpack with the air pressurization system. However, for this configuration, the helmet demand regulator was bypassed and a suit air pressurization regulator mounted in the backpack was utilized. As shown schematically in Figure 4.2-5, air for both suit pressurization and breathing is supplied to the suit regulator from the surface through a hookah, at about 100 psi and 4 cfm.

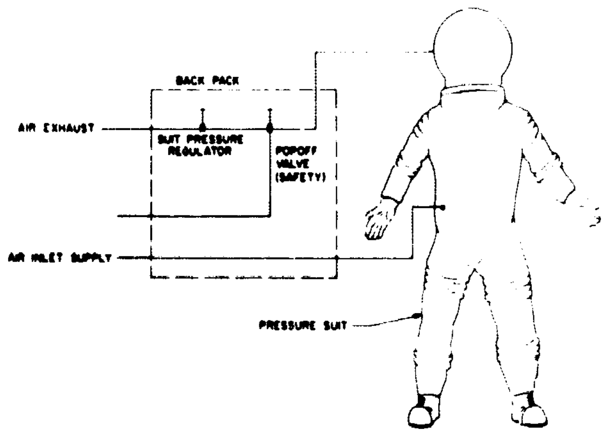


Figure 4.2-5. Air Pressurization/Air Breathing System

SECTION 5
FACILITIES

The facility used during the implementation of the experiment program discussed in this report is located at the Marshall Space Flight Center, Huntsville, Alabama, and consists of two below-surface water tanks, an instrumentation building, and a dressing room van.

5.1 NEUTRAL BUOYANCY TEST FACILITY TANKS

The experiment program was initiated utilizing the larger tank at the facility, Figure 5.1-1. This is an enclosed unit, 25 feet in diameter and 15 feet in depth. Approximately halfway through the experimental sessions, the experimental apparatus was shifted to a smaller tank, due to schedule maintenance and refurbishing of the larger facility. The small tank is 15 feet in diameter and 12 feet deep. For either facility, water heating was provided by a steam coil maintaining the temperature at $90^{\circ}F$.

5.2 INSTRUMENTATION BUILDING

The instrumentation required to operate the facility and conduct the experiment was located in a building adjacent to the tanks. All experiment-related activities and test operations were controlled from this building, with television controls, monitor, video recording equipment, communications, and data recording equipment located there. Figure 5.2-1 is a view of the interior of the instrumentation facility showing the test director's station.

The television equipment served the dual purpose of safety monitoring and data collection. In the safety function, two cameras were focused on the test subjects and monitored continuously by both the test director and safety monitor. In the data collection function, selected video was recorded together with an audio input from the test director. This was then available for motor performance analysis and detailed observation of bodily reactions to the force emissions under various restraint conditions.

5.3 PERSONNEL ACCOMMODATIONS

A locker room was provided in an air-conditioned van parked adjacent to the tank. This provided a convenient place for support personnel engaged in the test program to change clothes and for the test subject to suit up.

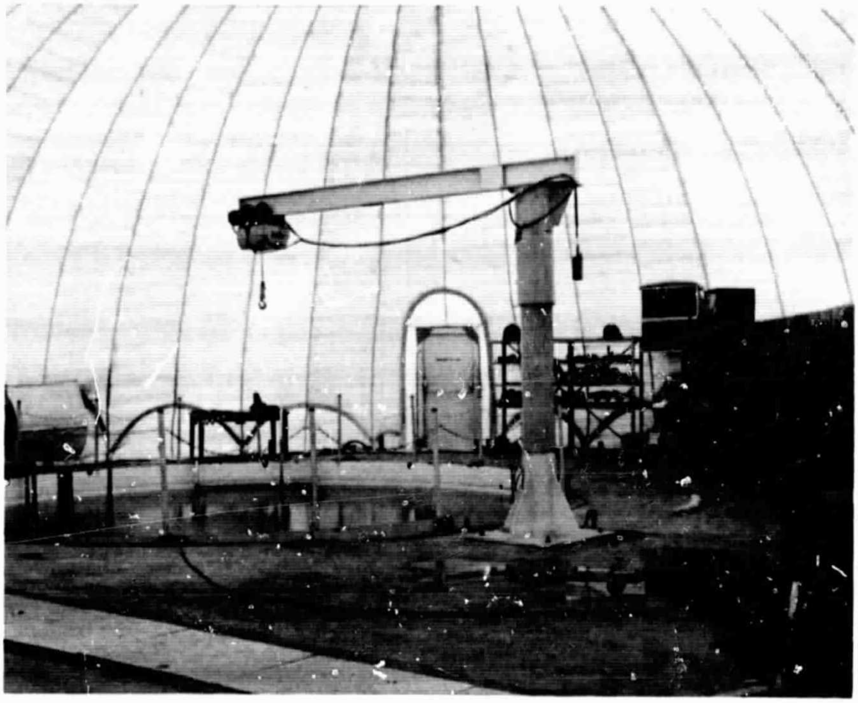


Figure 5.1-1. Neutral Buoyancy Simulation Facility

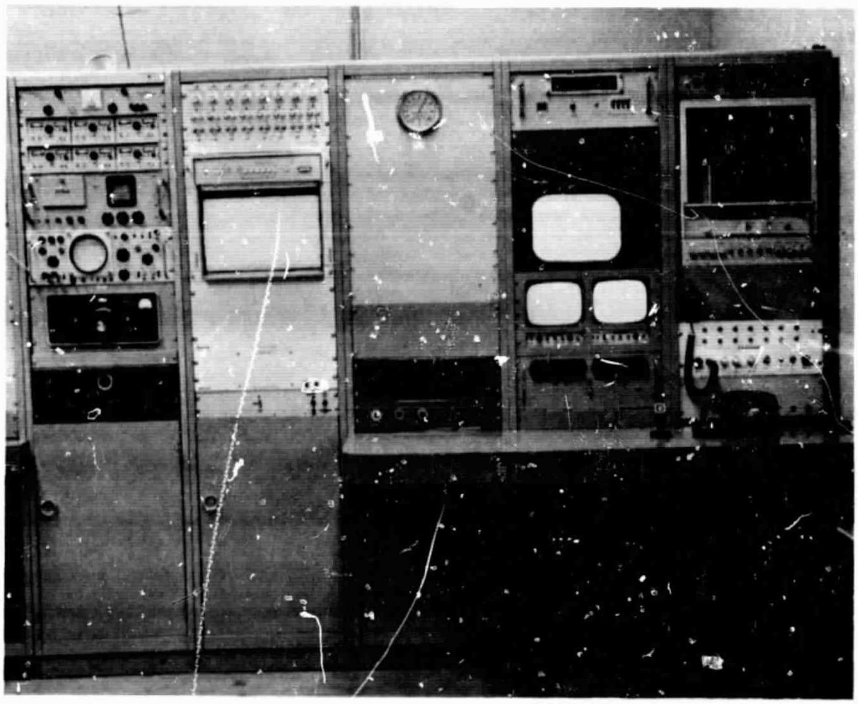


Figure 5.2-1. Instrumentation Facility

SECTION 6

EXPERIMENT 84A - FORCE APPLICATION IN ZERO-G

A summary description of Experiment 84A, the first to be implemented in this study program, is contained in this section. Experiment 84A is a combination of the variables of Experiments 8 and 4 with modifications as required by the NASA selection committee. These, plus those changes which were necessitated by the more detailed final design and/or operational considerations, are also described in this section.

6.1 INTRODUCTION

One of the most basic demands to be made on man by space systems, present and future, is the requirement to exert forces of various types and directions. The need to remove and stow, assemble and disassemble, and install various structural components, as well as the need to move himself will require the applications of forces by the space-suited astronaut. The experiment described here is designed to evaluate and quantify man's ability to generate impulsive and sustained forces under a variety of conditions which simulate various modes of restraint and accessibility. The resultant data is of special importance to spacecraft designers, since it provides 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 a space-suited astronaut?

6.2 OBJECTIVES

The systematic variation of restraint conditions while measuring maximum impulse and sustained force generation capability will provide the spacecraft designer with comparative data on the relative values of specific types of restraint systems. Varying the orientation and location of the force receiver will also provide comparative data to evaluate the relative effects of accessibility and variations of the work envelope on man's force application capabilities. Although many of the restraint conditions to be tested would appear unreasonable in certain situations, this experiment is 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 limits his movements, the availability of force emission capability data as a function of force receiver location and orientation will assist the designer in the solution of the man/machine interface problems. Therefore, the major objectives of this experiment were to:

a. Measure and evaluate the effects of restraint system on impulse and sustained force-producing capability in zero-g

b. Measure and evaluate the effects of force receiver orientation on impulse and sustained force-producing capability in zero-g

c. Measure and evaluate the effects of force receiver distance on impulse and sustained force-producing capability in zero-g

6.3 EXPERIMENT DESCRIPTION

6.3.1 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 restraints were varied in the number of energy sinks provided to the subject and the location of these energy sinks. Additionally, the accessibility conditions were evaluated by changing the location and orientation of the force receiver relative to the subject. The subjects performed all tasks wearing an Apollo State-of-the-Art spacesuit pressurized to 3.7 psig. Zero-gravity was simulated by the technique of neutral buoyancy submergence described in Section 4.0.

The experimental apparatus was designed and constructed 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), three force receiver distances, three force receiver angles, and two handle orientations. Maximum impulse and sustained forces were obtained from each of four 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 the initiation of each experimental sequence, 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 and at a selected orientation. When all personnel were ready, the experimentor initiated signals on a test director's panel 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 or 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 192 sessions to complete the data collection across all experimental conditions.

6.3.2 EXPERIMENTAL VARIABLES

Man's ability to emit forces in a zero gravity environment is influenced by several variables. Some of the most important are:

a. Type of restraint system

b. Force profile required

c. Position and location of the body relative to the force receiver

d. Orientation of force receiver

e. Type of space suit worn and pressurization conditions

Variations and combinations of the above have been included in the experiment protocol to the extent limited by practical, budgetary, and equipment considerations. The range of each variable is briefly discussed below.

6.3.2.1 Restraint

Selection was made based on feasibility and probability of being available for future manned space flights. Consideration was given to factors which influence the crew performance profile, such as the number and location of attachment points, rigidity of energy sinks, and freedom of movement. Selected restraints include:

a. None
b. Handhold
c. Two-point waist strap
d. Gemini-type Dutch shoes
e. Handhold and waist
f. Handhold and shoes
g. Waist and shoes
h. Handhold and waist and shoes

6.3.2.2 Force Profile

The type and direction of the applied forces were chosen to obtain data covering all directions of force application. Directions of application include:

a. Push
b. Pull
c. Left
d. Right
e. Up
f. Down

The left, right, up, and down directions also have direct applicability to torque generation. Both 1-second impulsive and 4-second sustained forces are included for each direction.

6.3.2.3 Force Receiver Location

Although an almost infinite number of force receiver locations are possible in the volume enclosed by the subject's reach envelope, it was necessary to limit this variable to the plane described by the horizontal sweep of the man's arm and his reach. Utilizing a line drawn perpendicular to the right side of the chest as the 0-degree reference point, two additional locations at +45 degrees (right) and -15 degrees (left) were selected. At each of these locations, 3 distances forward of the sagittal axis were chosen to sample the range in variations in force-producing capabilities and include:

a. Near (elbow angle approximately 90 degrees)

b. Medium (elbow angle approximately 135 degrees)

c. Far (elbow angle approximately 180 degrees)

6.3.2.4 Force Receiver Orientation

The handhold of the force receiver was oriented either in the horizontal plane (0 degrees) or vertical plane (90 degrees).

6.3.2.5 Space Suit and Personnel Variables

As previously stated, Apollo state-of-the-Art Suits are utilized in the conduct of this experiment.

Six subjects were used in this experiment, four extensively and two as alternates. Three of the subjects were selected to represent the 50th percentile and three the 90th percentile in height from the Anthropometry of Flying Personnel published in 1950 by Hertzberg, Daniels, and Churchill. The actual subject descriptive data is presented in Table 6.3-1. They ranged from 25 to 29 years in age (mean of 31), from 140 to 178 pounds in weight (mean of 163), and from 5'10" to 6'0" in height (mean of 5'11"). All subjects had high school diplomas or equivalent, one had 2 years of college and three had college degrees in engineering.

All subjects were experienced SCUBA divers and had been pressure suit indoctrinated. All subjects had passed the Air Force Category III flight physical and had normal vision in both eyes.

Table 6.3-1. Subject Data

Subject No.	Age	Weight (lb)	Height (in.)	Education (years)
1	37	170	72.55	16
2	33	178	71.50	14
3	39	150	70	12
4	30	140	69	16
5	25	165	72	12
6	25	178	70	16

6.3.2.6 Pressurization Method

Two methods of providing the required 3.7 psig pressure inside the space suits were utilized. The first was provided by an air pressurization system attached to an underwater backpack. Inlet and exhaust hoses were attached to the suit to provide air flow for cooling and CO_2 removal. The second was provided by a water pressurization system located in the underwater backpack. This configuration provided continuously pumped water into the suit through a single umbilical and dumped it through preset, parallel dump valves. Both of these systems are described in detail in Section 4.3.

The two pressurization methods were included as an experimental variable in order to provide an initial determination of the differential effects, if any, of the two pressurization modes.

6.4 EXPERIMENT APPARATUS

The underwater experiment apparatus (Figure 6.4-1) consisted of a force receiver that converted the forces applied by the subject into electrical output signals, a framework to support the force receiver and provide the proper restraints to the test subject, and a panel to display to the test subject the desired force direction and type. In addition to this equipment, a panel was provided to enable the test director to give instruction to the test subject in the water.

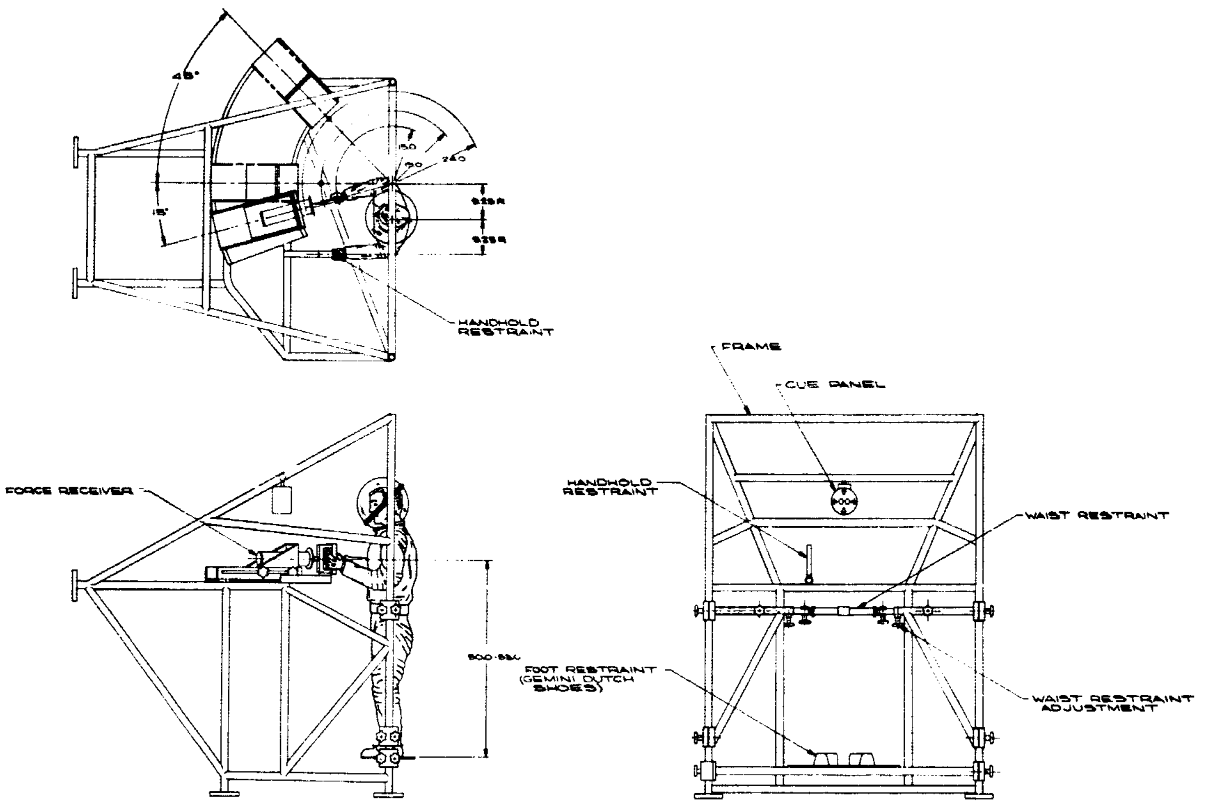


Figure 6.4-1. Experiment 84A Underwater Apparatus

The force receiver (Figure 6.4-2) consists of a cylindrical shaft, anchored at one end with the handle affixed to the other end. Force application is measured by bending deflections in the cantilevered shaft in the Y and Z axes and deflections of a calibrated spring in the X axis. Deflection is measured by three orthogonally placed differential transformers and is relatively small (approximately 0.200 in./100 lb in the X axis and 0.250 in./100 lb in the

Y and Z axes). The force receiver is mounted on a carriage which may be adjusted in the Y-Z and X-Z planes to vary elbow angle and horizontal locations, respectively. The carriage is mounted on a rigid frame which also provides attachment points for the subject to the various restraints.

Figure 6.4-2. Force Receiver

During the conduct of the experiment, the test subject is attached to one of the eight restraints, and the appropriate experimental conditions are set up by a technician who remains in the water with the test subject. Instructions as to force direction and type are programmed by the test director through his control panel (Figure 6.4-3) and received by the underwater test subject on his cue panel (Figure 6.4-4) for a 2-second cue period prior to the force application command. The type of force to be applied is denoted by appropriate illumination of either the "impulse" or "sustain" legends, while the direction of force application is shown by illumination of the appropriate arrow (left, right, up, or down) or legend (push or pull). At the end of the cue interval, a "go" light is illuminated for a period of 4 seconds for the sustained force command and 1 second for an impulsive force. The test subject applies maximum force for the duration of the "go" signal.

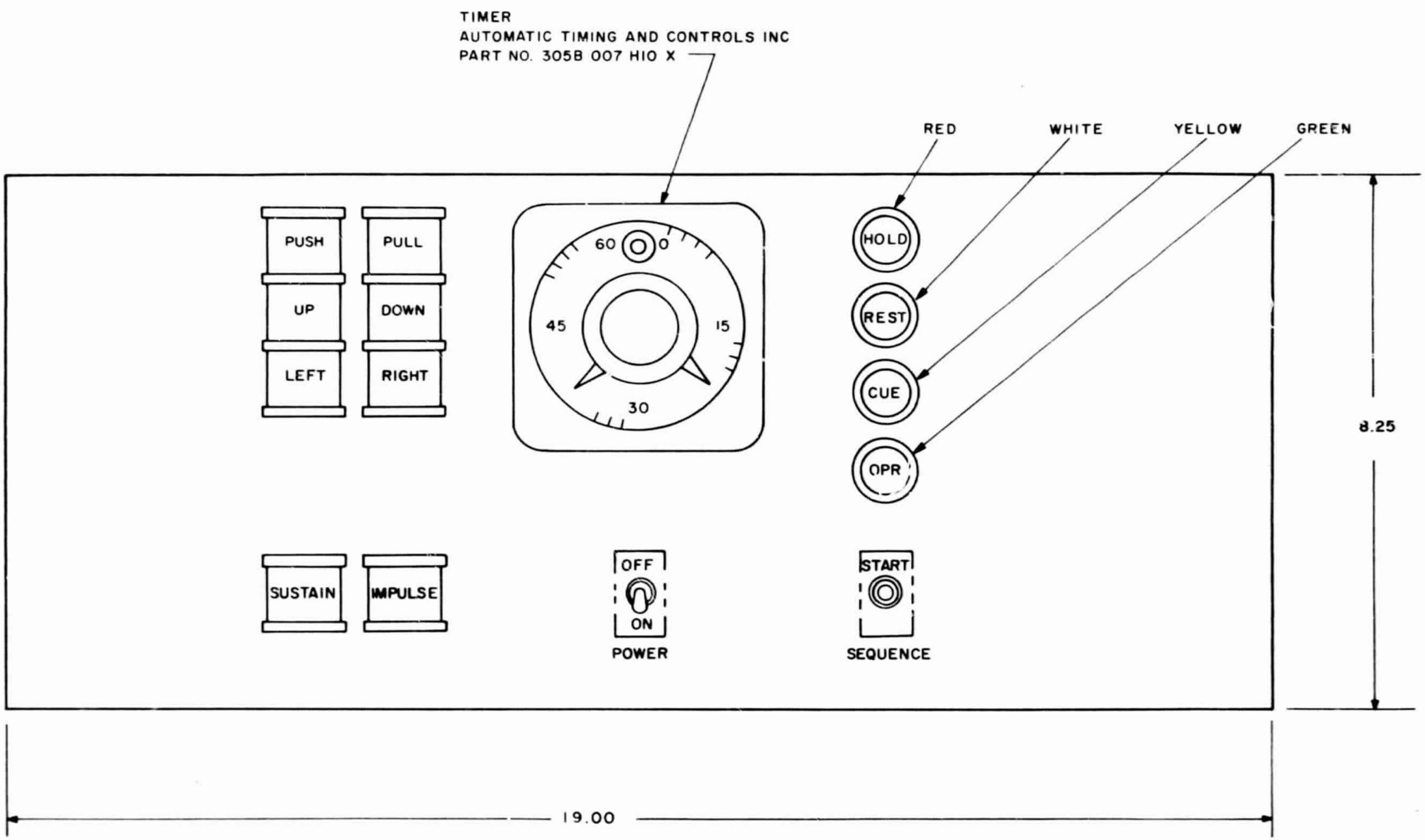


Figure 6. 4-3. Test Director's Control Panel

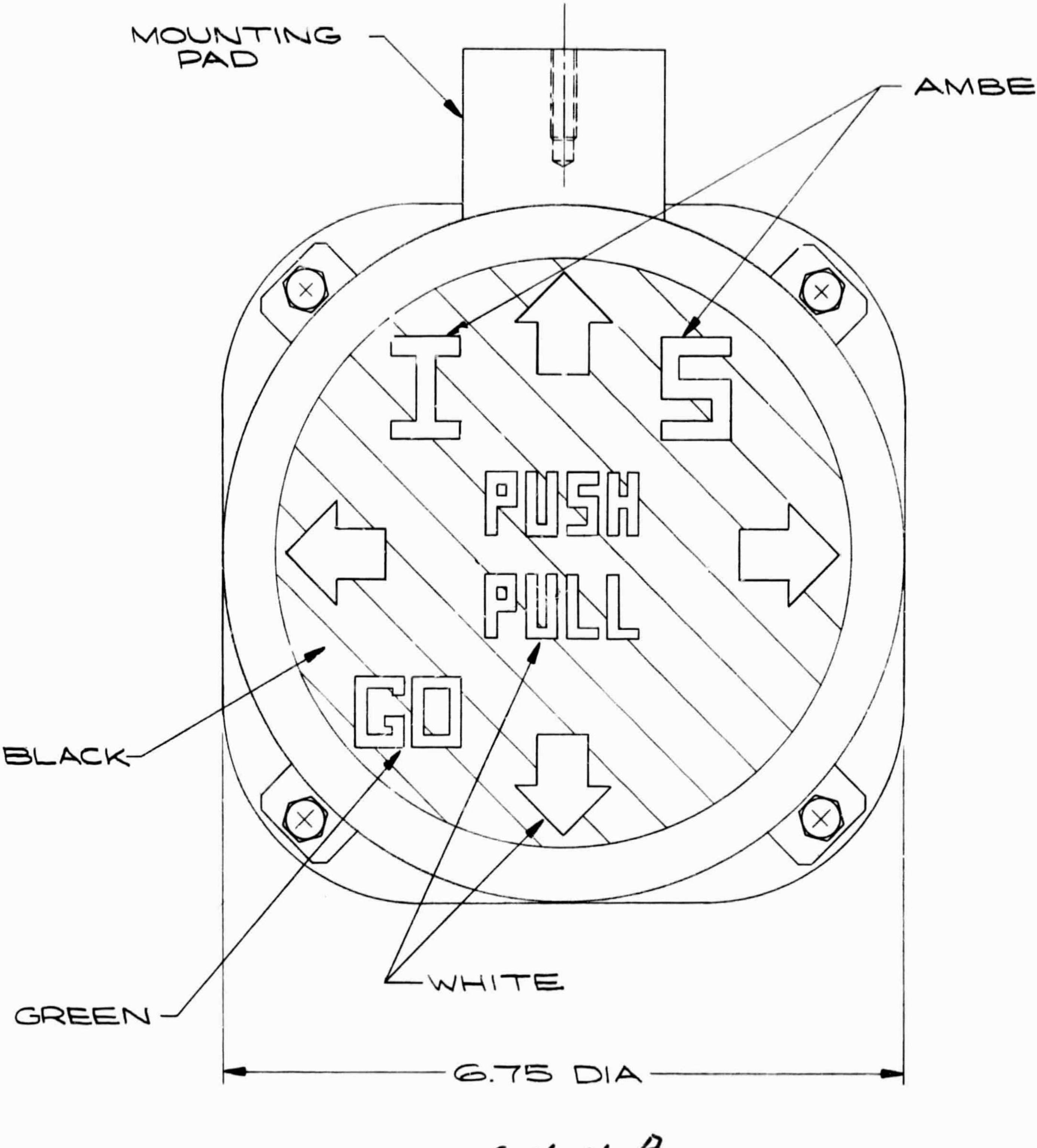


Fig. 6.4-4. A

FOLDOUT FRAME

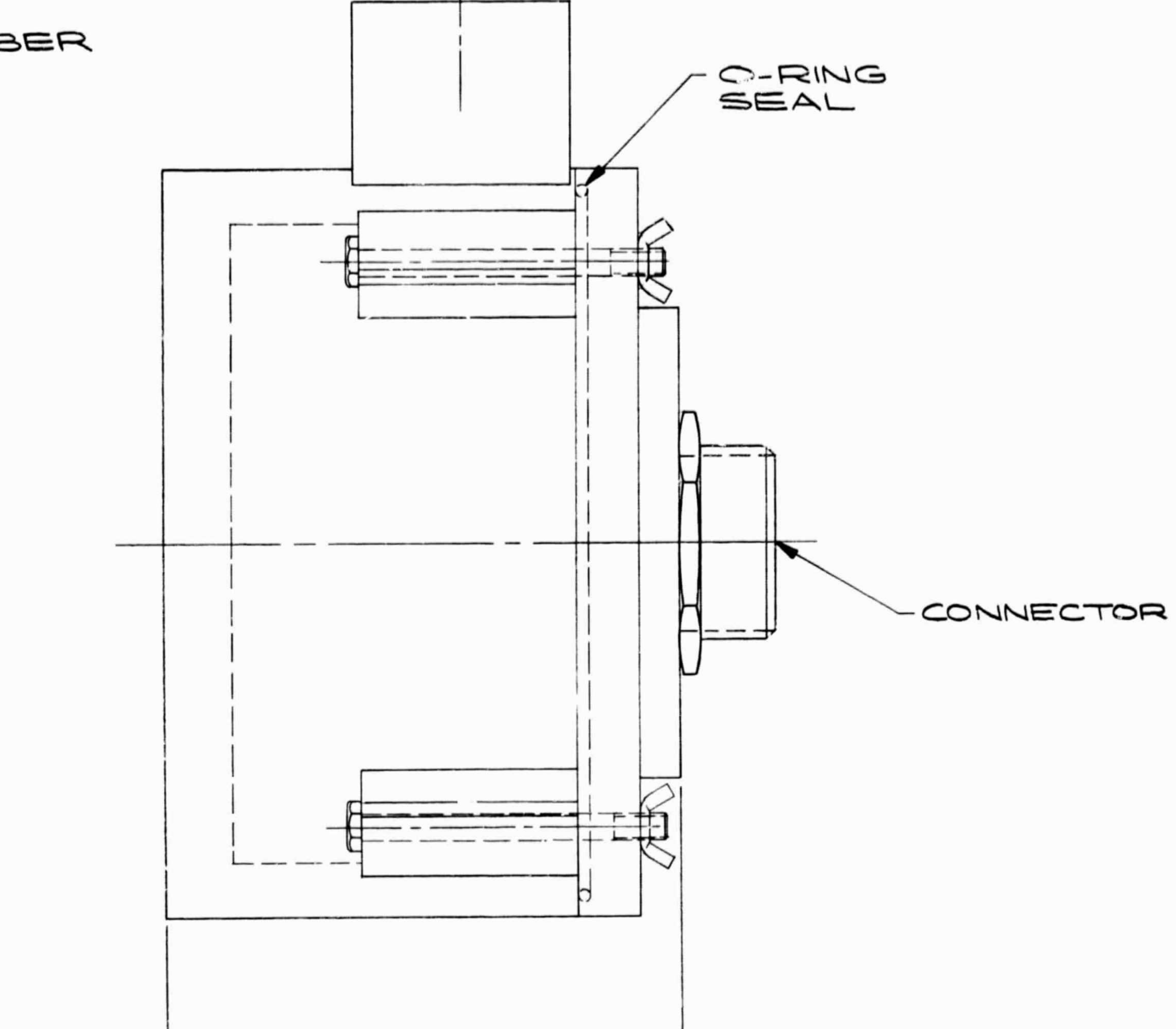


Figure 6.4-4B Test Subject's Cue Panel

FOLDOUT FRAME

6.5 EXPERIMENT SCHEDULING

The magnitude of the number of experimental conditions selected for investigation in this experiment required that great care be exercised in the scheduling and organization of the test sequences in order to minimize the possibility of systematically biasing the resultant data. The experiment was originally designed for 36 operational days with 768 trials on each day. The four subjects were to be tested in each of the 3456 experimental condition combinations twice, making a total of 27,648 data points or trials. The randomization of the variables and the required schedule revisions are discussed below.

6.5.1 RANDOMIZATION OF VARIABLES

In order to preclude the occurrence of such extraneous influences or systematic biases as transfer-of-training and order-of-presentation effects on the reliability of the data, it would be desirable to randomize the sequence of all the experimental condition combinations. Numerous practical considerations, however, made complete randomization impractical, as a relatively indeterminant number of changes in subject, suit pressurization, restraint type, etc., would extend the schedule beyond all reasonable bounds.

In actuality the condition combinations were arranged into sessions with 96 force applications or trials each, resulting in a total of 288 sessions. Figure 6.5-1 shows a typical session format sheet. A working schedule of eight sessions a day, with each subject participating in two sessions each day, was planned. The following were the constraints placed on the randomizing, or scheduling, of the experiment:

a. Pressurization method remained constant throughout a day and was alternated each working day.

b. The order of the four subjects was random for the first four sessions and repeated for the second four sessions each day.

c. The receiver angle remained constant within each session, but was random across sessions.

d. Restraints remained constant within each half session (48 trials), but were randomly assigned across half sessions.

e. Receiver orientation and receiver distance remained constant within each block of 12 trials, but were randomly assigned across blocks of 12 trials.

f. Within each block of 12 trials, every combination of force type and force direction occurred. The order of presentation was random within each block of 12 with the restriction that within each four trials (i.e., 1 through 4, 5 through 8, and 9 through 12), two sustained and two impulse trials occurred.

Rest periods were distributed throughout the session to minimize fatigue effects. Table 6.5-1 shows the resulting protocol along with rest periods.

6.5.2 SCHEDULE REVISIONS

The original experimental schedule, described in 6.5.1, was revised in a number of ways due to operational constraints and problems. These primarily resulted in a change in the running order of subjects and the number of replications of each trial point.

6.5.2.1 Subject Order Revisions

The completely random order of test subjects was restricted such that two subjects (1 and 2) were scheduled first during each day because of their availability only from 7:00 a.m. to 3:30 p.m. The other two subjects (3 and 4) always ran last because of their availability from 9:30 a.m. to 6:00 p.m. In addition, the limited availability of Apollo State-of-the-Art pressure suits required that the two 90th percentile subjects (1 and 3) alternate with the two 50th percentile subjects (2 and 4) to reduce session changeover time. These revisions resulted in only two possible subject running orders - 1, 2, 3, 4 or 2, 1, 4, 3. It was decided to use one running order for 2 days then alternate with the other running order for two days. This schedule was generally kept for the first four sessions of each day.

6.5.2.2 Replication Number Revisions

The original protocol design called for two replications of each experimental condition combination for a total of 288 sessions. Due to the considerable number of delays resulting from equipment failures and personnel problems, it was decided to terminate the experiment after obtaining only one replication of each condition combination and evaluate the feasibility of pooling some of the experimental conditions, specifically pressurization method and subjects.

EXP 84 FORCE EMISSION CAPABILITY IN ZERO GRAVITY

SUBJECT 4 — DAY 4 SESSION 8

REC. ANGLE 45° — DATE ----

PRESS. METHOD AIR — TIME START ---- STOP ----

EXPERIMENTER ----

RESTRAINT Waist

RO= 0° RD= N		RO= 90° RD= M		RO= 90° RD= F		RO= 90° RD= N	
TRIAL	FT/FD	TRIAL	FT/FD	TRIAL	FT/FD	TRIAL	FT/FD
1	I/B	13	S/R	25	S/L	37	I/U
2	S/R	14	I/F	26	I/D	38	I/R
3	I/U	15	I/D	27	S/F	39	S/L
4	S/U	16	S/U	28	I/U	40	S/U
REST 40 SEC		REST 40 SEC		REST 40 SEC		REST 40 SEC	
5	I/D	17	S/F	29	S/B	41	I/D
6	I/L	18	S/B	30	S/U	42	S/R
7	S/D	19	I/U	31	I/B	43	S/F
8	S/L	20	I/R	32	I/L	44	I/L
REST 40 SEC		REST 40 SEC		REST 40 SEC		REST 40 SEC	
9	I/R	21	I/B	33	S/D	45	S/D
10	S/F	22	S/D	34	I/R	46	I/F
11	S/B	23	I/L	35	I/F	47	S/B
12	I/F	24	S/L	36	S/R	48	I/B
REST 2 MIN		REST 2 MIN		REST 2 MIN		REST 4 MIN	

RESTRAINT Hand Hold & Foot

RO= 90° RD= M		RO= 90° RD= N		RO= 0° RD= M		RO= 0° RD= F	
TRIAL	FT/FD	TRIAL	FT/FD	TRIAL	FT/FD	TRIAL	FT/FD
49	S/D	61	S/L	73	S/U	85	I/R
50	I/L	62	S/D	74	I/D	86	S/D
51	S/L	63	I/F	75	I/R	87	I/D
52	I/D	64	I/B	76	S/D	88	S/L
REST 40 SEC		REST 40 SEC		REST 40 SEC		REST 40 SEC	
53	I/R	65	I/U	77	S/F	89	I/L
54	I/F	66	S/R	78	S/B	90	S/U
55	S/F	67	I/R	79	I/F	91	S/R
56	S/U	68	S/F	80	I/L	92	I/F
REST 40 SEC		REST 40 SEC		REST 40 SEC		REST 40 SEC	
57	S/R	69	I/D	81	I/B	93	S/F
58	I/B	70	S/B	82	I/U	94	I/B
59	S/B	71	S/U	83	S/L	95	I/U
60	I/U	72	I/L	84	S/R	96	S/B
REST 2 MIN		REST 2 MIN		REST 2 MIN			

LEGEND

RO = RECEIVER ORIENTATION (0°, 90°)	I = IMPULSE	U = UP
RD = RECEIVER DISTANCE	S = SUSTAINED	D = DOWN
FT = FORCE TYPE	N = NEAR DISTANCE (15'')	L = LIFT
FD = FORCE DIRECTION	M = MEDIUM DISTANCE (19'')	R = RIGHT
	F = FAR DISTANCE (24'')	F = FORWARD (PUSH)
		B = BACK (PULL)

Figure 6.5-1. Typical Session Format Sheet

Table 6.5-1A Sample Experiment Protocol

Time	Activity	Time (sec)	Location	Personnel
0730	Suit up Subject 1		Suit Room	S_1, SM_1
0730	Perform equipment activation check list		Control Room	TD
0740	Record environmental measures Air temp, water temp, water clarity, humidity, illumination level		Tank	TD
0740	Perform equipment calibration			ET_1, ET_2
0750	Perform suit/backpack operational check Verify suit pressure integrity and satisfactory operation of backpack		Suit Room	S_1, SM_1
0800	Prepare subject for experimental session		Tank	S_1, SM_1, ET_1
	Enter tank and go to test apparatus		Tank	S_1, SM_1
	Attach S1 to restraint 1		Tank	SM_1, ET_1
	Stabilize S1 in initial Expt 1. position		Tank	SM_1
	Take positions at experiment stations		Tank	SM_1, ET_1
0812	Conduct experiment session 1		Control Room and Tank	TD, S_1, SM_1, ET_1
	1. Run 1			
	Program push impulse		Control Room	TD
	Apply push impulse	1.0	Tank	S_1
	Rest	9.0	Tank	S_1
	Program push sustained		Control Room	TD
	Apply push sustained	4.0	Tank	S_1
	Rest	9.0	Tank	S_1
	Program pull impulse		Control Room	TD
	Apply pull impulse	1.0	Tank	S_1
	Rest	9.0	Tank	S_1
	Program pull sustained	4.0	Control Room	TD
	Apply pull sustained	40.0	Tank	S_1
	Rest		Tank	S_1
	Program up impulse	1.0	Control Room	TD
	Apply up impulse	9.0	Tank	S_1
	Rest		Tank	S_1
	Program down impulse	1.0	Control Room	TD
	Apply down impulse	9.0	Tank	S
	Program up impulse	1.0	Control Room	TD
	Apply up impulse	9.0	Tank	S_1

6-17

[redacted]

	Program up impulse	1.0	Control Room	TD
	Apply up impulse	9.0	Tank	S_1
	Rest		Tank	S_1
	Program down impulse	1.0	Control Room	TD
	Apply down impulse	9.0	Tank	S_1
	Rest		Tank	S_1
	Program up sustained	4.0	Control Room	TD
	Apply up sustained	9.0	Tank	S_1
	Rest		Tank	S_1
	Program down sustained	4.0	Control Room	TD
	Apply down sustained	40.0	Tank	S_1
	Rest		Tank	S_1
	Program left impulse	1.0	Control Room	TD
	Apply left impulse	9.0	Tank	S_1
	Rest		Tank	S_1
	Program right impulse	1.0	Control Room	TD
	Apply right impulse	9.0	Tank	S_1
	Rest		Tank	S_1
	Program left sustained	4.0	Control Room	TD
	Apply left sustained	9.0	Tank	S_1
	Rest		Tank	S_1
	Program right sustained	4.0	Control Room	TD
	Apply right sustained		Tank	S_1
	TOTAL (191 secs.)			
2.	Rotate force receiver handle (2 minutes) and change distance		Tank	ET_1
3.	Run 2 (Repeat run 1, change order) (191 seconds)		Control Room/ Tank	TD, S_1
4.	Rotate force receiver handle (2 minutes) and change distance		Tank	ET_1
5.	Run 3 (Repeat run 1, change order) (191 seconds)		Control Room/ Tank	TD, S_1
6.	Rotate force receiver handle (2 minutes) and change distance		Tank	ET_1
7.	Run 4 (Repeat run 1, change order) (191 seconds)		Control Room/ Tank	TD, S_1
8.	Attach S_1 to restraint 2 change receiver orientation and distance and rest (4 minutes)		Tank	S_1, ET_1, SM_1

[redacted]

Table 6.5-1a
6-11a

FOLDOUT FRAME

Table 6.3-1C

	7. Run 4 (Repeat run 1, change order) (191 seconds)	Control Room/ Tank	TD, S_1
	8. Attach S_1 to restraint 2 change receiver orientation and distance and rest (4 minutes)	Tank	S_1, ET_1, SM_1
	9. Repeat steps 1-7 on restraint 2 (18 minutes)	Control Room/ Tank	TD, S_1, ET_1
0830	Suit up subject 2	Suit Room	S_2, SM_2
0850	Perform suit/backpack operational check Verify suit pressure integrity and satisfactory operation of backpack	Suit Room	S_2, SM_2
0900	Complete experiment session 1 Remove S_1 from restraint and vacate water	Tank Suit Room	TD_1, S_1, SM_1, ET_1 S_1, SM_1, ET_1
0900	Prepare subject for experimental session Enter tank and go to test apparatus Attach S_2 to restraint 2 Stabilize S_2 in initial Expt 1 position	Tank	S_2, SM_2, ET_2
0912	Conduct experiment session 2 (See time 0812)	Control Room and Tank	TD, S_2, SM_2, ET_2

Legend

S - Subject
SM - Safety Monitor
TD - Test Director
ET - Experiment Technician
Subscripts are specific personnel identifiers

Combining the data collected under the conditions of water and air pressurization modes appeared to be justified on the basis of face validity from the test directors constant visual monitoring of the oscillographic tapes. Additionally, it was felt that the subjects percentile groupings could be combined. This pooling of the subject factor also appeared, from "eye-balling" the data, to be justified on the basis of the subjects not representing a 50th (or 65th) and 90th percentile grouping on the basis of force emission capability although they did represent the 50th (or 65th) and 90th percentile in height. Subsequent statistical analysis, presented in Section 6.7, confirmed the validity of these decisions.

When the above decision to combine experimental conditions was made, it was found that 84 percent of the data for the first replication had been collected. In addition, approximately 14 percent of the data for the second replication had been collected. However, for the remaining porition of the data, a revised session format would be required. In the new session format, restraint would remain constant for only 24 trials as compared to 48 new trials in the original sessions. Otherwise the session format remained unchanged. Approximately 14 percent of the data was collected under this new session format.

Finally, when the computer reduction of the data was completed, it was found that some data was missing due to instrumentation problems or excessive noise on the analog tape. This missing data, approximately 2 percent, was collected during makeup sessions using approximately the same session format with more frequent changes of the experimental variables. The deletion of individual trials, for one reason or another, combined with the variation in the number of replications discussed above, resulted in a variation from 6 to 12 in the number of trials for each experimental condition combination in the data printout.

6.6 INSTRUMENTATION

The instrumentation utilized in this experiment was designed to provide for both computerized data reduction as well as the capability for real-time monitoring of the data by the test director. These capabilities were provided by the use of magnetic tape and oscillographic recordings of both the instructions to the test subject and the outputs of the force receiver transducers. In addition to recording the applied force in the command direction, the forces in the other two axes were also recorded to provide a measure of the error forces. Figure 6.6-1 is a block diagram of the instrumentation used.

6.6.1 CONTROL PANEL

A description of the operation of the control panel is contained in Section 6.4 and will not be repeated here except to note that the programmed instructions to the test subject in the water were simultaneously recorded on the magnetic tape and oscillographic recorders.

6.6.2 MAGNETIC TAPE RECORDING

The outputs of the force receiver transducers were recorded on channels 1 through 3 of an Ampex Model CP-100 recorder, with the remaining channels used to record identifying information for the computer and verbal comments made by the test director. Channels 4 and 5 contain the trial identification numbers as listed on the session format sheet in Figure 6.5-1. The "go" signal, which was recorded on Channel 7, was a 4-second or 1-second full-scale deflection that served to indicate a commanded force as sustained or impulsive, respectively. Channel 8 identified the command force direction by coding as one of six discrete voltage levels, ranging from zero to full scale. Channels 9 and 10 recorded the IRIG "B" time code and the force receiver handle orientation.

The abort signal recorded on Channel 11 was used to indicate to the computer that a particular trial should be discarded from the data processing. This was done to prevent erroneous data from being incorporated in the data output and to save unnecessary computation time. A digitizing signal (Channel 12) served as a command signal for the A-D conversion beginning 2 seconds before the "go" signal and ending 1 second after the termination of the "go" signal. The data was later digitized during this 7-second (for sustained forces) or 4-second (for impulsive forces) time period at a rate of 100 samples per second. Channel 14 was used to record verbal comments by the test director. Channels 6 and 13 were unused spares.

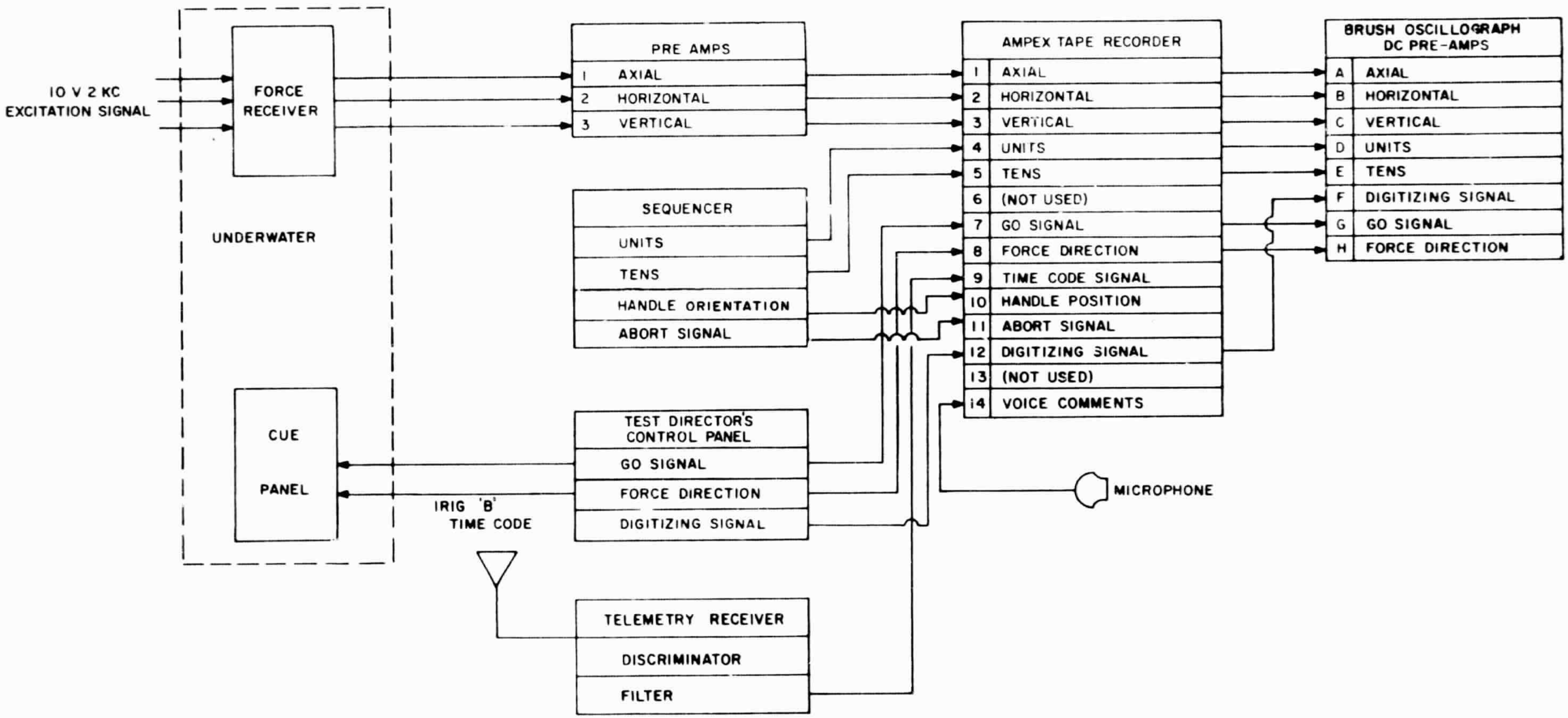


Figure 6.6-1. Instrumentation Block Diagram

6.6.3 OSCILLOGRAPHIC RECORDING

Real-time viewing of the data was provided by an eight-channel oscillographic recorder. The inputs to this recorder were obtained from selected playback heads of the analog tape recorder so that the test director could continuously monitor the status of pertinent recorded data. This was especially important in order to detect zero-level shifts in recording channels. Figure 6.6-2 is a sample of the oscillographic recording made during one of the sessions at a paper speed of 2 mm/second. This section contains 8 of the 96 trials from Session 5, Day 16. The experimental conditions being used in this session were:

Pressurization method:	Water
Restraint:	Hand only
Receiver angle:	45 degrees
Receiver orientation:	Vertical
Receiver distance:	Far

The trial numbers, reading from right to left, are 17 through 24. As is seen in the figure, the force direction instruction, Channel H, indicates the command force direction according to the height of the pulse. Channel G records the "go" signal on and off and also indicates the 2-second cue period described in Section 6.4. This channel also shows the 9-second rest period within the groups of 4 trials and the 40-second rest period between the groups of 4 trials. Channel F is the computer digitizing pulse which provides a rapid visual indication of the comparative span of data (across all channels) which will be accepted by the computer. Channels D and E record the trial number and Channels A, B, and C record the actual deflection of the transducers during a force application.

6.6.4 TRANSDUCERS

A key element in the instrumentation system was the force transducers. These were linear motion differential transformers, electromechanically proportional to the displacement of a movable core. The output of the transducer had infinite resolution over its specified range as displacement of the movable core on either side of a null point produced an increasing voltage directly proportional to the distance moved.

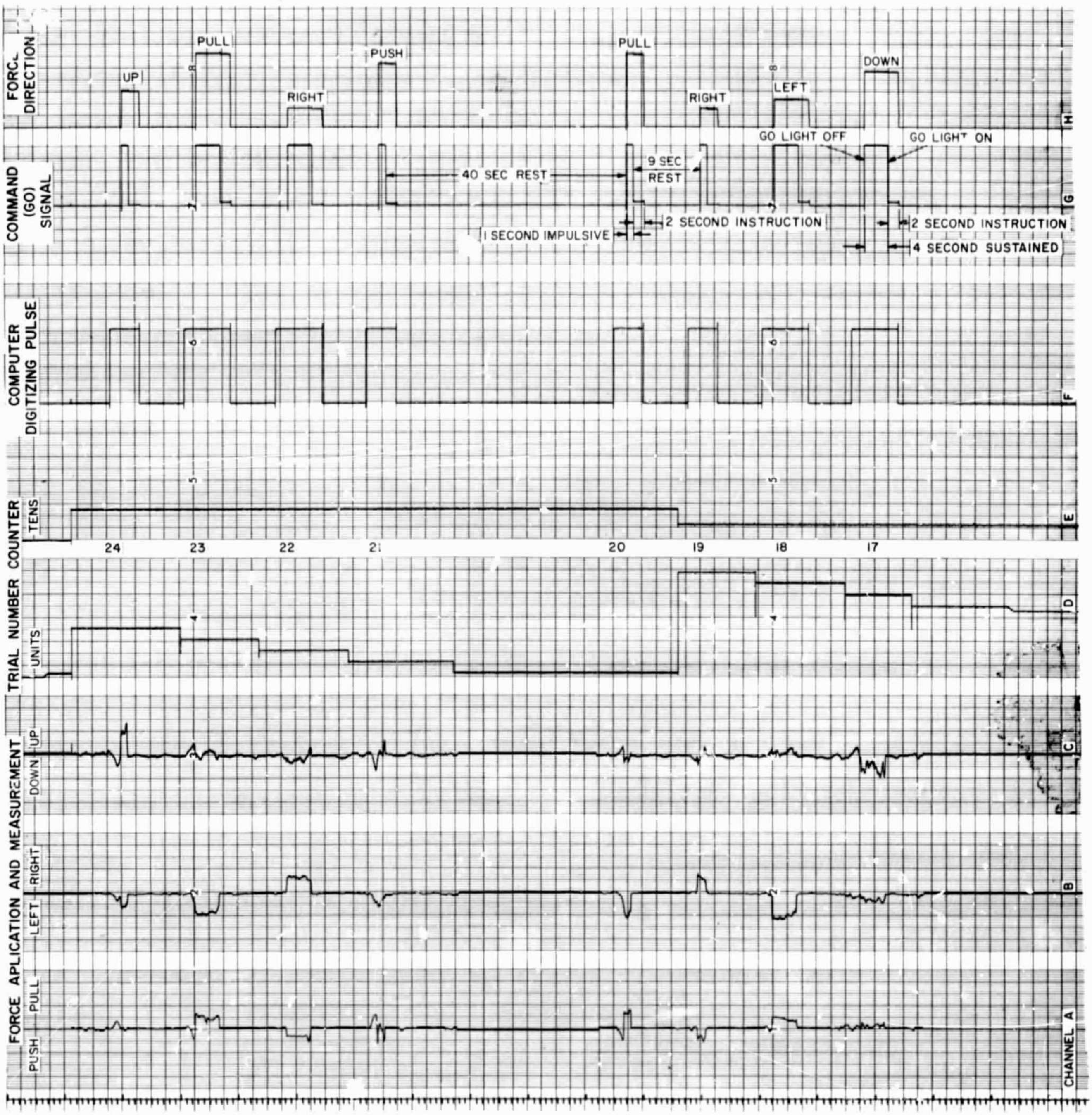


Figure 6.6-2. Sample Oscillographic Recording

6.6.5 INSTRUMENTATION SYSTEM CALIBRATION

Calibration of the instrumentation system was performed each day prior to the start of the first experiment session. This consisted of attaching accurate weights to a holder which was attached to the force receiver handle. Weights were added in 5-pound increments to 20 pounds, and then 10-pound increments to 80 pounds. The calibration was performed for all three axes. During the calibration, the excitation voltage of each transducer was adjusted so that, after amplification, the output at full scale deflection was 1.0 volts and was linear over the full range.

6.7 DATA REDUCTION

The data collection and recording system was described in Section 6.6. The important output of this system is the analog tape which contains all force data as well as identifiers of particular session conditions. These tapes formed the input to the data reduction system, as illustrated in Figure 6.7-1.

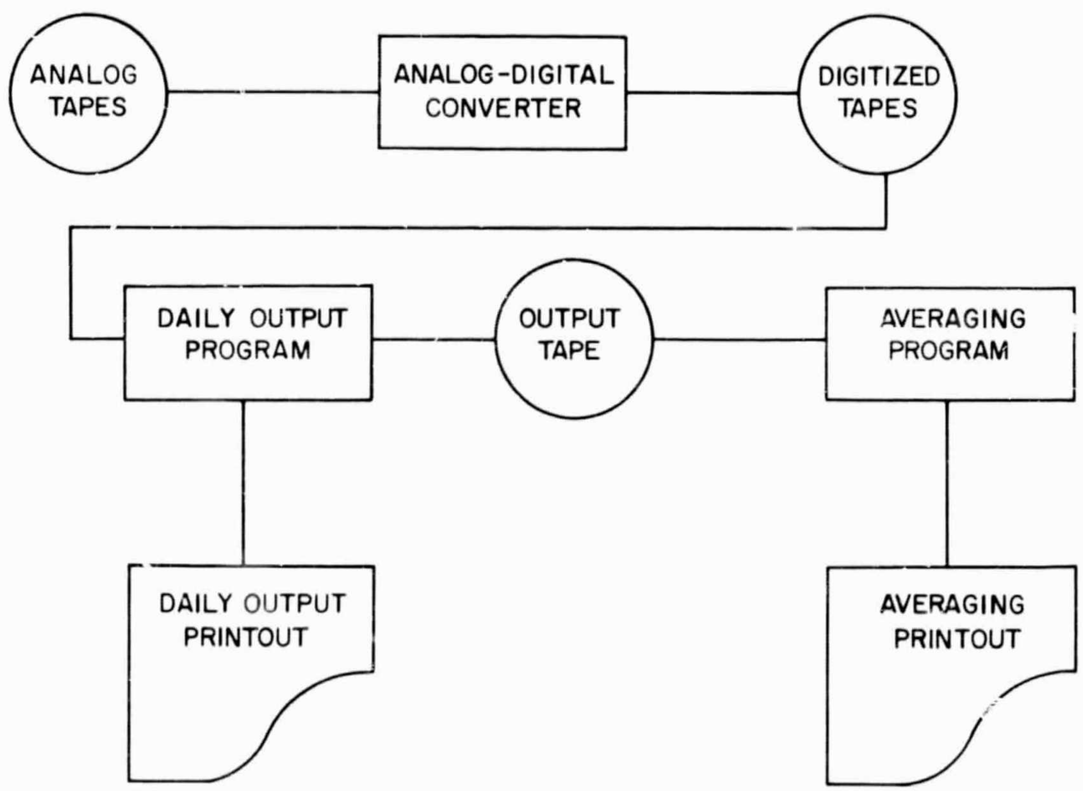


Figure 6.7-1. Data Reduction Block Diagram

In the analog-digital conversion process, the following channels were digitized:

a. Axial force data

b. Horizontal/vertical* force data

c. Vertical/horizontal* force data

d. Trial number, units

e. Trial number, tens

f. Go signal

g. Force direction

h. Force receiver orientation

i. Abort signal

Digitizing was performed by command of the 7-second (for sustained forces) and 4-second (for impulsive forces) digitizing pulse on Channel 12. A sampling rate of 400 samples per second was used; however, since the analog tapes were played at a speed 4 times greater than the record speed, the effective sampling rate was 100 samples per second. Low-pass filters were applied to all channels, except Channel 10, to eliminate as much noise as possible from the analog tapes. The filters had a cutoff frequency of 100 cycles per second, but the effective cutoff was at 25 cycles per second due to the 4-to-1 ratio of playback speed to record speed. Neither the sampling rate nor the filter cutoff frequency created any problem with respect to loss of data.

The digitized tapes then formed the input to the first of two computer programs, known as the Daily Output Program. The objective of this program was to provide a printout of the force data recorded for every trial in the experiment. A sample of the output of this program is shown in Figure 6.7-2. The program consisted of the following sequential operations:

*Depends on force receiver handle orientation

a. The digitized data was numerically converted into forces in pounds.

b. "Header cards," containing identification data not included on the tapes, (day, session, subject, pressurization method, receiver angle, and receiver distance), were read into the computer and combined with the proper data;

c. Data output was in blocks of 12 trials, with a complete set of identifiers.

Possible error messages were also printed out where applicable, and an editing feature was available for use where necessary to correct for errors.

Figure 6.7-2 illustrates the data printout for the first twelve trials of Day 18, Session 5. The significance of the printout headings of "MIN", "MAX", and "FIN" is explained below.

For sustained forces

a. In the correct (commanded) force direction:

   1. MAX is the largest force during the entire 4-second period the GO-light is on.

   2. MIN is the smallest force encountered during the last 3 seconds of the GO-signal unless the force changes sign (i.e., goes from positive to negative or vice-versa), in which case the minimum force is defined as zero.

   3. FIN is the force at GO-signal cutoff.

b. In the error axes:

   1. MAX is the largest force in either direction of an axis during the middle 3 seconds of GO-light.

   2. MIN is the smallest force in either direction of an axis during the middle 3 seconds of GO-light.

For impulsive forces

a. In the correct (commanded) force direction:

   1. MAX is the largest force that occurs for the 1 second that the GO-light is on and 1 second afterwards, i.e,. for a 2-second period.

2. MIN is the smallest force which occurs during this period.

3. FIN is the force at GO-signal cutoff.

b. In the error axes:

1. MAX is the largest force in either direction of an axis while the GO-light is on.

2. MIN is the smallest force in either direction of an axis while the GO-light is on.

Two of the four error message capabilities of the program are illustrated in the figure. The double asterisk (**) at the left of trials 4 through 8 indicates that the trial number on the digitized tape (and hence on the analog tape) does not agree with a sequentially increasing counter in the program. This is important to note, since this could result in a header card being combined with the wrong block of 12 trials.

The double asterisk on the right of the FIN column indicates that the force in the commanded direction for that trial is not the largest (in absolute value) force, i.e., an error force which is larger than the correct force has occurred. This message was required so that subject response errors could be detected and removed before final data analysis.

The program contains two other message capabilities which are not illustrated here. The 12 combinations of force type and force direction should occur once every 12 trials. In the event that a combination has not occurred, a message is printed stating what is missing. To the right of the force type-force direction columns, the word "HORIZ." appears, indicating a Horizontal force receiver orientation was recorded on the tape. The header card for this block also indicates this information. If these two do not agree, an error message is printed out. This is most important, since if the orientation is not indicated correctly the X-and Z-axis data will be interchanged.

These errors may result either from test director errors or from misinterpretation by the computer of the tape (due to noise, etc.). The last step of the program, the editing feature, allows for correct information could then be entered into the computer and take precedence over any other input.

DAY 18 | SESSIØN 5 | BLØCK 1

DAY 18 SESSIØN 5 SUBJECT 1

PRESSURIZATIØN METHØD - WATER RESTRAINT - HAND,WAIST AND SHØES

RECEIVER ANGLE = 45 DEGREES RECEIVER ØRIENTATIØN - HØRIZØNTAL RECEIVER DISTANCE - NEAR

	TRIAL	TYPE	DIRECTIØN	FØRCE	XMIN	XMAX	YMIN	YMAX	ZMIN	ZMAX	FIN	
	1	SUS.	DØ[illegible]	-Z	-6.33	1.55	-3.38	-0.17	-13.97	-14.47	-14.47	
	2	SUS.	R[illegible]Z.	+Y	-27.32	-4.53	19.52	26.12	1.90	[illegible].42	19.87	**
	3	IMP.	[illegible]IZ.	-Y	-16.55	1.55	0.00	-22.13	4.42	6.77	3.04	
**	4	IMP.	RI[illegible] HØRIZ.	+Y	-16.96	-0.11	1.39	29.93	-0.71	6.43	1.47	
**	[illegible]	IMP.	UP [illegible]ØRIZ.	+Z	0.72	4.17	-3.73	0.87	6.10	27.59	6.26	
**	6	SUS.	LEFT HØRIZ.	-Y	-3.98	0.72	-15.88	-19.87	5.76	8.11	-16.05	
**	7	SUS.	PUSH HØRIZ.	-X	-43.49	-55.09	0.69	3.38	3.58	7.10	-49.43	
**	8	IMP.	PUSH HØRIZ.	-X	0.00	-53.02	-0.26	3.82	4.50	8.28	1.55	
	9	SUS.	PULL HØRIZ.	+X	42.30	53.76	-1.56	1.82	5.09	9.54	47.82	
	10	IMP.	DØWN HØRIZ.	-Z	1.53	5.41	-0.69	2.08	0.00	-23.21	6.10	
	11	IMP.	PULL HØRIZ.	+X	1.82	54.73	-9.20	2.43	1.06	9.29	7.21	
	12	SUS.	UP HØRIZ.	+Z	1.55	12.74	-2.43	0.35	16.25	26.16	26.16	

Figure 6.7-2. Sample of Daily Output Program

After all the data from the experiment had been processed by this program, a composite output tape was prepared. This tape consisted of all the information necessary to identify the conditions for all experimental trials and all the data associated with these trials. This tape then formed the input to the second computer program, the Averaging Program. This program provided the capability to average various combinations of experimental conditions. In particular, the following conditions may be averaged either separately or in any combination:

a. Subject
b. Pressurization method
c. Receiver angle
d. Receiver distance
e. Receiver orientation
f. Restraint

A sample of the printout from the Averaging Program is shown in Figure 6.7-3. The asterisks (*) next to Subject and Pressurization Method indicate that these were the common factors for which all data points were considered; i.e., the data listed is an average of all the points which exist for all four subjects utilizing both the water and air suit pressurization methods. The numbers in parentheses to the right of the data indicate the number of trials contained in the average for the particular combination of force type and force direction and of the other specified conditions.

The meaning of "Range" in this data is best illustrated by example. In the first column of data in the lower table on Figure 6.7-3, it can be seen that a Sustained-Push force occurred six times under the conditions listed. For each of these trials, the Daily Output Program noted the minimum force which occurred, as previously defined. The Range shows that the minimum force for this condition ranged from 20.22 to 56.09 pounds, with a mean of 39.64 pounds. The interpretation of the remaining columns is similar.

Although the composite tape contains error forces, only the command direction forces are presented here. Furthermore, only the maximum forces in the impulse mode are presented. A graphic presentation of the mean and ranges of all experimental data is given in Section 6.8. A tabular listing of all means and ranges in given in Appendix A of Volume II.

EXPERIMENT 84A FORCE EMISSION CAPABILITY IN ZERO GRAVITY CONTRACT NAS8-18117

SUBJECT	*
PRESSURIZATION METHOD	*
RECEIVER ANGLE	0 DEGREES
RECEIVER DISTANCE	NEAR
RECEIVER ORIENTATION	HORIZONTAL
RESTRAINT	HAND, WAIST AND SHOES

	SUSTAINED MINIMUM MEAN	RANGE		SUSTAINED MAXIMUM MEAN	RANGE			IMPULSE MAXIMUM MEAN	RANGE		
PUSH	50.37	31.96	64.43	75.97	39.58	92.40	(10)	76.09	50.12	90.58	(10)
PULL	28.85	0.00	48.33	48.70	30.85	81.58	(10)	51.58	22.67	66.93	(10)
UP	17.11	6.89	24.95	25.66	9.11	46.87	(9)	24.60	9.36	42.59	(9)
DOWN	18.86	7.37	31.39	27.54	11.54	40.89	(10)	26.76	10.94	39.35	(9)
RIGHT	20.59	3.85	38.58	36.17	24.28	49.87	(11)	36.76	25.51	46.78	(9)
LEFT	16.09	1.38	29.33	32.83	20.97	45.45	(9)	28.91	12.30	47.12	(10)

SUBJECT	*
PRESSURIZATION METHOD	*
RECEIVER ANGLE	0 DEGREES
RECEIVER DISTANCE	NEAR
RECEIVER ORIENTATION	HORIZONTAL
RESTRAINT	HAND AND WAIST

	SUSTAINED MINIMUM MEAN	RANGE		SUSTAINED MAXIMUM MEAN	RANGE			IMPULSE MAXIMUM MEAN	RANGE		
PUSH	39.64	20.22	56.09	57.40	36.75	72.80	(6)	68.00	50.17	87.40	(7)
PULL	22.26	0.00	41.06	39.62	8.12	56.77	(8)	42.33	17.47	61.91	(8)
UP	16.04	2.04	24.52	23.86	4.88	36.05	(9)	22.80	8.55	32.62	(9)
DOWN	16.95	4.49	30.95	22.47	9.06	31.70	(9)	27.29	11.97	48.32	(9)
RIGHT	20.45	11.17	27.17	30.59	18.12	45.16	(8)	32.10	17.63	43.04	(8)
LEFT	22.20	13.82	34.87	33.53	22.82	51.93	(8)	35.85	27.16	51.08	(8)

Figure 6.7-3. Averaging Program Sample Printout

6.8 RESULTS AND CONCLUSIONS

6.8.1 METHODS OF ANALYSIS

The primary results of this experimental program are the means and ranges of the forces exerted under specific combinations of the experimental conditions. These means and ranges were derived from the Averaging Program described in Section 6.7 and are provided in a tabular listing in Appendix C. This listing, consisting of approximately 100 pages of tabulated information, provides all the design data collected in this study. However, the tabular listing is not the most efficient mode of data presentation for use by designers. The value of the data collected can only be realized by presentation in as efficient and utilitarian manner as possible. The resulting graphical presentation summarized the total data into 12 charts with 6 graphs on a page. These are presented in Figures 6.8-1 through 6.8-12. Table 6.8-1 is a Summary Data Chart Index that specifies the experimental condition combinations included on each of the charts.

Table 6.8-1. Summary Data Chart Index

Figure	Title	Force Type (F/T)	Receiver Angle (R/A) (degrees)	Receiver Orientation (R/O)
6.8-1	Summary Data Chart No. 1	Sustained	0	Horizontal
6.8-2	Summary Data Chart No. 2	Sustained	0	Vertical
6.8-3	Summary Data Chart No. 3	Sustained	-15	Horizontal
6.8-4	Summary Data Chart No. 4	Sustained	-15	Vertical
6.8-5	Summary Data Chart No. 5	Sustained	45	Horizontal
6.8-6	Summary Data Chart No. 6	Sustained	45	Vertical
6.8-7	Summary Data Chart No. 7	Impulse	0	Horizontal
6.8-8	Summary Data Chart No. 8	Impulse	0	Vertical
6.8-9	Summary Data Chart No. 9	Impulse	-15	Horizontal
6.8-10	Summary Data Chart No. 10	Impulse	-15	Vertical
6.8-11	Summary Data Chart No. 11	Impulse	45	Horizontal
6.8-12	Summary Data Chart No. 12	Impulse	45	Vertical

In addition to the primary design data discussed above, statistical comparisons were made across parameters of the experimental variables to determine the existence and direction of significant relationships. The data used for the statistical comparisons were the overall mean forces determined across experimental conditions and are presented in Table 6.8-2.

Nonparametric statistical analyses were considered appropriate for the analysis of these data because of the inability to meet the assumptions concerning the underlying distribution of the population of variables required by parametric analysis. Certain assumptions are also associated with most nonparametric statistical tests, i.e., that the observations are independent and that the variables under study have some underlying continuity, but these assumptions are fewer and more easily met than those for parametric tests. Moreover, most nonparametric tests apply to data in an ordinal scale, and some even apply to data in a nominal scale. The primary advantage of the nonparametric tests is that they can be used when the sample size is small.

Two nonparametric statistical analysis methods were selected for the data analysis. In situations where matched pairs of measures occur in two groups and the measures are in an ordinal scale, Siegel, 1956, recommends the use of the Wilcoxon Matched-Pairs Signed Ranks Test. This method was utilized to compare the following parameters: overall means across force types (sustain and impulse), mean forces across pressurization methods (air and water), and mean forces across receiver orientations (horizontal and vertical). In situations where K related samples of basically nonparametric measures on at least an ordinal scale are taken, Siegel recommends the Freedman Two-way Analysis of Variance. This method was utilized to compare the following parameters: mean forces across subjects, mean forces across receiver angles, mean forces across receiver distances, and mean forces across restraints.

6.8.2 STATISTICAL ANALYSES AND RESULTS

6.8.2.1 Sustained Versus Impulsive Forces

The results of the Wilcoxon Matched Pairs Signed Ranks Test indicate that the sustained mean forces were significantly different from the impulsive mean forces at the 0.01 level

	Overall	
	Sustain Min	Impulse Max
Push	20	52
Pull	21	51
Up	12	25
Down	16	29
Right	12	23
Left	14	26

	Subjects							
	1		2		3		4	
	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max	Sustain Min	Impulse Max
Push	18	51	24	51	21	59	16	45
Pull	24	58	24	49	18	54	18	45
Up	12	26	15	26	13	27	10	22
Down	11	25	18	29	21	36	12	24
Right	9	20	14	25	13	29	9	19
Left	11	23	16	27	16	32	11	23

	Receiver Angle					
	-15^{o}		0^{o}		45^{o}	
	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	In
Push	23	53	20	52	17	
Pull	[illegible]	46	21	52	25	
Up	14	27	12	25	11	
Down	16	29	16	29	15	
Right	12	24	11	24	11	
Left	15	28	13	26	13	

	Restraints													
	None		Hand		Waist		Shoes		Hand & Waist		Hand & Shoes		Waist & Sho	
	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	Imp M
Push	0	35	1	41	15	43	4	46	29	57	30	62	35	5
Pull	0	[illegible]	2	43	22	46	4	48	31	51	33	61	37	5
Up	0	19	5	21	10	23	17	28	14	23	18	31	17	2
Down	2	23	9	26	10	23	21	33	16	26	26	37	19	3
Right	0	18	10	22	12	22	9	22	15	25	16	28	14	2
Left	0	18	17	29	12	22	8	23	17	28	21	34	15	2

All Forces in Pounds

TABLE 6.8-2.A

FOLDOUT FRAME

Table 6.8-2.3 Summary Data - Means Across all Variables (in pounds)

	Pressurization			
	Air		Water	
	Sustain Min	Impulse Max	Sustain Min	Impulse Max
Push	20	52	20	51
Pull	22	53	20	50
Up	13	25	12	25
Down	15	27	16	30
Right	12	23	12	23
Left	14	27	13	26

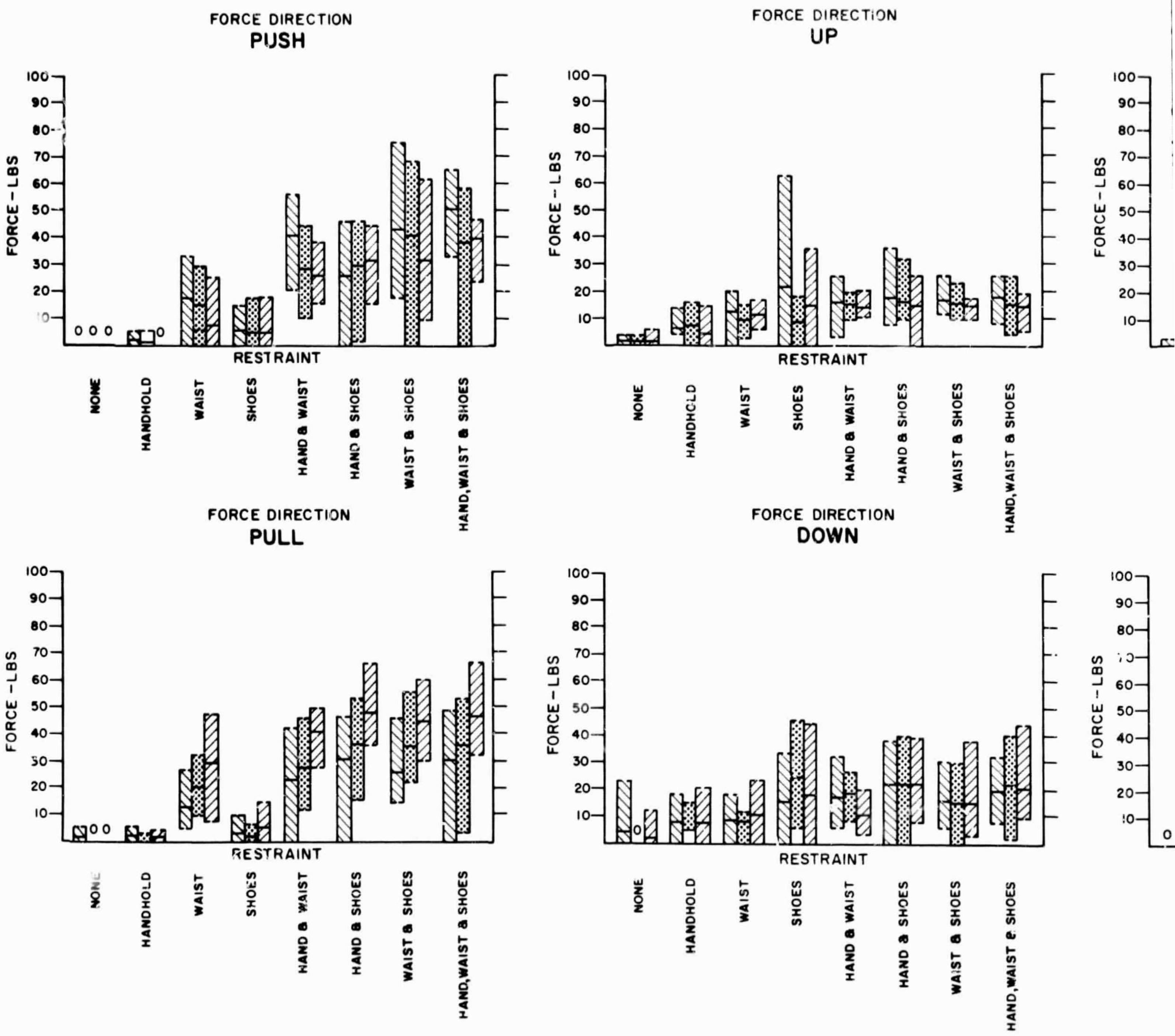
e	
Far	
Sustain Min	Impulse Max
17	49
25	56
11	24
15	28
11	22
13	25

	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
Down	14	26	17	31
Right	15	29	9	18
Left	14	26	14	26

Waist & Shoes		Hand, Waist & Shoes	
Sustain Min	Impulse Max	Sustain Min	Impulse Max
35	58	43	69
37	57	38	61
17	28	17	29
19	30	21	32
14	23	16	27
15	25	19	30

FOLDOUT FRAME

FORCE TYPE: **SUSTAIN** RECEIVER ANGLE: **0°** HAN

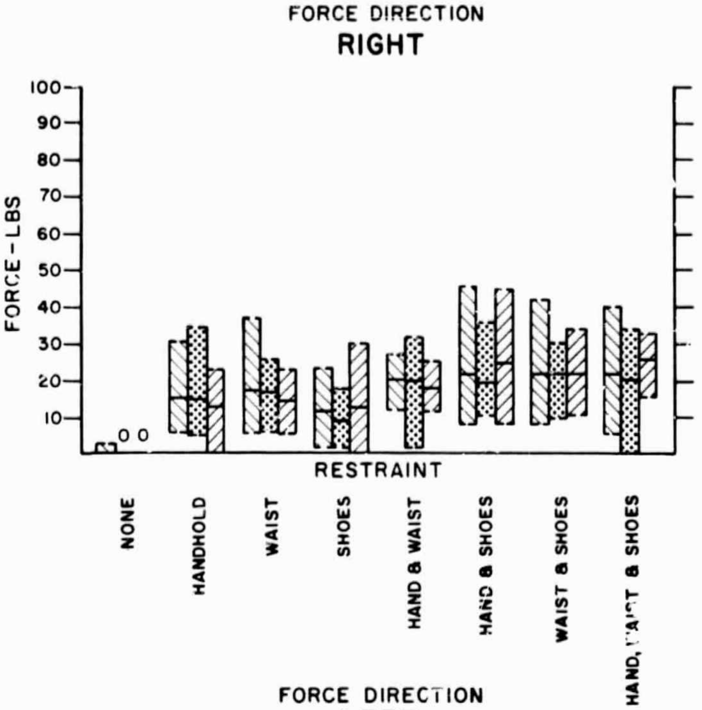


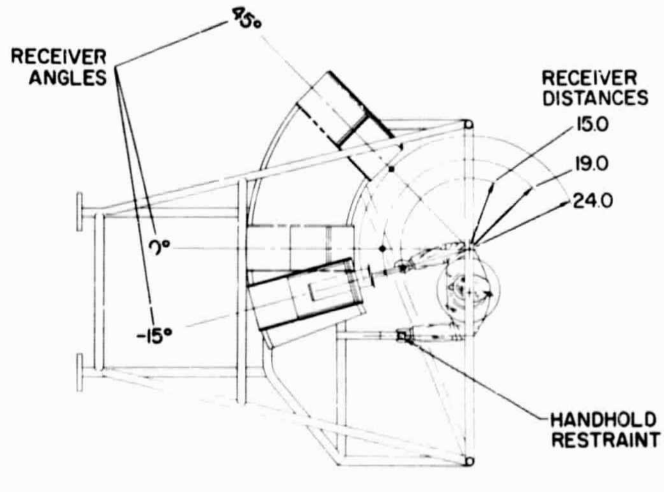
FOLDOUT FRAME

6-35A

Fig 6.8-1.A

HANDLE ORIENTATION: HORIZONTAL





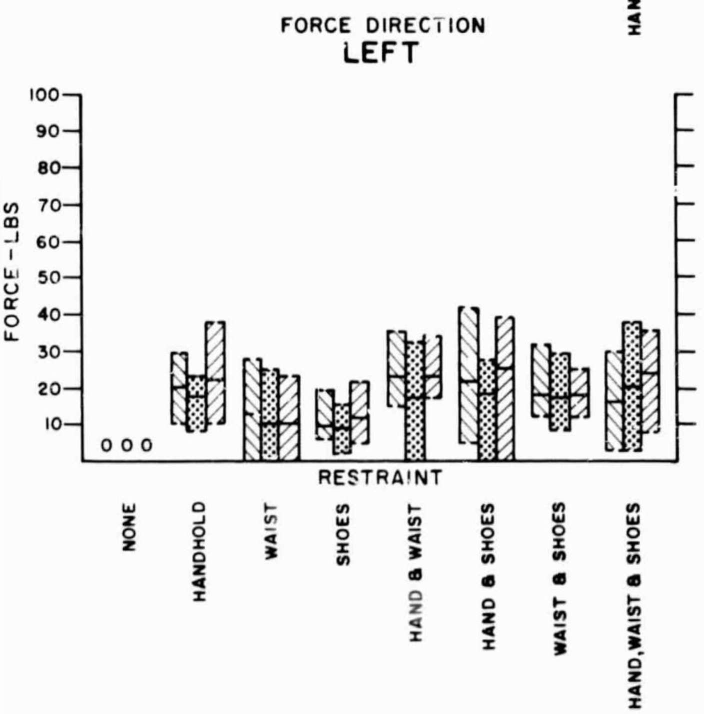


Fig. 6.8-1. B

6-35B

FOLDOUT FRAME

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

Figure 6.8-1. Summary Data Chart No. 1

FORCE TYPE: **SUSTAIN**

RECEIVER ANGLE: **0°**

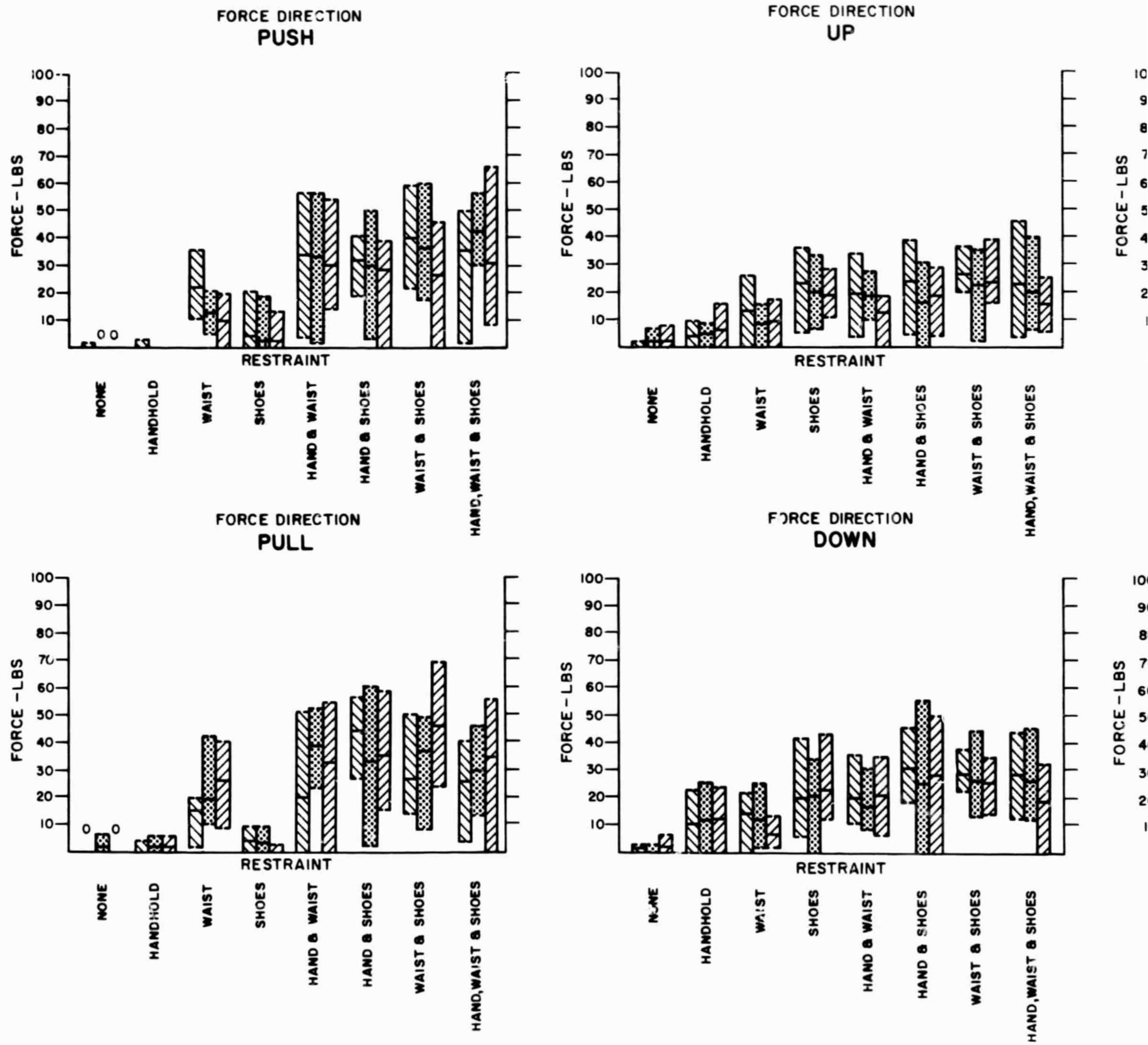
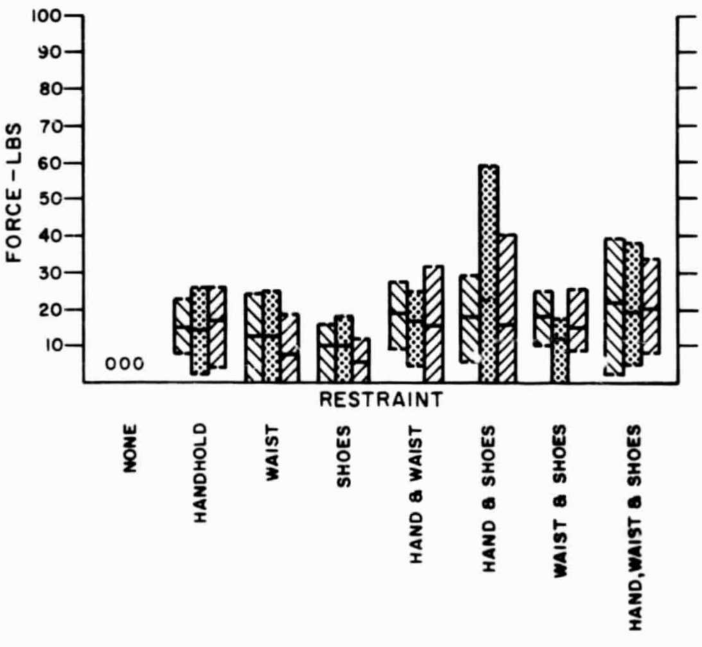


Fig. 6.8-2. A

6-37A

FOLDOUT FRAME

HANDLE ORIENTATION: **VERTICAL**



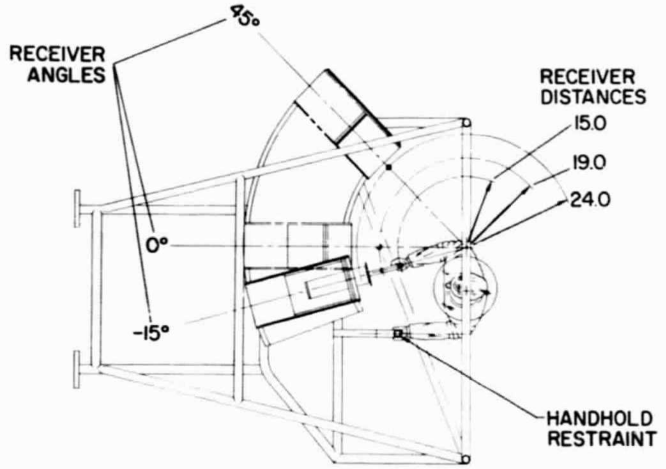


Fig. 6.8-2.B

FOLDOUT FRAME

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 . .
RANGE – MIN = SMALLEST FORCE

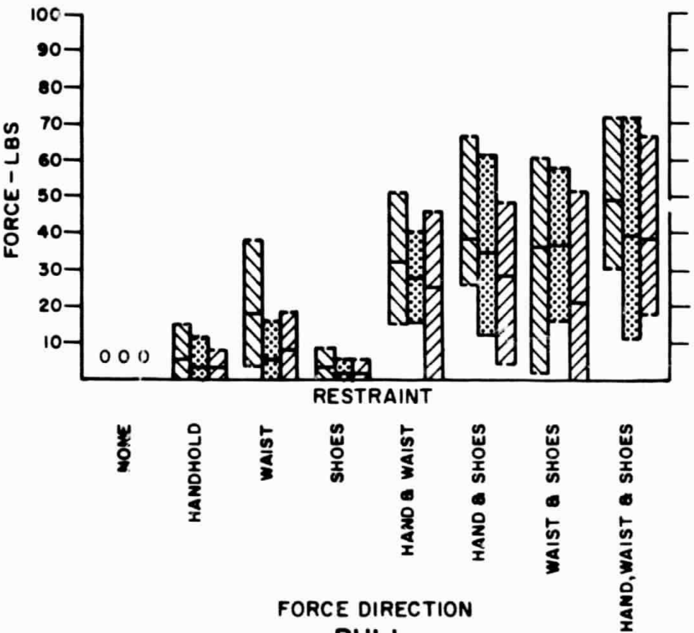
Figure 6.8-2. Summary Data Chart No. 2

FORCE TYPE: **SUSTAIN**

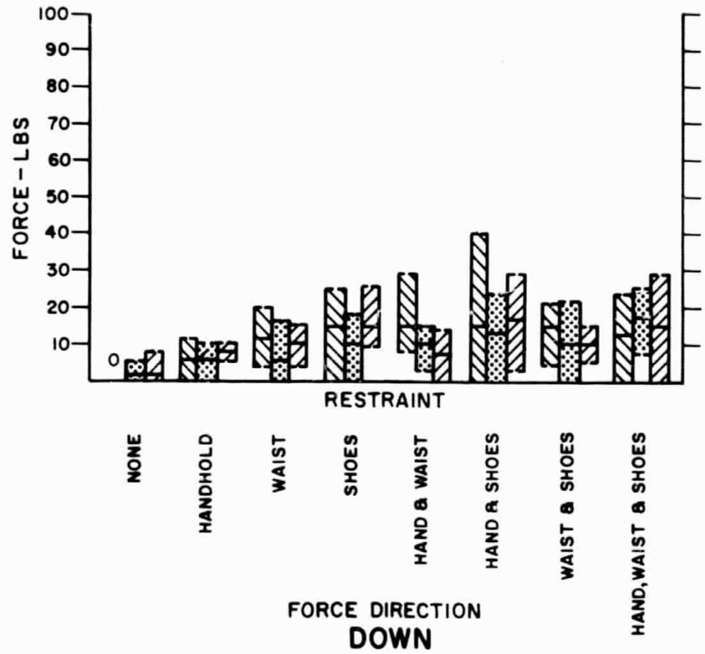
RECEIVER ANGLE: **-15°**

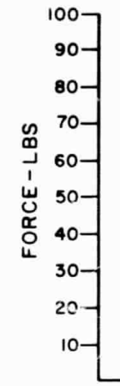
HAN

FORCE DIRECTION
PUSH

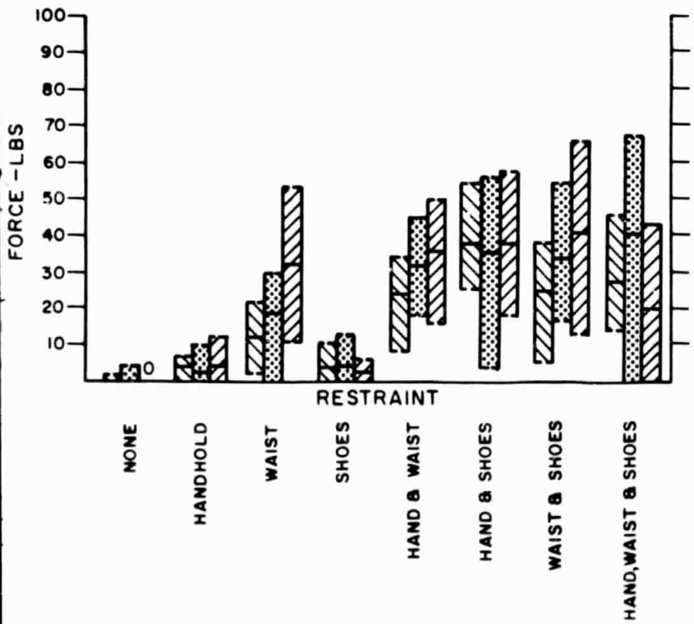


FORCE DIRECTION
UP

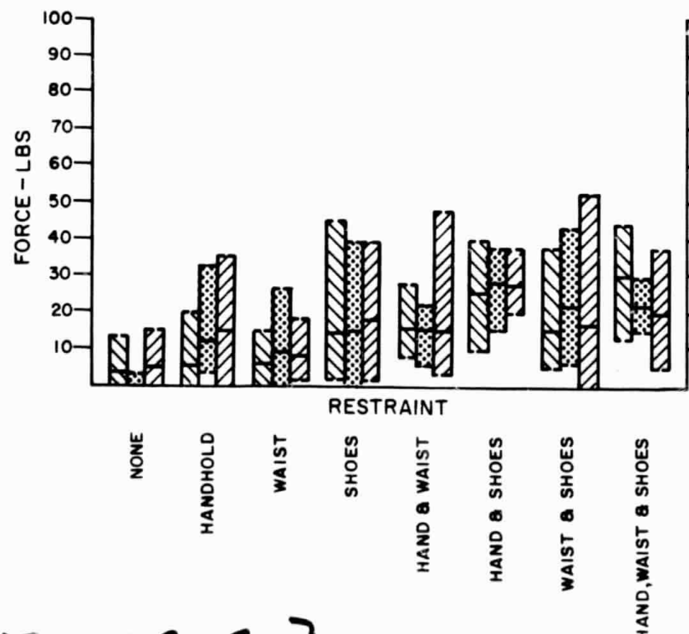




FORCE DIRECTION
PULL



FORCE DIRECTION
DOWN



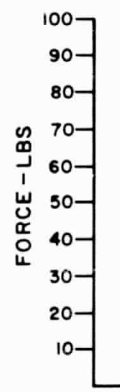
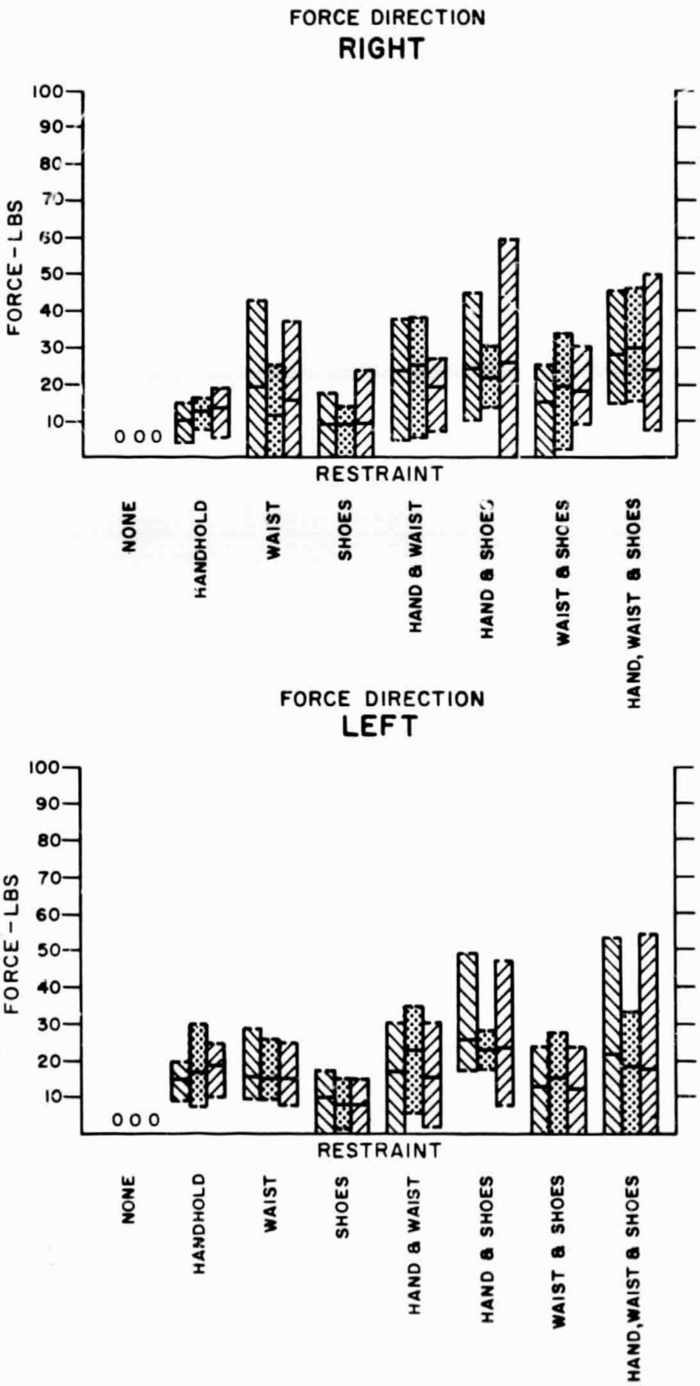


Fig. 6.8-3.A

FOLDOUT FRAME

6 - 39A

HANDLE ORIENTATION: **HORIZONTAL**



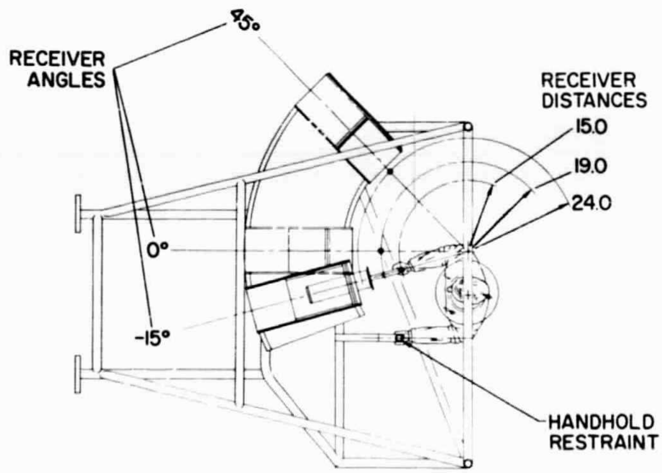


Fig. 6.8-2.B

FOLDOUT FRAME

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

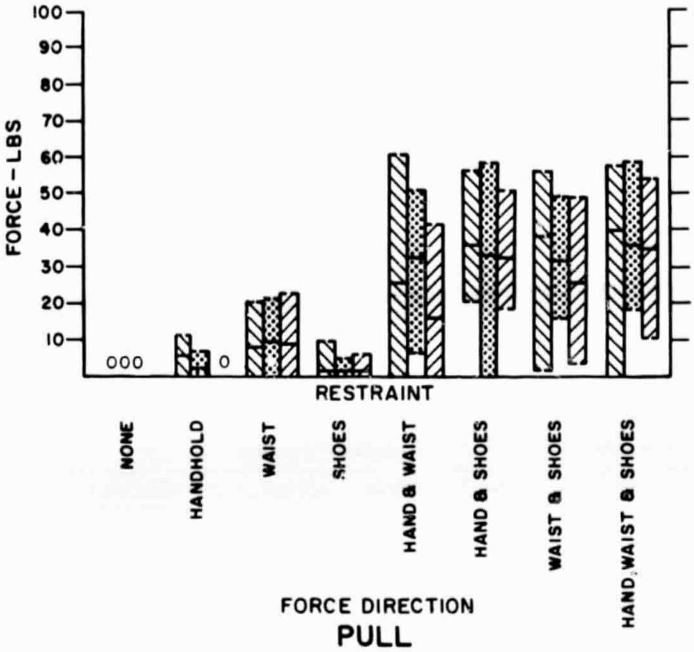
LOCAL VERTICAL
LOCAL HORIZONTAL

RANGE - MAX = LARGEST FORCE
MEAN = AVERAGE OF ALL FORCES
RANGE - MIN = SMALLEST FORCE

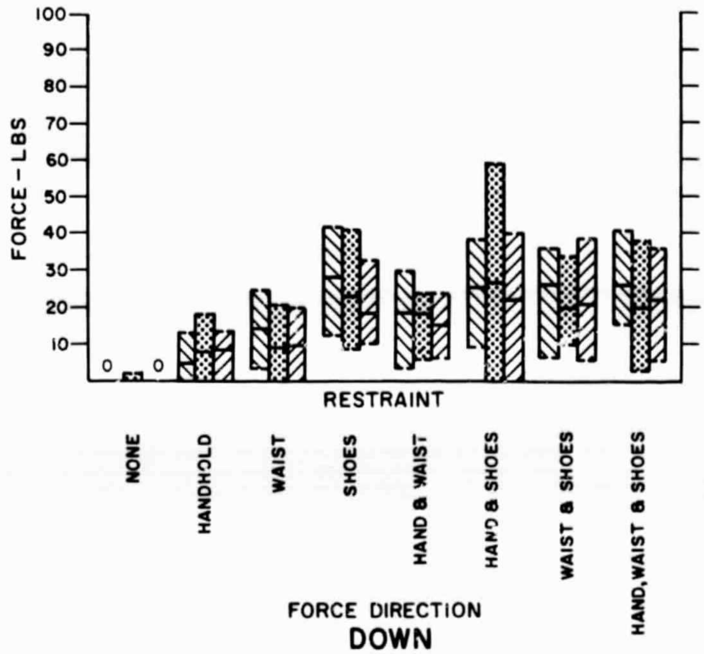
Figure 6.8-3.C Summary Data Chart No. 3

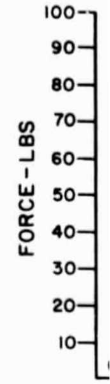
FORCE TYPE: **SUSTAIN** RECEIVER ANGLE: **-15°** HA

FORCE DIRECTION
PUSH

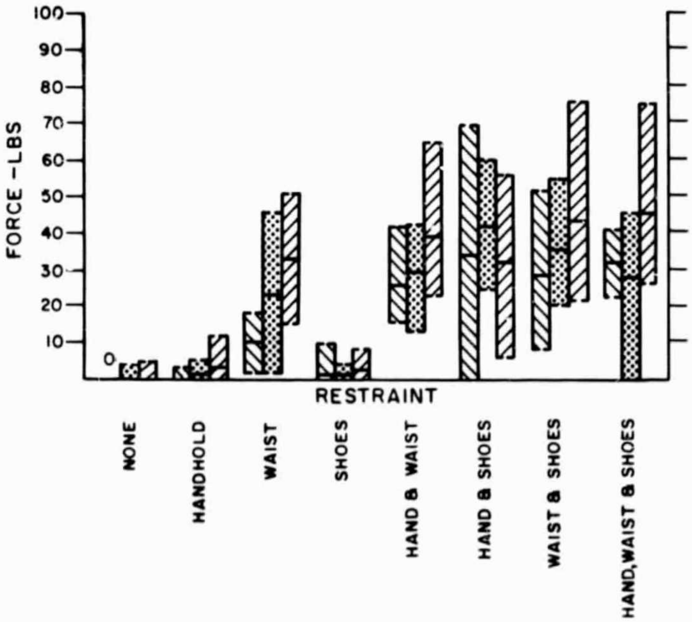


FORCE DIRECTION
UP

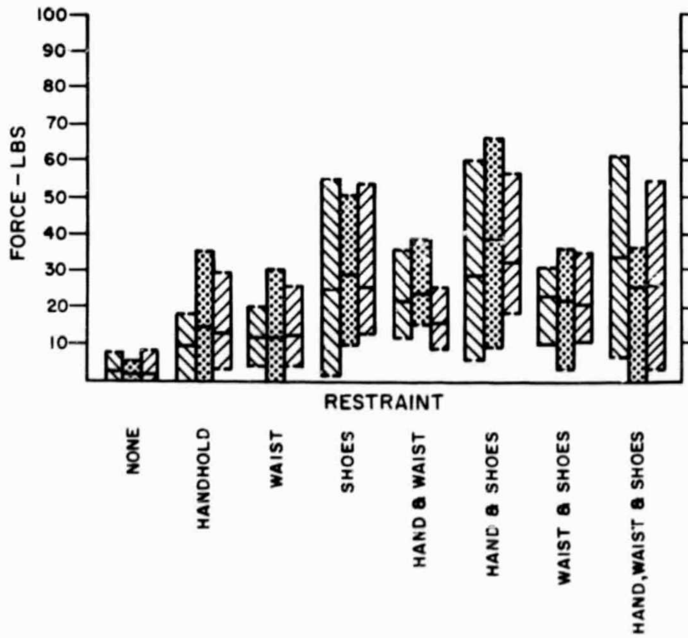


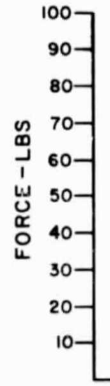


FORCE DIRECTION
PULL



FORCE DIRECTION
DOWN





6-41A

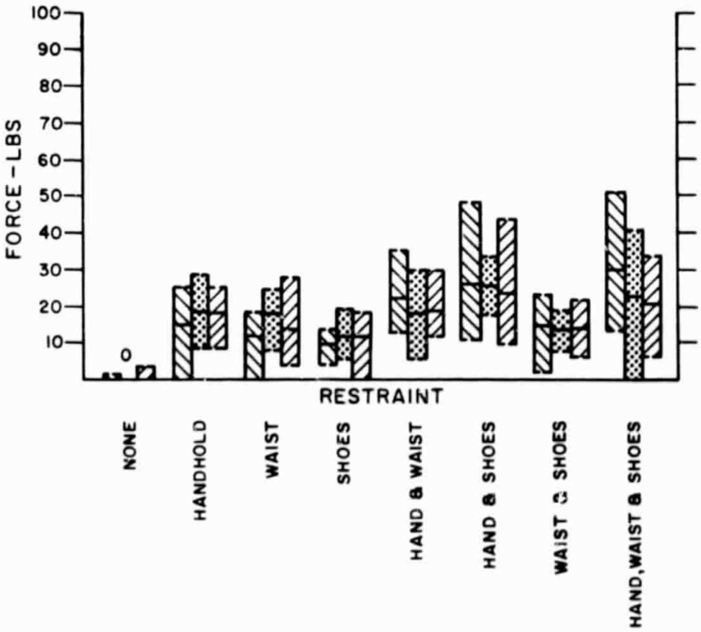
FOLDOUT FRAME

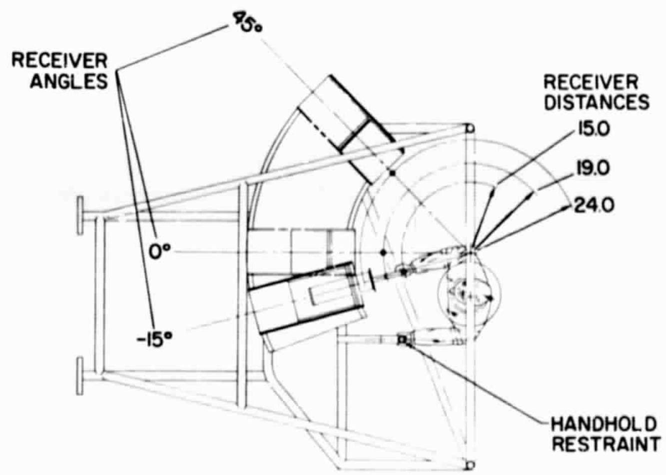
6.8-4.A

HANDLE ORIENTATION: **VERTICAL**

FORCE DIRECTION
RIGHT

FORCE DIRECTION
LEFT





6-41 B

FOLDOUT FRAME

6.8-4.B

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

Figure 6.8-4. Summary Data Chart No. 4

FORCE TYPE: **SUSTAIN** RECEIVER ANGLE: **45°** HA

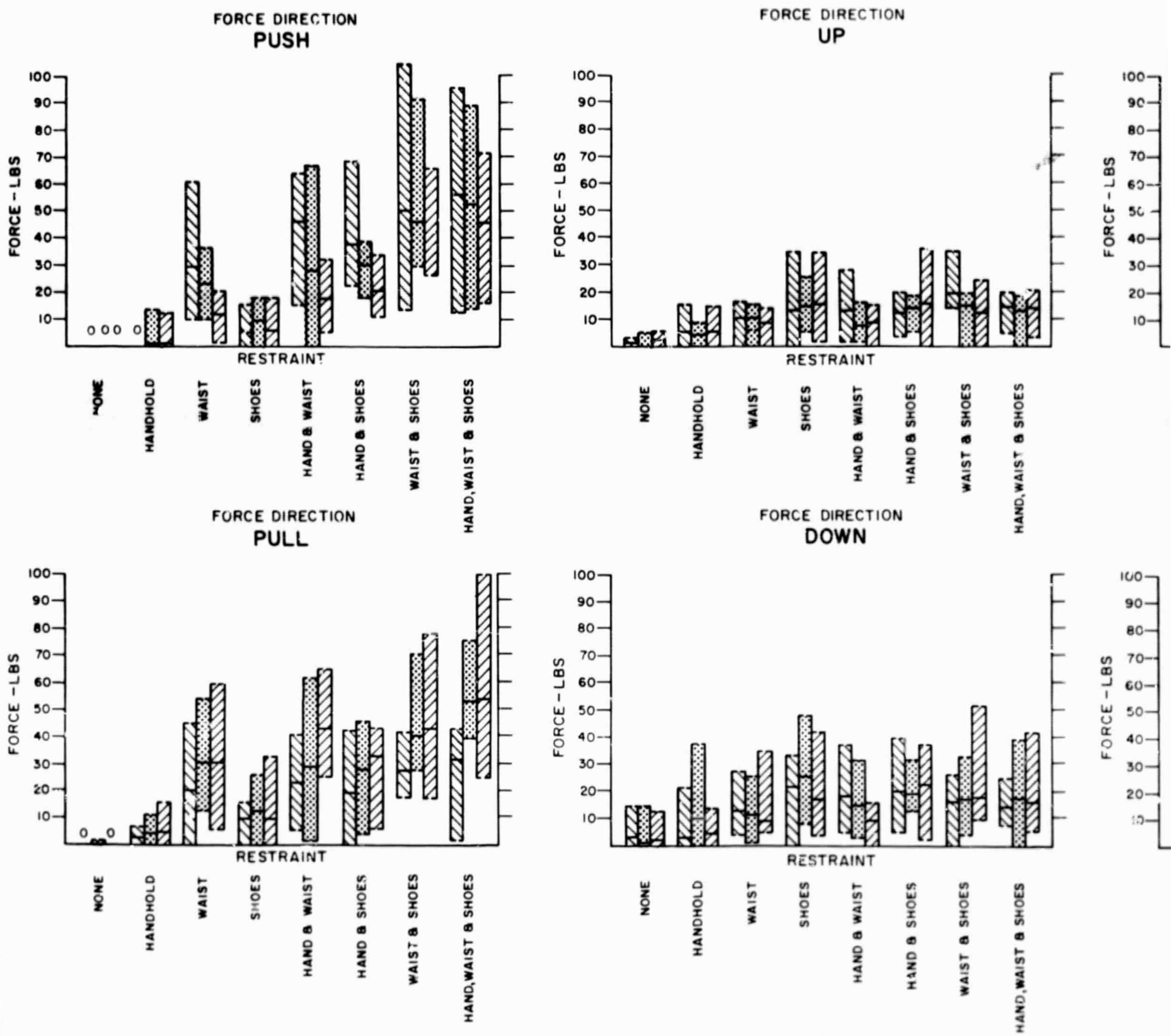
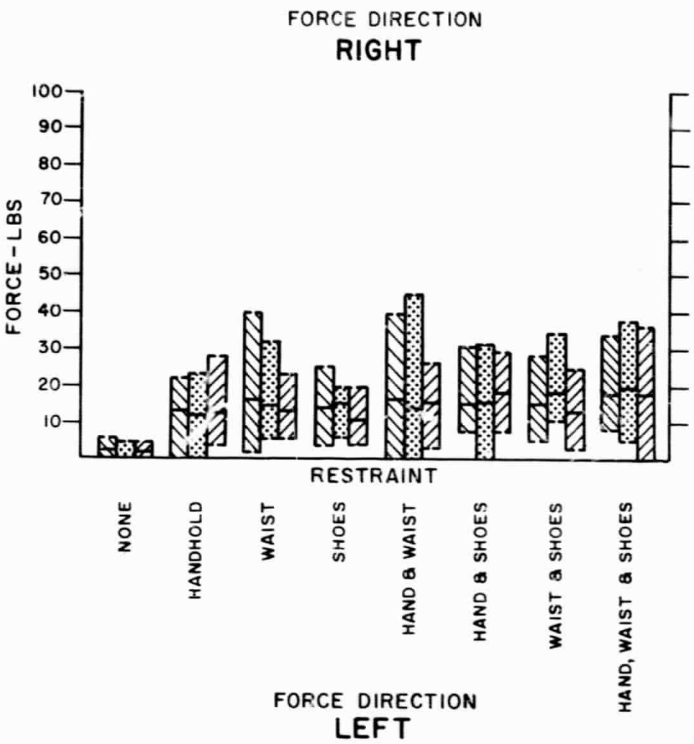


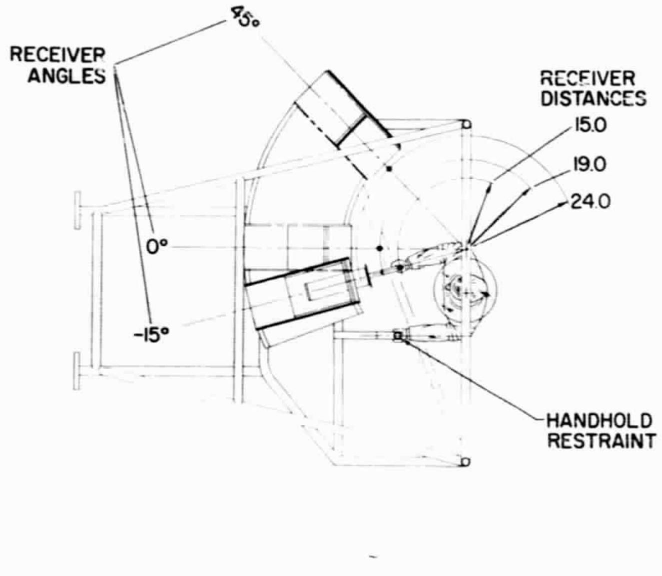
Fig. 6.8-5.A

FOLDOUT FRAME

6-43A

HANDLE ORIENTATION: **HORIZONTAL**





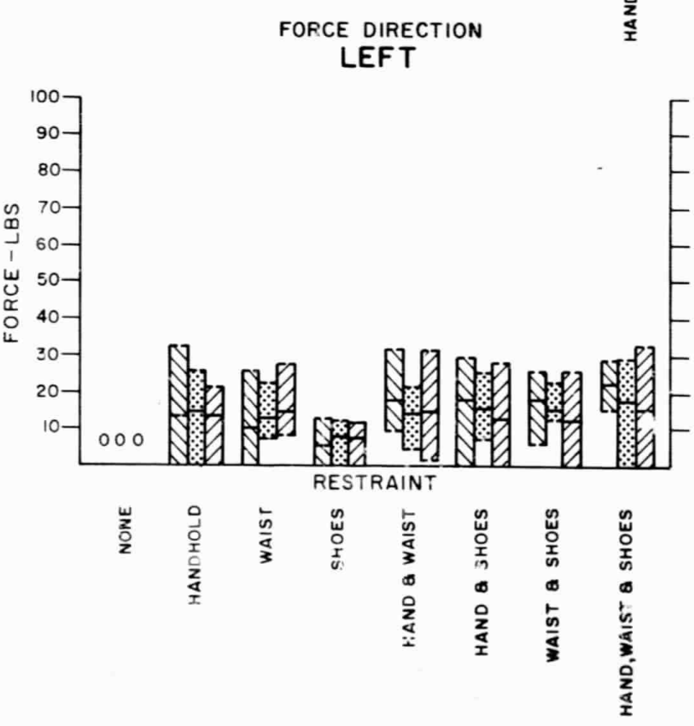


Fig. 6.8-5-B

FOLDOUT FRAME

FORCE TYPE

SUSTAINED = FORCE MAINTAINED FOR 4 SECONDS
IMPULSE = PEAK FORCE OBTAINED IN 1 SECOND

RECEIVER DISTANCES

15" ≃ [illegible]0° ELBOW ANGLE
19" ≃ 135° ELBOW ANGLE
24" ≃ 180° ELBOW ANGLE

HANDLE ORIENTATION

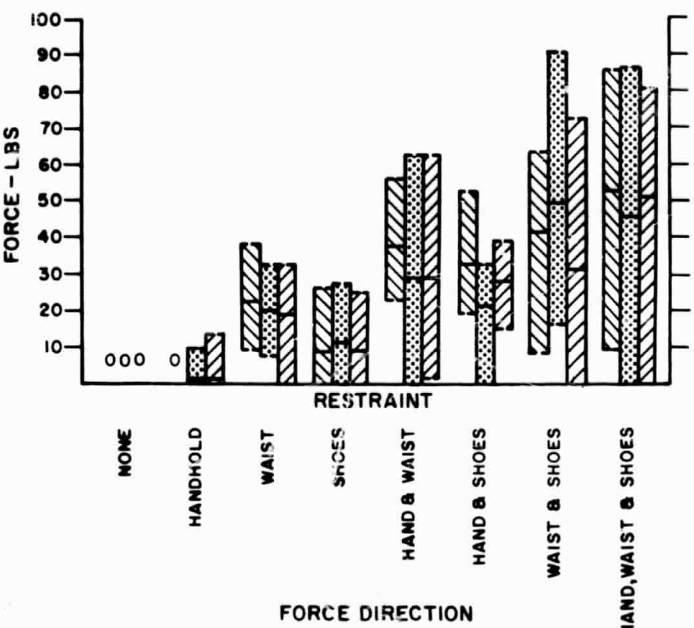
LOCAL VERTICAL
LOCAL HORIZONTAL

— RANGE — MAX = LARGEST FORCE
— MEAN = AVERAGE OF ALL FORCES
— RANGE — MIN = SMALLEST FORCE

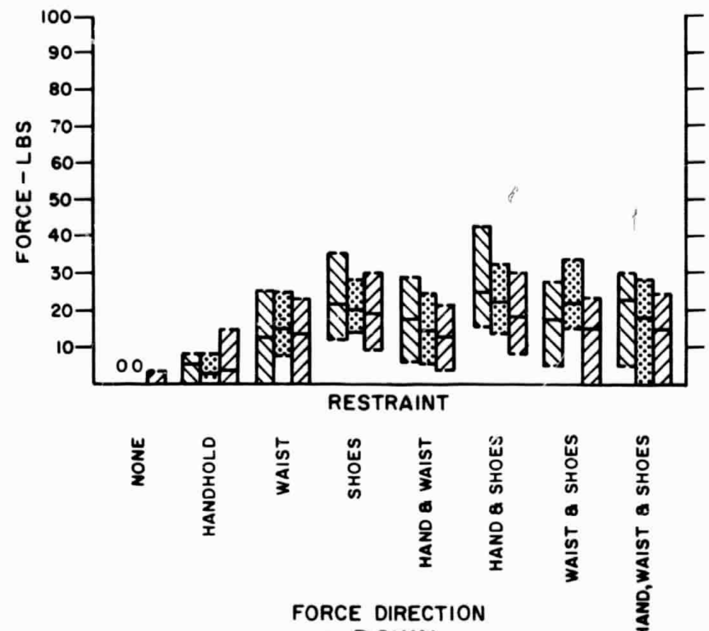
Figure 6.8-5.C Summary Data Chart No. 5

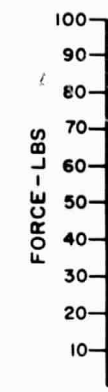
FORCE TYPE: **SUSTAIN** RECEIVER ANGLE: **45°** HA

FORCE DIRECTION
PUSH

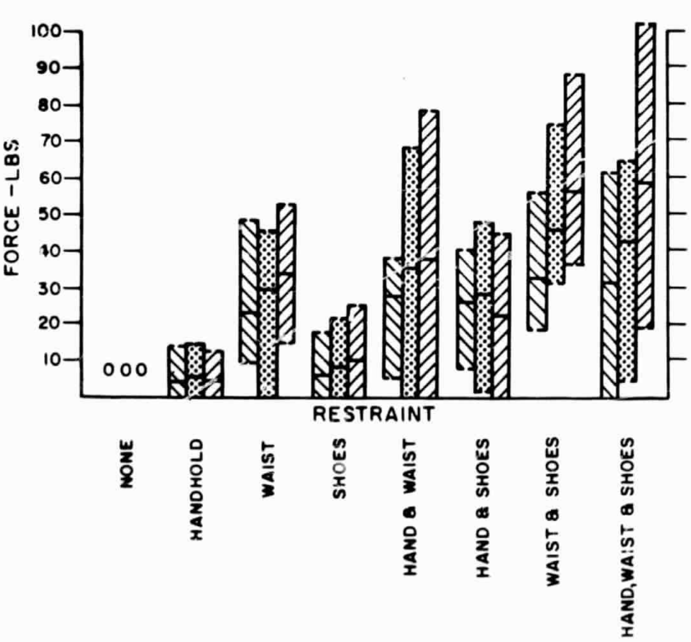


FORCE DIRECTION
UP

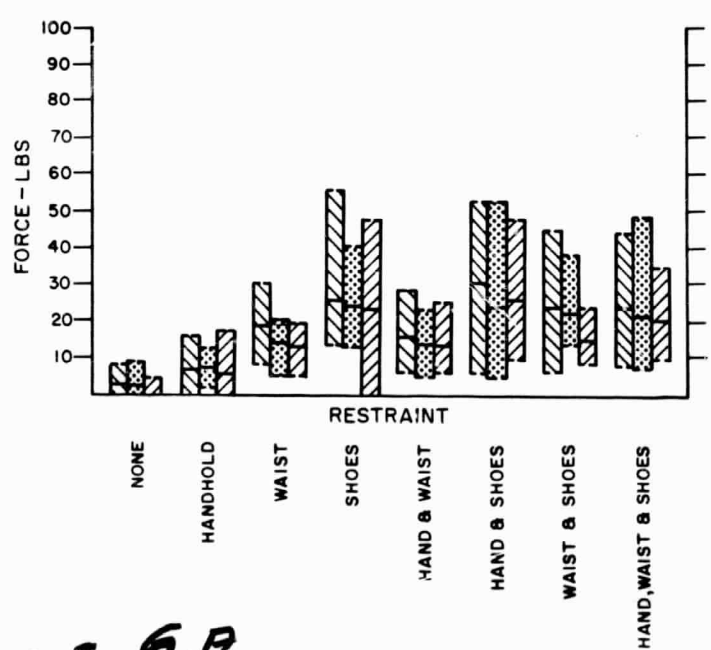




FORCE DIRECTION
PULL



FORCE DIRECTION
DOWN



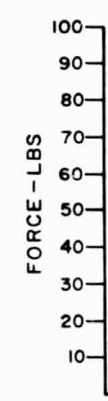
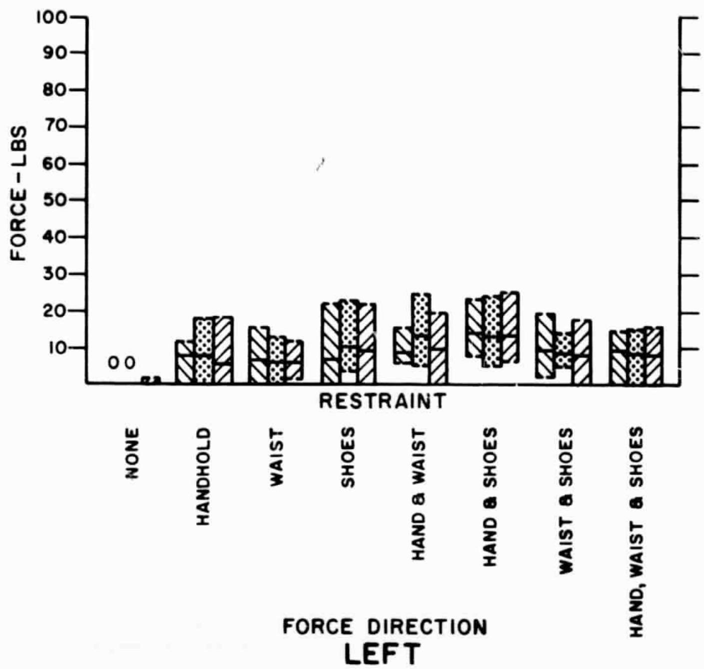


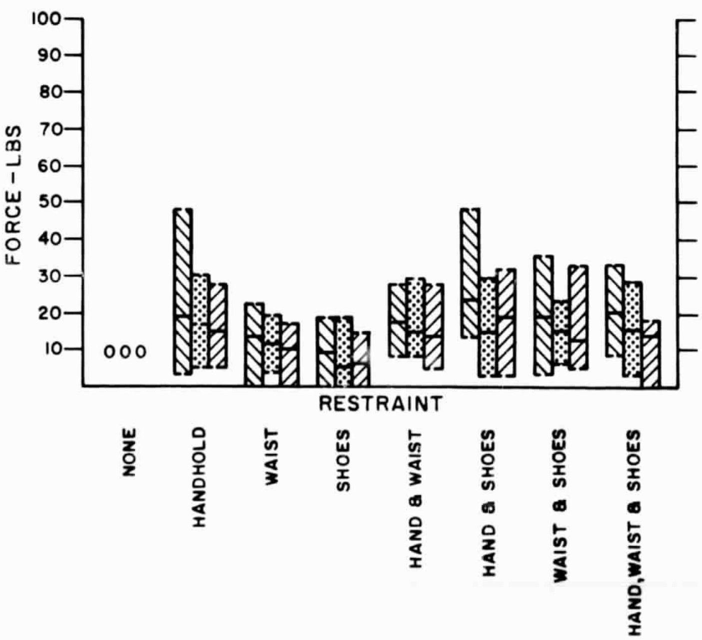
Fig. 6.8-6.A

FOLDOUT FRAME

5-4 A

HANDLE ORIENTATION: VERTICAL





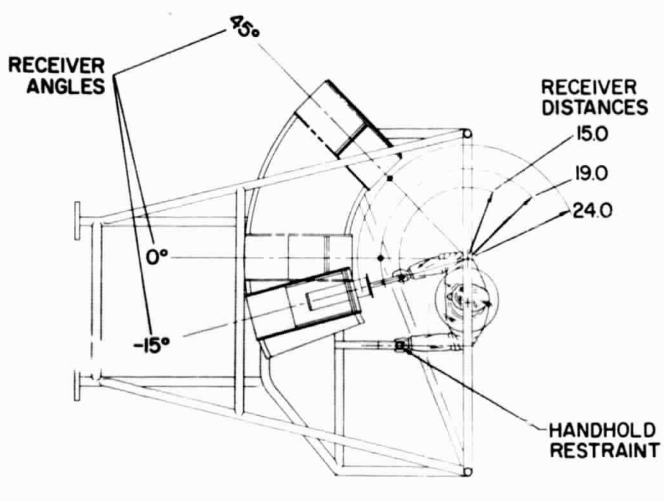


Fig 6.8-6B

FOLDOUT FRAME

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

Figure 6.8-6C Summary Data Chart No. 6

FORCE TYPE: **IMPULSE**

RECEIVER ANGLE: **0°**

HA

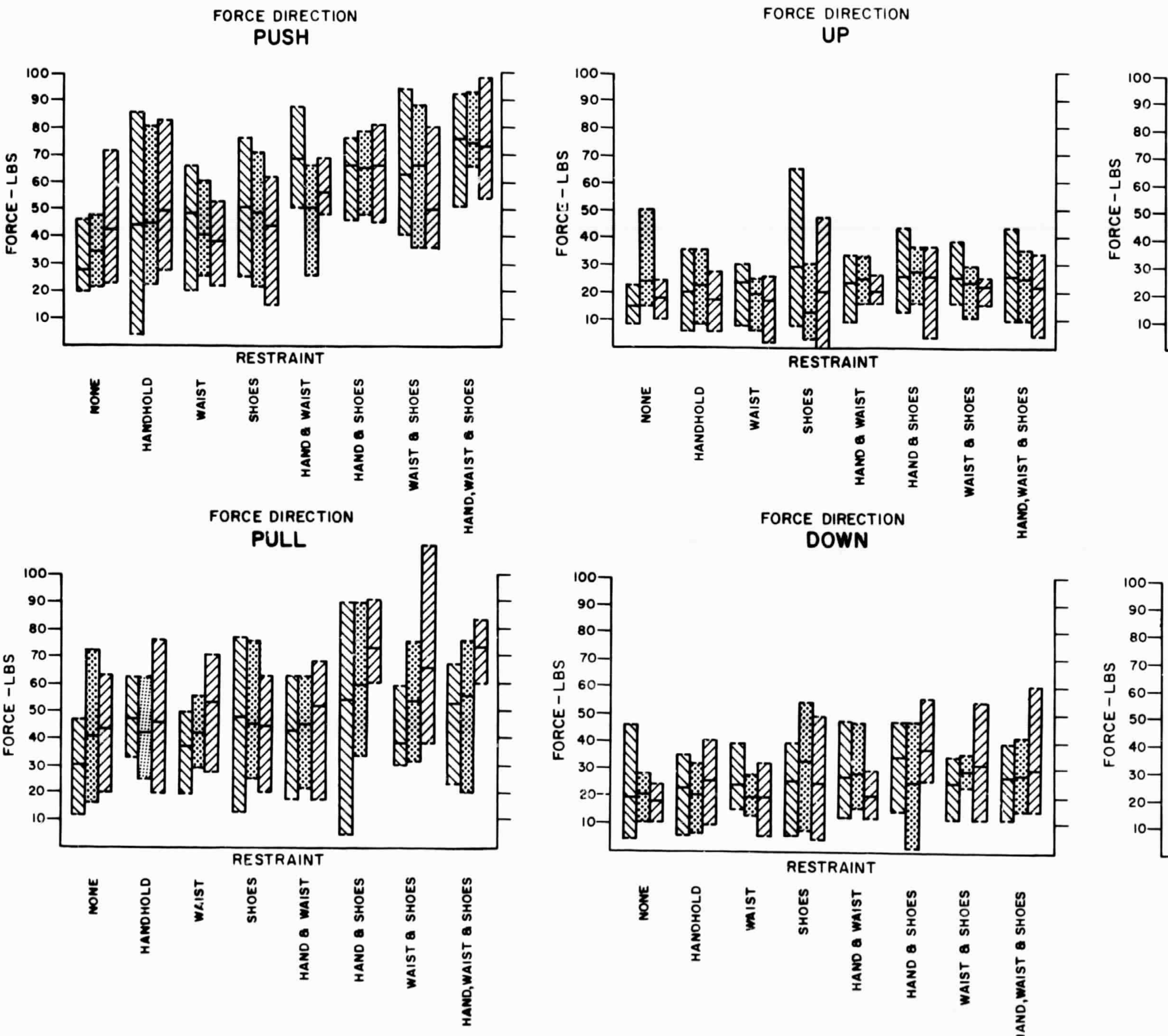
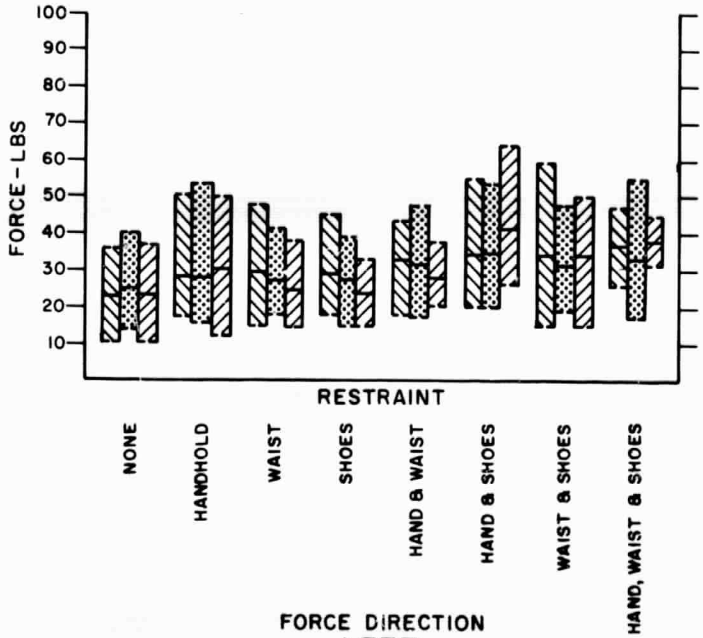


Fig. 6.8-7.A

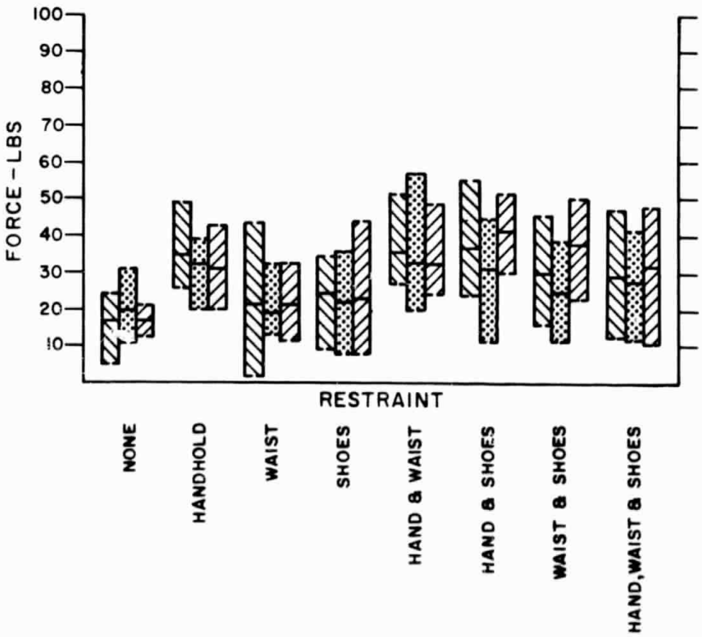
FOLDOUT FRAME 6-47A

HANDLE ORIENTATION: **HORIZONTAL**

FORCE DIRECTION
RIGHT



FORCE DIRECTION
LEFT



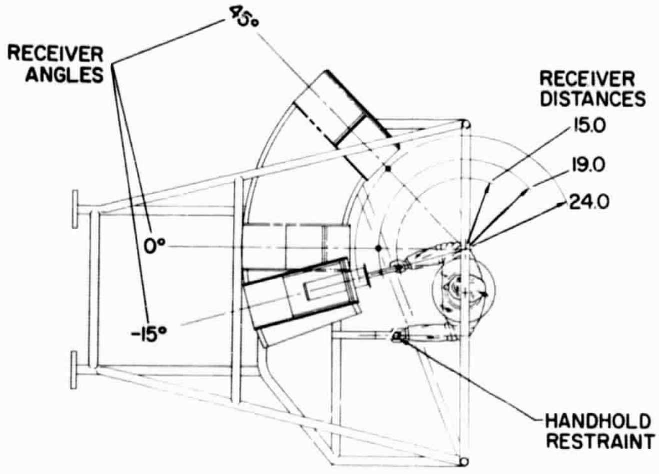


FIG 6.8-7.B

6-47B FOLDOUT FRAME

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

Figure 6.8-7.C Summary Data Chart No. 7

FOLDOUT FRAME

FORCE TYPE: **IMPULSE** RECEIVER ANGLE: **0°** HA

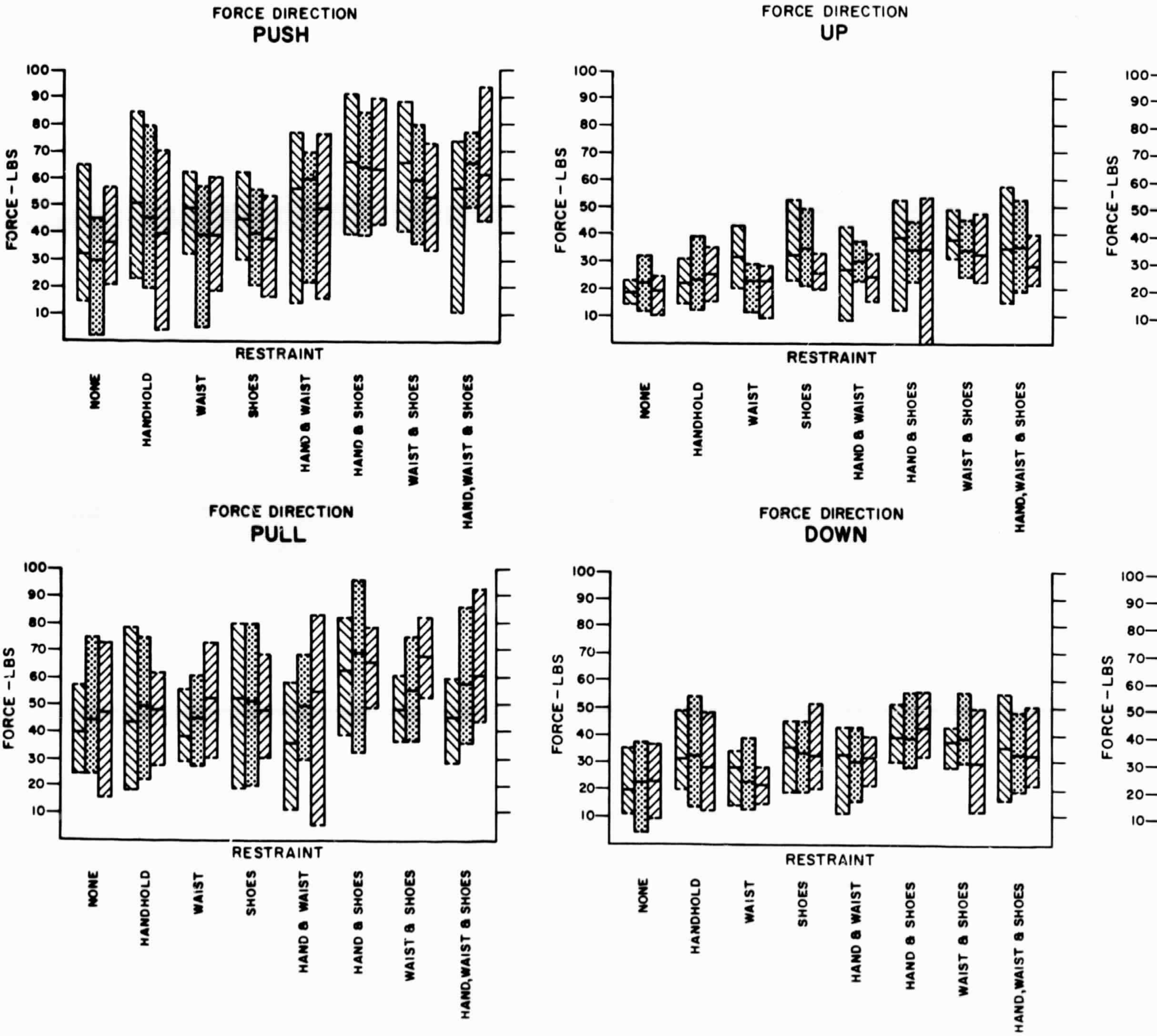
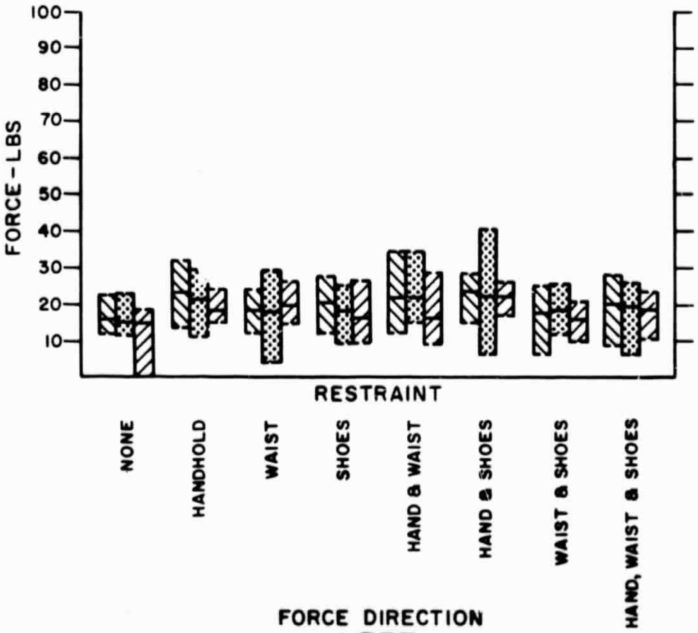


Fig 6.8-8.B
6-49A

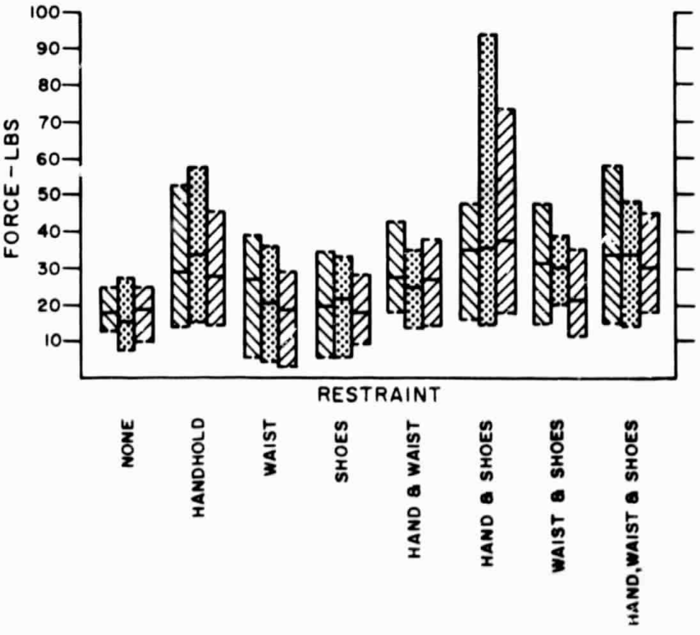
FOLDOUT FRAME

HANDLE ORIENTATION: VERTICAL

FORCE DIRECTION
RIGHT



FORCE DIRECTION
LEFT



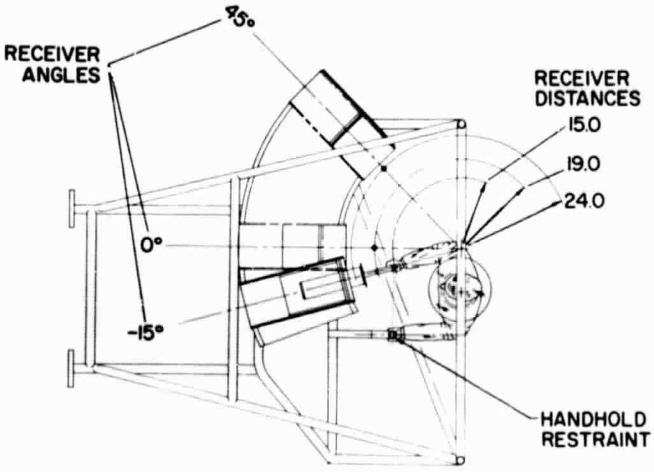


Fig 6.8-8 B

6-49B FOLDOUT FRAME

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

Figure 6.8-8. Summary Data Chart No. 8

FORCE TYPE: **IMPULSE**

RECEIVER ANGLE: **-15°**

HAN

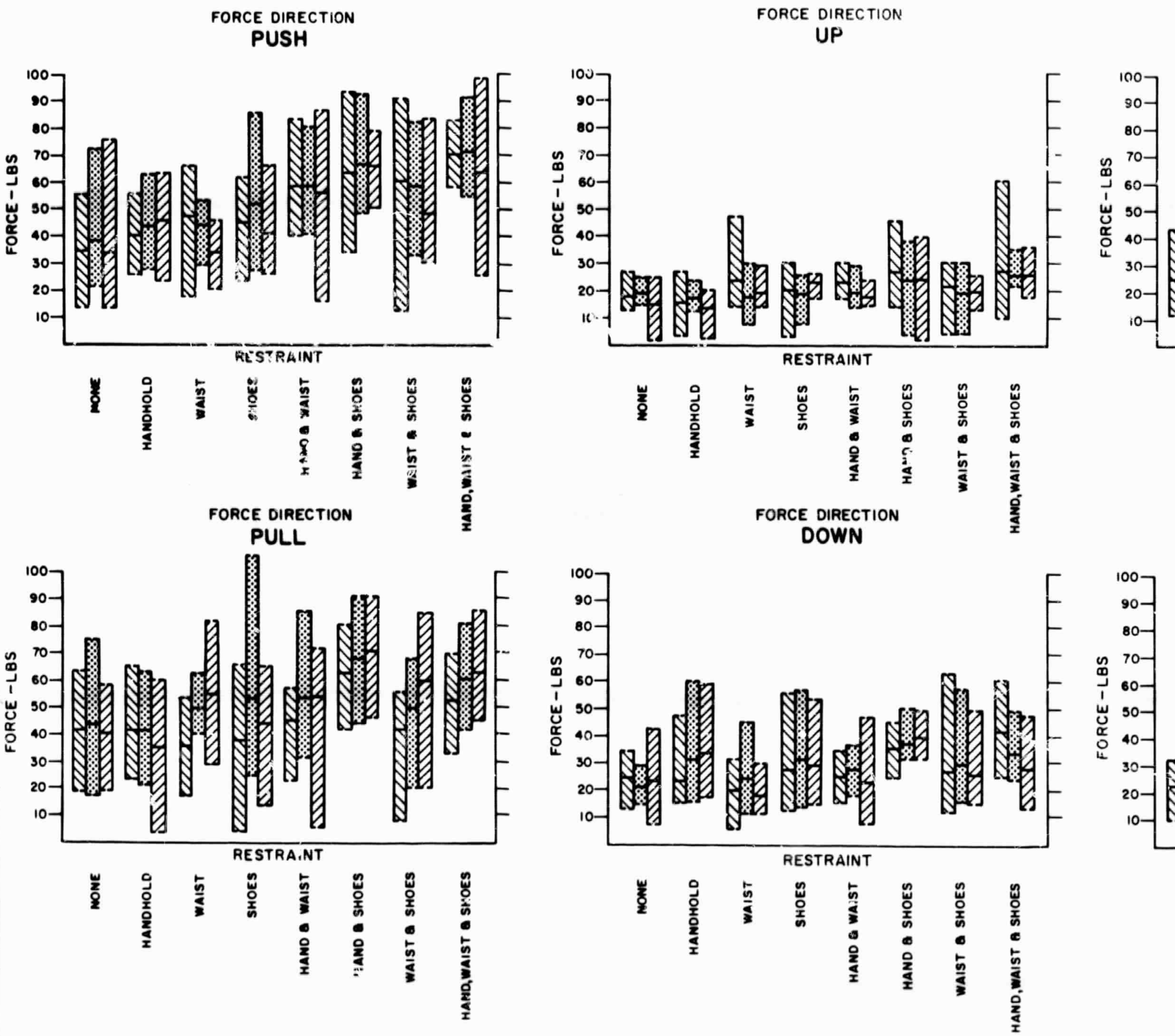
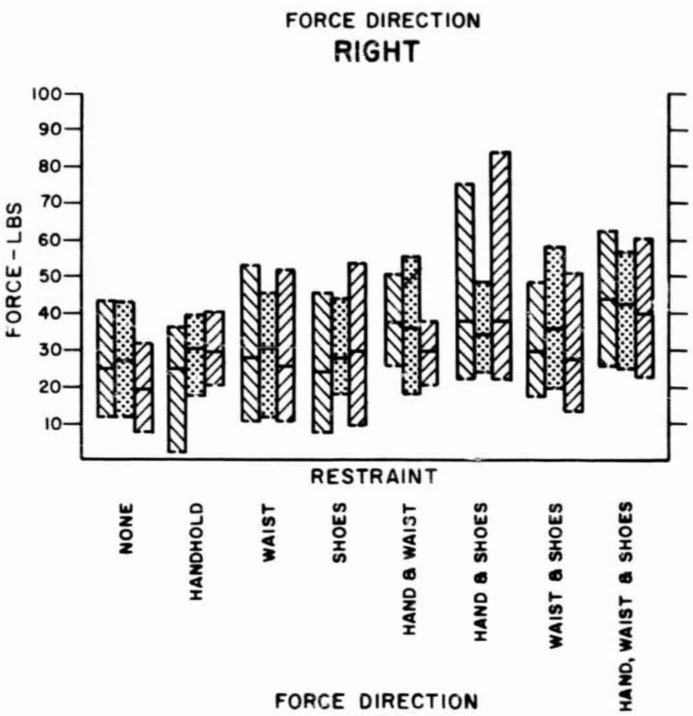


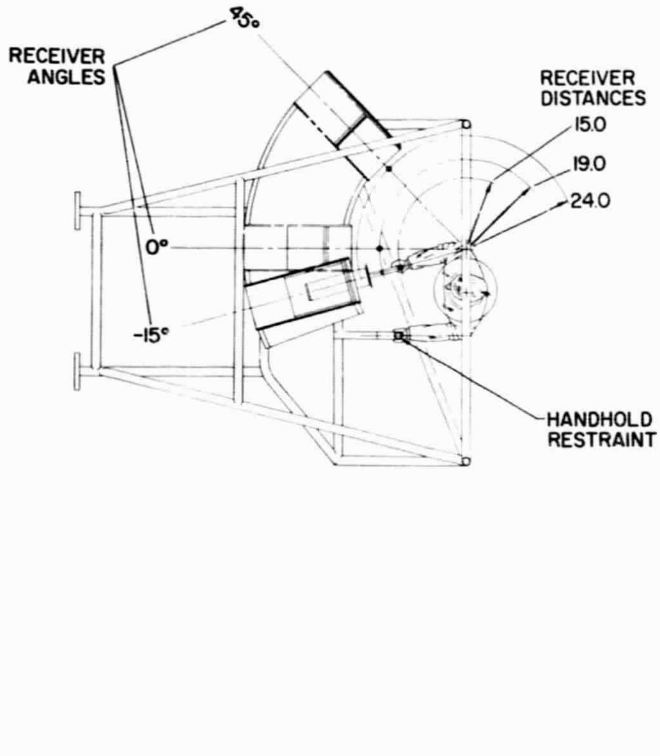
Fig 6.8-9 A

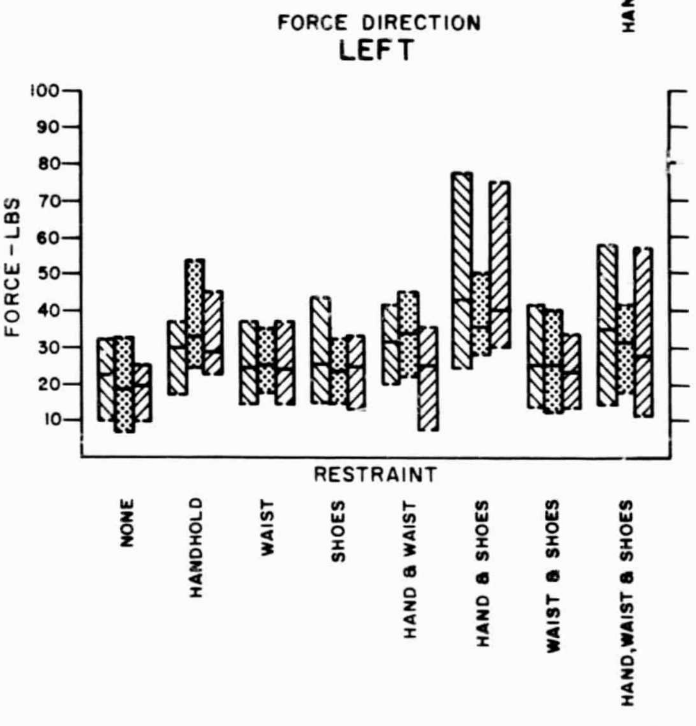
6-51 A

FOLDOUT FRAME

HANDLE ORIENTATION: **HORIZONTAL**







FO

RE

FIG 6.8-9 B

FOLDOUT FRAME

6-51 B

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

Figure 6.8-9c Summary Data Chart No. 9

FOLDOUT FRAME

FORCE TYPE: **IMPULSE**

RECEIVER ANGLE: **15°**

HA

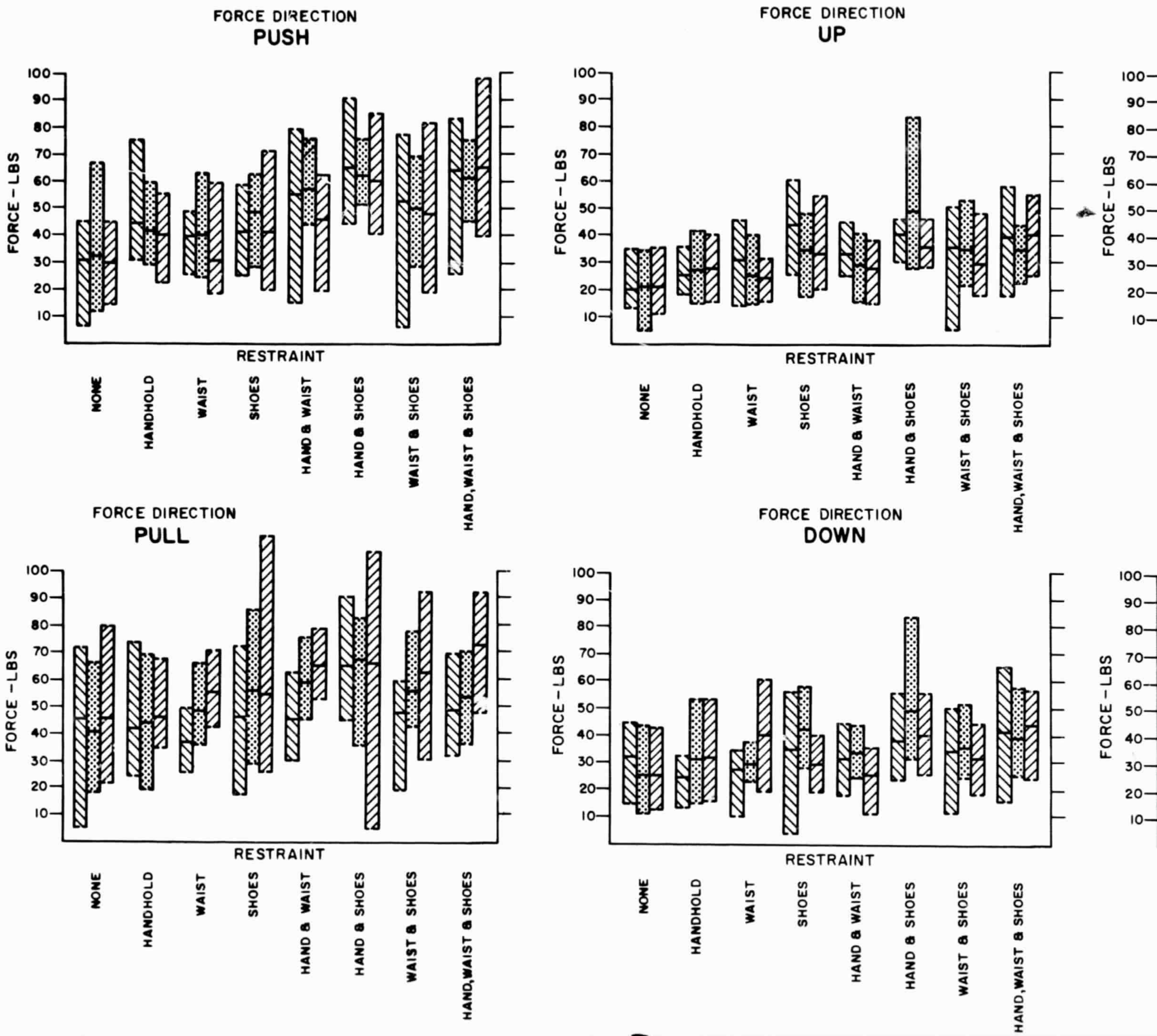
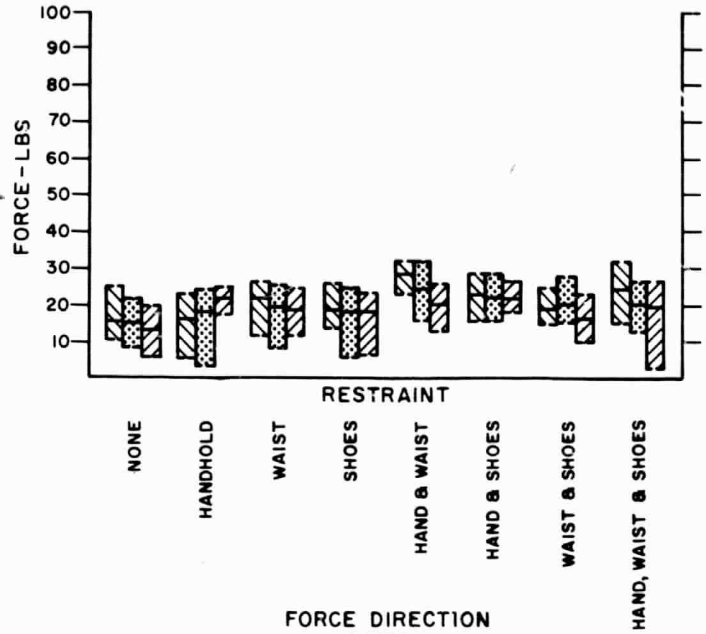


Fig 6.8-10A

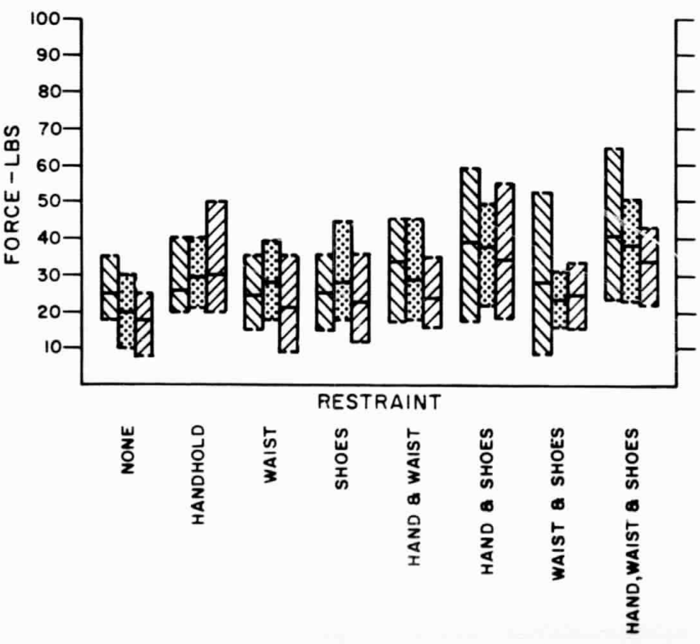
6-53A FOLDOUT FRAME

HANDLE ORIENTATION: **VERTICAL**

FORCE DIRECTION
RIGHT



FORCE DIRECTION
LEFT



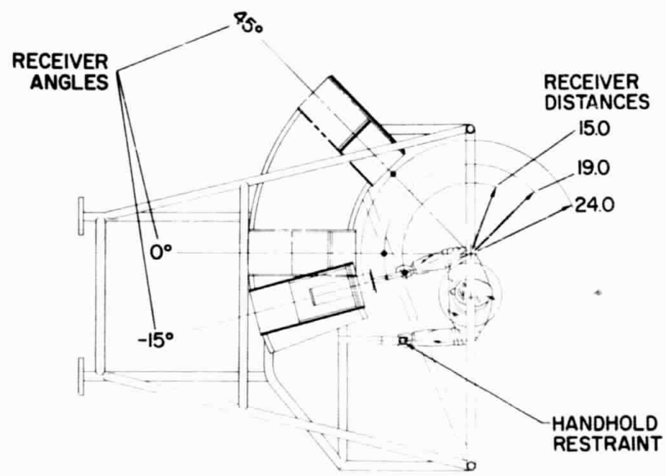


FIG. 68-10.B

FOLDOUT FRAME

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

Figure 6.8-10C Summary Data Chart No. 10

FOLDOUT FRAME

FORCE TYPE: **IMPULSE**

RECEIVER ANGLE: **45°**

HA

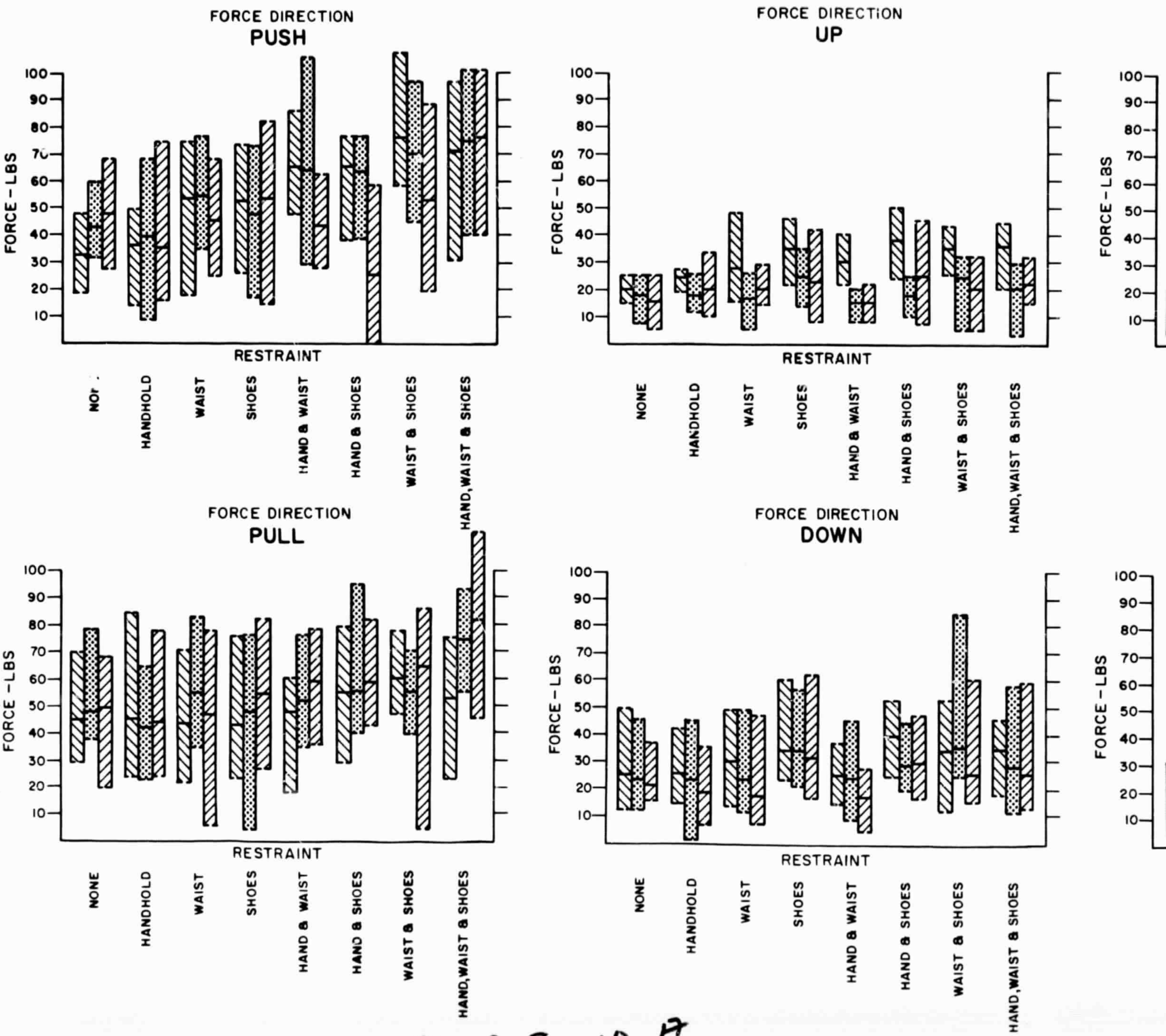
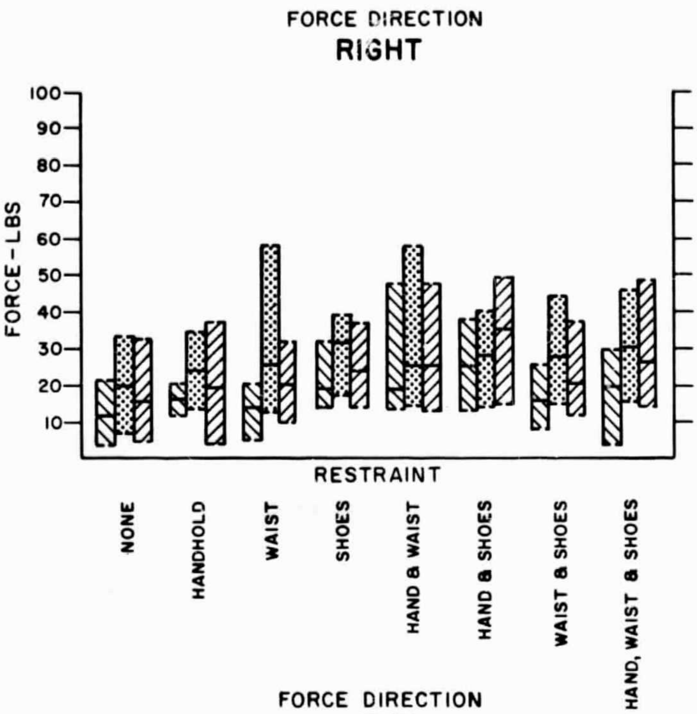
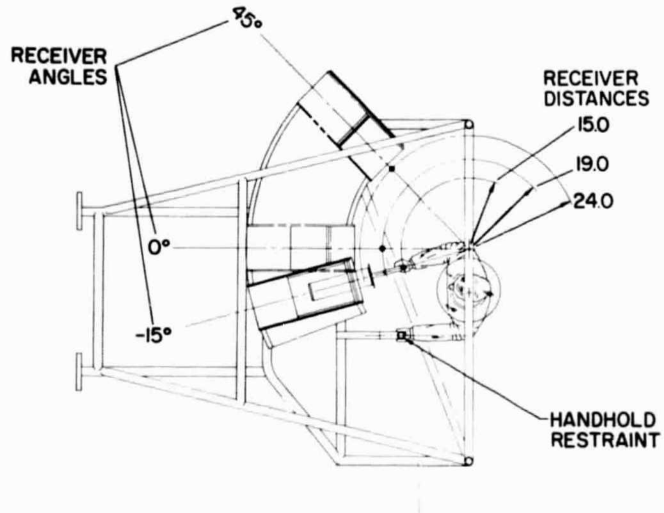


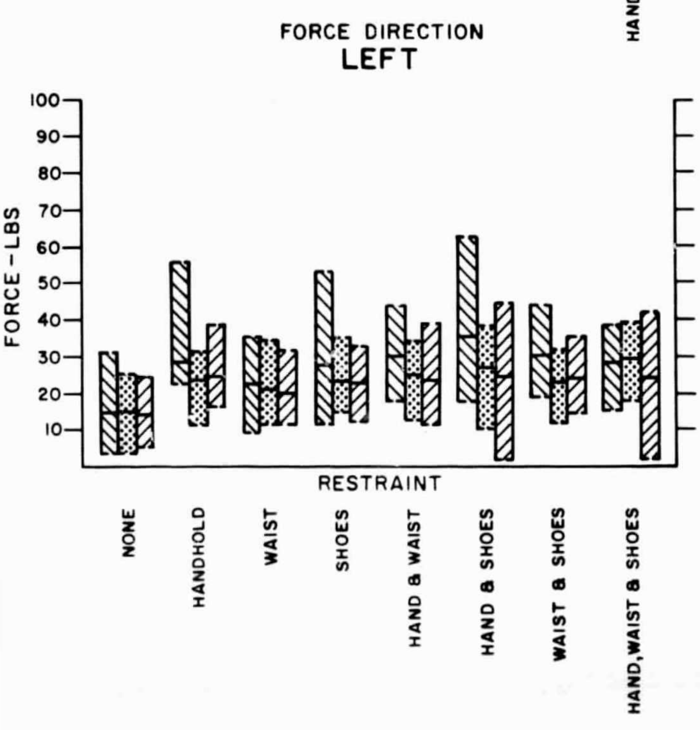
Fig 6.8-10. A
6-55 A

FOLDOUT FRAME

HANDLE ORIENTATION: **HORIZONTAL**







FOLDOUT FRAME

Fig 6.8-11 B
6-55 B

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

Figure 6.8-11c Summary Data Chart No. 11

FOLDOUT FRAME

FORCE TYPE: **IMPULSE** RECEIVER ANGLE: **45°**

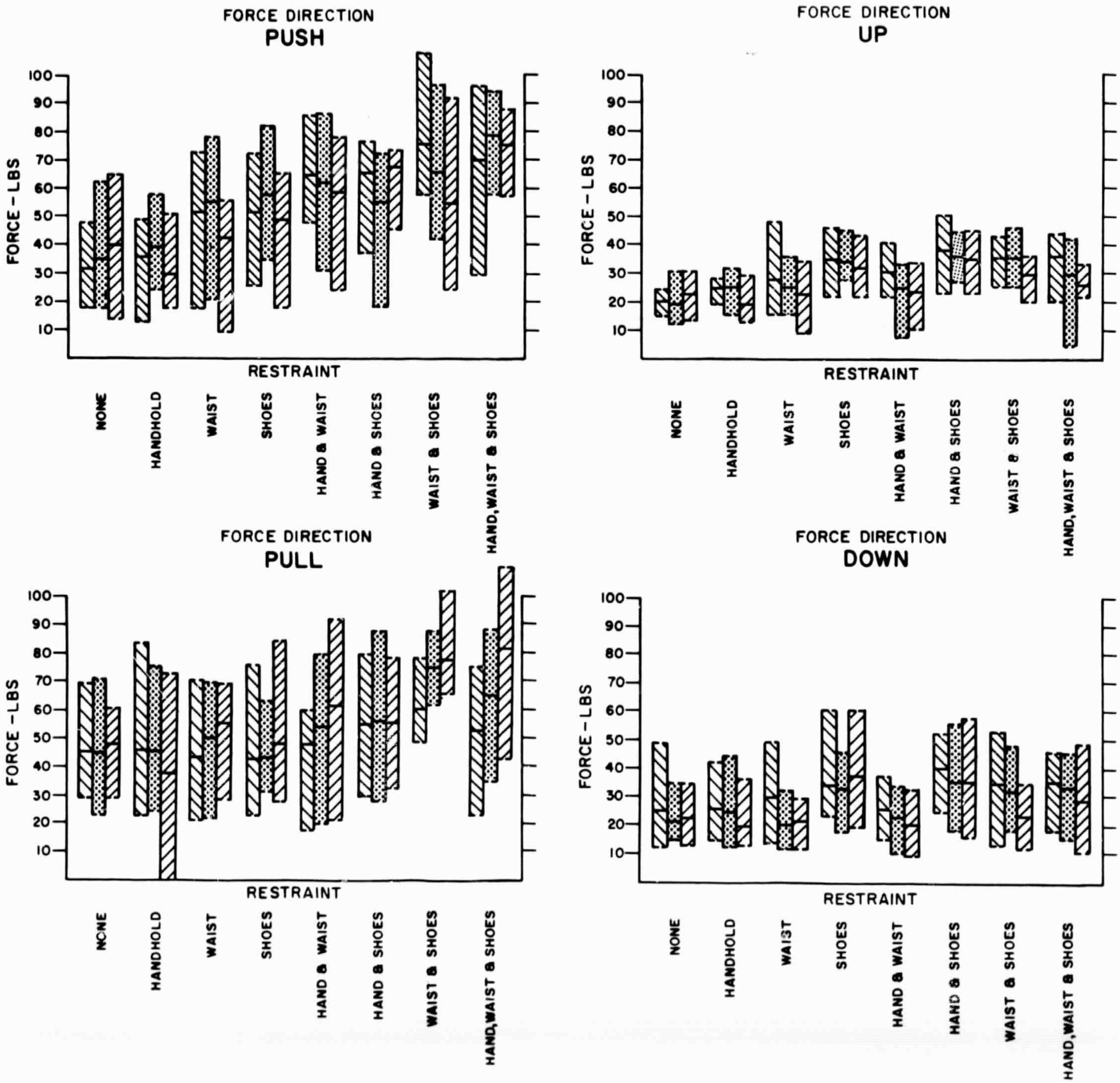
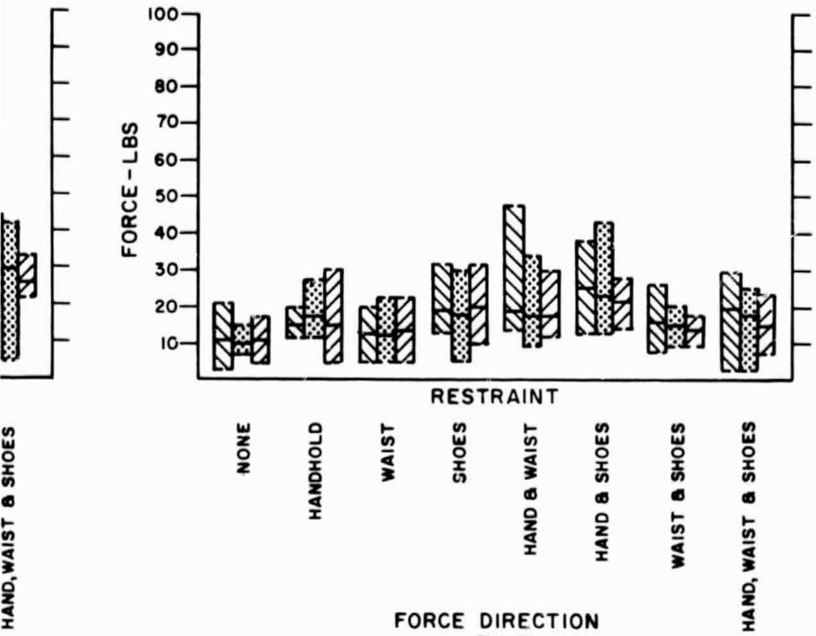
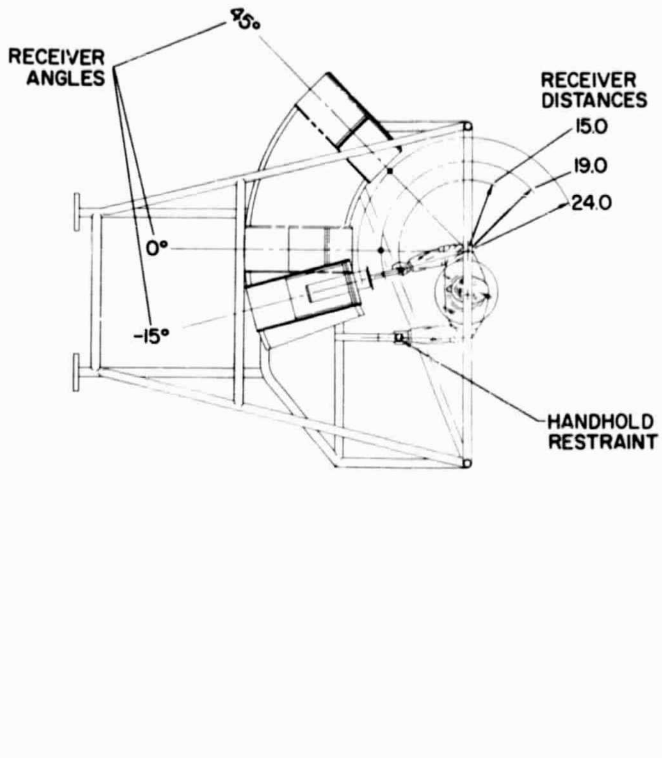


Fig. 6.8-12A

FOLDOUT FRAME

HANDLE ORIENTATION: **VERTICAL**





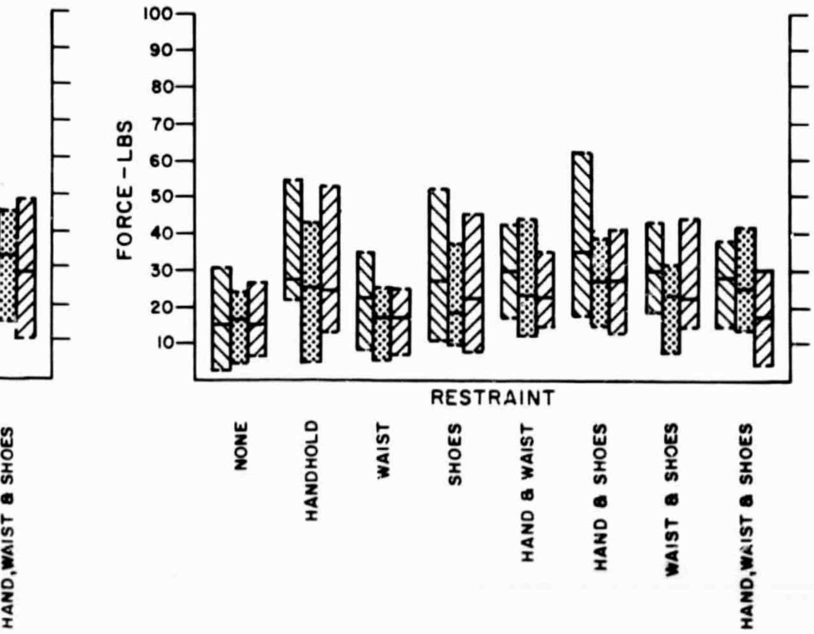


Fig 6.9-12.B

FOLDOUT FRAME

6-57B

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

Figure 6.8-12.C Summary Data Chart No. 12

of significance (Table 6.8-3). Sustained forces were those force magnitudes that could be maintained over a 4-second interval. Impulsive forces were the peak magnitudes that could be exerted in a 1-second interval.

In general, it can be seen that Push/Pull impulsive force emission capability is approximately 2 1/2 times as great as sustained Push/Pull force capability. Secondly, impulsive force capability in the Up/Down, Right/Left directions is approximately twice as great as sustained force capability in the corresponding directions. Finally, Push/Pull impulsive force emission capability appears to be about twice as great as the Up/Down, Right/Left force capability.

6.8.2.2 Air Versus Water Pressurization

The results of the Wilcoxon Matched Pairs Signed Ranks Test indicate that the sustained mean forces for air and water pressurization modes did not differ significantly (Table 6.8-4). Table 6.8-5 indicates that the impulsive mean forces for air and water pressurization modes also did not differ significantly.

The general conclusions regarding Push/Pull and impulsive over sustained force advantages presented in Section 6.8.2.1 above also apply here.

6.8.2.3 Horizontal Versus Vertical Handle Orientation (Tables 6.8-6 and 6.8-7)

The results of the Wilcoxon Matched Pairs Signed Ranks Test indicate that the sustained mean force for horizontal and vertical handle orientations did not differ significantly.

In general, it appears that handle orientation has little effect on force emission capability in the Push/Pull and Left directions. Also, it appears that a vertical handle orientation increases the capability to exert Up/Down forces and a horizontal handle orientation increases the capability to exert Right direction forces.

Table 6.8.3. Wilcoxon Test - Sustained Versus Impulse Mean Forces

Force Direction	Sustained Means (lb)	Impulse Means (lb)	Diff. Between Means (lb)	Rank	Least Common
PUSH	19.7	51.5	-31.8	-6	
PULL	20.8	51.2	-30.4	-5	
UP	12.4	25.2	-12.8	-3	
DOWN	15.6	28.7	-13.1	-4	
RIGHT	11.7	23.4	-11.7	-1	
LEFT	13.7	26.3	-12.6	-2	
					T = 0

T = 0 with an N of 6 - Significant at 0.01 level

Table 6.8.4. Wilicoxon Test Air Versus Water Pressurization, Sustained Means

Force Direction	Air Means (lb)	Water Means (lb)	Diff. Between Means (lb)	Rank	Least Common
PUSH	19.8	19.6	0.2	1	
PULL	21.7	20.1	1.6	6	
UP	12.7	12.2	0.5	3	
DOWN	15.2	15.8	-0.6	-4	4
RIGHT	11.9	11.5	0.4	2	
LEFT	14.2	13.3	0.9	5	
				T =	4

T = 4 with N of 6- Not significant

Table 6.8-5. Wilcoxon Test Air Versus Water Pressurization, Impulsive Means

Force Direction	Air Means (lb)	Water Means (lb)	Diff Between Means (lb)	Rank	Least Common
PUSH	51.8	51.3	0.5	2.5	
PULL	53.0	49.9	3.1	6	
UP	24.9	25.4	-0.5	-2.5	2.5
DOWN	27.5	29.6	-2.1	-5	5
RIGHT	23.3	23.4	-0.1	-1	1
LEFT	27.0	25.9	1.1	4	
				T =	8.5

T = 8.5 with an N of 6 - Not significant

Table 6.8-6. Wilcoxon Test-Horizontal Versus Vertical Handle Orientation, Sustained Means

Force Direction	Air Means (lb)	Water Means (lb)	Diff Between Means (lb)	Rank	Least Common
PUSH	20.2	19.2	1.0	3	
PULL	21.0	20.6	0.4	2	
UP	10.6	14.2	-3.6	-5	5
DOWN	13.8	17.3	-3.5	-4	4
RIGHT	14.7	8.6	6.1	6	
LEFT	13.8	13.6	0.2	1	
				T =	9

T = 9 with an N of 6 – Not Significant

Table 6.8-7. Wilcoxon Test-Horizontal Versus Vertical Handle Orientation, Impulsive Means

Force Direction	Air Means (lb)	Water Means (lb)	Diff Between Means (lb)	Rank	Least Common
PUSH	53.0	50.1	2.9	3	3
PULL	50.2	52.3	-2.1	-2	
UP	20.7	29.5	-8.8	-5	
DOWN	26.3	31.0	-4.7	-4	
RIGHT	28.8	17.9	10.9	6	6
LEFT	26.5	26.1	0.4	1	1
				T =	10

T = 10 with an N of 6 - Not significant

6.8.2.4 Mean Forces Across Subjects

The results of the Friedman Two-way Analysis of Variance Test indicate that the sustained mean force emission capability across subjects differed significantly at the 0.05 level (Table 6.8-8). Table 6.8-9 indicates that the impulsive mean force emission capability across subjects also differed significantly, but at the 0.01 level. Subjects 1 and 3 corresponded to the 90th percentile grouping and Subjects 2 and 4 corresponded to the 50th percentile groupings on the basis of stature.

In general, however, the force emission capability of the subjects did not follow these percentile groupings. Subjects 2 and 3 generally exerted the greatest mean forces which indicate a differential force capability within percentile groups. Also, there appears to be a differential force capability within subjects for sustained and impulsive forces. Subject 3 exerted the greatest impulsive forces, but Subject 2 generally exerted the greatest sustained forces.

6.8.2.5 Mean Forces Across Receiver Angles

The results of the Friedman Two-way Analysis of Variance Test indicate that the sustained mean force emission capability across receiver angles did not differ significantly (Table 6.8-10). Table 6.8-11 indicates that the impulsive mean force emission capability across receiver angles also did not differ significantly.

It appears, however, for both sustained and impulsive forces, that the capability to exert both sustained and impulsive Push/Pull forces increases as the location of 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 Right/Left sustained and impulsive force emission capability tends to decrease as the force receiver is moved laterally from in front of the subject.

6.8.2.6 Mean Forces Across Receiver Distances

The three receiver distances were Near (15 inches), Medium (19 inches) and Far (24 inches) and roughly corresponded to the elbow angles of 90 degrees, 135 degrees, and 180 degrees respectively. The results of the Friedman Two-way Analysis of Variance Test indicate that the sustained mean force emission capability across receiver distances did not differ significantly (Table 6.8-12). Table 6.8-13 indicates that the impulsive mean force emission capability across receiver distances also did not differ significantly.

It appears from the data that as the distance between the subject and the force receiver increases, the ability to exert Push forces decreases. Conversely, as the distance between the subject and the force receiver increases, the ability to exert Pull forces increases. Additionally, there appears to be a lesser tendency for the Up/Down and Right/Left force emission capability to increase as the distance between the subject and force receiver decreases.

6.8.2.7 Mean Forces Across Restraints

The eight restraint conditions were none (no restraint); handhold; rigid waist; Gemini dutch shoes; the combinations of handhold and waist; handhold and shoes; waist and shoes; and handhold, waist, and shoes. The first four, excluding the no-restraint case, were single-point restraints. The last four were considered as multiple point restraints. The results of the Friedman Two-way Analysis of Variance Test indicate that the sustained mean force emission capability across restraints differed significantly at the 0.001 level (Table 6.8-14). Table 6.8-15 indicates that the impulsive mean force emission capability across restraints also differs significantly at 0.001 level.

In addition to the statistical analysis, the data also appears to indicate the following design implications. It appears that a force cannot be sustained in a no restraint condition. Secondly, the single-point restraints have differential value for different force directions. For sustained forces, the waist restraint is best for Push/Pull, the Gemini Dutch shoes are best for Up/Down, and the handhold is best for Left directions. In addition, all single-point restraints are about equal in their inability to provide an assist for Right direction forces.

Table 6.8-8. Friedman Test Across Subjects, Sustained Mean Forces

Force Direction	Subject Means (lb) 1	2	3	4	Ranks by Rows 1	2	3	4
PUSH	18.0	23.8	20.7	16.2	2	4	3	1
PULL	24.4	23.9	17.6	17.7	4	3	1	2
UP	11.8	14.8	12.8	10.2	2	4	3	1
DOWN	11.1	17.9	20.8	12.0	1	3	4	2
RIGHT	9.4	14.3	13.4	9.4	1.5	4	3	1.5
LEFT	10.1	15.7	16.4	11.3	1	3	4	2
				ΣR_j	11.5	21	18	9.5

K = number of conditions = 4
N = number of replications = 6
R_j = sum of ranks in the j^{th} row

$$\chi_r^2 = \frac{12}{NK(K+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(K+1)$$

$$\chi_r^2 = \frac{12}{(6)(4)(4+1)} \left[(11.5)^2 + (21)^2 + (18)^2 + (9.5)^2\right] - 3(6)(4+1)$$

$$\chi_r^2 = \frac{12}{120} (132.25 + 441 + 324 + 90.25) - 90$$

χ_r^2 8.75 with K-1 or 3df - Significant at the 0.05 level

Table 6.8-9. Friedman Test Across Subjects, Impulsive Mean Forces

Force Direction	Subject Means 1	2	3	4	Ranks by Rows 1	2	3	4
	(forces in lbs)							
PUSH	50.9	50.9	59.4	44.5	2.5	2.5	4	1
PULL	57.9	49.3	53.5	44.5	4	2	3	1
UP	25.8	25.8	27.3	21.8	2.5	2.5	4	1
DOWN	25.3	29.1	35.8	23.8	2	3	4	1
RIGHT	20.2	24.8	28.7	19.2	2	3	4	1
LEFT	22.8	27.4	31.5	23.0	1	3	4	2
				ΣR_j	14	16	23	7

K = number of conditions = 4
N = number of replications = 6
R_j = sum of ranks in the j^{th} column

$$\chi_r^2 = \frac{12}{NK(K+1)} \sum_{j=1}^{k} (R_j)^2 - 3\,N(K+1)$$

$$\chi_r^2 = \frac{12}{(6)(4)(4+1)} \left[(14)^2 + (16)^2 + (23)^2 + (7)^2\right] - 3\,(6)\,(4+1)$$

χ_r^2 = 13 with K-1 or 3 df - Significant at the 0.01 level

Table 6.8-10. Friedman Test Across Receiver Angles, Sustained Mean Forces

Force Direction	Receiver Angle Means (lb) -15°	0°	45°		Ranks by Rows -15°	0°	45°
PUSH	18.1	18.7	22.2		1	2	3
PULL	20.3	19.4	22.7		2	1	3
UP	13.0	12.5	11.7		3	2	1
DOWN	17.2	14.9	14.5		3	2	1
RIGHT	12.6	12.4	10.1		3	2	1
LEFT	14.7	14.0	12.3		3	2	1
				ΣR_j	15	11	10

K = 3 receiver angles
N = 6 replications
R_j = Sum of the ranks in the jth row

$$\chi_r^2 = \frac{12}{NK(K+1)} \sum_{j=1}^{k} (Rj)^2 - 3(6)(3+1)$$

$$\chi_r^2 = \frac{12}{(6)(3)(3+1)} \left[(15)^2 + (11)^2 + (10)^2\right] - 3(6)(3+1)$$

χ_r^2 = 2.3 with K-1 or 2 df - Not significant

Table 6.8-11. Friedman Test Across Receiver Angle, Impulsive Mean Forces

Force Direction	Receiver Angle Means (lb) -15°	0	45°	Ranks by Rows -15°	0°	45°
PUSH	49.4	51.0	54.2	1	2	3
PULL	51.2	49.9	52.7	2	1	3
UP	26.4	25.2	24.0	3	2	1
DOWN	31.2	28.1	26.7	3	2	1
RIGHT	25.0	24.3	20.8	3	2	1
LEFT	28.2	27.1	23.6	3	2	1
			ΣR_j	15	11	10

K = 3 receiver angles
N = 6 replications
R_j = Sum of the ranks in the jth row

$$\chi_r^2 = \frac{12}{NK(K+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(K+1)$$

$$\chi_r^2 = \frac{12}{(6)(3)(3+1)} \left[(15)^2 + (11)^2 + (10)^2\right] - 3(6)(3+1)$$

$\chi_r^2 = 2.3$ with K-1 or 2 df - not significant

Table 6.8-12. Friedman Test Across Receiver Distance, Sustained Mean Forces

	Receiver Distance Means (lb)			Ranks by Rows		
Force Direction	Near	Medium	Far	Near	Medium	Far
PUSH	22.8	19.7	16.6	3	2	1
PULL	16.5	20.7	25.0	1	2	3
UP	14.3	11.6	11.5	3	2	1
DOWN	16.2	15.5	14.9	3	2	1
RIGHT	12.2	11.5	11.4	3	2	1
LEFT	14.7	13.4	13.0	3	2	1
			ΣR_j	16	12	8

K = 3 receiver distances
N = 6 replications
R_j = Sum of the ranks in the jth row

$$\chi_r^2 = \frac{12}{NK(k+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(K+1)$$

$$\chi_r^2 = \frac{12}{(6)(3)(3+1)} \left[(16)^2 + (12)^2 + (8)^2\right] - 3(6)(3+1)$$

χ_r^2 = 5.33 with K-1 or 2 df - Not Significant

Table 6.8-13. Friedman Test Across Receiver Distance, Impulsive Mean Forces

	Receiver Distance Means (lb)			Ranks by Rows		
Force Direction	Near	Medium	Far	Near	Medium	Far
PUSH	53.2	52.4	49.0	3	2	1
PULL	45.6	51.7	56.1	1	2	3
UP	27.0	25.0	23.7	3	2	1
DOWN	29.2	29.3	27.6	2	3	1
RIGHT	24.2	23.8	22.2	3	2	1
LEFT	28.0	25.9	25.1	3	2	1
			ΣR_j	15	13	8

K = 3 receiver distances
N = 6 replications
R_j = Sum of the ranks in the jth rows

$$\chi_r^2 = \frac{12}{NK(K+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(K+1)$$

$$\chi_r^2 = \frac{12}{(6)(3)(3+1)} \left[(15)^2 + (13)^2 + (8)^2\right] - 3(6)(3+1)$$

$$\chi_r^2 = 4.33 \text{ with } K-1\ 2\text{df} - \text{Not Significant}$$

Table 6.8-14. Friedman Test Across Restraints, Sustained Mean Forces

Force Direction	Restraint Means (lb) None	Hand	Waist	Shoes	H&W	H&S	W&S	H, W&S
PUSH	0.0	1.3	14.6	4.1	29.2	29.7	35.5	42.5
PULL	0.2	2.1	22.3	4.3	30.6	33.0	36.5	37.6
UP	0.5	4.8	10.4	17.5	13.6	18.0	17.2	17.0
DOWN	1.6	8.6	10.4	20.8	15.8	25.6	19.3	21.6
RIGHT	0.1	10.5	12.3	9.4	15.3	16.3	13.6	16.1
LEFT	0.1	16.6	12.1	8.4	17.4	20.6	14.8	19.3

Force Direction	Ranking by Rows							
PUSH	1	2	4	3	5	6	7	8
PULL	1	2	4	3	5	6	7	8
UP	1	2	3	7	4	8	6	5
DOWN	1	2	3	6	4	8	5	7
RIGHT	1	3	4	2	6	8	5	7
LEFT	1	5	3	2	6	8	4	7
ΣRJ	6	16	21	23	30	44	34	42

K = 8 restraints

N = 6 replications

R_j = Sum of the ranks in the jth column

$$\chi_r^2 = \frac{12}{NK(K+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(K+1)$$

$$\chi_r^2 = \frac{12}{(6)(8)(8+1)} \left[(6)^2 + (16)^2 + (21)^2 + (23)^2 + (30)^2 + (44)^2 + (34)^2 + (42)^2\right] - 3(6)(8+1)$$

χ_r^2 = 30 with K-1 or 7 df - Significant at .001 level

Table 6.8-15. Friedman Test Across Restraints, Impulsive Mean Forces (lb)

Restraint Means

Force Direction	None	Hand	Waist	Shoes	H&W	H&S	W&S	H, W&S
PUSH	35.4	40.9	43.3	45.8	56.6	62.4	58.5	69.2
PULL	43.2	43.2	46.0	47.6	50.7	61.3	56.8	60.9
UP	19.3	21.3	22.7	27.8	23.3	30.6	27.6	28.8
DOWN	22.5	25.8	22.8	32.7	26.0	36.6	30.4	32.1
RIGHT	17.5	22.2	21.8	22.1	25.4	28.2	22.8	26.7
LEFT	18.2	29.0	22.2	23.0	28.0	34.3	25.4	29.9

Force Direction	Ranks by Row							
PUSH	1	2	3	4	5	7	6	8
PULL	1.5	1.5	3	4	5	8	6	7
UP	1	2	3	6	4	8	5	7
DOWN	1	3	2	7	4	8	5	6
RIGHT	1	4	2	3	6	8	5	7
LEFT	1	6	2	3	5	8	4	7
ΣR_j	6.5	18.5	15	27	29	47	31	42

K = 8 restraints
N = 6 replications
R_j = Sum of the ranks in the jth row

$$\chi_r^2 = \frac{12}{NK(K+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(K+1)$$

$$\chi_r^2 = \frac{12}{(6)(8)(8+1)} \left[(6.5)^2 + (18.5)^2 + (15)^2 + (27)^2 + (29)^2 + (47)^2 + (31)^2 + (42)^2\right] - 3(6)(8+1)$$

χ_r^2 = 32.8 with K-1 or 7 df - significant at .001 level

The handhold, waist, and shoes restraint combination resulted in the greatest Push/Pull forces with the waist and shoes combination very close behind. The handhold and shoes restraint combinations resulted in the largest mean sustained forces for the Up/Down and Right/Left directions. Finally, the data would indicate that Right direction sustained forces should be avoided whenever possible.

For impulsive force emissions, there is very little difference between the means for the single-point restraints, including the no-restraint case. Also, all the multiple restraint conditions are better than the single-point restraints. The handhold and shoes combination permits the greatest impulsive mean force emissions in all six directions. Finally, the handhold and waist is generally the poorest of the multiple point restraint conditions for impulsive force emissions.

6.8.3 CONCLUSIONS

The conclusions resulting from this experimental program are divided into two general groups. In the first are those conclusions that can be drawn from the data analysis and results. The second group contains those conclusions that resulted from the operational experience of conducting an underwater experimental program of such a large magnitude as Experiment 84A.

6.8.3.1 Data Conclusions

The following major conclusions are summarized from the findings reported above in the analysis and results section.

a. The statistical analyses were performed on means derived across experimental conditions and should not be used to generalize to the individual case. The reader should go directly to the specific condition combination presented in the graphical or tabular format to obtain the pertinent design data.

b. The handhold and shoes restraint combination resulted in the greatest Up/Down and Left/Right sustained and impulsive force generating capability.

c. The handhold, waist, and shoes restraint combination and the waist and shoes restraint combination resulted in the greatest Push/Pull sustained forces.

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

e. The handhold restraint provided the capability for sustaining significant (above 10 pounds) mean forces in only the Left/Right directions.

f. The shoes restraint provided the capability for sustaining significant (above 10 pounds) mean forces in only the Up/Down directions.

g. The mean capability to exert impulsive forces in a no-restraint condition did not differ greatly (4 to 14 pounds differential range) from the capability provided by the single-point restraints (handhold, waist, and shoes restraints).

h. The mean capability to exert impulsive forces did not differ greatly (5 to 12 pounds differential range) across the multiple-restraint conditions (handhold and waist; handhold and shoes; waist and shoes; and handhold, waist, and shoes).

i. The space suit pressurization mode did not differentially affect the ability of subjects to exert forces.

6.8.3.2 Operational Conclusions

The following operational conclusions were drawn from the considerable number of experiences and observations noted during the conduct of this experimental program.

a. Planning of extensive underwater pressure-suited operations should include a 100 percent contingency time factor.

b. Extreme care should be exercised to insure the cleanliness of the neutral buoyancy facility, especially to minimize the frequency of ear infections.

c. Neutrally buoying space-suited subjects for an upright, nontranslational operation is a relatively simple and easy task.

d. The water pressurization mode was more efficient, from a subject preparation and experimental session changeover time-saving standpoint, than the air pressurization mode.

e. Future water pressurized suit operations should include a face mask that can accommodate a communication system.

f. The possible hazard resulting from the physical reaction of a pressure-suited subject exerting forces under minimal restraint conditions should be carefully considered when selecting restraints for space operations.

SECTION 7

EXPERIMENT 1A - TRANSPORT OF FREE MASSES IN ZERO GRAVITY

The second experiment selected for implementation in this study program is summarized in this section. The study program constraints limited the effort on Experiment 1A to a detailed design only, and actual test operations were not conducted. As for Experiment 84A, described in Section 6, modifications to the original Experiment 1 were made at the request of the NASA. These primarily consisted of variations in the course and limitations to the number of experimental modules.

7.1 INTRODUCTION

It is already known that simple, manned traversal in zero-gravity in a pressurized suit requires skills substantially different from those required in a 1-g environment. Although the Gemini program has shown that an astronaut can learn to control his body movements in zero-g, as yet unknown is the astronaut's ability to move components, tools, instruments, and structural material for repair, maintenance, construction, assembly, and many other purposes. Basic to all of these and of particular importance is data concerning the limits of mass which an astronaut can handle with different transport methods.

7.2 OBJECTIVES

A number of potential areas require extensive study if we are to adequately understand and be able to predict the ability of a suited astronaut to move "cargo" in zero-g. Although many factors influence man's ability to perform this function, this experiment is concerned with the three which most affect performance. These are the characteristics of the object to be transported, the method of transport, and the characteristics of the path which is to be traversed. In order to generate criteria which accurately define the limitations imposed by variations of these factors, this experiment is designed to:

a. Evaluate the effects of the object mass on the maneuvering, transporting, and manipulation of such objects

b. Determine the limits of mass transport capability for various modes of transport and attachment locations

c. Evaluate the effect of restricted work space areas on the maneuvering, transporting, and manipulation of objects in zero-g

The resultant data will allow the equipment designer to determine whether a particular mass can be handled in traversal and should be useful in all cases where an object must be transported without attachments, except to the man, from one point to another. It will still be necessary for the designer to consider additional variables, such as volume (if clearance is in doubt), center of gravity, mass distribution within the transported object, and mobility aid availability.

7.3 TEST VARIABLES

7.3.1 EXPERIMENT VARIABLES

The ability of a subject to transport masses in a zero gravity environment is influenced by several variables. Some of the more important are:

a. Characteristics of the transported object - mass, center of gravity

b. Relationship of mass to test subject - position and attachment point

c. Type of traversal, work site restrictions, and assist devices available

d. Type of spacesuit worn and pressurization conditions

To the extent limited by practical experimental limitations and facility availability, variations and combinations of the above are included in the experimental protocol. The range of each variable and the extent of these limitations are briefly discussed below.

7.3.2 MODULE CHARACTERISTICS

Selection of object mass was made on the basis of a pilot study using non-suited divers. Four masses, bracketing man's mass handling capability were selected and are:

a. 1.5 slugs (12-inch sphere)

b. 3.4 slugs (16-inch sphere)

c. 6.8 slugs (20-inch sphere)

d. 11.8 slugs (24-inch sphere)

Due to the limitations of hydrodynamic simulation, no attempt is made to vary the module center of gravity which is located at the center of the spherical module.

7.3.3 RELATIONSHIP OF OBJECT TO SUBJECT

Four object transport methods were selected as representative of probable transport methods in general. These consist of:

a. No attachment: subject pulls himself with one hand and controls the mass with the other

b. Upper back attachment: mass located at shoulder blades with both hands on mobility aid

c. Lower back attachment: mass located below waist with both hands on mobility aid

d. Module attached to shoes with both hands on mobility aid

In order to assist in interpreting the data, two baseline conditions are also included:

a. One hand on mobility aid, no mass

b. Two hands on mobility aid, no mass

7.3.4 SPACE SUIT AND PERSONNEL VARIABLES

The space suits and methods of pressurization described for the previous experiment are also utilized for this experiment. Similarly, four test subjects representing the 50th and 90th percentiles are utilized.

7.4 EXPERIMENT APPARATUS

7.4.1 TRAVERSAL COURSE

In this experiment, the course is not a true variable, as it is systematically and not experimentally varied. That is, the order of conditions of traversal is constant, but several types of traversal are involved. The fixed, three-dimensional course shown in Figure 7.4-1 consists of:

a. Straight traversals

b. Curved traversals - inside and outside surfaces

c. Right-angle turns - enclosed and open area

d. Traversal through a tunnel and a hatch

e. Traversals adjacent to and away from simulated walls

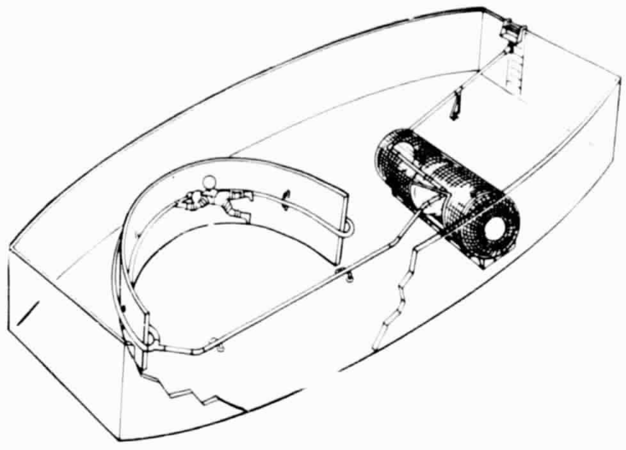


Figure 7.4-1. Traversal Course

7.4.2 MOBILITY AID

A single, non-varying mobility aid, similar to that planned for use in the Apollo Applications Program, will be employed to assist the subject and provides the sole aid to locomotion.

7.4.3 MODULE ATTACHMENTS

Figure 7.4-2 illustrates the various locations for attaching the experimental mass to the test subject. The attachment will be accomplished by connecting the mass to specially modified SCUBA tank backpack or to Gemini dutch shoes.

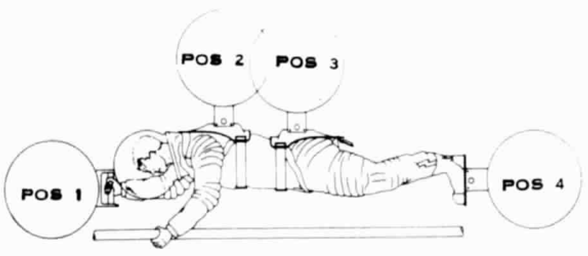


Figure 7.4-2. Module Attachment to Test Subject

7.5 TEST MEASURES AND ANALYSIS OF RESULTS

This section contains a brief description of the test measures, the data to be collected to satisfy the experimental program test objectives, and a general discussion on the analysis and presentation of results. The data to be collected can be generally categorized as gross motor performance observations, accelerations profiles, physiological data, and subjective observations.

7.5.1 MOTOR PERFORMANCE DATA

Motion picture or video tape recordings and observational data will be gathered throughout this experimental program. The data will be analyzed to determine the following types of information:

a. Task completion tactics or procedures utilized by individuals to permit successful transport of the mass around the traversal course

b. Errors: types, causality, frequency, and safety considerations

c. Motor effectiveness: mobility envelopes, frequency of starts/stops, thrust direction changes, strategy effectiveness in maneuver and manipulation procedures

7.5.2 ACCELERATION HISTORY PROFILES

Acceleration profiles for each experimental condition will be analyzed in terms of frequency of direction change and average magnitude in the forward direction and in the pitch axis. These acceleration profiles will be compared for each portion of the course configuration, and each type of traversal condition and will be used to further assess the motor effectiveness of the subject's performance.

7.5.3 PHYSIOLOGICAL DATA

The physiological data will be gathered by means of biomedical sensors attached to the subject and hardwired to surface-located recording apparatus. The data collected will be heart rate, respiration rate, oxygen consumption, deep body temperature, and tidal volume. This data will provide an experimental time history of the average and peak metabolic costs associated with various course profiles and transport modes. Where feasible and meaningful, the metabolic costs will be plotted as a function of time and in respect to absolute levels of deviation from baseline values to denote differences between test variables, differences between subjects, or fatigue effects. In order to make these data meaningful, baseline metabolic measures will be taken on all subjects in a rest condition.

7.5.4 SUBJECTIVE DATA

Subjective data will be collected after each experimental session and will come primarily from two sources, the subjects and the test director. A formal debriefing will be held with each subject after each experimental session to collect subjective comments concerning experimental problems, suggested procedural or equipment modification and comparative judgments about the experimental variables. An interview form or data questionnaire will be constructed and utilized when dictated by the situation and determined by the test director. These data will be used to provide assessments of crew acceptance of the various techniques as compared with interpretation of the objective data.

7.5.5 RESULTS

The data will be analyzed as required to provide the following information:

a. An evaluation of performance characteristics in the simulated zero-gravity conditions

b. Comparison of the relative effectiveness of the various object transport and attachment methods tested

c. The determination of criteria for work volume envelopes for the selected experimental tasks and conditions

d. The identification of recurrent performance related problem areas for future research

e. The identification of hardware related problem areas for future research

SECTION 8

PRELIMINARY HANDBOOK OF HUMAN ENGINEERING DESIGN DATA FOR REDUCED GRAVITY CONDITIONS

The preliminary handbook structure 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 structure upon which a handbook of human engineering data could be built for the use of engineers, designers, and human factors specialists during the developmental and detail design phases of manned spacecraft programs. The following tasks were sequentially implemented in order to achieve this objective:

Task A. Determination of the probable usage of such a document

Task B. Based on a consideration "probable usage," a first-draft content and structure was developed.

Task C. Based on preliminary content requirements, a broad-band literature search was initiated and implemented.

Task D. Consultation with Tufts University, HEIAS personnel for the taxonomy, indexing, and overall structure of such a document was implemented.

Task E. Preliminary analyses of abstract material developed during the literature search were completed. Selected documentation was ordered, reviewed in detail, and pertinent information, figures, and tables selected for possible inclusion in the Handbook.

Task F. Based on all preceding efforts, a "second" but still "preliminary" structure, content and index rationale were established.

Task G. Selections from the collected materials were compiled in coarse form in order to evaluate generic labels selected for the Table of Contents and to establish areas where additional data were needed but not available.

8.1 HANDBOOK DEVELOPMENT

In the process of accomplishing Task A (i.e., the probable usage of such a 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 standardization 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 standardized 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 wherever 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 standardization of design practice in respect to vehicle, equipment and operations, the document must also be capable of providing custom-tailored specifications for unique mission/equipment/environment interactions.

8.2 SOURCE MATERIAL

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 in the upcoming Volume III of the HEIAS Bibliography were also reviewed for relevancy. The NASA and DDC searches were arranged in ascending "AD" and "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 the DDC, STAR and HEIAS accession numbers. An informal check from approximately a 50 percent sampling of STAR accession numbers indicates that routine acquisition of NASA reports was fairly complete and current for HEIAS. An item-by-item check against the 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, an attempt was made to primarily gather empirical data generated in an actual reduced gravity environment.

A preliminary outline for tape storage of information was also developed. It was considered that future continued effort regarding the development of the handbook would result in the accumulation of an enormous amount of documentation. An indexed information storage system outline, with an appropriate amount of flexibility incorporated, is available for preliminary utilization.

8.3 APPLICATION

It was felt that a document of this type should permit deliberate and detailed data to be available for the 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.

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 insure 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 should detail all crew support facilities and equipments necessary to accomplish the transport and the 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 should 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 will be 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 ORGANIZATION OF THE HANDBOOK

In selecting the basic generic headings for Human Engineering Handbook, heavy emphasis was placed on potential usage. Part I 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 will also be provided in this section.

Part II has provisions for absolute value data which describes the composition and the various phenomena present in the orbital extravehicular environment.

Part III 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 will include sizing, configurational, operational, and dynamic considerations for the vehicle and all its facilities, including unique mission equipments, packaging, and access.

Part IV will contain special considerations pertaining to various support hardware, special constraints and environmental modifiers that must be considered in order to provide an acceptable working environment.

The Handbook development efforts performed during this study were directed towards establishing a point of departure for subsequent efforts. As such, some extra work was expended in developing the content of Part I in order to demonstrate not only the potential utility of such a Handbook, but to emphasize the wealth of information available, but not readily utilized by those who need it most, because of its dispersion in bits and pieces throughout the literature of several disparate professional areas.

SECTION 9

PROGRAM CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

Those conclusions which are directly or indirectly related to the Experiment 84A efforts are detailed in Section 6.8.4.

In general, it can be concluded that the gathering of statistically significant neutral buoyancy simulation data, which implies a relatively large quantity of repetitive trials, is only possible with a full-time, well-motivated, and competent team. That for this program we were fortunate enough to obtain these qualities in a multi-organization team effort is evident in the quantity and type of data obtained.

It can also be concluded that the problems associated with neutral buoyancy simulation are well understood and can be overcome; this can be evidenced by the analyses and tests discussed in Section 4.

9.2 RECOMMENDATIONS FOR FUTURE STUDY

The completion of the analytical and empirical portions of this study program is but a first step on the road to providing design engineers with the information necessary to insure that the capabilities of man are maximized in the design for maintenance and repair of space vehicles. It is recommended that the several areas discussed in this section be strongly considered for future experimental and study effort.

9.2.1 HANDBOOK OF HUMAN ENGINEERING DESIGN DATA FOR REDUCED GRAVITY CONDITIONS

It is strongly recommended that the handbook effort be continued and expanded. Although it is felt that the limited preliminary effort which was a part of this study will provide a firm foundation upon which to build the final handbook, considerable additional effort must be applied to obtain a final, reduced gravity design handbook. In addition to the continued attainment of zero-gravity design data, it will be necessary to apply an in-depth analytical effort to these data in order that nonconflicting, qualified criteria can be provided for the various design facets necessary for spacecraft development and operations.

9.2.2 SIMULATED ZERO-GRAVITY EMPIRICAL DATA COLLECTION

In order to satisfy the goals and purposes of the handbook as described in Section 8 and above, considerable future study effort should be applied toward increasing the data available to the aerospace community. Although it would be desirable to derive such data from actual space flight experience, the length of time and cost required for experimentation in that medium makes it more practical to use empirical data derived from experiments using simulated reduced gravity techniques.

The first experiment recommended for implementation is Experiment 1A, dealing with the transport of masses, as described in Section 7. Among the reasons for this recommendation are (1) the data is urgently needed for implementation of the AAP program and (2) a considerable amount of the work required to design the experiment has already been completed during this study. Although the AAP first flight vehicle is well along in its design, the data from this experiment would serve either to confirm the design decisions or point out possible serious shortcomings. If the latter were to happen, design changes would be necessary in order that the planned flight stand the greatest chance of success.

The implementation of Experiment 1A should be followed up by the conduct of Experiment 2 in order to fully develop the data bank relative to the transport and manipulation of objects in free space. These experiments should be followed by Experiments 3 and 5 (singly or combined), 7, and 6, in that order.

9.2.3 EXPERIMENT 84A BASELINE DATA

It is recommended that a selective program be conducted to obtain baseline data for Experiment 84A. This would involve the replication of a limited number of data points with the test subject in a neutrally buoyed shirtsleeves configuration or a 1-g suited condition. The former would provide comparative data relative to the effects of the spacesuit itself, while the 1-g trials would provide for a comparison of force-producing capabilities as a function of the gravitational environment.

9.2.4 SIMULATED 1/6-g EMPIRICAL DATA COLLECTION

Although 1/6-g data was deleted from this study effort due to the expansion of the zero-g effort and the limitation of resources, it should be emphasized that the need for this data is as great as the need for zero-g design information, if not greater. With the first lunar landing a definite probability in this decade, we find ourselves facing a similar problem in the design of lunar operational equipment as we race for zero-gravity designs today. The designers of lunar exploration systems, lunar bases, etc., must have the necessary information for use in this decade if we plan to expand our exploration during the next. Therefore, it is recommended that further short-term study efforts be made to identify critical 1/6-g data requirements and that an organized program be subsequently implemented to obtain these data.

9.2.5 SIMULATION VALIDATION

It can be expected that design data will continue to be derived primarily through the application of reduced gravity simulation techniques. In addition, simulation techniques have been, and are being used to train crews and verify the adequacy of vehicle designs for extravehicular, zero-gravity operations. However, these are being used prior to having established a sound technological data base regarding the validity of extrapolating from these ground simulation data to predicted flight results. Therefore, it is essential to know how well the technique utilized to simulate a particular behavioral activity relates to the actual reduced gravity condition.

There are at present several techniques in use for the simulation of reduced gravity conditions. These are:

a. Mechanical simulators, including frictionless support devices (air bearing) and force balance devices (Peter-Pan)

b. Keplerian trajectory flights

c. Neutral buoyancy

Each of these has been used extensively and have attendant limitations and strong points as a function of the type of behavior/study being simulated.

It is therefore recommended that a program be instituted to determine the most valid simulation methods for specific behaviors and therefore the features of each simulation technique which should be exploited in future programs. This would require the simulation of a known flight experiment utilizing each of the accepted techniques in order to gather empirical data on the fidelity of the various ground-based, subgravity simulation techniques, and the comparison of actual flight data with that obtained during simulation.