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DECK MOTION SIMULATOR PROGRAM

HORIZONTAL SINUSOIDAL OSCILLATION EFFECTS UPON PERFORMANCE OF STANDING WORKERS

by J. S. Seeman and R. B. Williams

George C. Marshall Space Flight Center
Huntsville, Ala.

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SUMMARY

This work was a preliminary attempt to determine on-tower-limitations of the capabilities of standing workers servicing the Saturn V Vehicle at a firing site on Launch Complex 39. It was determined that horizontal, linear, sinusoidal oscillation-frequencies of 0.33 cps and 0.80 cps were satisfactory samples of the wind conditions that could be expected; likewise the corresponding amplitudes of $\pm$ 6.3 inches and $\pm$ 7 inches.

A search of the technical literature was made for work done on such oscillations. Some such work had been done; however, that work was oriented toward requirements of the automotive and aircraft industries. Consequently, the frequencies and amplitudes investigated were not in the range of interest for this work, the personnel used as subjects were <u>seated</u>--making the results of those studies inapplicable to this work.

For such reasons, this work was done in the form of an experiment using a deck-simulator that reproduced some of the motions known to occur on the servicing platforms of the Saturn V Vehicle at a firing site on Launch-Complex 39. The deck-simulator does not reproduce the ellipsoidal pattern of motion known; yet its capability was considered adequate for this study.

The experiment was done in three tasks at each of the frequencies and amplitudes:

a. Hand-Assembly-Accuracy Test

b. Hand-Probe Steadiness Test

c. Visual Acuity Test

No significant differences were found in the results of the tests at 0.33 cps. But significance decrements of performance appeared at 0.80 cps.

The conclusions are several:

a. The conclusions are tentative only.

b. Precision tasks cannot be done readily at 0.80 cps.

c. More time is needed for tasks that do not require precision.

d. At 0.80 cps, an increase of time does not result in an increase of performance accuracy of precision-tasks.

e. Visual Acuity is lessened at 0.80 cps only when worker-subject is oscillated from shoulder-to-shoulder.

f. At 0.80 cps, workers can not perform tasks requiring two-hand operations.

g. At 0.80 cps, hand-operations requiring precision should be avoided.

h. Performance-time, at 0.80 cps, should be limited to compensate for increased human error from fatigue.

It is recommended that:

a. Further study be made of the ability of the eyes to perceive precise details of objects at 0.80 cps.

b. More exact information on criteria for exposure-duration should be determined.

c. The effects of longer exposure times should be explored.

INTRODUCTION

A Kennedy Space Center (KSC) Technical Report (Ref 1) dealing with the SATURN V Launcher/Umbilical Tower (L/UT) Service Arms at Launch Complex 39 (LC-39) (FIG 1) provides criteria for personnel and maintenance considerations as follows:

"Personnel access into the vehicle will be required from service arms. This access is required for installation, checkout, and maintenance of vehicle components and instrumentation.

The anticipated maximum package weight to be carried across the arms is 200 pounds.

Personnel access to each umbilical carrier will be required for routine and emergency maintenance.

Personnel will not be allowed on the extension platforms during winds greater than 30 knots, <u>except for emergency operations.</u>"**

ACKNOWLEDGEMENT

The authors wish to thank the following people who contributed significantly to the accomplishment of this study: Messrs. F. H. Smith, B. Jacobson, and W. M. Forbis of the George C. Marshall Space Flight Center, Mr. J. B. Downs of Kennedy Space Center and Messrs. P. Woodbury and C. Harvey of Brown Engineering Company.

** Author's Emphasis

Also in the technical report cited above there is an analysis of vehicle and L/UT wind-induced responses during firing-site operations at LC-39. This analysis indicates that the Saturn V will oscillate, bend, and increase in height from the imposition of environmental conditions such as winds, ambient temperatures and percentage of fuels or oxidizers on board.

The study herein deals solely with the effects of exposure to wind-induced oscillations of the vehicle and service platforms on maintenance personnel.

A number of extensible platforms of the L/UT will be attached physically to the vehicle during pre-flight operations at the Merritt Island Launch Area (MILA). This will permit transmission of vehicle-oscillation to work platforms (FIG 2). Extensible work platforms coupled to the skin of the vehicle are designed to track vehicle motion by sliding in and out of the basic service arms. Oscillation 90° to this axis can also be accommodated where necessary. If the two capabilities are combined, full tracking of vehicle motion--irrespective of the axis of the motion--can be done.

The Saturn V vehicle on the L/UT at the firing site at LC-39 will probably respond to wind-conditions as a unimodal reed (Ref 1 & 2). Its oscillation frequency will be 0.33 cycles per second (cps) when fully loaded with fuels and oxidizers and 0.80 cps when in an unloaded condition (Ref 2). Since response is assumed to occur about one oscillation mode, the amplitude of such oscillation can be predicted and will be proportional to the height of the vehicle. The greatest oscillation amplitude will occur at a point (Vehicle Station 4259.426) atop the Launch Escape System (LES). The L/UT provides no personnel access to the LES. The highest point on the Saturn V for access from the L/UT platforms, is the Command Module (CM) of the Apollo Spacecraft.

For the purposes of the experiment, the following were assumed:

(a) Wind condition is 99% wind probability. (38.7 knot steady state, 54.2 knot peak wind velocity) An emergency situation exists and maintenance is required.

(b) Vehicle is either fully fueled or empty. (Frequency of oscillation will be either 0.33 or 0.80 cps.)

(c) Platform upon which men will operate is the CM service-platform. (Vehicle Station 3791.555) Amplitude of oscillation will be $\pm$ 7 inches when at 0.80 cps and $\pm$ 6.3 inches when at 0.33 cps.

The above situation is assumed to be the most severe to which men will be exposed during MILA operations. Should wind velocities approach or exceed the 99% probability condition, ground rules (Ref 3) prescribe that the vehicle and L/UT shall return, if possible, to the shelter of the Vertical Assembly Building (VAB). A model of vehicle-oscillation is presented in FIG 3. Figure 3 is derived from Reference 4.

Assuming (a), (b) and (c) above, the worst frequency and amplitude will be 0.80 cps $\pm$ 7 inches with the vehicle in an unloaded condition. The greatest servicing activity will probably exist when the vehicle is in an unloaded condition. It has been calculated that the acceleration on erect personnel will be 0.45g.

The Human Factors Research Unit (HFRU) of the Layout and Human Engineering Section, Propulsion and Vehicle Engineering Laboratory, (R-P&VE-VSL), was contacted by Kennedy Space Center, Umbilical Arms Section, LO-DE24, for information on human performance decrement expected during the conditions stated. Also requested was specific information on the ability of maintenance-personnel to handle (manipulate) specific Saturn V hardware. This HFRU-study was oriented toward providing general information on gross psychomotor-behavior during exposure to vibration of the magnitude considered. It was thought that it would be safer to explore this route. Information on psychomotor-performance under these conditions was not in the literature; so, it was thought that harm could come to naive personnel if component-handling studies were not begun immediately.

A literature search was done to learn if available information could be used to measure performance decrement resulting from exposure to this vibration.

Hornick, et. al. (Ref 4) investigated the effects of low frequency, high amplitude, whole-body vibration upon human performance. Their study used frequencies of 1.5 to 5.5 cps with intensities of 0.15, 0.25, and 0.35g. These conditions were applied in the horizontal direction (longitudinal and transversely) to seated subjects. Tracking ability, choice-reaction time, foot-pressure constancy, and peripheral vision were affected undesirably. Visual acuity and body-equilibrium were unaffected.

Such information is valuable, but its applicability to the Saturn V system is limited and questionable, because there is no method known to extrapolate from data on seated subjects (S s) to data on standing S s. Saturn V servicing personnel will rarely be seated. Furthermore, the Saturn V, vehicle-oscillation frequency (0.33 to 0.80 cps) will not be as great as that used in the Hornick experiment (1.5 to 5.5 cps) and will produce an intensity of 0.45 g (Ref 2) which is greater than the 0.35g tested by Hornick.

D. L. Parks (Ref 5) reported a subjective evaluation of human reaction to low-frequency vibration. A review of such studies is available (Ref 6). Available also are reviews of vibration experiments such as those of Schaefer (Ref 7), Goldman and Von Gierke (Ref 8) and Ashe (Ref 9). Studies reported in the literature are concerned primarily with frequencies above the 0.33 and 0.80 cps Saturn V frequencies, deal with vibration imposed along the long axis of the human body, usually involve amplitudes much less than 7 inches, and characteristically pertain to seated S s. The reason for this is the goals of such research. Most of these studies deal with questions peculiar to the automotive and aircraft industries.

A typical statement in the area of vibration-research is made by Magid and Coermann:

"The studies discussed in this chapter demonstrate significant mechanical and therefore biological phenomena that last for relatively short periods of time. It has been shown that human beings are adversely affected in the frequency range of 1 to 20 cps and are particularly vulnerable in the range of 1 to 10 cps. Subjective response (including severe pain) and cardiovascular, respiratory, skeletal - muscular, and performance alterations are among the various effects of these extrinsically applied environmental forces. If these noxious forces are to be encountered, the acute and chronic effects on the health of the passenger must be anticipated. These observations are the result of investigations of carefully controlled short-time steady-state sinusoidal vertical vibrations with a specific seating and restraint configuration. It is necessary to extend this work to the study of long-term states, intermittent buffeting, and single repetitive impacts. Also needed is the investigation of combined multidirectional forces with varying seating and restraint systems." (Ref 10)

Finally, available information was not directly applicable to the vibration conditions of the Saturn V vehicle on the launch pad during 99% probability wind-conditions. Original research was needed.

Recognizing that performance (human and hardware) must be evaluated, KSC began to develop and provide equipment which would, at least partially, simulate motions then expected to occur on Saturn V, extensible work-platforms. The equipment was called a Deck Motion Simulator (DMS)(FIGS 4 and 5) and consisted of a platform surrounded by handrails. This platform could move along a single, linear axis. It could travel up to $\pm$ 15 inches, and could track electronic inputs from 0.2 to approximately 1.2 cps (sinusoidal) when loaded with 1000 pounds. Both travel and frequency were infinitely variable along their full range.

Though the simulator was not capable of reproducing the ellipsoidal oscillation expected on the Saturn V system (Ref 11), it was adequate for investigate vibration-inputs not previously studied.

This work was a preliminary attempt to evaluate human performance in restricted, vibrational conditions. This study offers limited applicability to actual, Saturn V, servicing tasks. Yet, it is hoped that the information gained will indicate the direction and advisability of further research.

METHOD

Subjects

Six mechanics, six designers and six engineers volunteered as subjects (S s). All were male employees at the George C. Marshall Space Flight Center (MSFC) and were grouped according to the type of work usually performed. S s ranged in age from 22 years to 39 years. (Mean = 30.6 years) and in height from 5' 9" to 6' 3" (Mean = 5' 11").

Apparatus

a. Deck-Motion Simulator (See FIGS 4 and 5)

The simulator is floor-mounted, electrohydraulically controlled, and capable of $\pm$ 15-inch travel; and continuously variable from 0.2 to 1.2 cps. The platform was constructed by MSFC Test Laboratory. Power supply and control/display were manufactured by Dennison Engineering, Division of American Brake Shoe Company (FIG 6).

b. Device for Steadiness-Test

There is a front plate of aluminum, 1/8-inch thick, with 14 holes (FIG 9). The back plate is solid aluminum and insulated from the front plate with a thin plastic sheet. Electrical circuitry provides feedback to S and measures response by oscillograph (FIG 7, 8, 9, 10).

c. Broken Ring Chart (Visual Acuity Test - Binocular Gap Resolution)

Fifteen vertical columns of rings with 5 rings per column constitute the chart. No columns were alike: breaks were positioned at random (FIG 7).

The largest ring was located at the top of a column; the smallest at the bottom. The outside diameter of the largest ring extended 12.5 degrees of retinal angle at a distance of 30". The outside diameter of each succeeding ring decreased by 2.5 degrees so that the smallest ring provided a visual angle of 2.5 degrees. The gap in each ring was drawn to one-fifth of the outside diameter. Instructions for making these figures are in Reference 12.

d. Device for Nut-and-Bolt-Assembly Task

This device includes:

(1) One Aluminum Angle, 13" long; 4" angle. Four, unevenly positioned, holes were drilled through one side of the angle.

(2) Two, flat, stainless-steel plates, 0.12 inches thick, 13 inches long and 4 inches wide, with holes drilled to match those in the aluminum angle.

(3) Four 0.50-inch nuts and four 0.50-inch bolts 1.50-inch long with eight, matching washers (FIG 9 and 10).

(4) A container for the aluminum angle, plates, nuts, bolts and washers, was placed on the floor of the D.M.S.

e. Two Test Stand Uprights

A test-board mount was interchangeable with either two test-stand board-uprights (FIG 8).

f. Communications

One wire-phone communication system was used for continuous voice-contact between S and E (FIG 6 and 8).

Procedure

S s were asked to read a brief written explanation of the study as an introduction to the situation (Appendix A). The experimenter (E) then read instructions to each S on specific task requirements (Appendix B). Familiarization with the test situation was allowed, with the D.M.S. held stationary. Questions were solicited and answered. Stationary practice was permitted for seven minutes after which S s began actual testing under stationary conditions. After data had been obtained on this base-line trial, S s were familiarized with the oscillations to be expected when the D.M.S. was moving. Such practice continued for another seven minutes--after which a two-minute rest was imposed. Then, a schedule of testing was followed as in Appendix I. This matrix was to negate, as far as possible, effects from fatigue and practice. S s were positioned to receive the oscillation in a chest-to-back or a shoulder-to-shoulder direction. The former direction was arbitrarily termed the 0° direction; the latter, the 90° direction. No other positions were tested. The task-board assembly (FIG 8) was intended to permit rapid relocation--as needed by the sequence of conditions. Relocation was accomplished easily within the two minute rest-periods between trial conditions.

During each vibration condition, S s were required to perform three tasks. The first of these was a nut-and-bolt, hand-assembly operation. Subjects had to do this as stated in Appendix C. Assembly and disassembly were timed by stopwatch. Both operations were scored.

The second task was a steadiness-test (FIG 7). S was required to touch the tip of a probe to a metal reset-plate, to activate the board (a white light flashed on); and then to touch the tip of the probe to a metal plate mounted behind 14 drilled holes (these decreased in diameter progressively). S was to begin at the largest hole, and after each hole, to touch the back-plate; then, return the probe to the reset plate before touching the next smaller hole, etc. The task was done three times while measurement of positioning errors was made by oscillograph. S received continual feedback on accuracy of his performance by use of a system of lights. A red light or a green light flashed--according to whether the probe was touched to the front plate (through which the holes were bored) or to the back plate (Appendix D). Measurement of front-plate, hole-entry touches was accomplished. Other data (performance time and probe withdrawal touches) were obtained but not analyzed.

The third task was intended to evaluate visual acuity. A broken-ring chart was designed to present progressively smaller rings in adjacent vertical columns (FIG 7). The chart, an ink-drawing on fiberglass cloth, was photostatically reduced to appropriate dimensions. The opening or gap in the ring was randomly positioned in an up, down, right or left position. Selection of gap-position was made with the use of a table of random numbers. S reported the position of each gap in three columns selected by E during testing. Each column had five rings. Incorrect responses were recorded by E.

During each rest-period, subjective data (solicited and spontaneous) were recorded by E. Examples of such comments are in Appendix F. Other information on S's instructions and E's procedures throughout testing are in Appendices E, G, and H.

Results

Statistical results are presented in Tables I, II and III and Figures 11, 12 and 13. Appendix J provides a brief explanation of the statistical techniques employed.

Psychomotor (Steadiness) Ability Test

Table Ia. Means
(Holes missed with probe in 42 attempts - each condition)

Group	Condition: 0° & 90° 0 cps	0° 0.33 cps	90° 0.33 cps	0° 0.80 cps	90° 0.80 cps	Mean
Technicians n=6	7.00	8.67	7.00	16.67	14.67	10.80
Engineers n=6	7.83	7.17	7.00	15.67	14.67	10.47
Designers n=6	8.00	7.83	7.83	16.17	17.17	11.40
Mean N = 18	7.61	7.89	7.28	16.17	15.50	

Table Ib. Analysis of Variance

Source	SS	Df.	V	F	Required F .01
Between Groups	13.42	2	6.71	<1	
Between Conditions	1474.22	4	368.56	39.38	3.58
Interaction GXC	27.58	8	3.45	<1	
Within Sets	701.67	75	9.36		
TOTAL	2216.89	89			

Table Ic. Duncan's New Multiple Range Test

	Conditions					Shortest Significant Ranges (.01 level)
	90° 0.33 cps	$0\&90^\circ$ 0 cps	0° 0.33 cps	90° 0.80 cps	0° 0.80 cps	
Means	7.28	7.61	7.89	15.50	16.17	
7.28		0.33	0.61	8.22	8.89	$R_2 = 2.69$
7.61			0.28	7.89	8.56	$R_3 = 2.81$
7.89				7.61	8.28	$R_4 = 2.89$
15.50					0.67	$R_5 = 2.94$

Any two test condition means not underscored by the same line are significantly different.
Any two test condition means underscored by the same line are not significantly different

Nut and Bolt Assembly Test

Table IIa. Means (Time to assemble and disassemble in minutes)

Group	Condition 0° & 90° 0 cps	0° 0.33 cps	90° 0.33 cps	0° 0.80 cps	90° 0.80 cps	Mean
Technicians n=6	3.47	3.27	3.22	4.70	4.21	3.77
Engineers n=6	3.37	3.13	2.85	4.64	4.89	3.78
Designers n=6	3.56	3.41	3.25	4.85	4.64	3.94
Mean N=18	3.47	3.27	3.11	4.73	4.58	

Table IIb. Analysis of Variance

Source	SS	Df	V	F	Required F .01
Between Groups	.56	2	.28	<1	
Between Conditions	41.93	4	10.48	31.76	3.58
Interaction GxC	1.92	8	.24	<1	
Within Sets	25.07	75	.33		
TOTAL	69.48	89			

Table IIc. Duncan's New Multiple Range Test

	Conditions: 90° 0.33 cps	0° 0.33 cps	0+90° 0 cps	90° 0.80 cps	0° 0.80 cps	Shortest Significant Ranges (.01 level)
Means	3.11	3.27	3.47	4.58	4.73	
3.11		0.16	0.36	1.47	1.62	R_2=0.51
3.27			0.20	1.31	1.46	R_3=0.53
3.47				1.11	1.26	R_4=0.54
4.58					0.15	R_5=0.55

Any two test condition means not underscored by the same line are significantly different.
Any two test condition means underscored by the same line are not significantly different.

Table IIIa. Means (Number of C s misjudged)

Visual Acuity Test (Landolt C Gap Eye Chart)

Group	Condition: 0°+90° 0 cps	0° 0.33 cps	90° 0.33 cps	0° 0.80 cps	90° 0.80 cps	Mean
Technicians n=6	3.00	2.50	3.00	3.83	6.17	3.70
Engineers n=6	2.33	2.50	2.17	2.83	4.83	2.93
Designers n=6	3.33	2.33	2.83	4.33	8.50	4.27
Mean N=18	2.89	2.44	2.67	3.67	6.50	

Table IIIb. Analysis of Variance

Source	SS	Df	V	F	Required F .01 level
Between Groups	26.87	2	13.44	2.72	4.90
Between Conditions	200.18	4	50.04	10.13	3.58
Interaction GXC	27.02	8	3.38	<1	
Within Sets	370.83	75	4.94		
TOTAL	624.90	89			

Table IIIc. Duncan's New Multiple Range Test

	Conditions					Shortest Significant Ranges (.01 level)
	0° 0.33 cps	90° 0.33 cps	0° + 90° 0 cps	0° 0.80 cps	90° 0.80 cps	
Means	2.44	2.67	2.89	3.67	6.50	
2.44		0.23	0.45	1.23	4.06	$R_2 = 1.96$
2.67			0.22	1.00	3.83	$R_3 = 2.04$
2.89				0.78	3.61	$R_4 = 2.10$
3.67					2.83	$R_5 = 2.14$

Any two test condition means not underscored by the same line are significantly different.
Any two test condition means underscored by the same line are not significantly different.

DISCUSSION OF RESULTS**

Motion on the Saturn V, extensible work-platforms will not normally be so severe as that employed in this study. However, neither will it be so regular or as easily adjusted to. Therefore, this study has serious limitations in its applicability to servicing of the Saturn V. Until more definitive information is available on the actual oscillation-characteristics, and equipment is available to simulate fully these actual conditions, conclusions drawn from work with the D.M.S. are tentative only.

An ANOVA* (Refs. 13 and 14) was used to test statistically for differences between groups of S s. Personnel servicing the Saturn V and related facilities will be technicians. So it had been planned that the S s used would be technicians. It was not possible, however, to obtain enough technicians. Engineers and Designers were used to increase the number of S s. But, the statistics established that no performance-differences exist between these groups. Therefore, the synthesized results may be used as guidelines for technicians.

Also, the ANOVA* was used to detect differences between the test conditions within each specific task. There was a difference. Duncan's New Multiple Range Test was employed to determine where those differences occurred (Refs. 13 and 14). The results indicated that the oscillation of 0.33 cps at $\pm$ 7 inch travel does not (a) significantly impair psychomotor (steadiness) performance (b) decrease the speed of a relatively complex psychomotor (nut and bolt assembly) task or (c) impair visual acuity. When the frequency was increased to 0.80 cps, there was a significant decrement in the speed of the nut-and-bolt task and a decrement in steadiness ability, irrespective of S position (0° or 90°). The impairment of the psychomotor-steadiness ability--even though S s had as much time available as desired--indicates that precision tasks probably cannot be done readily at the 0.80 cps frequency. Furthermore, the significantly increased time for the nut-and-bolt assembly-task indicates that more time is needed to do psychomotor tasks that do not require precision-abilities. Note that, if a highly

* Analysis of Variance - See Appendix J

** Underlined items are conclusions - for clarity.

precise eye-hand coordination capability is necessary for the performance of a task, that task will probably not be done accurately--even with increased time--when the oscillation frequency is 0.80 cps. Steadiness-test performance-time seemed to increase in proportion to increase of oscillation frequency. Further analysis of this increase was not made.

Visual acuity decreased at 0.80 cps but only if S was positioned in the 90° direction. This is curious. Subjective data usually indicate that lateral oscillation is accommodated more easily than any other. This impression was corroborated by E's experiences with the D.M.S. prior to testing with S s. Accommodation seems to be done by allowing the pelvic region to rotate, while keeping the upper body relatively stationary. However, while this mode of accommodation gives a feeling of "comfort", interference with precise, visual perception occurs. It is not clear why this happens. The ability of the eyes to perceive precisely under these conditions should be investigated more thoroughly.

Each change in position must be accommodated. At the oscillation of 0.80 cps, it seems to be a difficult task to become comfortable; i.e., to accommodate the head and body to the motion (either 0° or 90°), and requires continuing postural adjustment to kinesthetic cues. And after "comfort" is achieved, it is "undesirable" to change position. During performance of the Nut-and-Bolt Assembly-Task, S s came closer to falling than during any other task situation. Each subject had difficulty. He had to bend down to reach an item and then stand erect for task-accomplishment. S s characteristically held-on with one hand (Figure 5). Holding-on consisted of touching the sides of the platform with the fingers of one hand, while reaching for objects with the other hand. In some cases, S s retained a grip on the top handrail for this operation. Perhaps, changing the center of gravity (C.G.) of the body at 0.80 cps induces temporary postural instability. Such instability could be an extreme hazard during Saturn V servicing. Therefore, tasks performed at 0.80 cps requiring S accommodation to continually changing oscillation-direction and body-C.G. should be considered at best a one-hand operation.

Though a significant difference was found in visual acuity, this may not be a critical problem. It is interesting from a psychological point of view and it may interfere with the accomplishment of some reading-tasks. The size of the test figures was so small (FIG 7) that such situations would be rare. In cases when it does happen, it is a simple matter to increase the extended retinal angle by moving closer to the object. The directional dependence of this phenomenon can be offset easily by turning the head or body--or the object--to a more favorable position.

The findings above do not apply to the results of the steadiness-test. At 0.80 cps, it is nearly impossible to do precise, hand-positioning tasks. Task-conditions in this experiment were arranged to permit optimum "steadiness" performance by requiring each S to place his hand directly on the Steadiness-Test front-plate to steady himself. Short-travel finger movements were used to place the probe accurately. It is believed that in following this procedure, responses were as accurate as possible within the motion-conditions. Therefore, operations requiring precise hand-movements in adjusting, positioning, or measuring objects should be avoided.

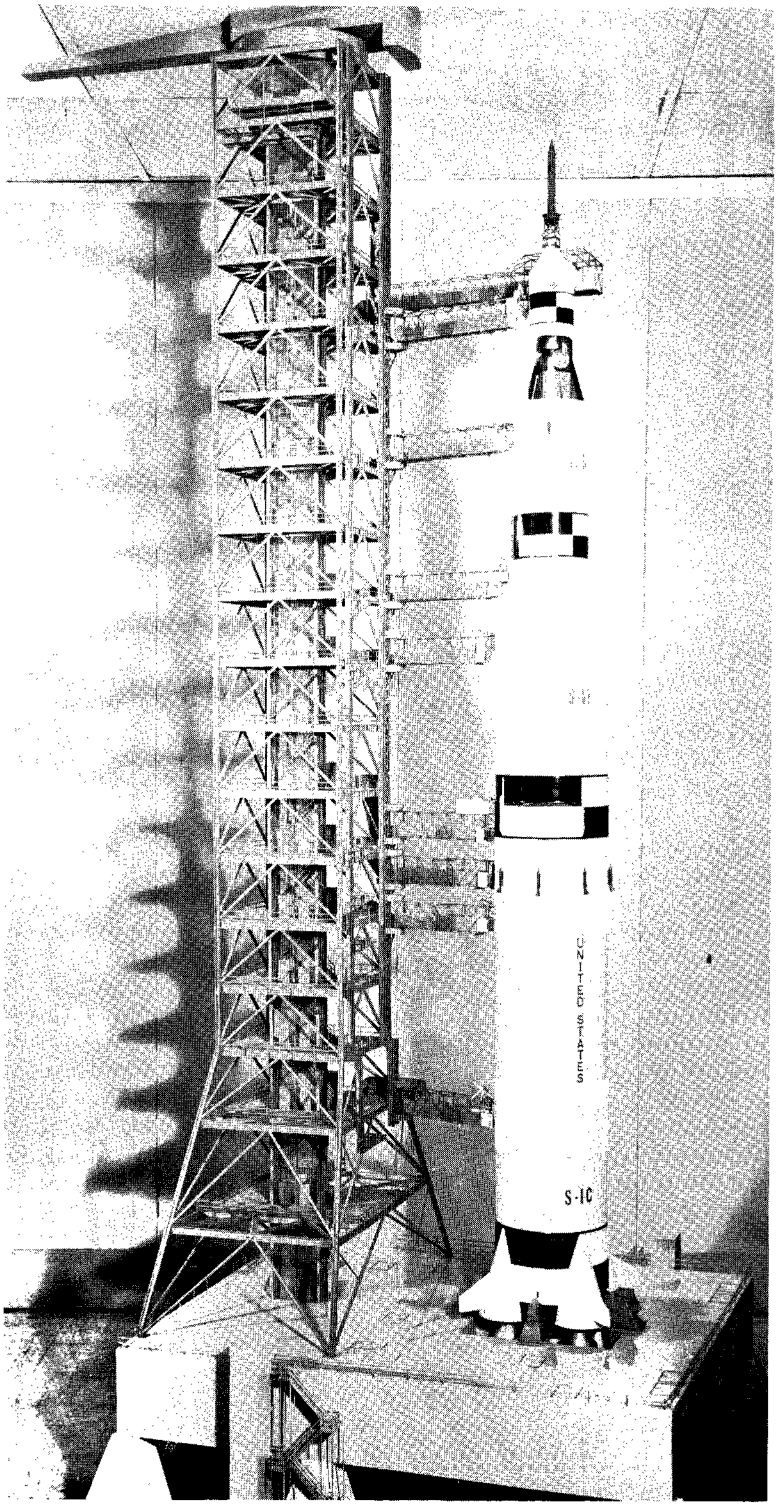
Most S s, after completing the experimental testing, reported that the test situation required more energy expenditure than they had expected. All perspired freely during the testing and some reported frequently that their legs were tired. E s, in preliminary exposures, observed that the continual adjustment to 0.80 cps caused unexpected fatigue. This observation was made before tasks had been devised. E s received the oscillation but did no tasks. So, it may be necessary to shorten performance-time to offset increased probability of human error from fatigue. More precise information on criteria for exposure-duration is unavailable and should be sought.

No information is available from this study on problems of positioning heavy objects (up to 200 pounds), performing complex servicing tasks, moving from stationary (service arm) to moving surfaces (extensible work platforms) or performance-effects of combined oscillation and height.

Simulation of wind-induced oscillations and task-conditions could be made more realistic by modifying the D.M.S. to oscillate on two axes, and by programmed "randomized" oscillation (randomized frequencies and amplitudes).

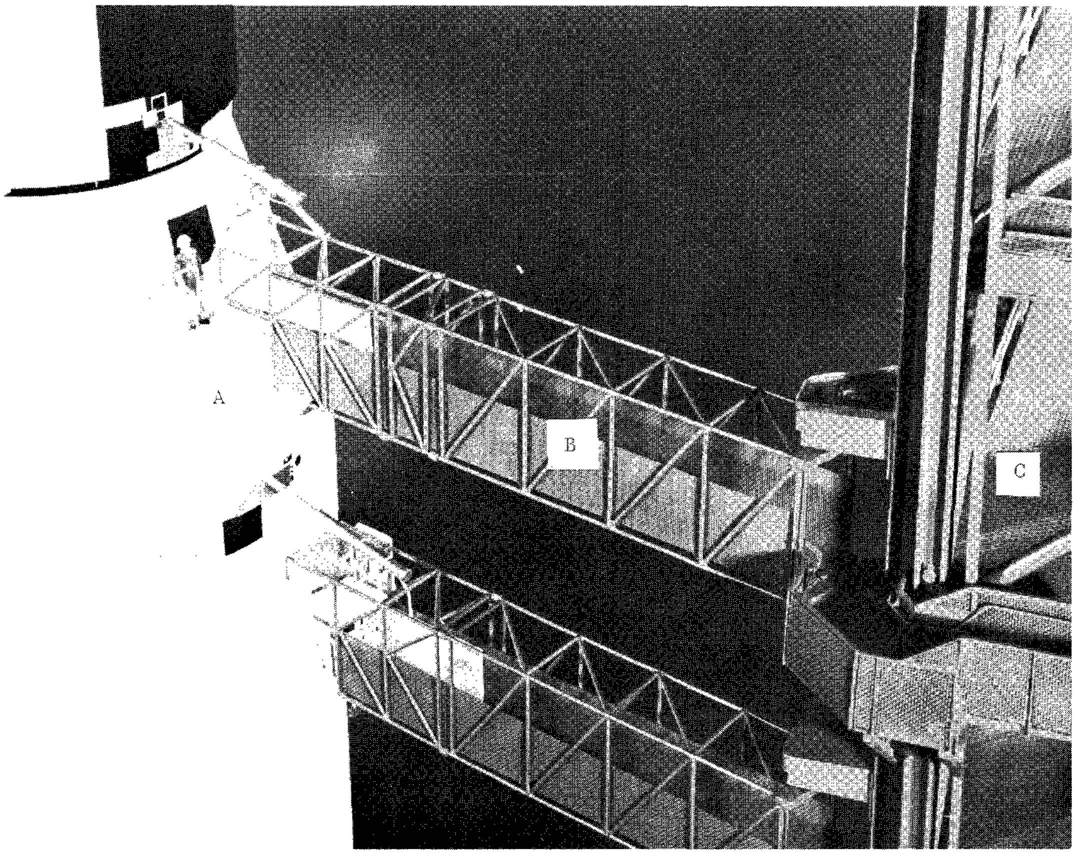
No vertigo or motion sickness was noticed. It had been expected. Two S s who experienced symptoms akin to motion-sickness had histories of ear infection and sensitivity to any, unusual body-motion. But their responses were no more than slight nausea. Measurable disequilibrium was not found. Effects of longer exposure-times should be investigated.

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama, July 5, 1966



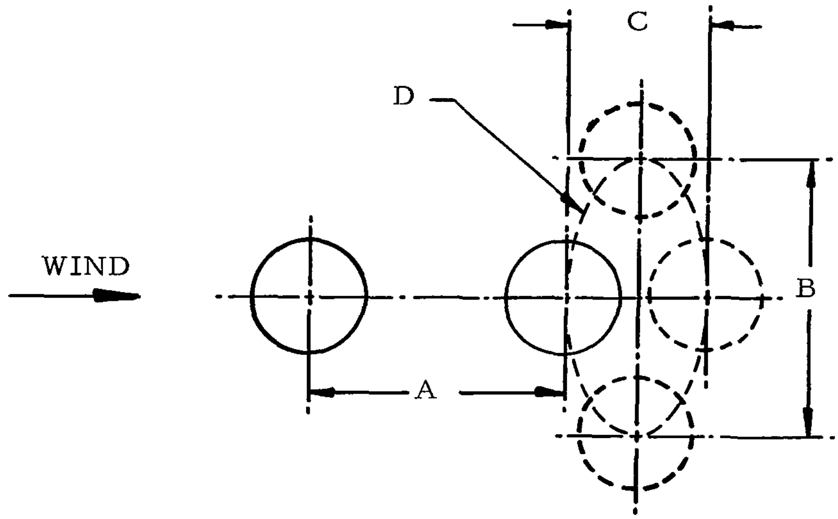
This model depicts the L/UT and the SATURN V as they would appear during servicing operations on a Launch Complex 39 Firing Site.

FIGURE 1. L/UT AND SATURN V



(a) Extensible work platform coupled to the vehicle skin (white structure), (b) Basic service arm leading from L/UT to vehicle and (c) L/UT basic structure. A model of a man can be seen on the work platform.

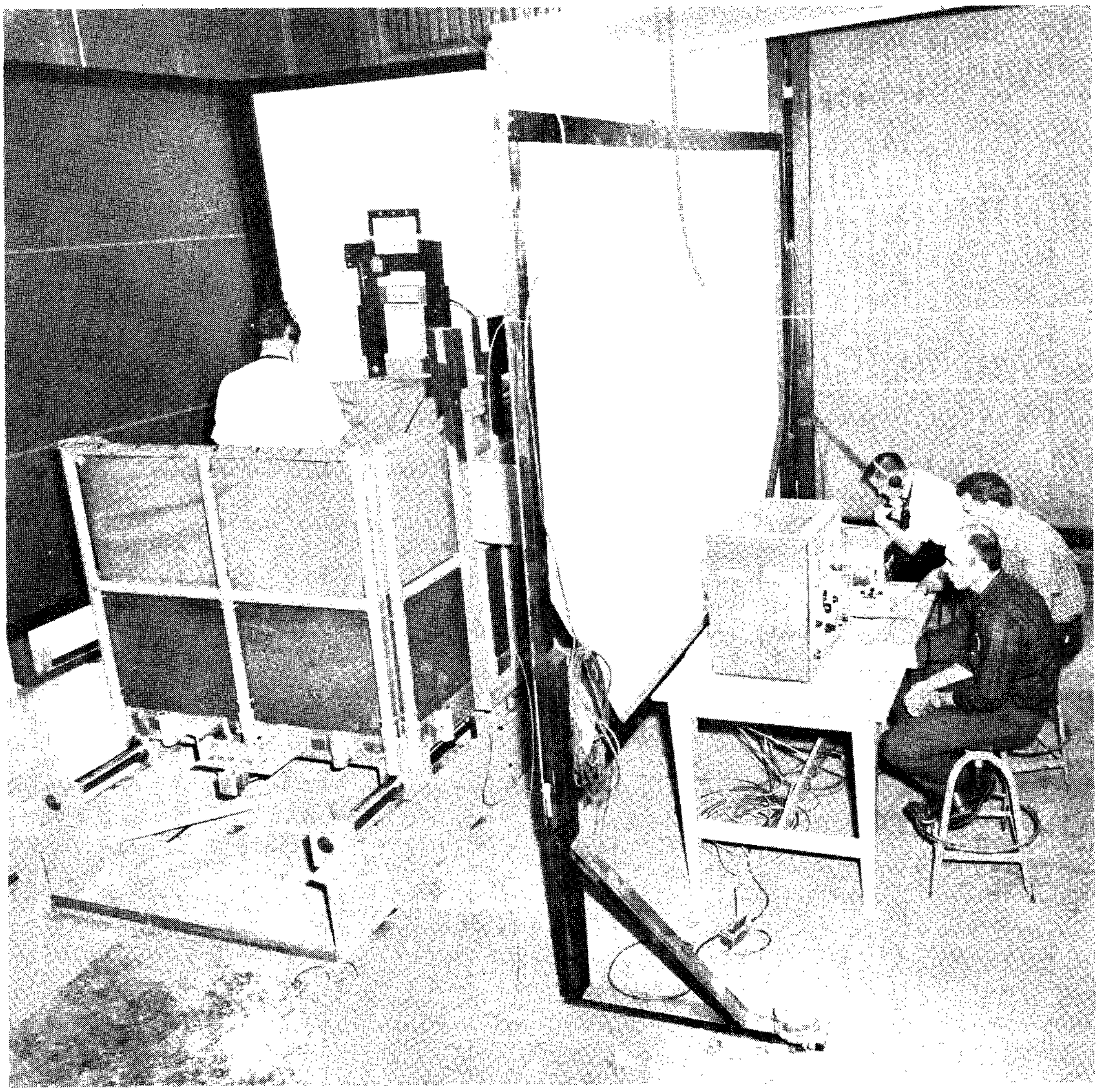
FIGURE 2. SECTION OF MODEL OF L/UT AND SATURN V



A - Deflection due to steady wind
B - Oscillation amplitude due to steady wind (Von Kármán Effect)
C - Deflection due to gusty winds
D - Outer limits of travel

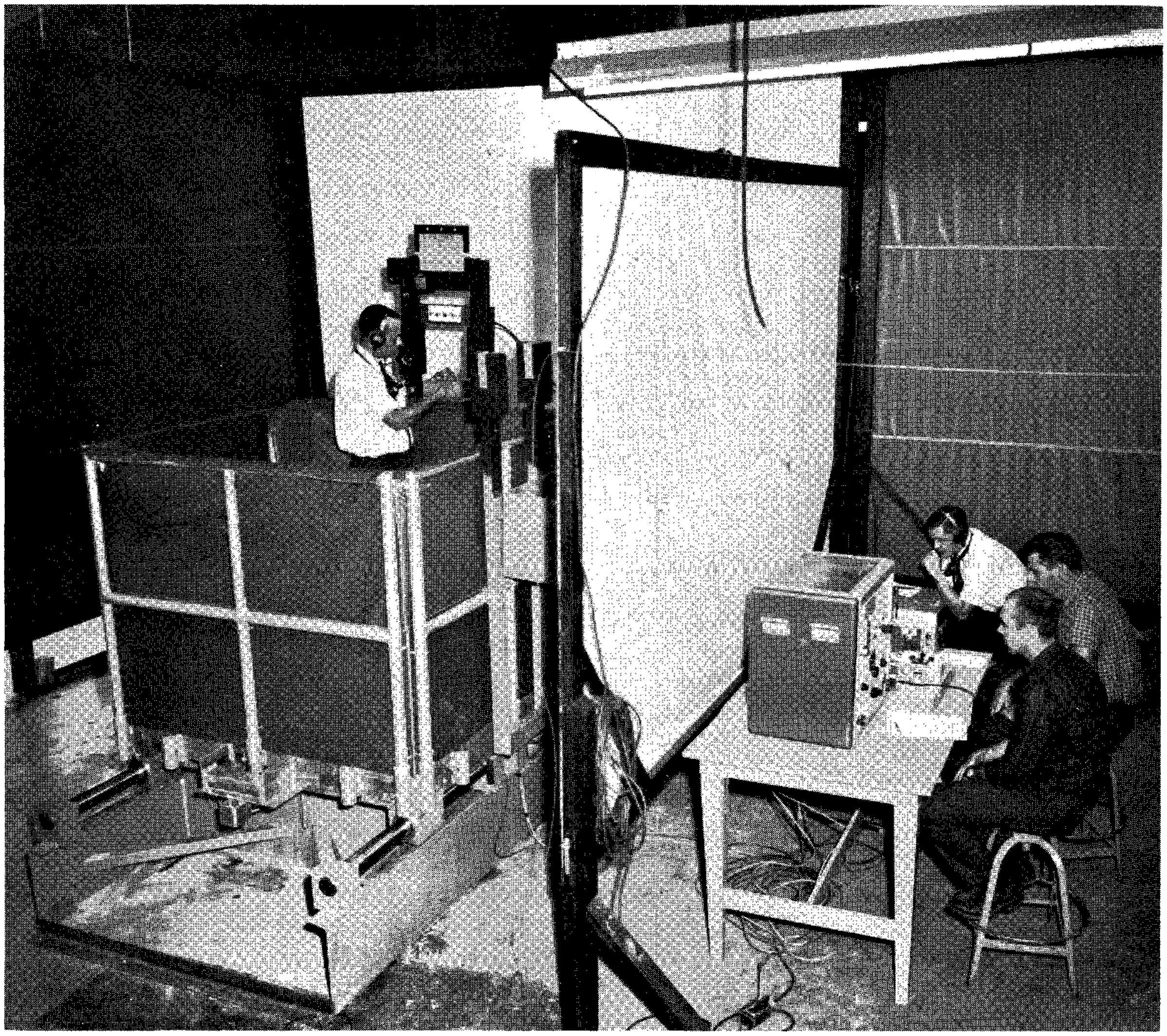
Total horizontal deflection due to combined steady and gusty winds (A+C). The above is expected on the basis of assuming unidirectional wind flow. Motion of vehicle will be linear within D. Directionality of motion will be approximately random. (Ref 11)

FIGURE 3. MODEL OF EXPECTED VEHICLE OSCILLATION



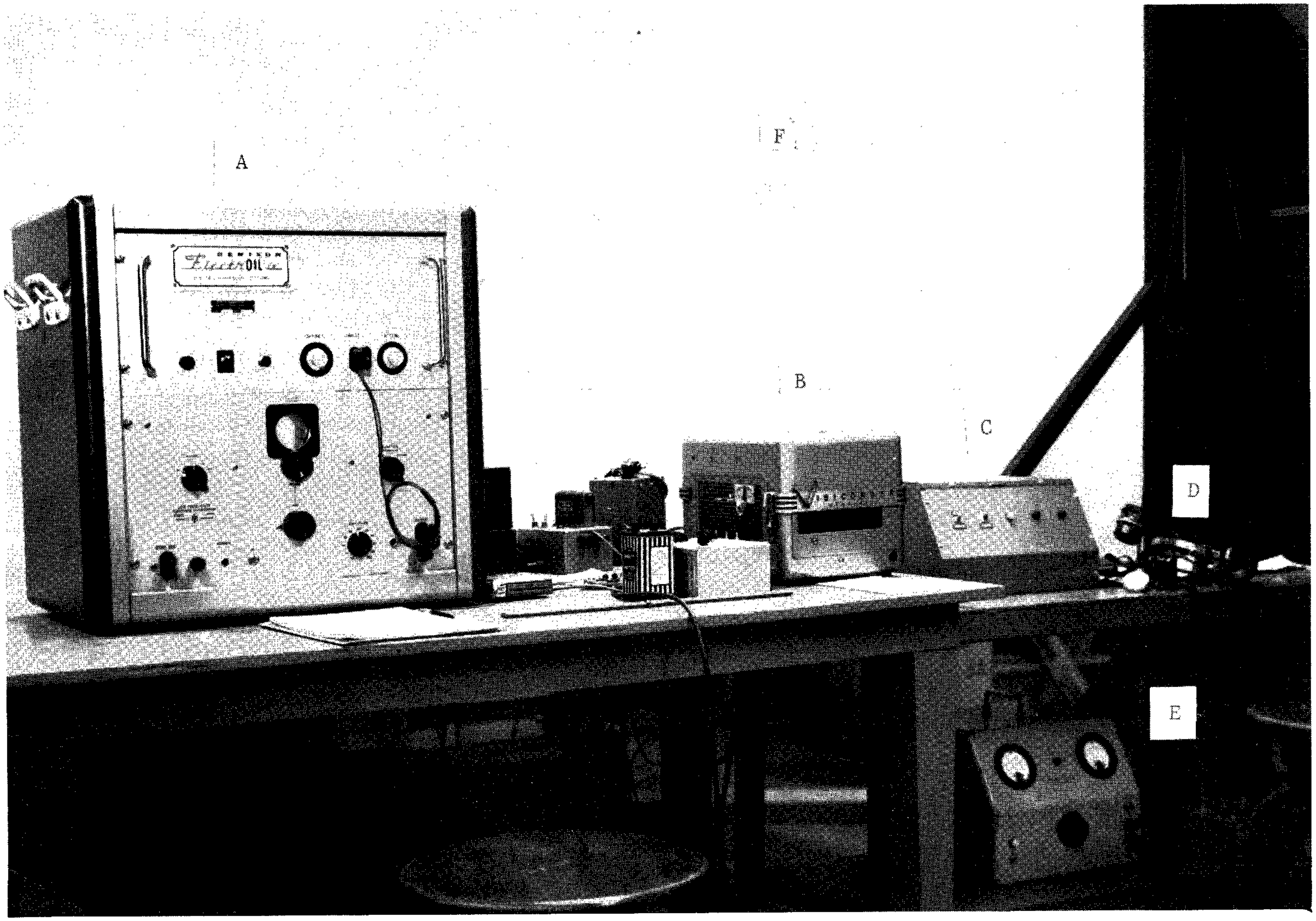
Subject in position for reading visual acuity chart.

FIGURE 4. OVERVIEW OF ENTIRE EXPERIMENTAL AREA



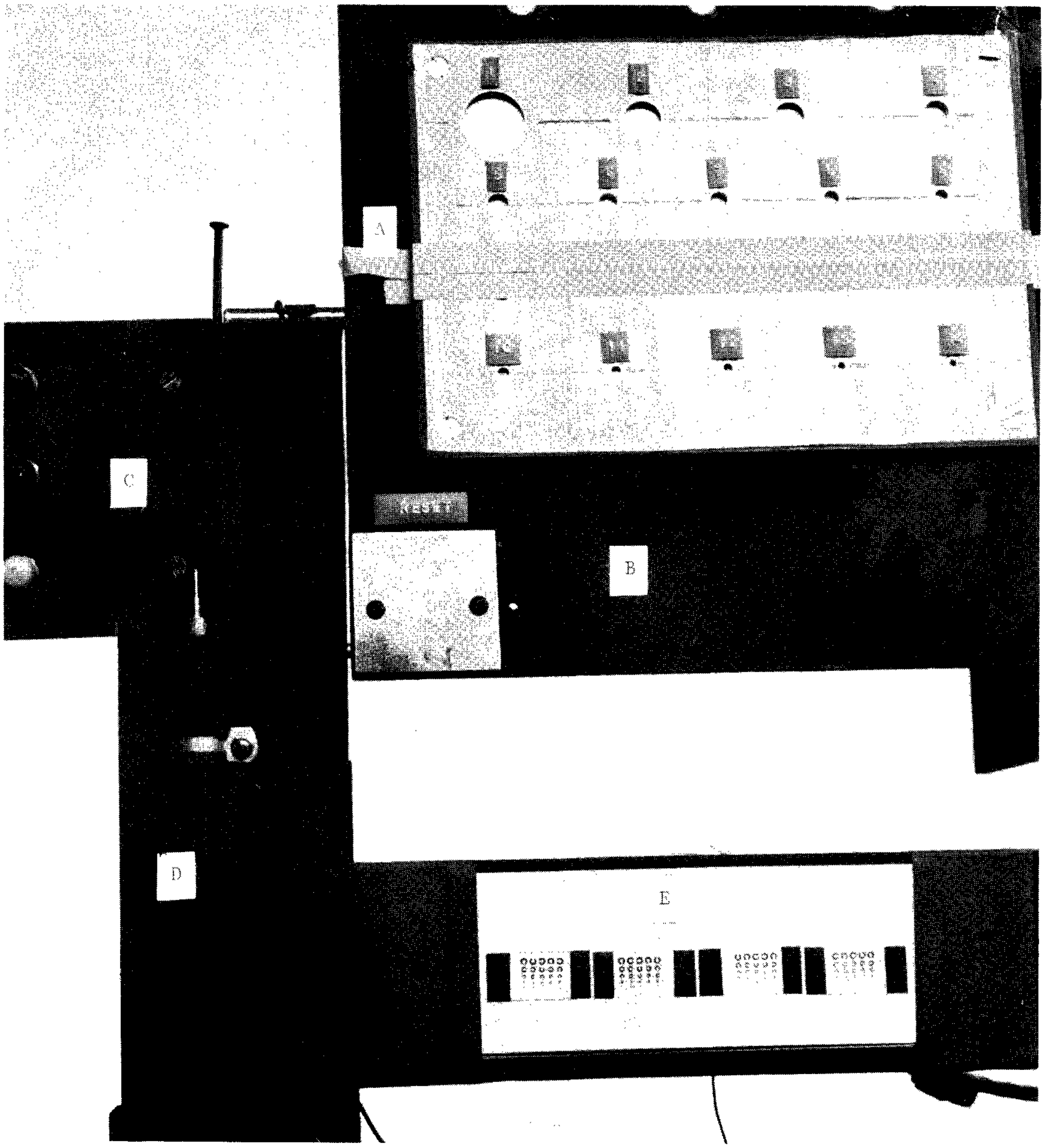
Subject, experimenter and technicians in position for testing. (Note position of subject. This is the preferred stance for nut & bolt assembly task during 0°, 0.80 cps condition. All subjects assumed this mode of operation without instructions.)

FIGURE 5. OVERVIEW OF ENTIRE EXPERIMENTAL AREA



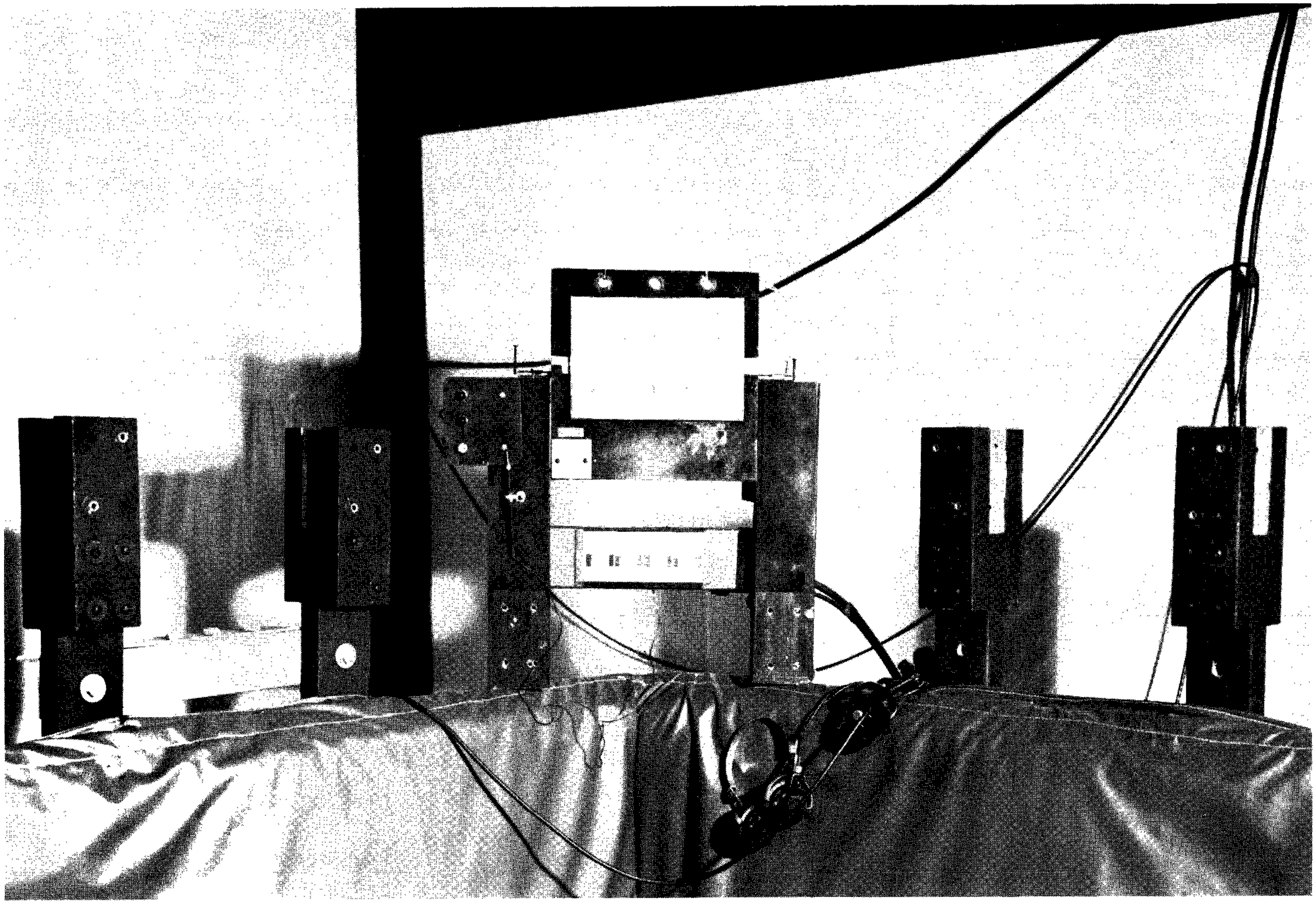
A. Controls for D.M.S., B. Oscillographic Recorder, C. Controls for Steadiness Test, D. Experimenter Communications Head-Set, E. Power Supply for Head Set, F. Slit in screen permitting view of D.M.S. from experimenter's position.

FIGURE 6. INSTRUMENTATION AREA



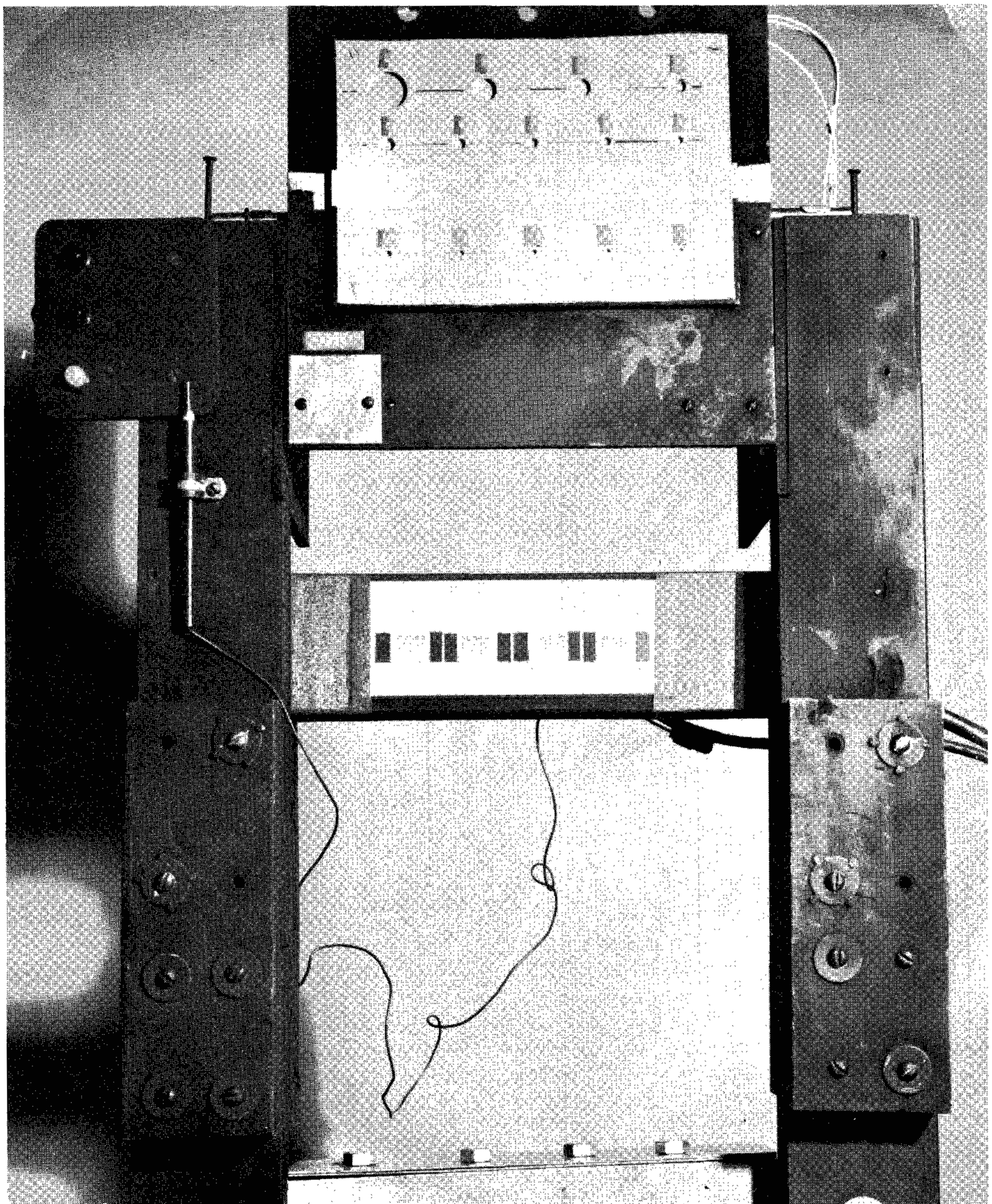
A. Steadiness Test (one row of holes tape covered - it was not used), B. Mounting Board with Reset Plate, C. Light Panel (Top to Bottom - Green, Red, White), D. Steadiness Probe in Receptacle, E. Visual Acuity Chart

FIGURE 7. TASK BOARD



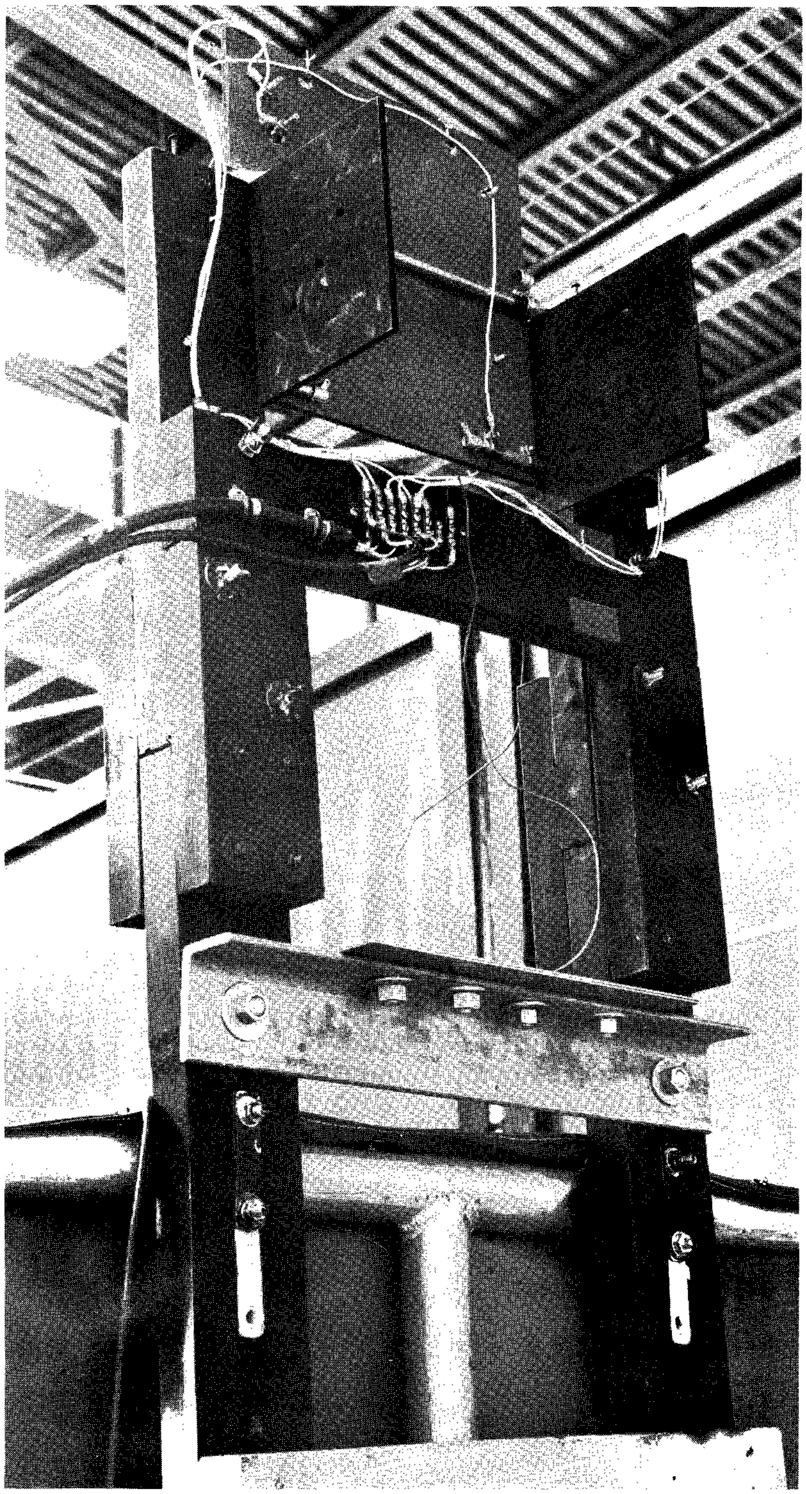
Above the padded handrails of the D. M. S. can be seen the task board (center assembly) and both task board support structures to permit rapid relocation of task board at either the 0° or 90° position during scheduled 2 minute rest periods with the use of wing nuts and bolts. (See Figure 10 for rear view.)

FIGURE 8. RAPID RELOCATION OF TASK BOARD



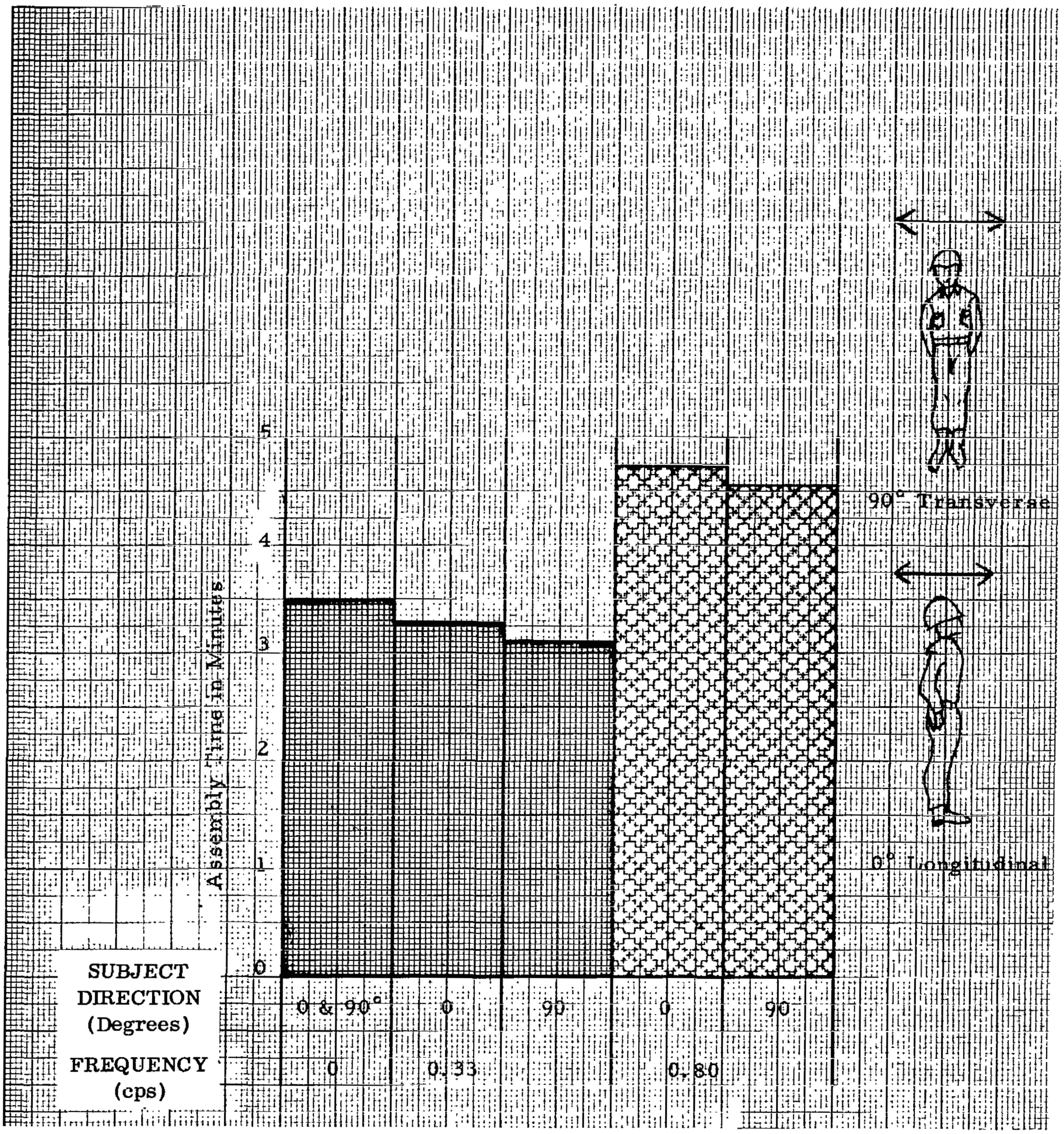
The task board mounted on D. M. S. support structure - nut and bolt assembly task assembled.

FIGURE 9. OVERVIEW OF TASK BOARD



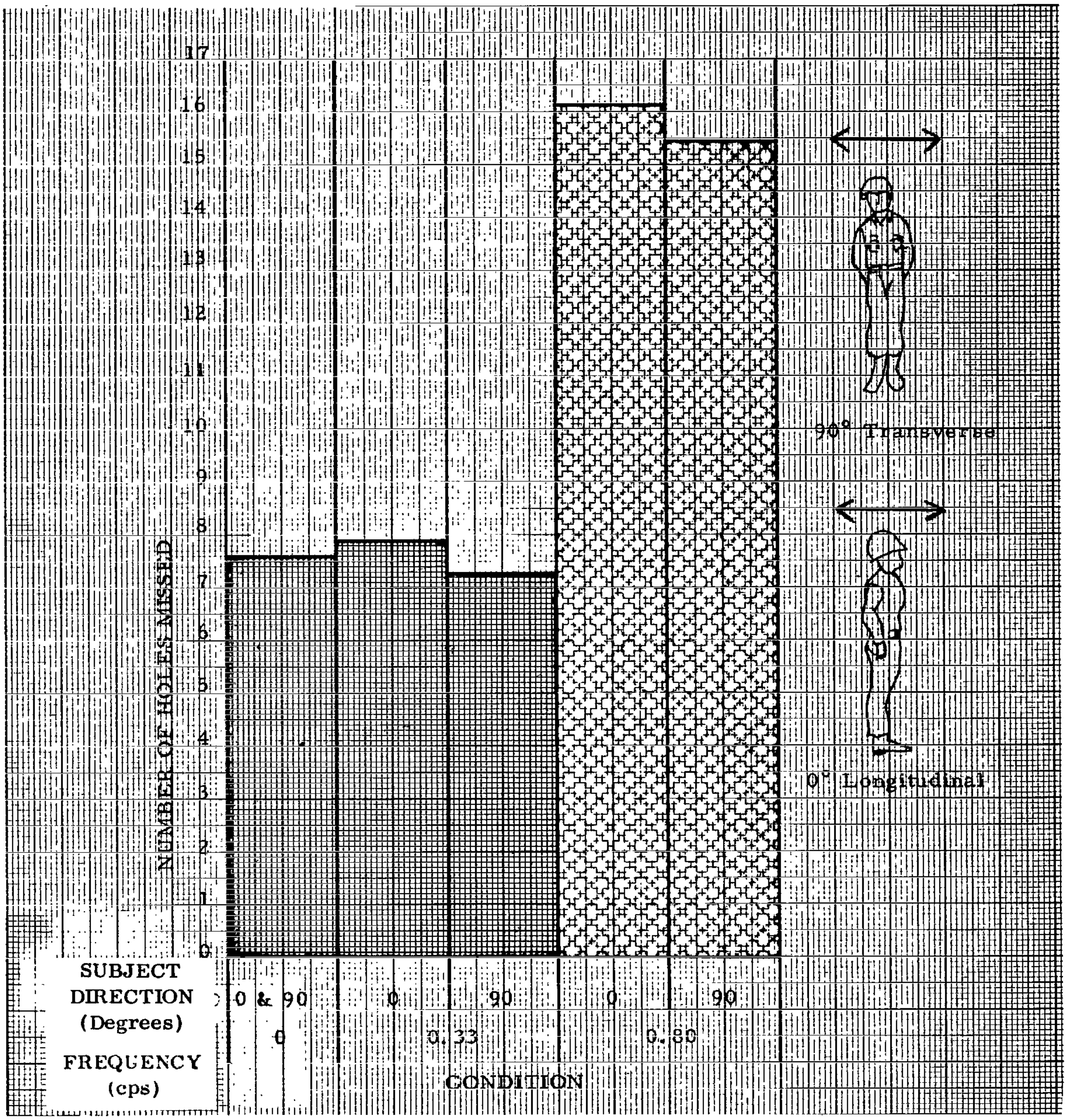
The photograph shows the wiring required to record steadiness test responses, wing nuts on D. M. S. support structures and the nut and bolt assembly. A corrugated carton was mounted below the latter assembly to catch dropped parts.

FIGURE 10. REAR VIEW OF TASK BOARD



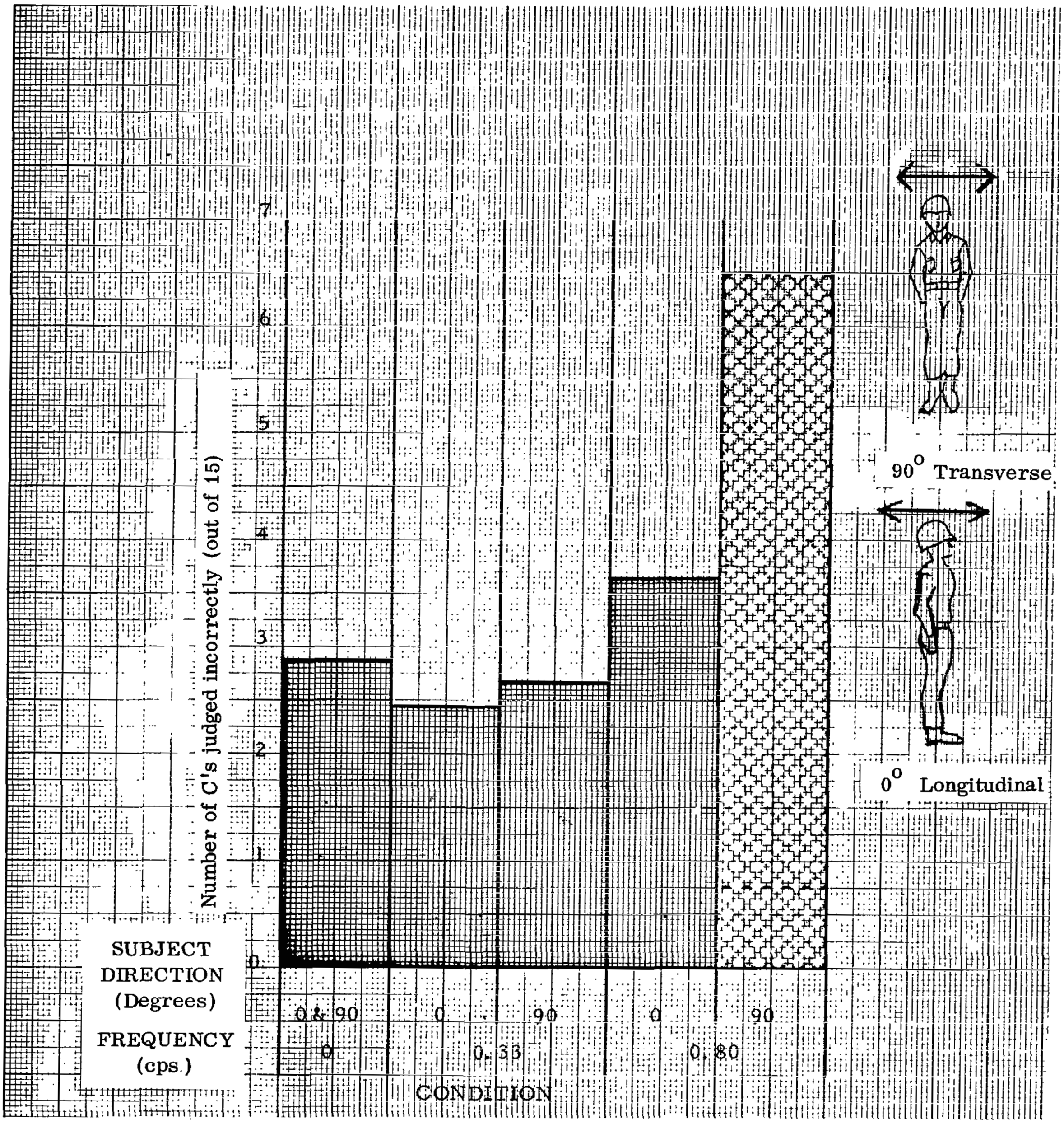
Note: The areas of dissimilar shading are statistically significantly different

FIGURE 11. THE EFFECTS OF OSCILLATION FREQUENCY (AT $\pm$ 7 INCHES TRAVEL) AND SUBJECT DIRECTION UPON A NUT AND BOLT ASSEMBLY TEST AS MEASURED BY TIME TAKEN FOR THE ASSEMBLY AND DISASSEMBLY OF THE PARTS.



Note: The areas of dissimilar shading are statistically significantly different

FIGURE 12. THE EFFECTS OF OSCILLATION FREQUENCY (AT $\pm$ 7 INCHES TRAVEL) AND SUBJECT DIRECTION UPON STEADINESS AS MEASURED BY THE NUMBER OF MISSES WITH A PROBE IN THREE ATTEMPTS AT EACH OF FOURTEEN HOLES.



Note: The areas of dissimilar shading are statistically significantly different

FIGURE 13. THE EFFECTS OF OSCILLATION FREQUENCY (AT $\pm$ 7 INCHES TRAVEL) AND SUBJECT DIRECTION UPON VISUAL ACUITY AS MEASURED BY THE NUMBER OF ERRORS IN READING A LANDOLT C CHART.

APPENDIX A

Introduction - Read By Subject

When the Saturn V is placed on the launch pad at the Cape, it will extend some 400' into the air. Because of gusty wind loads and thermal conditions the vehicle will vibrate or oscillate. The platform on the test stand simulates the oscillations which are expected.

The technicians working on the Saturn V at the Cape must perform their duties while the vehicle is oscillating. We do not, however, know what change in their performance to expect. This situation has never before been encountered. Rather than wait and find out what happens, this test stand has been built to tell us what to expect. Your performance on this test will indicate what precautions are necessary, what jobs can or cannot be accomplished satisfactorily, how much increased job time will be necessary and so on. Therefore, it is important that you do your best throughout the entire test. The measurements made on this test will give information from which task requirements will be designed. If you don't try to do your best or if you give up during the test, the information obtained will not be representative and poor design will result. The measures thereby taken may make us compensate for conditions which do not exist. This would defeat the whole purpose of the test stand and waste time and money.

So please, do your best at all times. If it is your turn to test and you do not feel well please tell me and I will test you some other day.

The oscillations of the platform are not extreme, and will cause you no ill effects. You may stop the experiment at any time however, by telling me you wish to do so.

You will be familiarized with the moving platform and be permitted to practice on the tasks before actual measurements are made.

Your cooperation on this test is appreciated.

APPENDIX B

Instructions Read To Subject

This is the test stand. The platform will oscillate back and forth on these rods. The vibration produced will not be extreme. You should be able to stand with little trouble. In just a moment you will have a chance to practice and familiarize yourself with this vibration. We will start the platform moving slowly and bring it up to test conditions. You will adjust easily.

Step up on the platform with me and I will describe the tasks you are to perform.

You will do these tasks while the board is here and also over there (illustrate the two positions.) You will be tested while stationary and at two different test speeds.

APPENDIX C

Instructions Read To Subject

The first task is a timed nut and bolt assembly test. You must remove this angle iron from this box and bolt it to the 2 x 4 uprights. Here is the sequence: (Illustrate)

1. Pick up the angle iron, a long bolt and a nut and 2 washers.
2. Put the bolt thru the 2 x 4 from the front side (Illustrate which hole) with a washer under the head.
3. Put the angle iron on the back, install a washer and start the nut.
4. Pick up another long bolt, a nut and two washers.
5. Put a washer on the bolt, and put the bolt thru the 2 x 4 and the angle iron, then install a washer and thread the nut.
6. Bring both nuts to finger tightness.
7. Pick up the flat plates, a short nut and bolt and 2 washers.
8. Place the plates in the proper position on top of the angle iron. Install a washer on the bolt and put the bolt thru all three pieces from the top.
9. Install a washer and thread the nut on.
10. Add three more nuts, bolts and washers, tightening all to finger tightness.

11. Say Stop (Experimenter will check that you have properly completed).

12. Reverse sequence - Remove the nuts and bolts.

13. Remove short bolts and nuts and flat plates - Place in basket. Do one bolt at a time.

14. Remove nuts and long bolts one at a time, remove angle iron and place in basket.

15. Say Stop.

NOTE: You will be penalized for nuts not being tight or missing washers.

APPENDIX D

Instructions Read To Subject

The next task is a steadiness test. Notice the test board with the holes in it, and here is a probe (pick up probe). The task is to insert the probe into the hole without touching the sides of the hole. The probe must touch the back plate for a correct score. If this is done satisfactorily a green light will come on (Illustrate). You must touch each hole - progressing from left to right and top to bottom. Before each attempt however, you must reset the equipment by touching the probe to this reset plate. A white light will come on here (Illustrate) when you do this.

After you finish a sequence you will start over and repeat the test until you have completed a total of 3 tests.

(Give subject the probe and tell him:) Try once to touch the back plate thru hole one. You will either get red or green. (If you should touch the side of the hole withdrawing the probe it will not count. The penetration is the task measured.) Now before starting the second hole, touch the reset plate and get the white light. Now, try to touch the back plate again through Hole 2. Withdraw the probe, touch the reset plate and try for the third hole. Touch the reset plate and try hole 4; etc. (Keep repeating until the subject has memorized the sequence.) You must rest your hand (right or left) on the plate but you may not otherwise hold on. Touch nothing with the other hand. (Preliminary testing revealed that this would optimize performance.)

The board is designed so that you cannot be 100% successful. Do not be disappointed if you cannot probe all the holes successfully.

After you have finished the three trials you will tell me over the headset and replace the probe here (Illustrate and point out headset).

APPENDIX E

Test Schedule

3 Minutes	Subject Reads Introduction
5 Minutes	E Reads Instructions to S
2 Minutes	Probe Practice
5 Minutes	Nut and Bolt Assembly Practice (Stationary)
10 Minutes	Stationary Probe. Visual Acuity and Nut and Bolt Base-Line Tests.
7 Minutes	Moving Practice (1 min. probe, 1 min. nut-bolt @ 0.33; 4 min. nut-bolt, 1 min. probe @ 0.80) Task Board at 0° or 90°
2 Minutes	Rest
10 Minutes	Condition 1* - 3 minute orientation 5 minute nut-bolt test 2 minute probe and visual acuity test
2 Minutes	Rest
10 Minutes	Condition 2* - Same as 1

NOTE: TEST TIME OF PROBE AND C TEST ABOUT 3-4 MINUTES.
* As Determined by Sequencing - Appendix I

2 Minutes	Rest (Move Test Board)
10 Minutes	Condition 3* - Same as 1
2 Minutes	Rest
10 Minutes	Condition 4* - Same as 1

1 Hours 20 Minutes - TOTAL TIME

APPENDIX F

Subjective Information: Subjects and Experimenters

UNSOLICITED COMMENTS

1. "The platform motion travel feels as though it moves farther one way than the other."

2. "The C's (Landolt C Gap Chart) floated together."

3. "I wouldn't work at 400 ft. on moving platform."

4. "My legs were tired at the end of test."

5. "This is a lot of work."

6. S had outer ear infection ending 10-16-63 (12 days prior to testing). Reported nausea, and slight dizziness, however, this symptom was common to previous ear infection complaints. S could not report to work on the following day due to continued nausea. (Believed to have been induced by motions tested because of incómplete recovery from illness.)

7. S's reported test to be a "good" one.

8. None reported boredom.

OBSERVATIONS

1. All S's perspired freely at the end of test. Looked worn out.

2. Upon recall for Phase II experimentation most S s would not participate. Reports of "bad back", "flu","too much work without extra pay", etc. (Novelty of test program may have worn off.)

3. All S s had difficulty bending over to pick up parts from floor. When moving at 0.80 cps all held on to do this but none fell.

4. E s found it difficult but not impossible to rise from a sitting position while the platform was moving at 0.80 cps ± 7-inch travel.

5. E's found that riding the platform required a substantial amount of energy expenditure. Legs felt "rubbery" after riding.

6. E's felt some movement after-effects following vibration exposure but could not measure any performance decrement due to these after-effects. Clinical test of equilibrium (Ref 12) attempted immediately after exposure. Criterion satisfactorily met.

7. E's noticed that "riding the platform" was not difficult as long as no tasks were performed.

APPENDIX G

Experimenter's Verbal Instructions
Pretest Procedure

"The next task will test how well you can see. This is a broken ring - or C Chart (Illustrate). Notice it has many Cs on it. The opening in the C however, may be up, down, right, or left (Illustrate). Your task will be to report which way the Cs face. You will stand back here and your feet should not pass this line on the floor. Stand here (Illustrate). You will be told which column of which chart to read. Try column 3 of Chart 1 (Check). You will be given a total of three columns. Do not hang on to anything. Stand erect when platform is not moving. Do not lean forward.

Put the headphones and mike on and we can check them out, while you are practicing.

You will now have two minutes probe practice and five minutes nut and bolt assembly practice with the platform stationary.

Start now with the probe practice. I will tell you when to stop.

(2 Minutes)

Stop (Said over Headphones)

Start Nut and Bolt Practice

Stop

Now we will test you with the platform stationary. This is a measurement.

(See Test)

You will now have moving practice.

I will start the platform moving.

Pick up the probe. Practice.

Stop - Try the nut and bolt test now.

I am increasing the speed.

Continue the nut and bolt test. Remove what you have assembled.

Stop. Try the probe at this speed.

Stop. You will now have a two minute rest. Stay on the platform - Do not sit down.

Start Test Procedure."

APPENDIX H

Test Procedure: Communications Between E and S.

1. Can you hear me? Fine. I hear you. We will start the test now. (Correct any malfunctions in the headsets if necessary.)

2. The platform will start in motion.
The platform is at test speed, - (2 seconds) (Omit this on stationary test)

3. You will now have a 3 minute period to orient yourself to this test condition. Please face the task board. (Omit on stationary test) Center yourself on the platform.

4. It is time to begin the nut and bolt assembly task. Step up to the task board. When I say GO you may pick up a nut, bolt, 2 washers and the angle iron and begin. Say STOP when you finish. READY - GO____________________(STOP)

(Start timer - stop timer)

(Time 5 minutes - If subject finishes before this, instruct him to step back into the center of the platform and wait for the next task. Be sure subject remains facing task board.)

5. The next task is the steadiness test. (You will start with Hole No. 1 and proceed to Hole No. 14 in order. Be sure you try each hole once and once only. Touch the rest board between each try.

Repeat the test three times and say STOP when you finish.

Step up to the task board.

Pick up the probe.

Start the test when you are ready by touching the probe to the reset plate. Begin.

(When S says STOP; tell him to step back into the center of the platform)

6. Step up to the tape mark on the floor. Be sure that neither foot passes the tape mark.

Look at the eye charts

	Chart ________	Column
Read Down	Chart ________	Column
	Chart ________	Column

(If the S finishes before the total sub-test time of 15 minutes, have him wait and keep the platform moving until sub-test period is complete.)

7. You now have a two minute rest. Please remain standing on the platform. (End rest period)

8. Repeat steps 1-7 for a new test condition.

9. Change task board position as required.

10. When all conditions have been tested thank the S for his participation.

Schedule of Task Conditions proceeded as in APPENDIX I.

APPENDIX I

Test Condition Schedule: Counterbalanced Matrix

First Condition		Second Condition		Third Condition		Fourth Condition		Number of Subjects
0°	0.33 cps	0°	0.80 cps	90°	0.33 cps	90°	0.80 cps	3
0°	0.33 cps	0°	0.80 cps	90°	0.80 cps	90°	0.33 cps	2
0°	0.80 cps	0°	0.33 cps	90°	0.33 cps	90°	0.80 cps	2
0°	0.80 cps	0°	0.33 cps	90°	0.80 cps	90°	0.33 cps	2
90°	0.33 cps	0°	0.80 cps	0°	0.33 cps	90°	0.80 cps	3
90°	0.33 cps	0°	0.80 cps	0°	0.80 cps	90°	0.33 cps	2
90°	0.80 cps	0°	0.33 cps	90°	0.33 cps	0°	0.80 cps	2
90°	0.80 cps	0°	0.33 cps	90°	0.80 cps	0°	0.33 cps	2

APPENDIX J

Results - Statistical Discussion

The averages reported in the results vary among the test conditions. Some variation is expected on the basis of chance alone; some variation is due to test conditions. It is necessary to determine the amount of variation due to chance, in order to discover the amount of variation resulting from test conditions. The probability of chance occurrences is calculated using mathematical probability models. E usually chooses a "confidence level" thereby setting limits or criteria for acceptance of data as "real" or resulting from chance. Es in this study chose the 0.01 confidence level. Thus, we say that had these measurements been made 100 times, according to the theory of probability, we would expect resulting variational differences to be the same or greater only once. E is therefore gambling that data of this magnitude will not occur, in the long run, on the basis of chance alone and data is accepted as "real" or "significant."

The Analysis of Variance (ANOVA) is used to determine whether or not there are any significant differences between obtained test averages. A two-way classification was used in this experiment. One classification was Ss and the other was Experimental Conditions. The groups of Ss did not differ significantly in performance scores on any of the test conditions. The ANOVA of the Experimental Conditions supports the contention that there are significant performance differences depending upon oscillation condition tested.

After determining that there were significant differences between performance scores, it was necessary to decide just where these differences lay. Duncan's New Multiple Range Test was used to provide that information. The confidence level selected for use in conjunction with this procedure was again 0.01.

For a more comprehensive discussion of these and other statistical techniques, see references 13 and 14.

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