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# PRELIMINARY STUDY OF DIAL READING PERFORMANCE DURING SUSTAINED ACCELERATION AND VIBRATION

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## FOREWORD

Because of similar operational requirements, the study presented here was conducted jointly by the National Aeronautics and Space Administration and the Air Force. Within NASA, the participation centers were the Manned Spacecraft Center, Houston, Texas; and the Ames Research Center, Moffett Field, California. The Aerospace Medical Research Laboratories was the participating organization from the Air Force. The AMRL portion of the effort was conducted under Project 7231, Biomechanics of Aerospace Operations, Task 723101, Effects of Vibration and Impact; and was partially funded by NASA-Defense PR R-58. The studies were conducted using the Ames Five Degree of Freedom Simulator modified for this purpose. The subjects and medical monitors were furnished by AMRL. The dial reading task was employed for vibration studies by the Cornell Aeronautical Laboratory, Inc., Buffalo, New York, under contract AF 33(657)-11729. This work was done during the period between March and August of 1963.

The authors are indebted to the staff of the Analog and Flight Simulator Branch and the Simulator and Systems Service Branch at the Ames Research Center for the excellent assistance given in operation of the five-degree simulator and associated equipment. Mr. James W. Brinkley, Vibration and Impact Branch, Aerospace Medical Research Laboratories, designed and supervised fabrication of the seat and restraint system. Our appreciation is extended to the volunteer subjects who were Air Force officers stationed at Wright-Patterson AFB, Ohio.

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This technical report has been reviewed and is approved.

J. W. HEIM, PhD  
Technical Director  
Biophysics Laboratory

**A  
M  
R  
L** *commander's  
fund*

## ABSTRACT

Booster induced spacecraft vibrations occur in combination with booster induced sustained acceleration. This was a joint NASA-AF study to provide a preliminary cursory evaluation of the effects of this environment on crewmen. Six subjects were used in 60 tests to measure the decrement in dial reading ability as a function of the level of 11 cps  $g_x$  vibration and the size of the dial, where a bias acceleration of  $3.85 G_x$  was superimposed on the vibration. Dial reading errors were inversely related to the arc length of the interval between dials and directly related to the amplitude of vibration. There was approximately 50% distortion of the 11 cps vibration acceleration, which markedly influences the interpretation of results and their comparison to measurements of visual decrements from 11 cps vibrations with  $1G_x$  bias loads. In most general terms, however, the  $3.85G_x$  bias, and/or the unidirectional force (i. e., the resultant acceleration was always greater than 0 G) creates a subjectively more tolerable environment than with a 1 G bias. Vibrations of  $3.85G_x \pm 3.0g_x$  were without serious subjective effects in exposures of 90 seconds duration. Gross comparisons of dial reading performance under the two conditions provide some indication that the greater bias acceleration is associated with less visual decrement.

## SECTION I

### INTRODUCTION

Booster motors are major sources of vibrations in aerospace vehicles, as the size of the booster increases, the frequency of vibration produced tends to decrease. The booster motor vibration is superimposed on the sustained boost acceleration, producing an environment of concern in terms of effect on the crewmen. This is particularly so when the energy at frequencies less than 20 cps is significant. The effects of vibration, alone, in the X-, Y- and Z-axes of the type expected for aerospace flight have been documented rather extensively (ref<sup>s</sup> 6,7), but no studies have been done on the effect of the combination of sustained acceleration and the vibration incident to booster burning.

The purpose of this effort was twofold: (1) to explore in a timely and, therefore, cursory way the subjective response to the combination of sustained acceleration and vibration and (2) to make objective measurements of the effect of this environment on visual ability in a dial reading task. The task chosen was one which had been previously employed to measure the effects of vibration alone (ref 6) on vision, thereby permitting a general comparison (with recognized limitations) between the decrement produced by vibration and by vibration plus sustained acceleration.

The present study provides results of only limited applicability and must be regarded as preliminary because of the harmonic distortion in the vibration produced. Nonetheless, this represents the first information obtained about the effects of an operational environment.

## SECTION II

### METHOD

For these tests, the Ames Five Degree Simulator was used as a centrifuge to produce the sustained bias acceleration of  $3.85 G_x$ . A specially made hydraulic vibration device was used to produce vibrations at 11 cycles per second, a frequency of current operational interest. This device utilized a hydraulic serve to produce translational motion along the axis of the vector resulting from the force of gravity and the centrifugal force. The subject was oriented facing the center of rotation so that there was a 98.5 degree forward inclination of his head and torso with respect to the resultant acceleration vector. To reduce the magnitude of oscillatory loads into the centrifuge arm, a counterbalancing weight was moved in the direction opposite the payload. A hydraulic pump near the rotational axis of the radial arm supplied fluid to a vertically mounted cylinder which produced the seat motion through toggle linkage. This toggle linkage also provided for movement of the counterweight.

Recordings of the accelerations of the chair showed that the 11 cps acceleration was combined with higher frequency components presumably resulting from the wheels that roll on the circular rail, from a small amount of play in the seat driving mechanism, resonance of the seat, and inputs from the centrifuge drive mechanism. To determine the magnitude of the higher frequencies superimposed on the 11 cps fundamental, an analysis of the  $g_x$  chair wave form was made. A dc Analog Power and Cross Power Spectrum Analyzer was used to determine the power content in the frequency range from 1 to 140 cps with a bandwidth of  $\pm 7.95$  cps. The spectrum analysis is accurate to within  $\pm 5$  percent. Although a negligible amount of power was present at various other frequencies in the range analyzed, the 11, 33, and 55 cps power accounted for 95 percent of the total power. No attempt was made to determine the phasing of these frequencies. Figure 1 indicates the frequency content of the vibration at various amplitudes of the 11 cps fundamental.

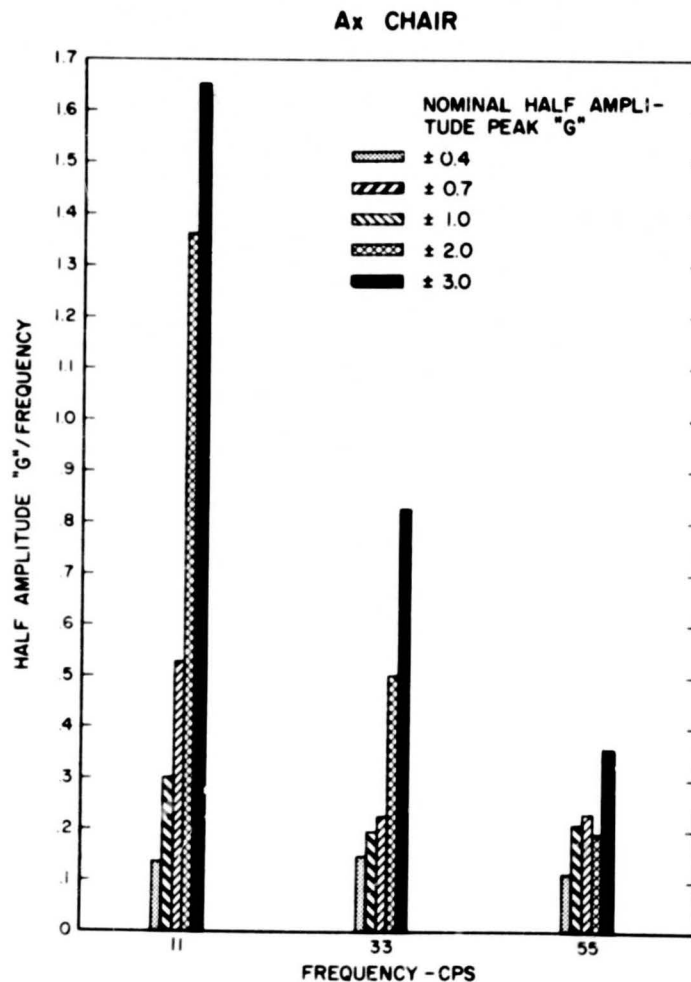


FIGURE 1. POWER DENSITY SPECTRUM OF VIBRATION INPUT ACCELERATION

This figure shows, for instance, that an acceleration of  $+ 3.0 g_x$  contained third and fifth harmonics which comprised approximately 45% of the input signal. In other words, where the vibration amplitude was  $+ 3.0 g_x$ , the 11 cycles per second component was only  $\pm 1.65 g_x$ .

The sheet aluminum seat was essentially rigid at the vibration frequencies studied. No personnel cushioning was used. The instrument panel was rigidly attached to the seat structure. There was a negligible phase shift between accelerometer readings taken at 11 cycles per second on the panel and seat. Measurements of acceleration in the Y- and Z-axes showed cross axis coupling of 0.16 g or less (single amplitude) on the seat and instrument panel.

A B-5 restraint harness was used (figure 2). Thigh straps were used to couple the legs to the seat pan. Subjects wore a Mercury full pressure suit helmet with appropriate size liner for individual fit.

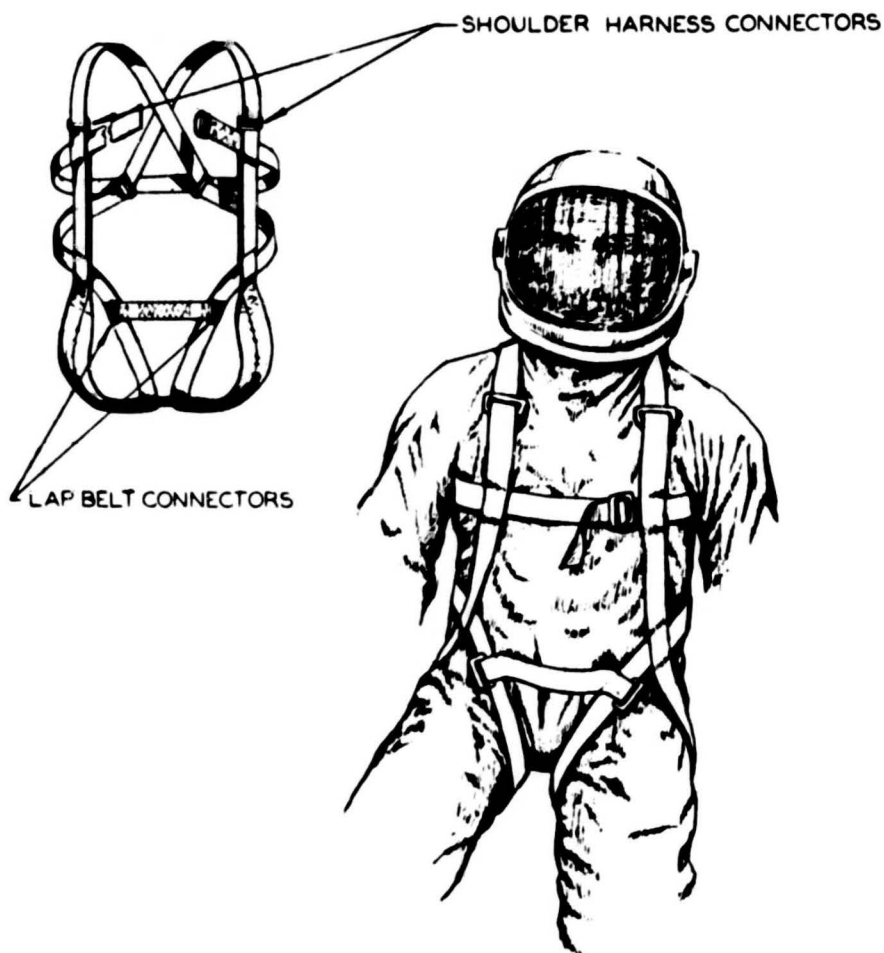


Figure 2. B-5 Restraint Harness Utilized in Conjunction with Mercury Full Pressure Suit Helmet

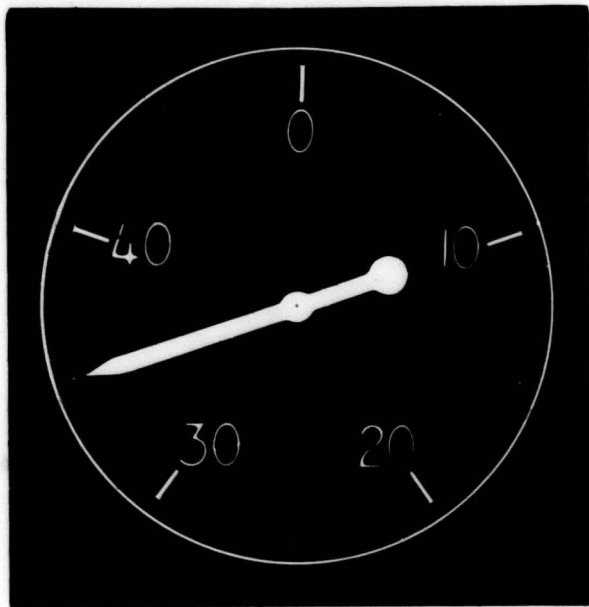
A Navy Mark IV pressure suit communication system was used. The helmet was attached to the standard neck ring which was in turn attached by straps from around the subjects torso. Balsa wood seat inserts were used to adjust the eye height to the instrument panel angle for the range of subjects seated height.

All subjects had a prior class III physical examination, double Masters electrocardiogram and complete skull and spine radiographs. Medical monitoring was done by continuous video display of the subjects face and "hot" microphone voice communication. Facial expressions were not significantly obscured by the vibration. ECG leads I and III were recorded. A frontal plane vectorcardiogram was recorded as magnitude and phase angle, and the vector loop was displayed on an oscilloscope. A Corbin-Farnsworth pulse transducer was attached to the fossa of the helix of the subjects left ear. An accelerometer sensitive to X-axis loads was firmly attached by the restraint system to the mid sternal area. ECG traces were frequently obscured during the higher levels of vibration, but heart rate could always be determined by the (QRS) wave in lead I. The recording of ear pulse remained undistorted during vibration and also served as a reliable index of pulse rate.

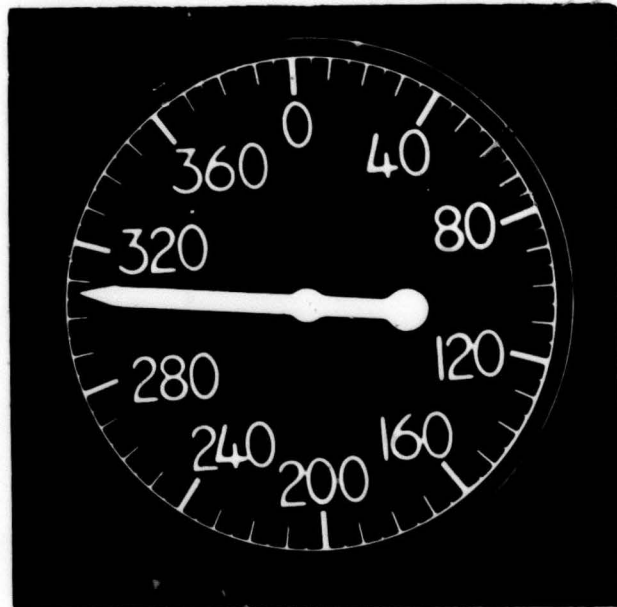
In initial tests, the gross subjective responses to this new environment were explored by setting the bias acceleration at  $3.85 G_x$  and gradually increasing the level of vibration at 11 cycles per second in incremental steps (separate exposures) until the acceleration (as recorded) of  $\pm 3.0 g_x$  had been reached and subjectively evaluated for exposures lasting up to  $\times 90$  seconds. These tests were run to obtain information to apply to experimental design for the subsequent visual studies and to seek tolerance limiting symptoms and levels. In these initial evaluations, the experimenters took part in 5-7 tests with approximately 3 to 5 minutes rest between tests.

The dial reading task, which was used to assess decrements in visual performance, consisted of static displays of 12 circular aircraft instrument dials with black backgrounds and white markers and numerals. Similar dial reading tasks have previously been used in studies without vibration (ref 3), in centrifuge studies (ref 8) and in vibration studies with a  $1 G_x$  bias (ref 6). Each panel was 28 x 34.3 cm and contained 12 dials ranged in a 3 by 4 matrix. All dials were 7.1 cm in diameter. Two types of dials were used to investigate the effects of difficulty of dial reading tasks (figure 3). The dials for the easy task had a range from 0 to 50 with minor markers at units of 5 and major markers and numbers at units of 10. The arc length of the interval between markers was 2.235 cm. The dials for the difficult task had a range of from 0 to 400 with minor markers at units of 5, intermediate markers at units of 10 and major markers with numbers at units of 40. The arc length of the interval between markers was 0.279 cm.

All panels were mounted on plywood for use in a 46 by 38 by 9.5 cm display box. The panels were clamped on the back of the box to permit viewing through a front window which became transparent when the interior of the box was illuminated. The distance between the subject's eye and the dial panel was approximately 53 cm, while the angle of sight through the



**50 RANGE = EASY DIAL**



**400 RANGE = DIFFICULT DIAL**

**FIGURE 3. SAMPLES OF THE TWO TYPES OF DIALS USED**

center of the panel box was  $16.5^\circ$  below normal line of vision (figure 4). The illumination at the surface of the glass of the display box was 34 foot candles; at the eye, it was four foot candles.

Each of the six subjects performed in five vibration conditions with each of two dials. The vibration levels (combined in each case with the  $3.85 G_x$  bias) were  $\pm 1.2 g_x$ ,  $\pm 1.6 g_x$ ,  $\pm 2.0 g_x$ ,  $\pm 2.4 g_x$ , and  $3.0 g_x$  for the easy dial (50 by 5) and  $\pm 0.8 g_x$ ,  $\pm 1.2 g_x$ ,  $\pm 1.6 g_x$ ,  $\pm 2.0 g_x$ , and  $\pm 2.4 g_x$  for the difficult dial (400 by 5). Thus, there are three overlapping vibration conditions that may be used for comparing performance on the two dial tasks. A complete range of identical conditions was not employed since the preliminary tests indicated that performance on the easy task would not be affected at low levels of vibration, while performance with the difficult task might be impossible with maximum vibration levels. The accelerations given here represent readings of peak values from the raw data and involve harmonic distortion indicated in figure 1. The bias acceleration from the centrifuge was always greater than the vibration acceleration by at least  $0.5 G_x$ . This condition was dictated by equipment safety considerations rather than by choice in experimental design.

To control for possible learning or residual fatigue effects, half of the subjects completed all trials with the easy dial before performing with the difficult dial, while the other half performed in the reverse order. Further

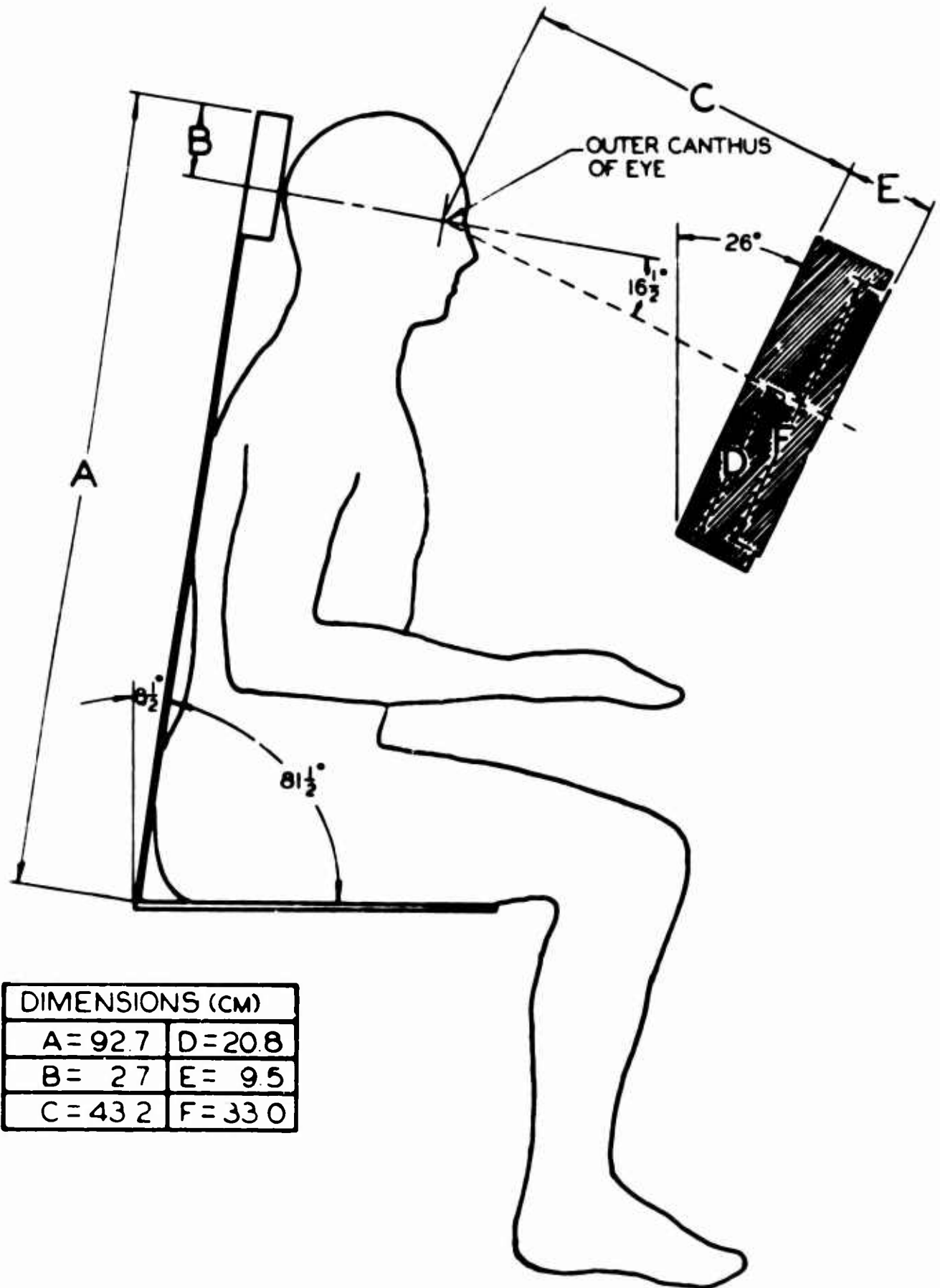


FIGURE 4. GEOMETRY OF SUBJECT - SEAT - DISPLAY RELATIONSHIPS

controls were implemented within each of the dial reading tasks by randomly assigning the order of vibration exposures in which each subject performed.

Each subject prior to his initial experience with this study had received at least five indoctrination exposures under varying combinations of vibration and  $3.85 G_x$  bias acceleration. Most subjects had experienced the physical symptoms characteristic of their own limit of tolerance under  $1 G_x \pm ng_x$  vibrations. One subject had previous experience with the dial reading task. Each subject received three practice sessions. In the first practice session, subjects received the general overview of the conditions of the experiment and initial practice with each type of dial. The second and third training sessions consisted of practice with the dial reading task, using the actual support system and panel box. During all three practice sessions the accuracy of the readings was stressed rather than the time for each of the responses. To aid in improving accuracy during practice, subjects were provided with feedback when an error was made.

Following the three days of practice, each subject performed for two consecutive days of tests. Five vibration exposures were given on each of the days. In each test trial, the lights of the box were turned on only after the  $3.85 G$  bias acceleration and pre selected vibration level had been reached. All subjects were required to begin reading as soon as the panel was illuminated, to read all 12 dials as accurately as possible, and to signal for the termination of the stress condition immediately upon completion. In all cases, subjects were required to read the dials to the nearest whole unit and to interpolate when necessary. The procedure for each experimental condition was as follows: (a) restraining the subject in the couch, (b) two appropriate practice trials without vibration, (c) a control test without vibration, (d) five experimental runs with vibration and sustained acceleration.

### SECTION III

#### RESULTS AND DISCUSSION

Subjective comparison of the test environment with the  $1 G_x \pm ng_x$  condition is subject to considerable reservation, since the vibration produced in the present study had such a large harmonic distortion. In actuality, this distortion prevents comparison of even subjective feelings about the severity of the two environments except on a gross scale. With these severe restrictions on the interpretation, the subjects general statements were that the motion of the body in response to the vibration appeared to be less with the addition of the bias acceleration than when the bias of gravity alone, was present. The maximum accelerations investigated here were subjectively more tolerable than vibrations on the order of  $1 G_x \pm 1.5 g_x$ . There were no deviations from normal limits of the physiologic variables monitored throughout any of the preliminary or later exposures in any of the subjects. The 90-second exposures at  $3.85 G_x + 3.0 g_x$  (raw data) were tolerable without serious effects and were limited in duration by equipment only. There was no subjective sensation of excessive cumulative fatigue resulting from repeated exposures.

The dial reading data were scored in terms of the total number of errors made by each subject on each of the panels for each of the dial tasks. Each of these error scores was converted into a percentage and will be referred to as "total errors." A second dependent measure, defined as "gross error score," was used only for the difficult dial (400 by 5). This measure eliminated the errors of precision or rounding off to the nearest markers and consisted of the percentage of errors which were three units or greater. Figure 5 and table I present a summary

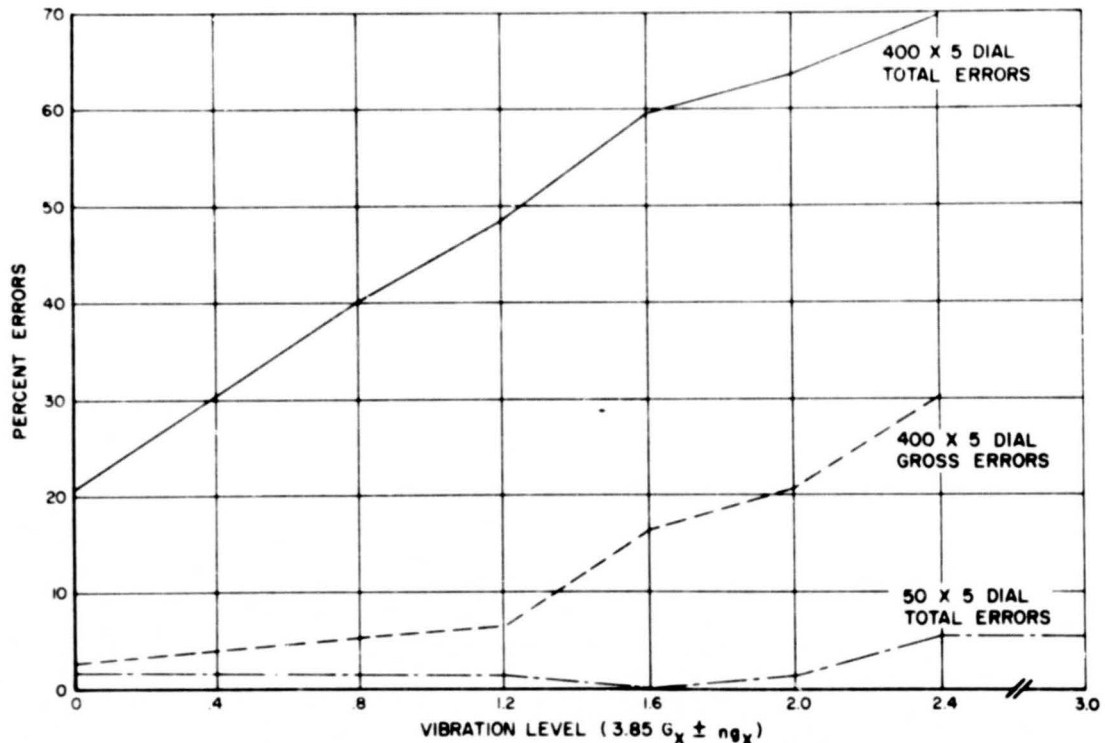


FIGURE 5. SUMMARY OF MEAN ERROR SCORES AS A FUNCTION OF THE EXPERIMENTAL CONDITIONS.

of the mean error scores as a function of the experimental conditions. Each data point represents a mean for six subjects. Inspection of this figure indicates that there was a large difference in total errors on the two dial tasks. It further suggests that increasing the amplitude of vibration produced corresponding increases in total errors for the difficult dial task, but had little or no effect on the percentage errors with the easy dials. The gross error scores for the difficult dials suggests that the environment did not appear to affect performance with this measure until the level of vibration reached  $\pm 1.6 g_x$  (raw data).

Owing to the extremely small number of errors associated with the easy dial, no analyses were performed with this task.

TABLE I  
MEAN ERROR (%) FOR THE  
TWO TYPES OF DIALS

400-range dial task						
Error Criteria	Vibration $\pm g_x$					
	0	0.8	1.2	1.6	2.0	2.4
Total Errors	20.83	40.27	48.61	59.72	63.88	69.44
Gross Errors	2.77	5.55	6.94	16.66	20.83	30.55

50-range dial task						
Error Criteria	Vibration $\pm g_x$					
	0	1.2	1.6	2.0	2.4	3.0
Total Errors	1.39	1.39	0.00	1.39	5555	5.55

TABLE II  
SUMMARY OF ANALYSIS OF VARIANCE OF  
TOTAL ERROR AND GROSS ERROR SCORES  
ON THE 400 X 5 DIAL TASK

Source	df	Total Errors		Gross Errors	
		MS	F	MS	F
Vibration Level (V)	5	1933.64	17.07**	689.65	10.79**
Subjects (Ss)	5	637.35		851.70	
Ss x V	25	113.29		63.88	

\*\*P < .01

Table II presents a summary of the analyses of variance of the total error and gross error scores with the difficult dials. Table II confirms the suggestion that errors with the difficult dial varied as a function of amplitude of vibration ( $P < 0.01$ ). A Newman-Keuls test of the differences among the individual means further confirms the suggestions from figure 5. That is, for the total error measure, all of the vibration conditions differed significantly from the control ( $P < .01$ ); while for the gross error scores, only the comparison between the control condition and the vibration levels of  $\pm 1.6 g_x$  ( $P < .05$ ),  $\pm 2.0 g_x$  ( $P < .01$ ), and  $\pm 2.4 g_x$  ( $P < .01$ ) yielded significant differences.

Although this experiment was designed to permit a semi quantitative comparison of vibration effects with either a  $3.85$  or  $1.0 G_x$  bias, the large distortion in the vibration acceleration makes impossible other than a qualitative evaluation of the effects of the bias acceleration on visual performance with  $11$  cps vibration. Other than this difficulty in comparison of data, there are recognized differences in geometry of support, restraint, and subject display relationships, as well as slight differences in subject training and experience (i. e., the usual factors which concern one in attempting to compare subjective data across experiments), which would also cause some reservations. If one recognizes these rather severe restrictions, one can still perhaps make some very general statements regarding the dial reading ability under these two conditions. The data for dial reading under  $1 G_x \pm n g_x$  comes from the recently completed studies of one of the authors (ref 6). Specifically, the environment chosen for comparison was  $1 G_x \pm g_x$  (less than 10% total distortion) at  $11$  cps (ref 5). With the helmet restrained, as the  $3.85 G$  bias acceleration tended to do in this study, the absolute error was 70% and the gross error was 27% using the same 400 by 5 dial configuration as was used here.

One way to grossly compare these two bias acceleration effects is to express the vibration environment of the present study in terms of the acceleration amplitude of its  $11$  cps component. This comparison for the effects of the two vibration amplitudes of interest is shown in table III with results of the previous study with the  $1-G$  bias. Peak vibrations of  $3.85 G_x \pm 1.2 g_x$  have only a  $\pm 0.6 g_x$  component at  $11$  cps so that the resulting error scores cannot be compared to those of the previous study ( $1.0 G_x \pm 1.2 g_x$ ). However, by subtracting the distortion of the  $3.85 G_x \pm 2.4 g_x$  vibration from the raw signal, it can be shown that an approximately equivalent amount of  $11$  cps vibration ( $1.4$  vs  $1.2 g_x$ ) was applied under two conditions of bias acceleration ( $3.85$  and  $1.0 G_x$ ). The error scores under these two conditions are approximately the same.

There are two basic differences in the acceleration environments for these two conditions which have approximately equal error scores. First, in the present studies, the bias acceleration is  $3.85$  rather than  $1.0 G$ . Taken alone, this would not be expected to produce significant visual decrement (ref 1). It may have been beneficial in that the bias load was always greater than the vibration load so that the head was not exposed to a force which changed direction (i. e., it was always positively coupled to the head-rest). The other difference between the two acceleration environments is that the higher bias acceleration occurred in conjunction with a high frequency

TABLE III

COMPARISON OF ERROR SCORES FOR DIFFERENT BIAS ACCELERATIONS  
WITH CALCULATED AMPLITUDES OF 11CPS ACCELERATION

Bias Acceler- ation	Measured Peak Vibration ( $\pm g_x$ )	Percent of Peak Acceleration at 11 cps	Vibration Amplitude At 11 cps ( $\pm g_x$ )	Error Scores(%)	
				Total	Gross
3.85	1.2	50%	0.6	48	20
3.85	2.4	60%	1.4	70	20
1.0*	1.2	>90%	1.2	70	26

\* From Taub (ref 6)

harmonic distortion of a magnitude which, taken alone, would be expected to produce some decrement in visual ability (refs 2, 4). Although this conclusion cannot be at all vigorously defended on the basis of the present data, one could speculate that the expected visual decrement from the high frequency component is offset by the benefit accrued from the unidirectional loading of the larger bias acceleration. If this were the case, the approximately equal scores for the two different bias acceleration conditions could result.

The rather small percentage of errors with the easy (50 range) dial implies that the designer of displays for vehicles with predicted environments such as those studied here can improve crew performance, if necessary, by choice of instrument displays.

Further, more controlled studies, utilizing equipment which provides improved fidelity of vibration input, are planned by both of the participating agencies. The complex visual tasks required of crewmen under operational conditions have not been simulated in this preliminary study. In addition to supplementing this basic and rather small initial effort, more sophisticated tasks must be evaluated to obtain a realistic estimate of pilot performance ability under this environment.

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166-12376  
Ad 622298

AMRL-TR 65-110

August 1965

ERRATA - April 1966

The following corrections apply to Technical Report No. AMRL-TR-65-110, Preliminary Study of Dial Reading Performance During Sustained Acceleration and Vibration. (AD 622 298)

Page 10

Paragraph 2, line 14: change "(ref 6)." to read "(ref 6, exp II)."  
Change " $1G_x \pm g_x$ " to read " $1G_x \pm 1.2g_x$ "

Page 11

Table III, the two columns of numbers on the extreme right, change to read:

Error Scores (%)	
<u>Total</u>	<u>Gross</u>
49	7
69	31
70	27

Table III: Change "\* From Taub (ref 6)" to read "\* From Taub (ref 6, exp II)"

AEROSPACE MEDICAL RESEARCH LABORATORIES  
AEROSPACE MEDICAL DIVISION  
AIR FORCE SYSTEMS COMMAND  
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