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Boeing Wichita  
Human Factors

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Visual-Motor  
Performance  
during  
Whole-Body  
Vibration

AS AC HC.

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Contract NONR 2994(00)  
Office of Naval Research

Technical Report No. 5  
VISUAL-MOTOR PERFORMANCE  
DURING  
WHOLE-BODY VIBRATION

R. E. Chaney  
and  
D. L. Parks

Research Accomplished Under  
Office of Naval Research  
Contract Nonr-2994(00)

"Research On  
Low Frequency Vibration Effects  
On Human Performance"

Principal investigator  
J. E. Beaupeurt

HUMAN FACTORS STAFF

THE BOEING COMPANY  
Wichita, Kansas

D3-3512-5

NOVEMBER 1964

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ABSTRACT

Seven male employees of the Boeing Company were tested in the company's human vibration facility to determine the effect of whole body vibration on visual-motor performance. Six controls; a large and a small knob; a horizontal and a vertical lever; and a horizontal and a vertical thumbwheel were used to adjust a standard 3 inch dial indicator to a prescribed setting. Independent variables included variations in vibration frequency and severity, control force requirements, and task complexity. Speed and accuracy of task accomplishment were recorded for each condition.

A high work load condition, vibration independent of frequency and level, and control force requirements, individually affected the speed and accuracy of operator adjustment. The type of control used did not influence accuracy, and had only minor influence on adjustment time with mounting position apparently producing the noted differences.

Test design  
and analysis

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2. Boeing document D3-3512-1, "Human Reaction to Low Frequency Vibration", D. L. Parks and F. W. Snyder, 24 July 1961.
3. Boeing document D3-3512-2, "A Comparison of Sinusoidal and Random Vibration Effects on Human Performance", D. L. Parks, 28 July 1961.
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5. Boeing document D3-3512-4, "Visual Performance during Whole-Body Vibration", R. J. Teare and D. L. Parks, November 1963.
6. AFSC Manual 80-1, Vol. 11f, "Handbook of Instructions for Aircraft Designers", 1 April 1963.
7. Magid, E. G. & Coermann, R. R., "The Reaction of the Human Body to Extreme Vibrations", 1960 Proceeding of the Institute of Environmental Sciences.
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## INTRODUCTION

Definition of operator performance capability, as influenced by system environmental conditions, is becoming increasingly important as modern manned systems become more complex. To the system designer, the accuracy and speed with which an operator can accomplish assigned visual-motor and tracking tasks within the operational environment is probably the largest contributing factor to the selection of a final display-control configuration.

Low frequency vibration is an important part of many operational environments, and is perhaps the most difficult to design out of the system. Consequently, a critical need exists for data concerning vibration effects on human ability to perform perceptual and motor control activities, and design features which will enhance their accomplishment.

The program reported herein is the fifth in a series of Boeing conducted research studies designed to expand the fund of data on the effects of vibration on these various types of operator activity. Previously reported experiments (Refs. 2, 3, 4, 5) have considered the establishment of subjective levels of vibration and the effects of these levels on hearing, speech and vision. Future studies will be concerned with their effect on operator tracking and additional vibration effects on relatively complex behavior.

This report is concerned with four vibration performance relationships:

1. Vibration effects on the accuracy of visual-motor task accomplishment using various types and sizes of controls.
2. Vibration effects on the speed of visual-motor task accomplishment using various types and sizes of controls.
3. The effects of various control forces on the performance of visual-motor tasks in a vibration environment.
4. The effects of increased work load on the speed and accuracy of visual motor task accomplishment under vibration.

It is divided into three major sections. The first is concerned with the general experimental conditions; the second describes results of the first three specified relationships and the third examines performance differences as affected by increased operator work load.

## METHODOLOGY

### Experimental Subjects

The subjects of the study were seven male Boeing employees who had participated in previous phases of the vibration program and had qualified for this phase by passing an extensive physical examination. Individual descriptions are included in Appendix A.

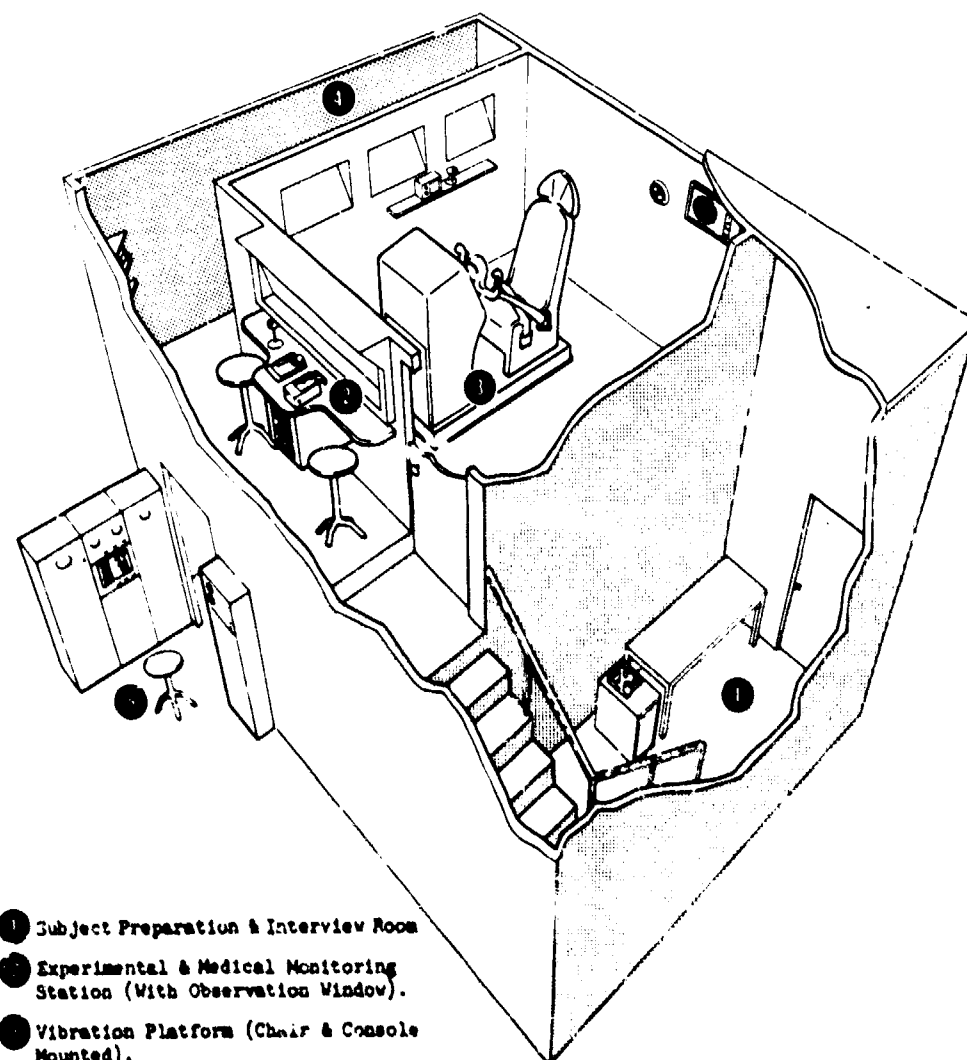
### Vibration Apparatus and the Vibration Environment

The Boeing Human Vibration Facility (Figure 1) provided the vibration conditions required for these experiments. A detailed description of the facility is contained in reference 1.

The subject's general test configuration for the study is shown in Figure 2. A reinforced standard aircraft seat was used to provide vibration inputs to the subjects. To increase fidelity of vibration transmission, plywood inserts covered with 3/4 inch hard felt were used in preference to the standard survival kit, cushions and parachute pack. Subject restraint was accomplished by means of a military type lap belt. No shoulder harness was used.

A variety of controls and displays were provide for these experiments. An illustration of what was available to the subject may be seen in Figure 3. An aircraft control column and wheel were mounted in the proper control position (reference 6), and a throttle type control was provided for use by the operator's left hand. An instrument display and control panel was mounted 28 inches in front of the average subject eye position, with the display center located 10° below and perpendicular to the average line of sight. Included on the panel were:

1. Two toggle switches
2. A clock
3. Five 5-digit counter readouts
4. An airspeed indicator
5. A cathode ray tube
6. A heading indicator
7. A 360° manual task indicator
8. A large control knob
9. A small control knob
10. A horizontal control lever
11. A vertical control lever
12. A horizontal thumbwheel
13. A vertical thumbwheel
14. Jeweled indicator lights adjacent to most controls and displays



- ① Subject Preparation & Interview Room
- ② Experimental & Medical Monitoring Station (With Observation Window).
- ③ Vibration Platform (Chair & Console Mounted).
- ④ Observation Area (With 3 One-Way Viewing Windows).
- ⑤ Equipment Operator's Station (Signal Generation, Feed back, & Monitoring).

FIGURE 1. BOEING HUMAN VIBRATION FACILITY

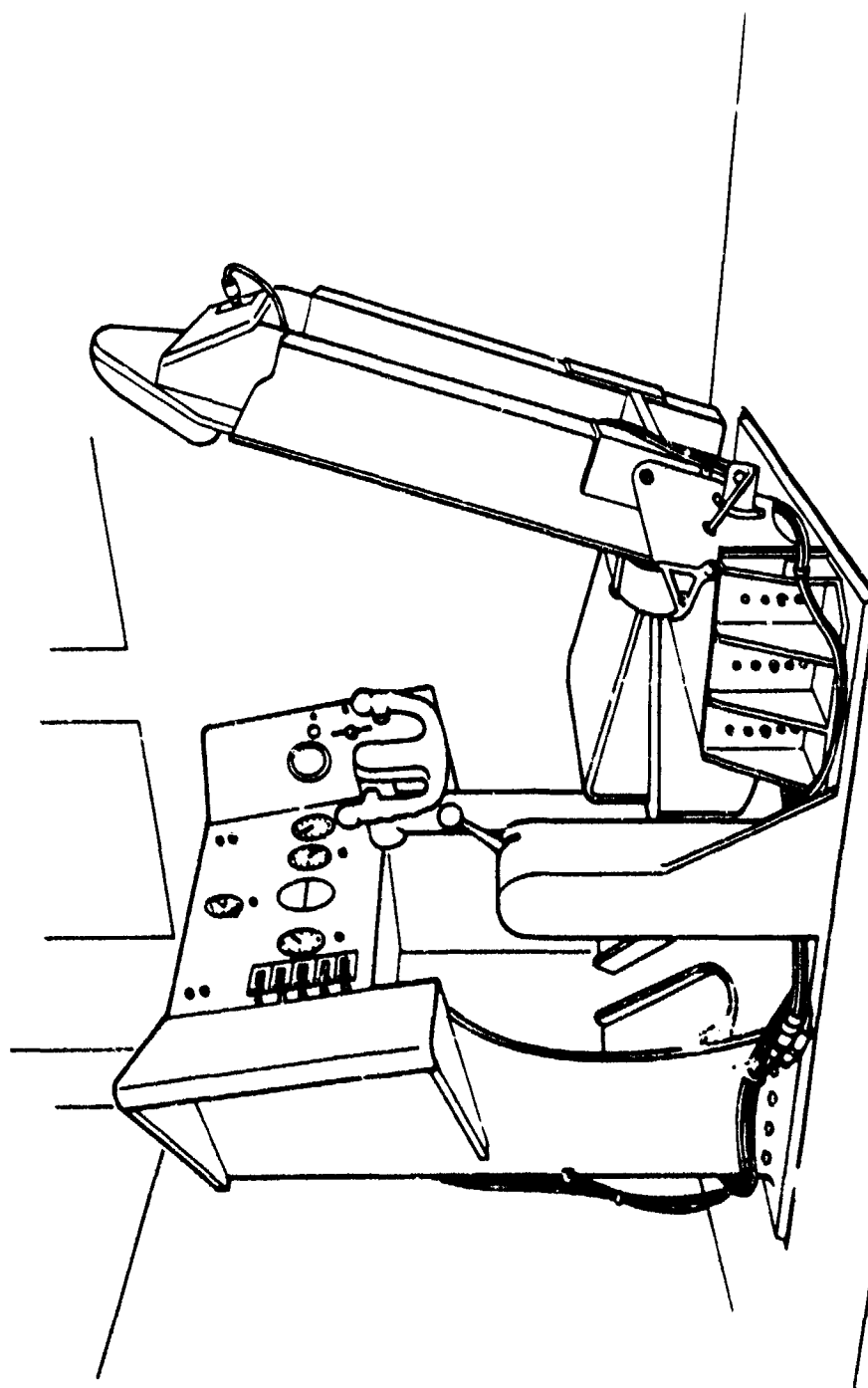


FIGURE 2. TEST STATION CONFIGURATION

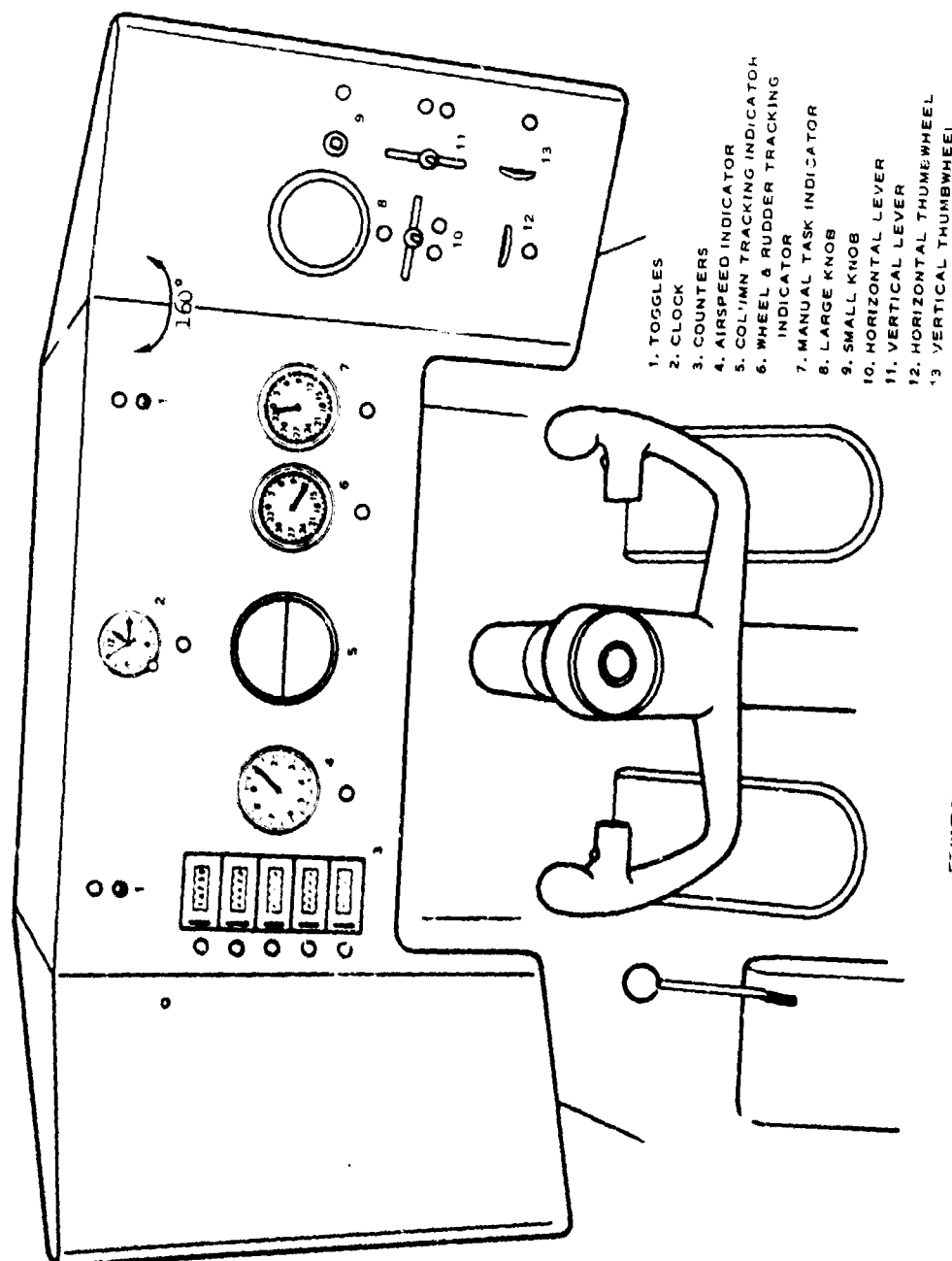


FIGURE 3. DISPLAY-CONTROL PANEL

### Control Column and Wheel

The control column and wheel used for these tests were the standard heavy aircraft type and had been used in a previous program (experiment (reference 3)). The only modification made for this phase was to provide an additional cut-off switch on the back of the right handgrip similar to that on the left, so that vibration would continue when either hand was grasping the wheel. Fore and aft movement of the column was used for compensatory tracking of a projected horizontal line on the cathode ray tube (CRT), and the wheel control was utilized for compensatory tracking of the needle on a modified heading indicator located to the immediate right of the CRT.

### Vertical Tracking Indicator

The centrally located CRT was a five inch display tube with a horizontal crosshair etched on the face. When being used in the tests, a projected horizontal line of light .05 inch wide was programmed to move between top and bottom of the display at a rate which varied sinusoidally. Display response to control column movement was delayed by a two second time constant to simulate "aircraft" response to control action. Control action requirements were patterned after a terrain following type display with forward movement of the column required to bring the projected light beam up to the desired position, and aft column movement required when the projected line was above the position desired. An additional feature built into the response system would drive the projected line off the CRT if the subject failed to maintain reasonable alignment control. Full 7-1/4 inches forward and full 9-1/2 inches aft column movement required 64 and 84 pounds force respectively.

### Lateral Tracking Indicator

To the right of the CRT display were two standard 3 inch aircraft heading indicators with all identifying markings except graduation marks and numbers removed from the faces. Both were north oriented indicators with heading numbers located every 30° and graduation marks each 2°. The one on the left, nearest the CRT, served as the display for control wheel or "rudder" movement with the servo regulated needle programmed to move at a sinusoidally varying rate, 15° to right and left of the 360° position. Clockwise rotation of the control wheel or depression of the right foot pedal when appropriate, produced clockwise rotation of the needle with no incorporation of control feedback delay. Control wheel force ranged essentially linearly from zero to ten pounds through left or right rotation of 65°, and foot pedal force could be set at 40 pounds, 100 pounds or 150 pounds, as desired, for a maximum forward displacement of four inches with either foot. Forward movement of either pedal produced an equal and opposite movement of the alternate pedal.

### Right Hand Manual Task Indicator and Controls

The heading indicator on the right of the panel served as the display for controls located on the right wing of the control-display panel. The servo driven needle was displaced in each case  $1/3$  the distance of the active control at the location of applied force. Included in the controls were a large and a small knob, a horizontal and a vertical lever and a horizontal and a vertical thumbwheel. Operating force requirements at the point of application could be set at  $2/3$  pound,  $1-1/3$  pound or 2 pounds for each.

#### Knobs

The two knurled knobs were the uppermost controls of the series and were located side by side with the small knob on the right. They were  $5/8$  inch thick with skirts added at the base; diameters were 3 inches and  $3/8$  inch. Clockwise rotation produced a similar movement of the display.

#### Levers

The center controls were the levers, located side by side with the vertically moving lever to the right. Diameters of the levers were  $3/8$  inch, heights were 1 inch and skirts were again provided at the base. Right and upward movement respectively produced clockwise rotation of the indicator needle.

#### Thumbwheels

The final controls of the series were the thumbwheels located at the lower right console position. They were  $1/4$  inch wide and protruded  $1/4$  inch above the panel surface which subtended a  $1-1/2$  inch chord on the control. Control edges were serrated. Right movement of the horizontal control and downward movement of the vertical control were necessary to move the pointer of the indicator in a clockwise direction. The vertical control was located to the right.

### Left Hand Indicators and Controls

To the left of the CRT on the display panel were five 1-digit counter readouts and an airspeed indicator. The airspeed indicator was controlled by "throttle" movement with 3 inches control movement required to produce 1 inch needle movement on the display. Forward throttle adjustment increased indicated "airspeed".

The throttle consisted of a 5-1/2 inch lever on top of an aisle stand located adjacent to the left hand side of the seat. In the rear position the tip of the lever was 16 inches forward of the subject elbow position and 24 inches from the floor. Force requirements could be set at 1/2, 5, or 10 pounds.

At the upper portion of the central display panel were two toggle switches located toward each edge, and a centrally located clock. Jeweled indicator lights adjacent to these, and all panel displays and controls except the tracking indicators, served to inform the subject of the action required in the testing sequence.

#### Vibration Conditions

Vibration conditions used in this phase of the study, as in the case of earlier program performance studies, were selected from four subjective reaction levels to vertical, sinusoidal vibration. These levels: definitely perceptible; mildly annoying; extremely annoying; and alarming, were established as the first phase of the program (Ref. 2). In establishing curves for the levels, 16 discrete frequencies ranging from 1 through 27 cycles per second (cps) were used. Means of individual amplitude selections at each frequency used to derive the curves were selected for use for additional testing, making 64 vibration conditions available. However, only 40 were used in these experiments. Magid and Coermann (Ref. 7) indicated decreased physical tolerance for vibration in the 4 to 8 cps frequency range. With the time required at each vibration condition for this study, it was deemed advisable in light of these findings to eliminate those frequencies from the test sequence at the extremely annoying and alarming levels to avoid the possibility of subject tissue damage. In addition, because of suspected similarities in performance of the realitively simple tasks at level 1 and with no vibration, level 1 conditions were not used for testing except in that range where levels 3 & 4 could not be used.

Table I describes the vibration conditions of the experiment in terms of double amplitude (DA) and acceleration (G). Shaded portions of the table identify conditions not tested.

TABLE I  
VIBRATION CONDITIONS USED IN VISUAL-MOTOR PERFORMANCE EXPERIMENT

| FREQUENCY<br>(CPS)  | 1     | 1.5   | 2    | 3    | 4    | 5    | 6    | 8    | 10   | 12    | 14    | 16    | 18    | 20    | 23   | 27   |
|---------------------|-------|-------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|------|------|
| DA<br>..            |       |       |      | .057 | .038 | .026 | .017 | .040 |      |       |       |       |       |       |      |      |
| LEVEL 1<br>***<br>G |       |       |      | .026 | .031 | .034 | .032 | .130 |      |       |       |       |       |       |      |      |
| DA<br>3.600         | 2.574 | 1.477 | .942 | .370 | .172 | .148 | .113 | .055 | .082 | .056  | .068  | .053  | .035  | .019  | .012 |      |
| LEVEL 2<br>G        | .184  | .296  | .302 | .433 | .303 | .220 | .273 | .371 | .281 | .604  | .565  | .894  | .871  | .711  | .515 | .436 |
| DA<br>4.877         | 3.974 |       |      |      |      |      |      |      | .103 | .118  | .079  | .096  | .068  | .055  | .027 | .024 |
| LEVEL 3<br>G        | .249  | .457  |      |      |      |      |      |      | .526 | .871  | .796  | 1.260 | 1.132 | 1.129 | .737 | .878 |
| DA<br>5.656         |       |       |      |      |      |      |      |      | .145 | .155  | .110  | .105  | .085  | .074  | .034 | .026 |
| LEVEL 4<br>G        | .289  |       |      |      |      |      |      |      | .740 | 1.141 | 1.097 | 1.368 | 1.408 | 1.518 | .919 | .987 |

SUBJECTIVE REACTION LEVELS (REFERENCE 2 FIGURE 5)

LEVEL 1 "DEFINITELY PERCEPTIBLE"

LEVEL 2 "MILDLY ANNOYING"

LEVEL 3 "EXTREMELY ANNOYING"

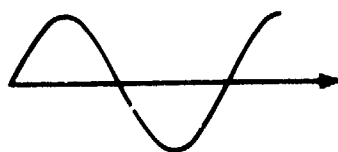
LEVEL 4 "ALARMING"

\*\*Double Amplitude Displacement in inches

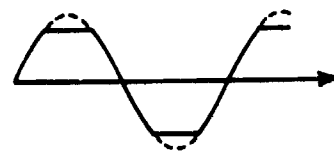
\*\*\*Acceleration Force,  $G = .0511 F^2 DA$

#### Vibration Fidelity

It had been evident that mechanical and hydraulic properties of the equipment system were introducing distortion into the sine wave output of the vibration table. An analysis of table input versus table output revealed that the distortion was due primarily to table friction. This friction was greatest at the peak of the sine waves and thus resulted in a clipping of the wave form output of the table. This is illustrated in the drawing below.



Wave Input Shape



Displacement Wave Output Shape

This distortion of the wave form resulted in significant third and fifth harmonics being generated in the output. Since the distortion source was essentially constant, it exerted a proportionately greater influence at lower amplitudes than at higher amplitudes.

Distortion also varied as a function of frequency (cps). The relationship with frequency is not a regular one since other factors, i.e. resonant frequency of the table itself and occurrence of odd and even harmonics, complicated the frequency picture.

The resulting distortion was analyzed with a describing function (see Boeing document D3-4937, reference 8) and empirically verified on the table. The functional relationship between distortion  $E_d$  and fundamental amplitude (subjective reaction levels 1, 2, 3, and 4) is presented in Figure 4. It can be seen that in the three frequencies chosen (2 cps, 12 cps, and 27 cps) the greatest proportionate distortion occurs at subjective reaction level 1.

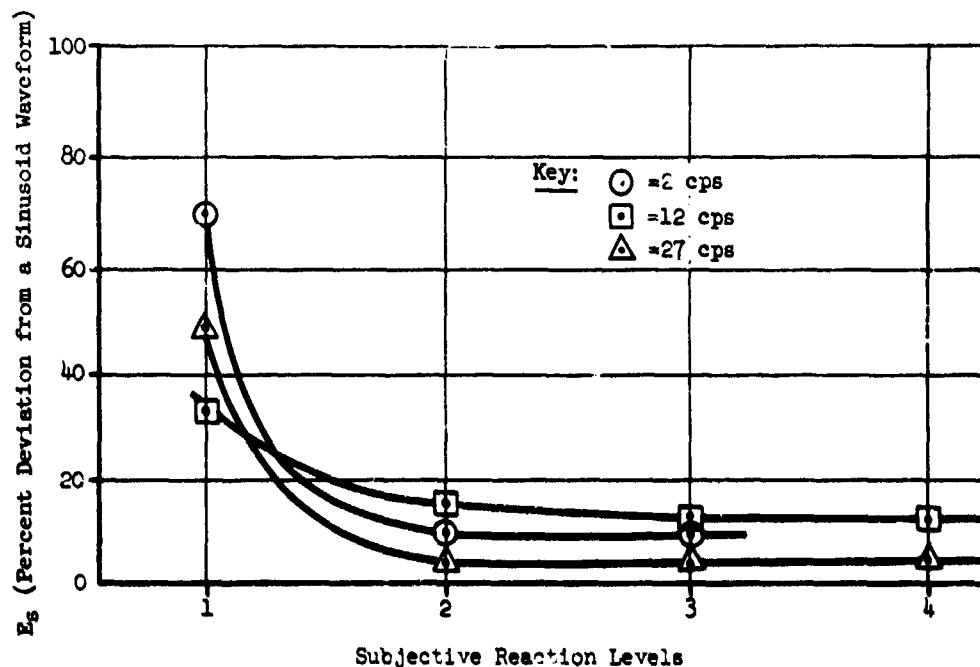


FIGURE 4. DISTORTION CURVES FOR SELECTED FREQUENCIES (AT FOUR REACTION LEVELS)

#### Experimental Sequence and Procedures

Test procedures for this phase of the program were very much as they had been throughout program testing. Two hours were scheduled for each test session, with individual subject sessions at least 72 hours apart. Subjects wore flight coveralls, street shoes and light gloves, and were fitted with ECG leads for medical monitoring during each test.

Prior to each session the subject was given a limited medical examination by the attending physician and a briefing on test procedures and instructions by the experimenter (Appendix A). After proceeding to the test area, the subject was situated in the test facility, ECG leads were connected to monitoring equipment and checked, and a lead were reviewed.

During initial sessions, practice runs were made until subjects had become familiar with the experiment, the apparatus and the tasks involved. If this was completed during the allotted 2 hour time period, vibration testing started. If not, the subject was released with practice continuing at the next session. Performance stabilization served as the criterion for practice completion.

At the start of each day's testing, performance data with no vibration were gathered for use as controls against which vibration data for that day could be compared. A test sequence lasted approximately eight and one half minutes with three minutes allowed between tests. Tasks for the tests were presented in random order according to one of eight pre-determined programs. An average of five test sequences were completed each session. A medical doctor monitored all vibration sessions.

## SPEED, ACCURACY & CONTROL FORCE EXPERIMENT

### Data Collection Procedures

The right hand manual task controls located on the right wing of the control-display panel were utilized in this portion of the program. Adjustment error to the nearest .1 degree and time requirements to the nearest .1 second were obtained for each control under the various control forces ( $2/3$ ,  $1-1/3$ , & 2 lbs.) and vibration conditions (Table 1).

Eight predetermined random programs were utilized to provide stimulus inputs to the subjects. Upon illumination of an indicator light adjacent to any of the controls, subjects, as previously instructed, utilized that control to adjust the right heading indicator to the  $350^\circ$  position. Deviations 10, 20 or  $30^\circ$  to either right or left of the command position were utilized in random order, with three time and error measurements taken for each control at each of the force and vibration conditions. Seven seconds were available in which to make each setting.

### Data Analysis

The conditions of the experiment involved variations in the type of control being utilized, control force requirements, vibration severity (subjective reaction levels), and vibration frequency, all of which varied simultaneously in repeated observations of six subjects. Two dependent variables (error & time scores) were sampled under each condition.

Four dimensional analyses of variance (ANOV) were utilized in the analysis procedures. It will be recalled that certain frequencies were omitted from the experiment at the "extremely annoying" and "alarming" levels to avoid the possibility of bodily harm to subjects. Thus, two analyses of each type desired were required to cover the whole range of vibration conditions used. Analysis I of each type involved 9 frequencies (1, 10, 12, 14, 16, 18, 20, 23, & 27 cps) at 3 subjective reaction levels (2, 3, & 4). Analysis II, in each case, was concerned with 5 frequencies (3, 4, 5, 6, & 8 cps) at 2 levels (1 & 2). The vibration conditions used in each of the analyses are shown respectively in Tables II and III.

Initially, analyses utilizing time and error scores obtained under the median control force ( $1-1/3$  lb.) were performed with subjective reaction levels (A), control type (B), vibration frequency (C) and subjects (D) making up the four dimensions. (Subjects emerge as a dimension because of repeated measurements on each of the other dimensions.) Thus a  $3 \times 6 \times 9 \times 6$  and a  $2 \times 6 \times 5 \times 6$  factorial each for time and error scores were required. Also, in order to ferret out differences in the results due to vibration from those inherent in the controls themselves,

TABLE II  
THE 9 VIBRATION FREQUENCY AND 3 REACTION LEVEL CONDITIONS USED IN  
ANALYSES OF VARIANCE I

|         | 1     | 1.5 | 2 | 3 | 4 | 5 | 6 | 8 | 10   | 12    | 14    | 16    | 18    | 20    | 23   | 27   |
|---------|-------|-----|---|---|---|---|---|---|------|-------|-------|-------|-------|-------|------|------|
| DA      |       |     |   |   |   |   |   |   |      |       |       |       |       |       |      |      |
| LEVEL 1 |       |     |   |   |   |   |   |   |      |       |       |       |       |       |      |      |
| G       |       |     |   |   |   |   |   |   |      |       |       |       |       |       |      |      |
| DA      | 3.600 |     |   |   |   |   |   |   | .055 | .082  | .056  | .068  | .053  | .035  | .019 | .012 |
| LEVEL 2 |       |     |   |   |   |   |   |   |      |       |       |       |       |       |      |      |
| G       | .184  |     |   |   |   |   |   |   | .281 | .604  | .565  | .894  | .871  | .711  | .515 | .436 |
| DA      | 4.877 |     |   |   |   |   |   |   | .103 | .118  | .079  | .096  | .068  | .055  | .027 | .024 |
| LEVEL 3 |       |     |   |   |   |   |   |   |      |       |       |       |       |       |      |      |
| G       | .249  |     |   |   |   |   |   |   | .526 | .871  | .796  | 1.260 | 1.132 | 1.129 | .737 | .878 |
| DA      | 5.656 |     |   |   |   |   |   |   | .145 | .155  | .110  | .105  | .085  | .074  | .034 | .026 |
| LEVEL 4 |       |     |   |   |   |   |   |   |      |       |       |       |       |       |      |      |
| G       | .289  |     |   |   |   |   |   |   | .740 | 1.141 | 1.097 | 1.368 | 1.408 | 1.518 | .919 | .987 |

TABLE III  
THE 5 VIBRATION FREQUENCY AND 2 REACTION LEVEL CONDITIONS USED IN ANALYSES OF VARIANCE II

|         | 1 | 1.5 | 2 | 3    | 4    | 5    | 6    | 8    | 10 | 12 | 14 | 16 | 18 | 20 | 23 | 27 |
|---------|---|-----|---|------|------|------|------|------|----|----|----|----|----|----|----|----|
| DA      |   |     |   | .057 | .038 | .026 | .017 | .040 |    |    |    |    |    |    |    |    |
| LEVEL 1 |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |
| G       |   |     |   | .026 | .031 | .034 | .032 | .130 |    |    |    |    |    |    |    |    |
| DA      |   |     |   | .942 | .370 | .172 | .148 | .113 |    |    |    |    |    |    |    |    |
| LEVEL 2 |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |
| G       |   |     |   | .433 | .303 | .220 | .273 | .371 |    |    |    |    |    |    |    |    |
| DA      |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |
| LEVEL 3 |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |
| G       |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |
| DA      |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |
| LEVEL 4 |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |
| G       |   |     |   |      |      |      |      |      |    |    |    |    |    |    |    |    |

and those due to normal day-to-day fluctuations, each of the analyses were performed using scores obtained under vibration, and difference scores between vibration and the no-vibration condition performances for a given test sequence.

To determine the effects of control forces on the accuracy and speed of the various assigned tasks, additional analyses with levels, required control forces, frequencies, and subjects serving as the dimensions were performed for each of the six controls. As before, two analyses ("3 x 3 x 9 x 6" and "2 x 3 x 5 x 6" factorials) were required to cover the vibration conditions used and both vibration and difference scores were analyzed. Again, time and error scores served as the dependent variables.

#### Results and Interpretation

Significance columns from each of the eight ANOV summary tables used in the speed and accuracy analyses are shown in Table IV. Since each of the analyses is intended to clarify an individual portion of the same problem, a composite approach to both data presentation and discussion is utilized in this report. Individual analysis summary tables are included in Appendix B, Pages 40 - 43.

As may be seen from Table 4, the only significant main effect in any of the analyses, other than the variations in scores between subjects, is that concerned with the differences in time required to adjust the various controls under the vibration condition. Also, because of the lack of a significant difference in the time to adjust the controls when analyzed using difference scores, an adjustment time difference under the non-vibration condition is a logical conclusion. Plots of the main effects of the analysis under both the vibrating and the non-vibrating conditions are shown in Figure 5. This also contains the most significant of the differences between subjects.

As is evident in the Figure, the small knob is adjusted most quickly under vibration, with the large knob and the horizontally mounted lever and thumbwheel approximately equal in second place and the vertically mounted controls requiring the most time. Also, as indicated by the analyses, this pattern remains much the same under the no-vibration condition, with a small increase in time produced on all controls except one with the addition of vibration.

It should be pointed out, that although the differences between adjustment times utilizing the various controls proved significant in this analysis, the real differences in terms of adjustment time are in all cases less than .3 second, or less than 10% of the total. With equal error production between controls, it is felt that this difference is of minor significance from a practical design standpoint, and should be given consideration only if and when other human factor considerations have been optimized.

TABLE IV  
INDICES OF SIGNIFICANCE ON SPEED AND ACCURACY ANALYSES

| ANALYSIS        | ERROR SCORES |     |              |     | TIME SCORES |     |              |    |
|-----------------|--------------|-----|--------------|-----|-------------|-----|--------------|----|
|                 | VIB. SCORES  |     | DIFF. SCORES |     | VIB. SCORES |     | DIFF. SCORES |    |
|                 | I            | II  | I            | II  | I           | II  | I            | II |
| A (LEVELS)      |              |     |              |     |             |     |              |    |
| B (CONTROLS)    |              |     |              |     | *           |     |              |    |
| C (FREQUENCIES) |              |     |              |     |             |     |              |    |
| P (SUBJECTS)    |              | *   | **           |     | ***         | *   |              |    |
| AB              |              |     |              |     |             |     |              |    |
| AC              |              |     |              |     |             |     |              | ** |
| AP              |              |     |              | **  |             | *** |              | ** |
| BC              |              |     |              |     |             |     |              |    |
| BP              |              |     | **           |     | ***         | *   | **           |    |
| CP              | ***          |     | ***          |     | ***         |     | **           | *  |
| ABC             |              |     |              |     |             |     |              |    |
| ABP             |              | *   |              |     |             |     |              |    |
| ACP             | ***          | *** | ***          | *** | ***         | *** |              |    |
| BCP             |              |     |              |     |             |     |              |    |
| ABCP            |              |     |              |     |             |     |              |    |

ANALYSIS I 9 FREQUENCIES AT 3 LEVELS  
ANALYSIS II 5 FREQUENCIES AT 2 LEVELS  
\*  $p < .05$   
\*\*  $p < .01$   
\*\*\*  $p < .001$

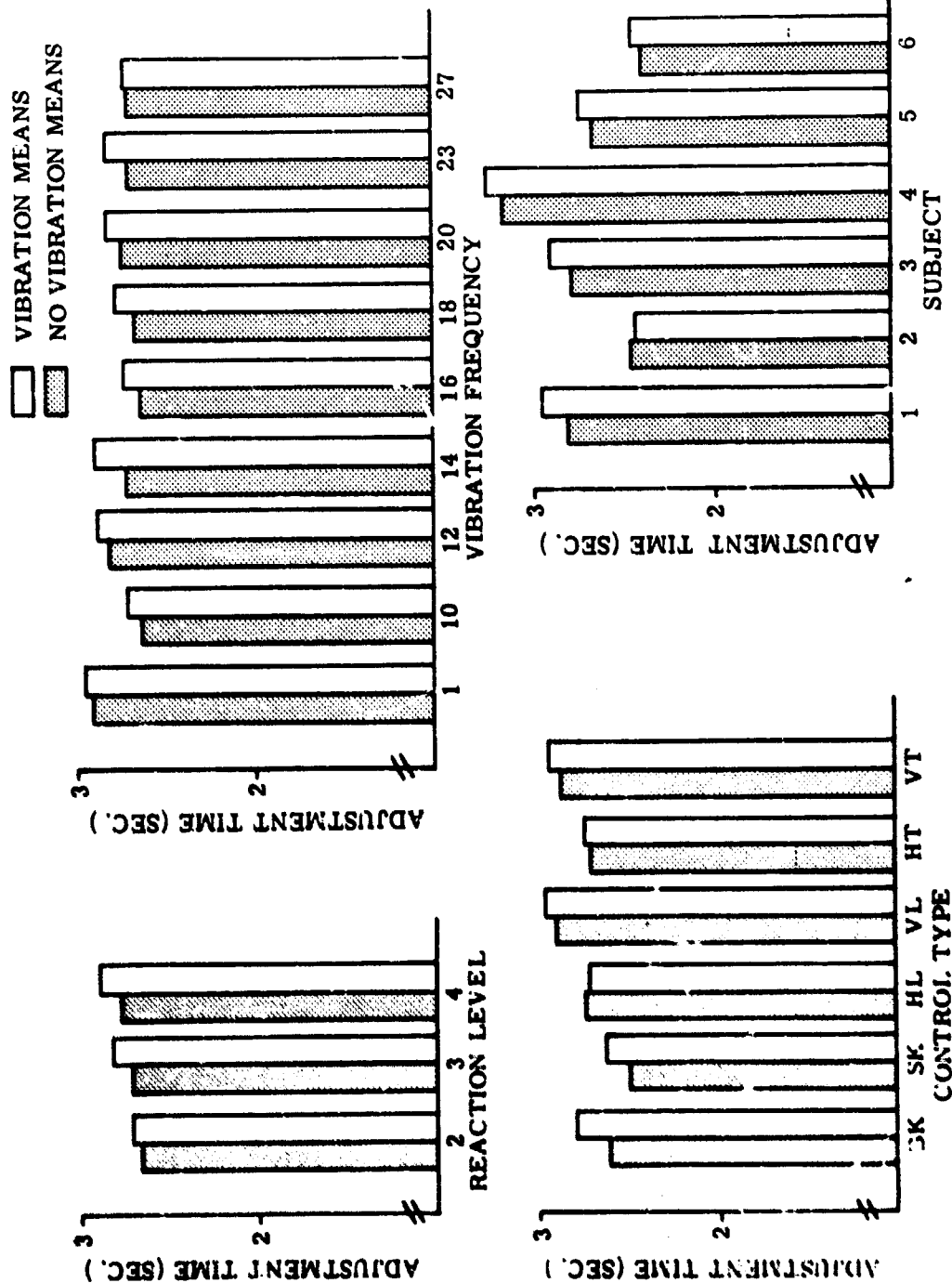


FIGURE 5  
 TIME SCORE MAIN EFFECTS, ANALYSIS I  
 (3 LEVELS X 6 CONTROLS X 9 FREQUENCIES X 6 SUBJECTS)

Also apparent from Figure 5, is evidence of the fact that subjects were the major source of variation in the experiment. With the degrees of freedom involved in the repeated design, little is to be gained by an attempt to interpret the numerous higher order interactions of subjects with the other variables, and no such attempt has been made.

Results of the control force analyses are shown in Tables V, VI, VII, and VIII. Tables V and VII respectively show the results of analyses performed on error and time scores obtained under vibration; VI and VIII show results of similar analyses performed on the differences between scores obtained under the vibration and no-vibration conditions. Individual ANOV summary sheets are included in Appendix B, pages 44 - 67.

As may be seen in Tables V and VI, differences in error scores due to variations in control force are significant only for the horizontal lever under vibration, and for the large knob when using vibration-no-vibration difference scores (significant main effects B). In addition, the difference scores for the large knob vary not only as a function of the control force required, but these differences vary significantly between subjects (BP interaction). Plots of the mean scores obtained under the two conditions using each control are shown in Figure 6.

Again, although there are two items of significance present, Figure 6 clearly shows that no control or control force is markedly different in its effect on control error than its counterparts, with only a slight overall decrease in error under the vibration condition when utilizing the median control force (1-1/3 lb). There is however, a consistent increase in error production in all cases when encountering vibration. Further, the significance tables indicate that these composite effects are generally independent of the frequency or level of vibration present in this experiment although apparently random differential effects occur between subjects.

Utilizing the median control force where errors are minimal, vibration produced an average error increase of 25% over all controls. In the experimental task employed to obtain these data, this difference means an error increase of slightly over .1 degree. From a design standpoint, the critical accuracies of the various tasks to be performed in a vibrating environment would need to be considered prior to a decision on the practical significance of such a difference. It is entirely feasible that situations could exist where a 25% error increase even in terms of .1 degree, could mean the difference between mission success or failure, and of course, situations also could occur where it would make no difference whatsoever. These are conditions which must be considered by the design engineer specific to a particular design situation.

TABLE V  
INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS  
VIBRATION ERROR SCORES

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|                | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL |
|----------------|------------|------------|--------------|-------------|-------------------|------------------|------------|------------|--------------|-------------|-------------------|------------------|
| A (LEVELS)     |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| B (FORCES)     |            |            | *            |             |                   |                  |            |            |              |             |                   |                  |
| C(FREQUENCIES) |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| P (SUBJECTS)   |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AB             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AC             | *          |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AP             |            |            |              |             |                   |                  | **         | *          |              |             |                   |                  |
| BC             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BP             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| CP             | ***        | ***        | ***          | ***         | ***               | ***              |            |            |              |             |                   |                  |
| ABC            |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| ABP            |            |            |              |             |                   |                  |            | *          |              |             |                   |                  |
| ACP            | ***        | ***        | ***          | ***         | ***               | ***              | **         | ***        | ***          | ***         | ***               | ***              |
| BCP            |            |            |              |             |                   |                  |            | *          |              | *           |                   |                  |
| ABCP           |            |            |              |             |                   |                  |            |            |              |             |                   |                  |

9 FREQUENCIES, 3 LEVELS    5 FREQUENCIES, 2 LEVELS

\*  $p < .05$   
 \*\*  $p < .01$   
 \*\*\*  $p < .001$

TABLE VI  
INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS  
ERROR DIFFERENCE SCORES

|                 | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL |
|-----------------|------------|------------|--------------|-------------|-------------------|------------------|------------|------------|--------------|-------------|-------------------|------------------|
| A (LEVELS)      |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| B (FORCES)      | *          |            |              |             |                   |                  |            |            |              |             |                   |                  |
| C (FREQUENCIES) |            |            |              |             |                   | *                |            |            |              | *           |                   |                  |
| P (SUBJECTS)    | **         | **         | *            | *           |                   | ***              | *          |            |              |             |                   |                  |
| AB              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AC              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AP              |            |            |              |             |                   |                  |            | ***        | **           | *           | **                | **               |
| BC              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BP              | *          |            | *            |             |                   |                  | **         |            |              |             |                   |                  |
| CP              | ***        | ***        | ***          | ***         | **                |                  |            |            |              |             |                   |                  |
| ABC             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| ABP             |            |            | *            |             |                   |                  |            | *          |              |             |                   |                  |
| ACP             | ***        | ***        | ***          | ***         | *                 | ***              | **         | ***        | *            | ***         | ***               | ***              |
| BCP             |            |            |              |             |                   |                  |            | *          |              | *           |                   |                  |
| ABCP            |            |            |              |             |                   |                  |            |            |              |             |                   |                  |

9 FREQUENCIES, 3 LEVELS    5 FREQUENCIES, 2 LEVELS

\* p < .05  
\*\* p < .01  
\*\*\* p < .001

TABLE VII  
INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS  
VIBRATION TIME SCORES

|                 | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL |
|-----------------|------------|------------|--------------|-------------|-------------------|------------------|------------|------------|--------------|-------------|-------------------|------------------|
| A (LEVELS)      |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| B (FORCES)      | **         | **         | *            | ***         | **                | **               |            |            |              |             | **                |                  |
| C (FREQUENCIES) |            |            |              |             |                   | **               |            |            |              |             |                   |                  |
| P (SUBJECTS)    | ***        | ***        | ***          | ***         | ***               | ***              | **         |            | *            |             | **                | *                |
| AB              |            |            |              |             |                   |                  | *          |            |              |             |                   |                  |
| AC              |            |            |              |             |                   |                  |            |            |              |             |                   | **               |
| AP              |            |            |              |             |                   |                  | *          |            | *            |             |                   | *                |
| BC              |            |            |              |             |                   |                  |            | **         |              |             |                   |                  |
| BP              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| CP              | **         | ***        | ***          | ***         | ***               |                  |            |            |              |             |                   |                  |
| ABC             | *          | *          |              |             | *                 |                  |            |            |              |             |                   | **               |
| ABP             |            | *          |              |             |                   |                  |            |            |              |             |                   |                  |
| ACP             | ***        | ***        | ***          | ***         | ***               | ***              | ***        |            | *            |             | *                 | **               |
| BCP             |            |            |              |             | *                 |                  | *          |            |              |             |                   |                  |
| ABCP            |            |            |              |             |                   |                  |            |            |              |             |                   |                  |

9 FREQUENCIES, 3 LEVELS\* 5 FREQUENCIES, 2 LEVELS\*\*

\* p < .05  
\*\* p < .01  
\*\*\* p < .001

\* p < .05  
\*\* p < .01

TABLE VIII  
INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS  
TIME DIFFERENCE SCORES

|                 | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL |
|-----------------|------------|------------|--------------|-------------|-------------------|------------------|------------|------------|--------------|-------------|-------------------|------------------|
| A (LEVELS)      |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| B (FORCES)      |            | *          |              |             |                   | *                |            |            |              |             |                   |                  |
| C (FREQUENCIES) |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| P (SUBJECTS)    | *          |            | *            |             |                   | *                |            |            |              |             | *                 |                  |
| AB              |            |            |              |             |                   |                  | **         |            |              |             |                   |                  |
| AC              |            |            |              |             |                   |                  |            |            |              |             |                   | *                |
| AP              |            |            |              | *           |                   |                  | **         |            | **           |             | *                 |                  |
| BC              |            |            |              |             |                   |                  | **         |            |              |             |                   |                  |
| BP              |            |            | *            | ***         | **                | **               | **         |            |              |             |                   |                  |
| CP              | *          | **         | *            |             | ***               |                  |            |            |              |             |                   |                  |
| ABC             |            | *          |              |             | **                |                  |            |            |              |             |                   | **               |
| ABP             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| ACP             | *          | *          |              |             |                   | *                | *          |            |              |             |                   |                  |
| BCP             |            |            |              |             |                   |                  | *          |            |              |             |                   |                  |
| ABCP            |            |            |              |             |                   |                  |            |            |              |             |                   |                  |

9 FREQUENCIES, 3 LEVELS \* 5 FREQUENCIES, 2 LEVELS

\* p < .05  
\*\* p < .01  
\*\*\* p < .001

□ VIBRATION MEANS  
 ■ NO VIBRATION MEANS

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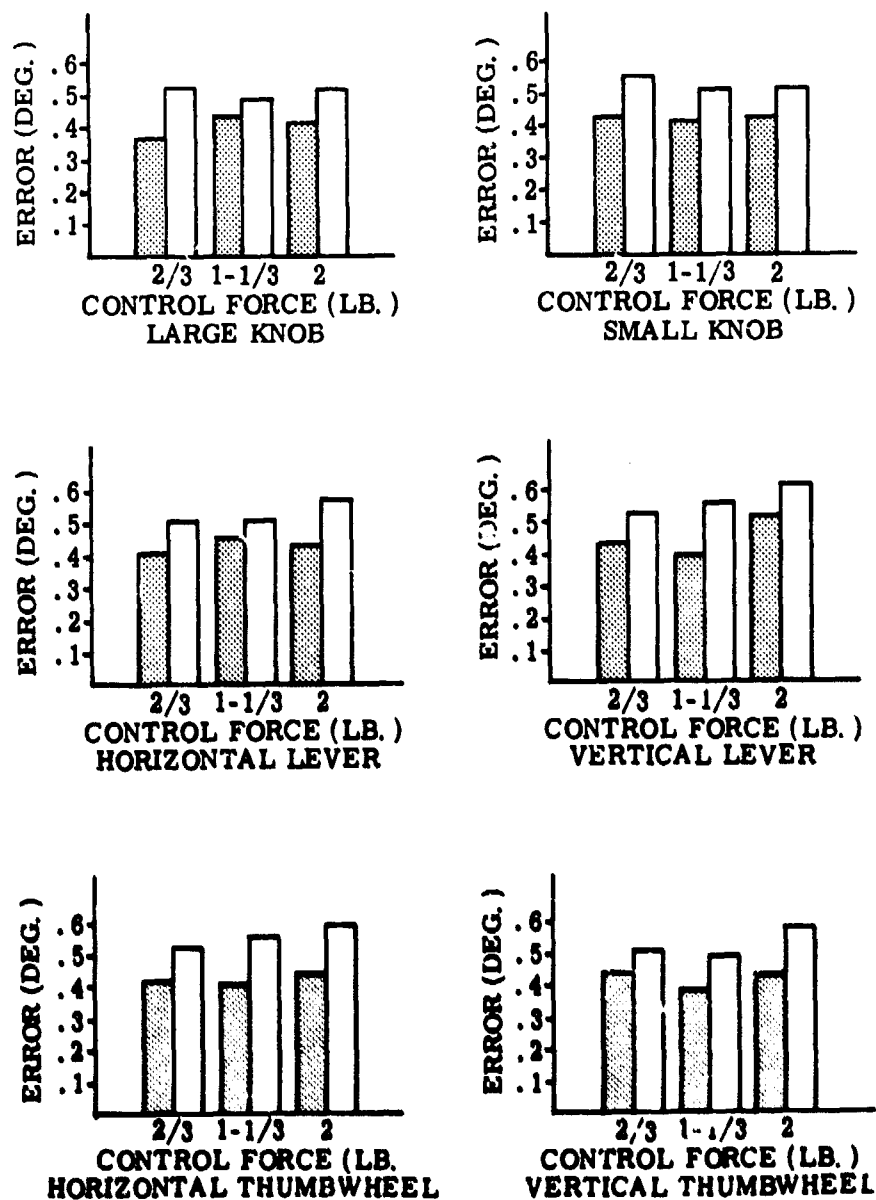


FIGURE 6  
 MEAN ERROR SCORES, CONTROL VERSUS REQUIRED FORCE

Tables VII and VIII show that the times necessary to adjust all controls vary as a function of the control force required, and that, in the case of the small knob and vertical thumbwheel, the differences in time between the vibration and no-vibration conditions also vary.

Times required for adjustment of each control with each of the required control forces under the vibration and no-vibration conditions are shown in Figure 7.

Several things are evident from an inspection of the figure. Initially it can be seen that little difference exists between adjustment times of the two knobs, while the lever and thumbwheel mounted in the plane of vibration take considerably longer to adjust than their counterparts mounted perpendicular to the vibration. Secondly, as would be predicted and as was noted in the previous analysis, adjustment time in nearly every case increases with the addition of vibration to the environment. And finally, adjustment times for each control are nearly equal between the first two required control force values ( $2/3$  &  $1-1/3$  lbs.) with a notable increase produced by the third. Thus, from a design standpoint, adjustment time can be expected to increase if vibration is to be encountered in the operational environment; controls should be mounted perpendicular to the expected plane of vibration; and less than 2 pounds control force at the point of application should be used if controls similar to those employed in this experiment are to be used.

□ VIBRATION MEANS  
 ■ NO VIBRATION MEANS

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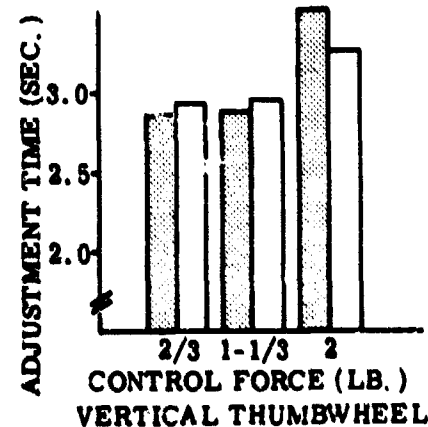
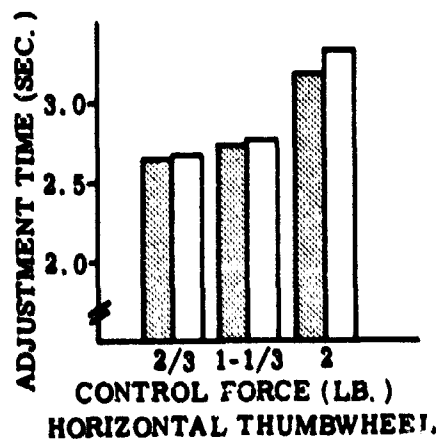
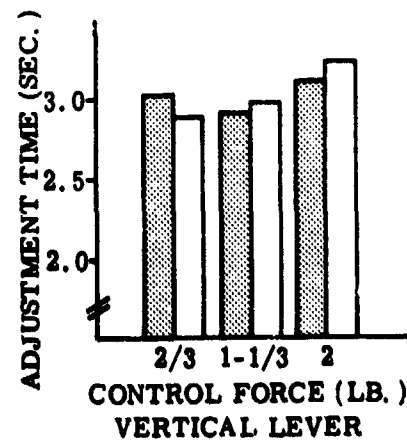
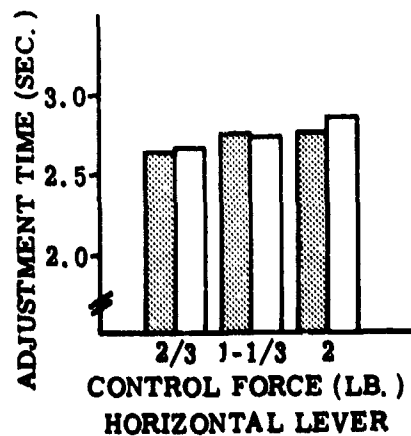
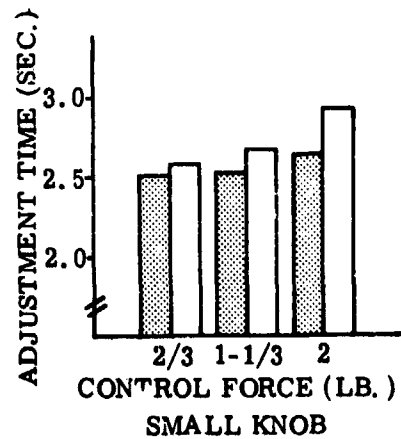
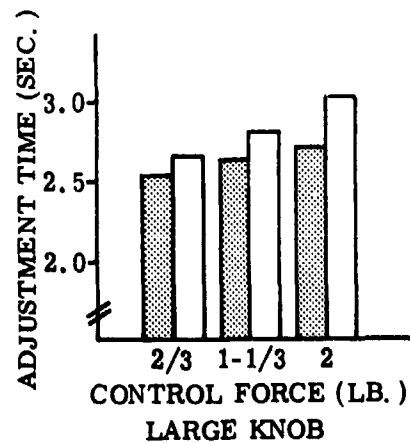


FIGURE 7  
 MEAN ADJUSTMENT TIMES, CONTROL VERSUS REQUIRED FORCE

### INCREASED WORK LOAD EXPERIMENT

#### Data Collection Procedures

All controls and displays available to the subjects except the rudder pedals were utilized in this portion of the program. The right hand manual task controls again served as the controls from which the dependent variables (error and time) were recorded for analysis purposes. However, only the 1-1/3 pound control force requirement was used, with 4 readings of error and time on each control utilized for each test run.

In addition to the knob, lever, and thumbwheel settings, subjects were required to accomplish a number of increased work load tasks consisting of the following items:

- A. Continuous compensatory tracking of "pitch" and "heading" utilizing the wheel and column to center the heading indicator and the projected line on the panel CRT.
- B. Verbal reports of 4 readings each of the five five-digit counters.
- C. Four adjustments of "airspeed" utilizing the "throttle".
- D. Three actuations each of the two toggle switches.
- E. Four verbal reports of the clock indication to the nearest minute.

Although subjects were not notified of the fact, these additional tasks served only to increase operator work load, and data were not recorded.

As in the previous experiment, eight predetermined random programs were utilized to provide the stimulus inputs for the discrete tasks to the subjects. Illumination of an indicator light adjacent to the display or control cued the subject to the appropriate task, with time limitations the same as before.

Vibration conditions for this portion of the program were selected to representatively sample those used in the speed, accuracy, and control force experiment, and are shown in Table IX. With the lack of a consistent difference in results due to frequency in the previous experiment, deletion of approximately one-half the vibration conditions to achieve a comparable reduction in test time seemed appropriate.

#### Data Analysis

Error and time scores obtained under the increased work load situation were to be compared with similar scores obtained during the previous tests. Thus, repeated measurements for all subjects were obtained for each control

TABLE IX  
THE 5 VIBRATION FREQUENCY AND 3 REACTION LEVEL CONDITIONS USED IN THE  
INCREASED WORK LOAD ANALYSIS

|         | 1  | 1.5   | 2 | 3 | 4 | 5 | 6 | 8 | 10   | 12    | 14    | 16 | 18 | 20 | 23 | 27   |
|---------|----|-------|---|---|---|---|---|---|------|-------|-------|----|----|----|----|------|
| LEVEL 1 | DA |       |   |   |   |   |   |   |      |       |       |    |    |    |    |      |
|         | G  |       |   |   |   |   |   |   |      |       |       |    |    |    |    |      |
| LEVEL 2 | DA | 3.600 |   |   |   |   |   |   | .055 | .056  | .053  |    |    |    |    | .012 |
|         | G  | .184  |   |   |   |   |   |   | .281 | .569  | .871  |    |    |    |    | .436 |
| LEVEL 3 | DA | 4.877 |   |   |   |   |   |   | .103 | .079  | .068  |    |    |    |    | .024 |
|         | G  | .249  |   |   |   |   |   |   | .526 | .796  | 1.132 |    |    |    |    | .878 |
| LEVEL 4 | DA | 5.656 |   |   |   |   |   |   | .145 | .110  | .085  |    |    |    |    | .026 |
|         | G  | .289  |   |   |   |   |   |   | .740 | 1.097 | 1.408 |    |    |    |    | .987 |

under conditions which varied simultaneously between operator work load, vibration frequency, and vibration severity. These data were again cast into four dimensional ANOV's for each control. Vibration scores and the difference between vibration and no vibration scores for both control accuracy and adjustment time served as the respective dependent variables.

#### Results and Interpretation

As in previous sections of the report, results of this experiment are treated and discussed as a unit. Significance columns from each of the analyses performed are shown in Tables X and XI. Table X shows results of tests on adjustment error. Table XI shows results of similar tests on adjustment times.

From Table X, the effect of different work loads on the accuracy of the operator are seen to be highly significant for all controls, (main effect B) and this is the only consistent effect present. However, these effects do vary on the knobs and horizontal thumbwheel as a function of the subject involved. Also, as a conclusion from the lack of significance values when utilizing difference scores, the differences are seen to exist in both the vibration and no vibration conditions. Figure 8 illustrates these relationships for each of the controls.

Table XI shows a similar variance in adjustment time between the two work load situations, both in the vibration and no vibration conditions. Also present, however, is a consistent difference in time requirements between subjects, as was the case in the previous experiment. Plots of mean adjustment times for each of the controls and work situations are shown in Figure 9.

Immediately apparent from inspection of the Figures is the degrading effect a work overload has on operator performance. Adjustment error is approximately tripled, and the time required for adjustment is approximately doubled between the two conditions of this experiment. Also evident is the fact that the effect is independent of the vibration conditions, on both variables.

A composite look at the results of this portion of the vibration program indicates that operator work load is singularly the most important item to which consideration should be given in the design of manned systems. Although under moderate work load conditions, the vibration and control force situations considered in the program are seen to affect operator performance to some degree, these effects are completely overbalanced by the degradation produced in a high work load condition. Thus, it appears that the operator, although a good environment and control design facilitate his performance, can within the limits of these experiments, adjust to less than optimum control conditions if alternate demands do not compromise his attention to the assigned task.

TABLE X  
INDICES OF SIGNIFICANCE ON INCREASED WORK LOAD ANALYSIS  
ERROR SCORES

|                 | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL |
|-----------------|------------|------------|--------------|-------------|-------------------|------------------|------------|------------|--------------|-------------|-------------------|------------------|
| A (LEVELS)      |            |            |              |             |                   | *                |            |            |              |             |                   |                  |
| B (WORK LOAD)   | **         | **         | ***          | **          | **                | **               |            |            |              |             |                   |                  |
| C (FREQUENCIES) |            |            |              |             |                   |                  | **         |            |              |             |                   |                  |
| P (SUBJECTS)    |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AB              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AC              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AP              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BC              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BP              | *          | *          |              |             | *                 |                  | *          | *          |              | *           |                   |                  |
| CP              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| ABC             |            |            |              |             |                   |                  | *          |            |              |             |                   |                  |
| ABP             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| ACP             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BCP             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| ABCP            |            |            |              |             |                   |                  |            |            |              |             |                   |                  |

\* p < .05  
\*\* p < .01  
\*\*\* p < .001

VIBRATION SCORES

DIFFERENCE SCORES

TABLE XI  
INDICES OF SIGNIFICANCE ON INCREASED WORK LOAD ANALYSIS  
TIME SCORES

|                 | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL | LARGE KNOB | SMALL KNOB | HORIZ. LEVER | VERT. LEVER | HORIZ. THUMBWHEEL | VERT. THUMBWHEEL |
|-----------------|------------|------------|--------------|-------------|-------------------|------------------|------------|------------|--------------|-------------|-------------------|------------------|
| A (LEVELS)      |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| B (WORK LOAD)   | **         | **         | ***          | ***         | **                | ***              |            |            |              |             |                   |                  |
| C (FREQUENCIES) |            |            |              |             |                   |                  |            |            | *            |             |                   |                  |
| P (SUBJECTS)    | ***        | ***        | ***          | ***         | ***               | ***              | *          |            |              | *           | **                |                  |
| AB              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AC              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| AP              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BC              |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BP              | ***        | ***        | *            | *           |                   | *                |            |            | *            |             |                   | **               |
| CP              |            |            | *            |             |                   |                  |            |            |              |             |                   |                  |
| ABC             |            |            |              |             |                   |                  |            |            |              |             | **                |                  |
| ABP             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| ACP             |            |            |              |             |                   |                  |            |            |              |             |                   |                  |
| BCP             |            |            |              |             |                   |                  |            |            |              |             | *                 |                  |
| ABCP            |            |            |              |             |                   |                  |            |            |              |             |                   |                  |

VIBRATION SCORES

DIFFERENCE SCORES

\* p < .05  
\*\* p < .01  
\*\*\* p < .001

□ VIBRATION MEANS  
 ■ NO VIBRATION MEANS

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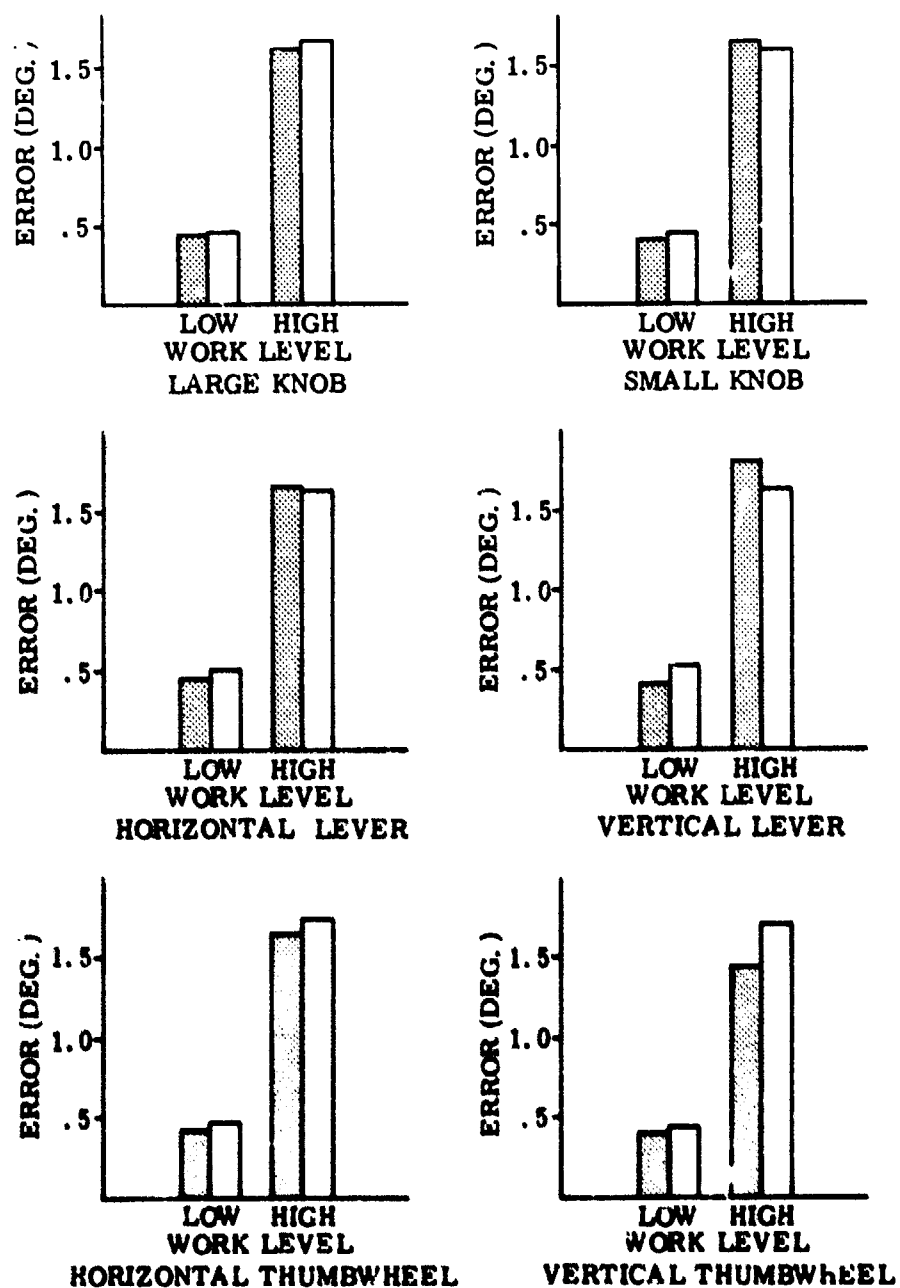


FIGURE 8  
 MEAN ERROR SCORES, CONTROL VERSUS OPERATOR WORK LEVEL

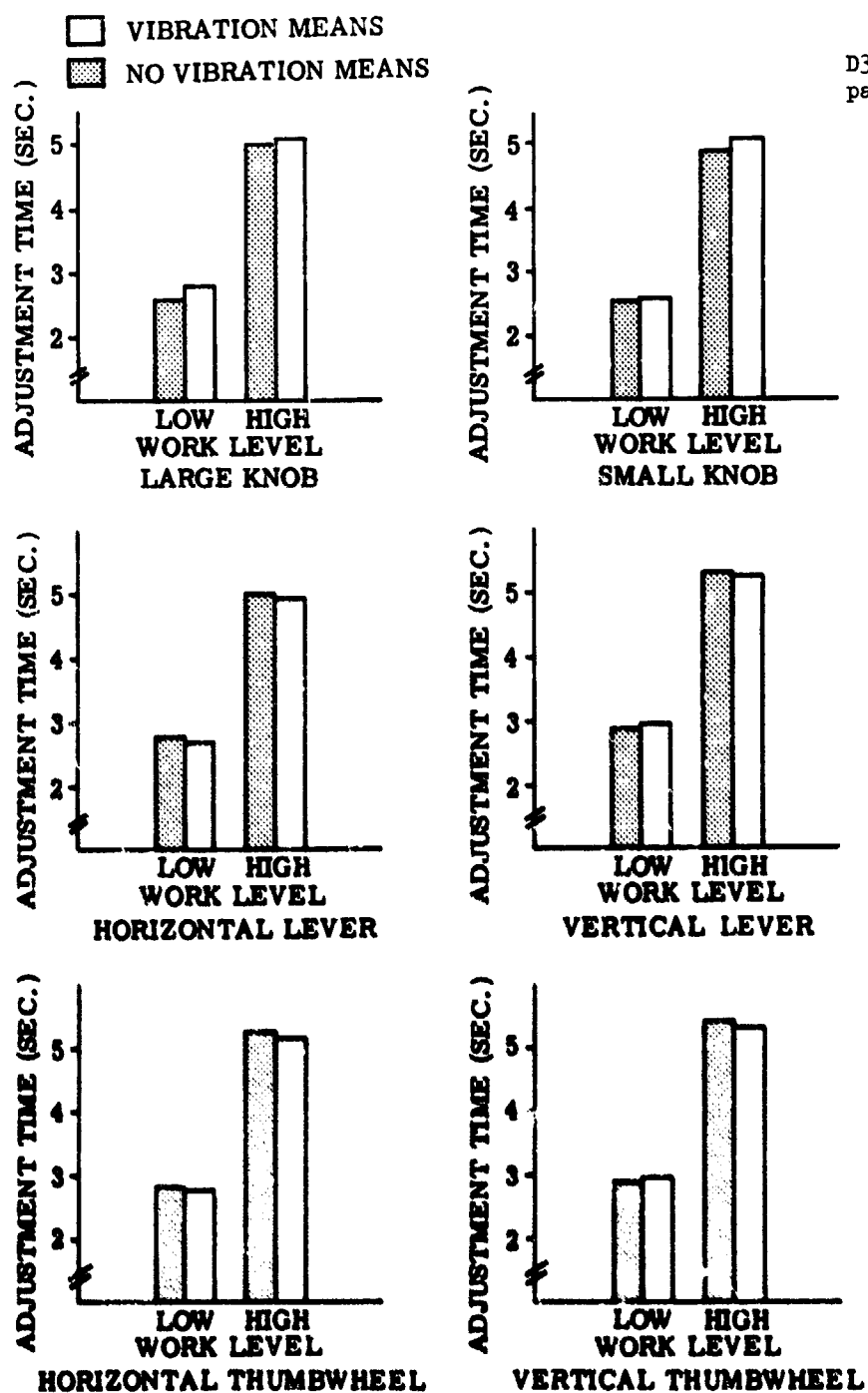


FIGURE 9  
MEAN ADJUSTMENT TIMES, CONTROL VERSUS OPERATOR WORK LEVEL

#### SUMMARY AND CONCLUSIONS

Seven subjects participated in two experiments to determine the effects of vibration, control force, and work load on the speed and accuracy of visual-motor performance utilizing various types and sizes of controls. Several conclusions can be drawn from the results of these experiments.

1. Comparisons between controls used in the experiments show no significant differences in the accuracy of accomplishing the assigned task.
2. The times required to accomplish the assigned task vary significantly between controls, with the controls which moved vertically requiring the most time.
3. In a moderate work load condition, the addition of vibration to the operational environment produces increases in both adjustment error and time at all of the intensities and frequencies of vibration encountered in this study. However, the vibration environment decreases in relative significance as the operator work level approaches an overload condition.
4. Control forces of 2 pounds produce slight increases in error and significant increases in adjustment time over those produced by the lower control forces.
5. High work load conditions nearly double the time and triple the error of adjustments made by the operator with the controls used in these experiments.

Although the data generated in these experiments provide some insight into the effects of vibration on the accomplishment of visual-motor tasks, they are, as expected, quite limited in scope. Similar investigations are needed on other tasks typical of jobs commonly performed in a vibration environment such as tracking, and more detailed research with tighter control is required to completely cover the areas reported in this study. Based on these data, additional effort in the visual-motor area should first be directed toward a better understanding of the manner in which vibration interacts with varying degrees of operator work load. We have seen that with a moderate work load, vibration has a serious effect on performance, and that with a very high work assignment, vibration makes little difference. Knowledge of what happens between these conditions, and where within the range it happens, would greatly enhance our understanding of human capabilities in a vibration environment.

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APPENDIX A

Subject Descriptions and Instructions

Subject Descriptions

| <u>Subject</u> | <u>Age</u> | <u>Height</u> | <u>Weight</u> |
|----------------|------------|---------------|---------------|
| 1.             | 41         | 72            | 225           |
| 2.             | 40         | 72            | 180           |
| 3.             | 34         | 71            | 190           |
| 4.             | 44         | 68            | 160           |
| 5.             | 41         | 67            | 175           |
| 6.             | 43         | 67            | 170           |
| 7.             | 45         | 67            | 160           |

SPEED, ACCURACY, AND CONTROL FORCE EXPERIMENT INSTRUCTIONS

This experiment is designed to study vibration effects on linear and rotary control adjustments. The test requirements are to set the pointer on the right panel indicator by adjusting a knob, lever, or thumbwheel control located on the right wing of the display-panel.

Use natural hand and arm movements to regulate the controls for an indicator setting of 350°. Rightward, clockwise or upward movement of all controls but one will move the needle clockwise. The vertically oriented thumbwheel reverses the order, a downward movement causes clockwise pointer movement. An amber caution light located by each will identify the control to be adjusted. The sequence of presentations will be random. Time and accuracy for each task will be recorded, with settings to be scored to 0.1° and 0.1 second.

Since vibration is expected to affect capability to perform some of these tasks and to have no effect on others, it is very important that any performance change be related to vibration only. For this reason, you are asked to avoid discussing details of tasks, procedures, and related details for any of the remaining tests with anyone but the experimenter. This is particularly important since even slight changes in your method of operation can be reflected in data changes. Since these would not be related to task or vibration changes and cannot be readily determined, the cause of change could become extremely difficult to analyze, at best.

INCREASED WORK LOAD EXPERIMENT INSTRUCTIONS

This test is designed to study effects of vibration on performance in a complex task. The additional tasks required involve readout of counters; time readout; operation of a throttle-type lever to control a dial pointer; depressing toggle switches, keeping a moving CRT displayed line aligned with a fixed line by control column fore and aft movement and keeping a moving pointer aligned with a fixed scale mark by control wheel rotary movement.

The procedures for operation will be the same as in prior tests. Verbal readouts are required for counter presentations and time indicated on the clock in response to the appropriate caution light. Toggles, knobs, levers and thumbwheels will be operated in response to caution light signals, and moving CRT and pointer alignment will be required as a continuous operation. The control display feedback for the vertically moving display and column arrangement is delayed. The moving pointer response to control wheel rotation will not feature any delay.

Release of both hands from the control wheel will immediately stop vibration and this is your prerogative if you feel the vibration levels unacceptable.

Are there any questions?

APPENDIX B

INDIVIDUAL ANALYSIS OF VARIANCE SUMMARY TABLES

TABLE XII SPEED AND ACCURACY  
ANALYSES, VIBRATION ERROR SCORES

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'   |
|--------------------------|----------------|-----|-----------------|-----------|
| A (levels)               | 2.509          | 2   | 1.254           | 1.953     |
| B (controls)             | .696           | 5   | .139            | 2.317     |
| C (frequencies)          | 3.490          | 8   | .436            | < 1       |
| P (subjects)             | 3.229          | 5   | .646            | < 1       |
| AB                       | .124           | 10  | .012            | < 1       |
| AC                       | 9.568          | 16  | .604            | 1.678     |
| AP                       | 3.975          | 10  | .398            | 1.106     |
| BC                       | 1.423          | 40  | .036            | < 1       |
| BP                       | 1.735          | 25  | .069            | 1.533     |
| CP                       | 26.544         | 40  | .664            | 15.810*** |
| ABC                      | 3.379          | 80  | .042            | 1.000     |
| ABP                      | 2.174          | 50  | .043            | 1.024     |
| ACP                      | 28.790         | 80  | .360            | 8.571***  |
| BCP                      | 9.022          | 200 | .045            | 1.071     |
| ABCP                     | 16.981         | 400 | .042            |           |

#### ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'  |
|--------------------------|----------------|-----|-----------------|----------|
| A (levels)               | .035           | 1   | .035            | < 1      |
| B (controls)             | .451           | 5   | .090            | 90.00    |
| C (frequencies)          | .338           | 4   | .084            | 2.049    |
| F (subjects)             | 2.037          | 5   | .407            | 6.075*   |
| AB                       | .128           | 5   | .026            | < 1      |
| AC                       | .090           | 4   | .022            | < 1      |
| AP                       | .333           | 5   | .067            | 1.970    |
| BC                       | .885           | 20  | .044            | < 1      |
| BP                       | .997           | 25  | .040            | < 1      |
| CP                       | 5.501          | 20  | .275            | 1.074    |
| ABC                      | .909           | 20  | .045            | 1.324    |
| ABP                      | 1.618          | 25  | .065            | 1.912*   |
| ACP                      | 5.122          | 20  | .256            | 7.529*** |
| BCP                      | 4.075          | 100 | .041            | 1.206    |
| ABCP                     | 3.442          | 100 | .034            |          |

#### ANALYSIS II

TABLE XIII SPEED AND ACCURACY  
ANALYSES, ERROR DIFFERENCE SCORES

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'  |
|--------------------------|----------------|-----|-----------------|----------|
| A (levels)               | .825           | 2   | .412            | 1.648    |
| B (controls)             | 1.510          | 5   | .302            | 2.221    |
| C (frequencies)          | 2.624          | 8   | .328            | < 1      |
| P (subjects)             | 7.200          | 5   | 1.440           | 4.286**  |
| AB                       | .555           | 10  | .056            | < 1      |
| AC                       | 5.453          | 16  | .340            | 1.156    |
| AP                       | 2.037          | 10  | .204            | < 1      |
| BC                       | 2.185          | 40  | .055            | < 1      |
| BP                       | 3.589          | 25  | .144            | 2.286**  |
| CP                       | 13.442         | 40  | .336            | 5.333*** |
| ABC                      | 5.597          | 80  | .070            | 1.111    |
| ABP                      | 3.998          | 50  | .080            | 1.270    |
| ACP                      | 23.519         | 80  | .294            | 4.667*** |
| BCP                      | 12.610         | 200 | .063            | 1.000    |
| ABCP                     | 25.142         | 400 | .063            |          |

ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'  |
|--------------------------|----------------|-----|-----------------|----------|
| A (levels)               | .256           | 1   | .256            | 1.032    |
| B (controls)             | .791           | 5   | .158            | 2.026    |
| C (frequencies)          | .296           | 4   | .074            | < 1      |
| P (subjects)             | 4.137          | 5   | .827            | 3.335    |
| AB                       | .260           | 5   | .052            | < 1      |
| AC                       | .788           | 4   | .197            | < 1      |
| AP                       | 1.239          | 5   | .248            | 4.203**  |
| BC                       | 1.111          | 20  | .056            | < 1      |
| BP                       | 2.468          | 25  | .099            | 1.356    |
| CP                       | 4.811          | 20  | .241            | < 1      |
| ABC                      | 1.818          | 20  | .241            | 1.542    |
| ABP                      | 1.831          | 25  | .073            | 1.237    |
| ACP                      | 5.564          | 20  | .278            | 4.712*** |
| BCP                      | 5.472          | 100 | .055            | < 1      |
| ABCP                     | 5.923          | 100 | .059            |          |

ANALYSIS II

TABLE XIV SPEED AND ACCURACY  
ANALYSES,VIBRATION TIME SCORES

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'   |
|--------------------------|----------------|-----|-----------------|-----------|
| A (levels)               | 4.719          | 2   | 2.360           | 3.367     |
| B (controls)             | 12.136         | 5   | 2.427           | 3.492*    |
| C (frequencies)          | 5.727          | 8   | .716            | 1.095     |
| P (subjects)             | 87.827         | 5   | 17.565          | 26.858*** |
| AB                       | 1.763          | 10  | .176            | <1        |
| AC                       | 12.587         | 16  | .787            | 1.019     |
| AP                       | 6.858          | 10  | .686            | <1        |
| BC                       | 9.745          | 40  | .244            | 1.099     |
| BP                       | 16.832         | 25  | .673            | 3.032***  |
| CP                       | 26.148         | 40  | .654            | 3.042***  |
| ABC                      | 22.522         | 80  | .282            | 1.312     |
| ABP                      | 8.402          | 50  | .168            | <1        |
| ACP                      | 61.789         | 80  | .772            | 3.591***  |
| BCP                      | 44.481         | 200 | .222            | 1.033     |
| ABCP                     | 86.158         | 400 | .215            |           |

ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'  |
|--------------------------|----------------|-----|-----------------|----------|
| A (levels)               | .006           | 1   | .006            | <1       |
| B (controls)             | 3.533          | 5   | .707            | 1.234    |
| C (frequencies)          | 3.664          | 4   | .916            | <1       |
| P (subjects)             | 34.479         | 5   | 6.896           | 5.575*   |
| AB                       | 1.595          | 5   | .319            | 1.271    |
| AC                       | 4.596          | 4   | 1.149           | 1.974    |
| AP                       | 6.183          | 5   | 1.237           | 7.069*** |
| BC                       | 4.986          | 20  | .249            | <1       |
| BP                       | 12.636         | 25  | .505            | 2.012*   |
| CP                       | 22.773         | 20  | 1.139           | 1.957    |
| ABC                      | 5.189          | 20  | .259            | 1.480    |
| ABP                      | 6.272          | 25  | .251            | 1.434    |
| ACP                      | 11.647         | 20  | .582            | 3.326*** |
| BCP                      | 21.301         | 100 | .213            | 1.217    |
| ABCP                     | 17.463         | 100 | .175            |          |

ANALYSIS II

TABLE XV SPEED AND ACCURACY  
ANALYSES, TIME DIFFERENCE SCORES

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F' |
|--------------------------|----------------|-----|-----------------|---------|
| A (levels)               | .897           | 2   | .448            | < 1     |
| B (controls)             | 4.649          | 5   | .930            | 1.553   |
| C (frequencies)          | 1.802          | 8   | .225            | < 1     |
| P (subjects)             | 3.511          | 5   | .702            | 1.162   |
| AB                       | 2.486          | 10  | .249            | < 1     |
| AC                       | 9.008          | 16  | .563            | 1.609   |
| AP                       | 5.241          | 10  | .524            | 1.497   |
| BC                       | 10.387         | 40  | .260            | < 1     |
| BP                       | 15.852         | 25  | .634            | 2.149** |
| CP                       | 24.147         | 40  | .604            | 1.961** |
| ABC                      | 27.961         | 80  | .350            | 1.136   |
| ABP                      | 10.496         | 50  | .210            | < 1     |
| ACP                      | 28.008         | 80  | .350            | 1.136   |
| BCP                      | 58.947         | 200 | .295            | < 1     |
| ABCP                     | 123.016        | 400 | .308            |         |

#### ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F' |
|--------------------------|----------------|-----|-----------------|---------|
| A (levels)               | .073           | 1   | .073            | < 1     |
| B (controls)             | 1.280          | 5   | .256            | < 1     |
| C (frequencies)          | .512           | 4   | .128            | < 1     |
| P (subjects)             | 1.094          | 5   | .219            | < 1     |
| AB                       | 1.730          | 5   | .346            | 1.189   |
| AC                       | 5.557          | 4   | 1.389           | 6.910** |
| AP                       | 5.888          | 5   | 1.178           | 3.764** |
| BC                       | 7.913          | 20  | .396            | 1.158   |
| BP                       | 11.549         | 25  | .462            | 1.583   |
| CP                       | 9.435          | 20  | .472            | 2.348*  |
| ABC                      | 6.413          | 20  | .321            | 1.026   |
| ABP                      | 7.282          | 25  | .291            | < 1     |
| ACP                      | 4.027          | 20  | .201            | < 1     |
| BCP                      | 33.350         | 100 | .334            | 1.067   |
| ABCP                     | 31.256         | 100 | .313            |         |

#### ANALYSIS II

TABLE XVI CONTROL FORCE ANALYSES  
VIBRATION ERROR SCORES, LARGE KNOB

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .758                   | 2         | .379                    | < 1            |
| B (forces)                       | .070                   | 2         | .035                    | < 1            |
| C (frequencies)                  | 2.169                  | 8         | .271                    | < 1            |
| P (subjects)                     | 1.630                  | 5         | .326                    | < 1            |
| AB                               | .073                   | 4         | .018                    | < 1            |
| AC                               | 6.279                  | 16        | .392                    | 1.815*         |
| AP                               | 2.169                  | 10        | .217                    | 1.00           |
| BC                               | .439                   | 16        | .027                    | < 1            |
| BP                               | .561                   | 10        | .056                    | 1.556          |
| CP                               | 15.493                 | 40        | .387                    | 9.923***       |
| ABC                              | 1.591                  | 32        | .050                    | 1.282          |
| ABP                              | .838                   | 20        | .042                    | 1.077          |
| ACP                              | 16.849                 | 80        | .216                    | 5.538***       |
| BCP                              | 2.907                  | 80        | .036                    | < 1            |
| ABCP                             | 6.265                  | 160       | .039                    |                |

ANALYSIS I

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .057                   | 1         | .057                    | 2.280          |
| B (forces)                       | .066                   | 2         | .033                    | 2.538          |
| C (frequencies)                  | .262                   | 4         | .065                    | < 1            |
| P (subjects)                     | .265                   | 5         | .053                    | 2.120          |
| AB                               | .015                   | 2         | .008                    | < 1            |
| AC                               | .421                   | 4         | .105                    | < 1            |
| AP                               | .123                   | 5         | .025                    | 1.087          |
| BC                               | .120                   | 8         | .015                    | < 1            |
| BP                               | .228                   | 10        | .023                    | 1.278          |
| CP                               | 2.916                  | 20        | .146                    | < 1            |
| ABC                              | .234                   | 8         | .029                    | 1.261          |
| ABP                              | .185                   | 10        | .018                    | < 1            |
| ACP                              | 3.285                  | 20        | .164                    | 1.130**        |
| BCP                              | 1.120                  | 40        | .028                    | 1.217          |
| ABCP                             | .920                   | 40        | .023                    |                |

ANALYSIS II

TABLE XVII CONTROL FORCE ANALYSES  
VIBRATION ERROR SCORES, SMALL KNOB

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'  |
|--------------------------|----------------|-----|-----------------|----------|
| A (levels)               | .773           | 2   | .386            | < 1      |
| B (forces)               | .235           | 2   | .118            | 1.686    |
| C (frequencies)          | 3.852          | 8   | .482            | 1.470    |
| P (subjects)             | 2.316          | 5   | .463            | 1.412    |
| AB                       | .036           | 4   | .009            | < 1      |
| AC                       | 6.028          | 16  | .377            | 1.456    |
| AP                       | 2.760          | 10  | .276            | 1.066    |
| BC                       | 1.225          | 16  | .077            | 1.481    |
| BP                       | .453           | 10  | .045            | < 1      |
| CP                       | 13.128         | 40  | .328            | 5.964*** |
| ABC                      | 1.731          | 32  | .054            | < 1      |
| ABP                      | 1.165          | 20  | .058            | 1.055    |
| ACP                      | 20.730         | 80  | .259            | 4.709*** |
| BCP                      | 4.144          | 80  | .052            | < 1      |
| ABCP                     | 8.836          | 160 | .055            |          |

ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'   |
|--------------------------|----------------|----|-----------------|-----------|
| A (levels)               | .173           | 1  | .173            | 2.507     |
| B (forces)               | .203           | 2  | .104            | 2.311     |
| C (frequencies)          | .196           | 4  | .049            | 1.324     |
| P (subjects)             | .945           | 5  | .189            | 2.739     |
| AB                       | .128           | 2  | .064            | 1.730     |
| AC                       | .211           | 4  | .053            | < 1       |
| AP                       | .344           | 5  | .069            | 4.929**   |
| BC                       | .222           | 8  | .028            | < 1       |
| BP                       | .180           | 10 | .018            | < 1       |
| CP                       | 2.767          | 20 | .138            | < 1       |
| ABC                      | .231           | 8  | .029            | 2.071     |
| ABP                      | .368           | 10 | .037            | 2.643*    |
| ACP                      | 3.076          | 20 | .154            | 11.000*** |
| BCP                      | 1.055          | 40 | .026            | 1.857*    |
| ABCP                     | .573           | 40 | .014            |           |

ANALYSIS II

TABLE XVIII CONTROL FORCE ANALYSES  
VIBRATION ERROR SCORES, HORIZONTAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (Levels)            | .488        | 2   | .244         | < 1      |
| B (Forces)            | .553        | 2   | .276         | 6.732*   |
| C (Frequencies)       | 1.090       | 8   | .136         | < 1      |
| P (Subjects)          | .918        | 5   | .184         | < 1      |
| AB                    | .118        | 4   | .030         | < 1      |
| AC                    | 4.520       | 16  | .282         | 1.752    |
| AP                    | 2.021       | 10  | .202         | 1.255    |
| BC                    | .475        | 16  | .030         | < 1      |
| BP                    | .485        | 10  | .048         | 1.297    |
| CP                    | 14.627      | 40  | .366         | 9.632*** |
| ABC                   | .892        | 32  | .028         | < 1      |
| ABP                   | .887        | 20  | .044         | 1.158    |
| ACP                   | 12.912      | 80  | .161         | 4.231*** |
| BCP                   | 2.964       | 80  | .037         | < 1      |
| ABCP                  | 6.139       | 160 | .038         |          |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F'  |
|-----------------------|-------------|----|--------------|----------|
| A (Levels)            | .008        | 1  | .008         | < 1      |
| B (Forces)            | .190        | 2  | .095         | < 1      |
| C (Frequencies)       | .128        | 4  | .032         | < 1      |
| P (Subjects)          | .789        | 5  | .158         | 1.145    |
| AB                    | .163        | 2  | .081         | 1.125    |
| AC                    | .182        | 4  | .046         | < 1      |
| AP                    | .692        | 5  | .138         | 3.450*   |
| BC                    | .433        | 8  | .054         | 1.227    |
| BP                    | .891        | 10 | .089         | 1.236    |
| CP                    | 3.030       | 20 | .152         | 1.000    |
| BCP                   | .320        | 8  | .040         | 1.000    |
| ABP                   | .723        | 10 | .072         | 1.800    |
| ACP                   | 3.039       | 20 | .152         | 3.800*** |
| BCP                   | 1.751       | 40 | .044         | 1.100    |
| ABCP                  | 1.615       | 40 | .040         |          |

#### ANALYSIS II

TABLE XIX CONTROL FORCE ANALYSES  
VIBRATION ERROR SCORES, VERTICAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (Levels)            | 1.237       | 2   | .618         | 1.850    |
| B (Forces)            | .624        | 2   | .312         | 2.737    |
| C (Frequencies)       | 2.090       | 8   | .261         | < 1      |
| P (Subjects)          | 2.251       | 5   | .450         | 1.351    |
| AB                    | .085        | 4   | .021         | < 1      |
| AC                    | 4.639       | 16  | .290         | 1.349    |
| AP                    | 2.593       | 10  | .259         | 1.205    |
| BC                    | 1.544       | 16  | .096         | 1.655    |
| BP                    | .757        | 10  | .076         | 1.310    |
| CP                    | 13.314      | 40  | .333         | 5.371*** |
| ABC                   | 1.983       | 32  | .062         | 1.000    |
| ABP                   | 1.228       | 20  | .061         | < 1      |
| ACP                   | 17.201      | 80  | .215         | 3.468*** |
| BCP                   | 4.669       | 80  | .058         | < 1      |
| ABCP                  | 9.843       | 160 | .062         |          |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F'  |
|-----------------------|-------------|----|--------------|----------|
| A (Levels)            | .136        | 1  | .136         | 3.886    |
| B (Forces)            | .054        | 2  | .027         | < 1      |
| C (Frequencies)       | .901        | 4  | .225         | 4.167    |
| P (Subjects)          | .394        | 5  | .079         | 2.257    |
| AB                    | .067        | 2  | .034         | < 1      |
| AC                    | .267        | 4  | .067         | < 1      |
| AP                    | .175        | 5  | .035         | 1.667    |
| BC                    | .138        | 8  | .017         | < 1      |
| BP                    | .364        | 10 | .036         | < 1      |
| CP                    | 1.688       | 20 | .084         | < 1      |
| ABC                   | .141        | 8  | .018         | < 1      |
| ABP                   | .393        | 10 | .039         | 1.810    |
| ACP                   | 2.429       | 20 | .121         | 5.762*** |
| BCP                   | 1.733       | 40 | .043         | 2.048*   |
| ABCP                  | .846        | 40 | .021         |          |

#### ANALYSIS II

TABLE XX CONTROL FORCE ANALYSES  
VIBRATION ERROR SCORES, HORIZONTAL THUMBWHEEL

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (Levels)            | 1.252       | 2   | .626         | 1.501    |
| B (Forces)            | .445        | 2   | .223         | 1.088    |
| C (Frequencies)       | 3.661       | 8   | .458         | 1.101    |
| P (Subjects)          | 2.677       | 5   | .535         | 1.286    |
| AB                    | .236        | 4   | .059         | < 1      |
| AC                    | 6.231       | 16  | .389         | 1.581    |
| AP                    | 2.737       | 10  | .274         | 1.114    |
| BC                    | 1.690       | 16  | .106         | < 1      |
| BP                    | 2.474       | 10  | .247         | 1.669    |
| CP                    | 16.642      | 40  | .416         | 3.176*** |
| ABC                   | 4.814       | 32  | .150         | 1.145    |
| ABP                   | 1.970       | 20  | .098         | < 1      |
| ACP                   | 19.642      | 80  | .246         | 1.878*** |
| BCP                   | 11.826      | 80  | .148         | 1.130    |
| ABCP                  | 20.892      | 160 | .131         |          |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F'  |
|-----------------------|-------------|----|--------------|----------|
| A (Levels)            | .172        | 1  | .172         | 4.410    |
| B (Forces)            | .255        | 2  | .128         | 1.196    |
| C (Frequencies)       | .443        | 4  | .111         | 1.776    |
| P (Subjects)          | .792        | 5  | .158         | 4.051    |
| AB                    | .090        | 2  | .045         | < 1      |
| AC                    | .146        | 4  | .036         | < 1      |
| AP                    | .193        | 5  | .039         | < 1      |
| BC                    | .204        | 8  | .026         | < 1      |
| BP                    | 1.144       | 10 | .114         | 2.192    |
| CP                    | 2.675       | 20 | .134         | < 1      |
| ABC                   | .512        | 8  | .064         | 1.600    |
| ABP                   | .521        | 10 | .052         | 1.300    |
| ACP                   | 3.026       | 20 | .151         | 4.775*** |
| BCP                   | 1.699       | 40 | .042         | 1.050    |
| ABCP                  | 1.586       | 40 | .040         |          |

#### ANALYSIS II

TABLE XXI CONTROL FORCE ANALYSES  
VIBRATION ERROR SCORES, VERTICAL THUMBWHEEL

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (levels)            | 1.073       | 2   | .536         | 2.694    |
| B (forces)            | .631        | 2   | .316         | 4.158    |
| C (frequencies)       | 3.525       | 8   | .441         | 1.142    |
| P (subjects)          | 1.744       | 5   | .349         | < 1      |
| AB                    | .027        | 4   | .007         | < 1      |
| AC                    | 3.093       | 16  | .193         | < 1      |
| AP                    | 2.145       | 10  | .214         | 1.029    |
| BC                    | .669        | 16  | .042         | < 1      |
| BP                    | .913        | 10  | .091         | 1.596    |
| CP                    | 15.448      | 40  | .386         | 6.031*** |
| ABC                   | 1.158       | 32  | .036         | < 1      |
| ABP                   | .967        | 20  | .048         | < 1      |
| ACP                   | 16.610      | 80  | .208         | 3.250*** |
| BCP                   | 4.573       | 80  | .057         | < 1      |
| ABCP                  | 10.207      | 160 | .064         |          |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F'  |
|-----------------------|-------------|----|--------------|----------|
| A (levels)            | .184        | 1  | .184         | 4.182    |
| B (forces)            | .036        | 2  | .018         | 1.059    |
| C (frequencies)       | .104        | 4  | .026         | 1.408    |
| P (subjects)          | .475        | 5  | .095         | 2.159    |
| AB                    | .007        | 2  | .004         | < 1      |
| AC                    | .083        | 4  | .021         | < 1      |
| AP                    | .219        | 5  | .044         | < 1      |
| BC                    | .321        | 8  | .040         | 2.000    |
| BP                    | .444        | 10 | .044         | < 1      |
| CP                    | 2.179       | 20 | .109         | < 1      |
| ABC                   | .296        | 8  | .037         | < 1      |
| ABP                   | .312        | 10 | .031         | < 1      |
| ACP                   | 3.137       | 20 | .157         | 3.413*** |
| BCP                   | 1.166       | 40 | .029         | < 1      |
| ABCP                  | 1.850       | 40 | .046         |          |

#### ANALYSIS II

TABLE XXII CONTROL FORCE ANALYSES  
ERROR DIFFERENCE SCORES, LARGE KNOB

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (levels)            | .206        | 2   | .103         | < 1      |
| B (forces)            | .850        | 2   | .425         | 4.620*   |
| C (frequencies)       | 1.656       | 8   | .207         | 1.020    |
| P (subjects)          | 3.573       | 5   | .713         | 3.512**  |
| AP                    | .251        | 4   | .063         | < 1      |
| AB                    | 4.141       | 16  | .259         | 1.506    |
| AP                    | .737        | 10  | .074         | < 1      |
| BC                    | .684        | 16  | .043         | < 1      |
| BP                    | .966        | 10  | .097         | 2.021*   |
| CP                    | 8.113       | 40  | .203         | 3.691*** |
| ABC                   | 2.494       | 32  | .078         | 1.418    |
| ABP                   | 1.439       | 20  | .072         | 1.309    |
| ACP                   | 13.749      | 80  | .172         | 3.127*** |
| BCP                   | 3.811       | 80  | .048         | < 1      |
| ABCP                  | 8.730       | 160 | .055         |          |

ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (levels)            | .116        | 1  | .116         | 5.800   |
| B (forces)            | .605        | 2  | .302         | 1.841   |
| C (frequencies)       | .399        | 4  | .100         | < 1     |
| P (subjects)          | .925        | 5  | .185         | 9.250*  |
| AB                    | .126        | 2  | .063         | 2.864   |
| AC                    | .811        | 4  | .203         | 1.167   |
| AP                    | .100        | 5  | .020         | < 1     |
| BC                    | .170        | 8  | .021         | < 1     |
| BP                    | 1.233       | 10 | .123         | 5.591** |
| CP                    | 1.823       | 20 | .091         | < 1     |
| ABC                   | .702        | 8  | .085         | 1.466   |
| ABP                   | .216        | 10 | .022         | < 1     |
| ACP                   | 3.478       | 20 | .174         | 3.000** |
| BCP                   | 1.212       | 40 | .030         | < 1     |
| ABCP                  | 2.326       | 40 | .058         |         |

ANALYSIS II

TABLE XXIII CONTROL FORCE ANALYSES  
ERROR DIFFERENCE SCORES, SMALL KNOB

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'  |
|--------------------------|----------------|-----|-----------------|----------|
| A (levels)               | .214           | 2   | .107            | < 1      |
| B (forces)               | .121           | 2   | .060            | < 1      |
| C (frequencies)          | 2.108          | 8   | .264            | 1.375    |
| P (subjects)             | 3.456          | 5   | .691            | 3.599**  |
| AB                       | .127           | 4   | .032            | < 1      |
| AC                       | 4.441          | 16  | .278            | 1.203    |
| AP                       | 1.522          | 10  | .152            | < 1      |
| BC                       | 1.144          | 16  | .072            | 1.000    |
| BP                       | 1.138          | 10  | .114            | 1.583    |
| CP                       | 7.675          | 40  | .192            | 2.560*** |
| ABC                      | 1.518          | 32  | .047            | < 1      |
| ABP                      | 1.432          | 20  | .072            | < 1      |
| ACP                      | 18.449         | 80  | .231            | 3.080*** |
| BCP                      | 5.776          | 80  | .072            | < 1      |
| ABCP                     | 11.971         | 160 | .075            |          |

ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'  |
|--------------------------|----------------|----|-----------------|----------|
| A (levels)               | .265           | 1  | .265            | 2.054    |
| B (forces)               | .384           | 2  | .192            | 4.085    |
| C (frequencies)          | .055           | 4  | .014            | 1.214    |
| P (subjects)             | .982           | 5  | .196            | 1.519    |
| AB                       | .122           | 2  | .061            | 1.271    |
| AC                       | .141           | 4  | .035            | < 1      |
| AP                       | .843           | 5  | .129            | 5.609*** |
| BC                       | .243           | 8  | .030            | < 1      |
| BP                       | .335           | 10 | .034            | < 1      |
| CP                       | 2.656          | 20 | .133            | < 1      |
| ABC                      | 3.11           | 8  | .038            | 1.652    |
| ABP                      | .481           | 10 | .048            | 2.087*   |
| ACP                      | 3.797          | 20 | .190            | 8.261*** |
| BCP                      | 1.586          | 40 | .040            | 1.739*   |
| ABCP                     | .904           | 40 | .023            |          |

ANALYSIS II

TABLE XXIV CONTROL FORCE ANALYSES  
ERROR DIFFERENCE SCORES, HORIZONTAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (Levels)            | .054        | 2   | .027         | < 1      |
| B (Forces)            | .572        | 2   | .286         | 1.810    |
| C (Frequencies)       | .924        | 8   | .103         | < 1      |
| P (Subjects)          | 2.146       | 5   | .429         | 2.480*   |
| AB                    | .429        | 4   | .107         | 1.081    |
| AC                    | 2.113       | 16  | .132         | 1.048    |
| AP                    | .849        | 10  | .085         | < 1      |
| BC                    | 1.016       | 16  | .064         | 1.000    |
| BP                    | 1.579       | 10  | .158         | 2.469*   |
| CP                    | 6.938       | 40  | .173         | 2.932*** |
| ABC                   | 1.741       | 32  | .054         | < 1      |
| ABP                   | 2.090       | 20  | .104         | 1.763*   |
| ACP                   | 10.104      | 80  | .126         | 2.136*** |
| BCP                   | 5.105       | 80  | .064         | 1.085    |
| ABCP                  | 9.442       | 160 | .059         |          |

ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (Levels)            | .001        | 1  | .001         | < 1     |
| B (Forces)            | .070        | 2  | .035         | < 1     |
| C (Frequencies)       | .093        | 1  | .023         | < 1     |
| P (Subjects)          | 1.889       | 5  | .378         | 1.518   |
| AB                    | .209        | 2  | .104         | 1.518   |
| AC                    | .810        | 4  | .202         | 1.295   |
| AP                    | 1.247       | 5  | .249         | 3.609** |
| BC                    | .677        | 8  | .085         | 1.545   |
| BP                    | 1.470       | 10 | .147         | 1.771   |
| CP                    | 2.759       | 20 | .103         | 1.493   |
| ABC                   | .476        | 8  | .060         | < 1     |
| ABP                   | .931        | 10 | .083         | 1.203   |
| ACP                   | 3.116       | 20 | .156         | 2.261*  |
| BCP                   | 2.545       | 40 | .064         | < 1     |
| ABCP                  | 2.765       | 40 | .069         |         |

ANALYSIS II

TABLE XXV CONTROL FORCE ANALYSES  
ERROR DIFFERENCE SCORES, VERTICAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (Levels)            | .565        | 2   | .282         | 1.709    |
| B (Forces)            | .421        | 2   | .210         | 1.707    |
| C (Frequencies)       | 2.007       | 8   | .251         | 1.224    |
| P (Subjects)          | 3.567       | 5   | .713         | 3.478*   |
| AB                    | .038        | 4   | .010         | <1       |
| AC                    | 4.153       | 16  | .260         | 1.135    |
| AP                    | 1.337       | 10  | .134         | <1       |
| BC                    | 1.773       | 16  | .111         | 1.542    |
| BP                    | .835        | 10  | .084         | 1.167    |
| CP                    | 8.184       | 40  | .205         | 3.015*** |
| ABC                   | 1.561       | 32  | .049         |          |
| ABP                   | 1.571       | 20  | .079         | 1.162    |
| ACP                   | 18.345      | 80  | .229         | 3.368*** |
| BGP                   | 5.780       | 80  | .072         | 1.059    |
| ABCP                  | 10.802      | 160 | .068         |          |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F'  |
|-----------------------|-------------|----|--------------|----------|
| A (Levels)            | .319        | 1  | .319         | 3.097    |
| B (Forces)            | .218        | 2  | .109         | <1       |
| C (Frequencies)       | .468        | 4  | .117         | 2.395*   |
| P (Subjects)          | .615        | 5  | .123         | 1.194    |
| AB                    | .249        | 2  | .124         | 2.818    |
| AC                    | .199        | 4  | .050         | <1       |
| AP                    | .517        | 5  | .103         | 3.433*   |
| BC                    | .126        | 8  | .016         | <1       |
| BP                    | .594        | 10 | .059         | 1.568    |
| CP                    | 1.395       | 20 | .069         | <1       |
| ABC                   | .132        | 8  | .016         | <1       |
| ABP                   | .448        | 10 | .044         | 1.419    |
| ACP                   | 3.355       | 20 | .168         | 5.419*** |
| BGP                   | 2.236       | 40 | .056         | 1.806*   |
| ABCP                  | 1.235       | 40 | .031         |          |

#### ANALYSIS II

TABLE XXVI CONTROL FORCE ANALYSES  
ERROR DIFFERENCE SCORES, HORIZONTAL THUMBWHEEL

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F' |
|--------------------------|----------------|-----|-----------------|---------|
| A (Levels)               | .588           | 2   | .294            | <1      |
| B (Forces)               | .216           | 2   | .108            | <1      |
| C (Frequencies)          | 2.568          | 8   | .321            | 1.249   |
| P (Subjects)             | 2.233          | 5   | .447            | 1.739   |
| AB                       | .451           | 4   | .113            | <1      |
| AC                       | 4.000          | 16  | .250            | 1.269   |
| AP                       | 2.853          | 10  | .285            | 1.447   |
| BC                       | 1.54           | 16  | .096            | <1      |
| BP                       | 2.265          | 10  | .226            | 1.527   |
| CP                       | 10.299         | 40  | .257            | 1.977** |
| ABC                      | 5.535          | 32  | .173            | 1.331   |
| ABP                      | 2.552          | 20  | .128            | <1      |
| ACP                      | 15.753         | 80  | .197            | 1.515*  |
| BCP                      | 11.829         | 80  | .148            | 1.138   |
| ABCP                     | 20.759         | 160 | .130            |         |

#### ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'  |
|--------------------------|----------------|----|-----------------|----------|
| A (Levels)               | .355           | 1  | .355            | 1.740    |
| B (Forces)               | .284           | 2  | .142            | 1.060    |
| C (Frequencies)          | .677           | 4  | .169            | 11.267   |
| P (Subjects)             | .715           | 5  | .143            | <1       |
| AB                       | .167           | 2  | .084            | 1.787    |
| AC                       | .446           | 4  | .111            | <1       |
| AP                       | 1.022          | 5  | .204            | 3.643**  |
| BC                       | .207           | 8  | .026            | <1       |
| BP                       | .969           | 10 | .097            | 2.064    |
| CP                       | 1.774          | 20 | .089            | <1       |
| ABC                      | .637           | 8  | .080            | 1.429    |
| ABP                      | .470           | 10 | .047            | <1       |
| ACP                      | 3.692          | 20 | .185            | 3.304*** |
| BCP                      | 1.900          | 40 | .048            | <1       |
| ABCP                     | 2.258          | 40 | .056            |          |

#### ANALYSIS II

TABLE XXVII CONTROL FORCE ANALYSES  
ERROR DIFFERENCE SCORES, VERTICAL THUMBWHEEL

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .389                   | 2         | .194                    | 1.780          |
| B (forces)                       | .552                   | 2         | .276                    | 4.246          |
| C (frequencies)                  | 2.464                  | 8         | .308                    | 2.990*         |
| P (subjects)                     | 3.187                  | 5         | .637                    | 6.184***       |
| AB                               | .029                   | 4         | .007                    | <1             |
| AC                               | 2.697                  | 16        | .169                    | <1             |
| AP                               | 1.554                  | 10        | .155                    | <1             |
| BC                               | .792                   | 16        | .050                    | <1             |
| BP                               | .848                   | 10        | .085                    | 1.214          |
| CP                               | 6.110                  | 40        | .103                    | 1.288          |
| ABC                              | 1.481                  | 32        | .046                    | <1             |
| ABP                              | 1.176                  | 20        | .059                    | <1             |
| ACP                              | 17.188                 | 80        | .215                    | 2.687***       |
| BCP                              | 5.603                  | 80        | .070                    | <1             |
| ABCP                             | 12.844                 | 160       | .080                    |                |

ANALYSIS I

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .578                   | 1         | .578                    | 2.429          |
| B (forces)                       | .330                   | 2         | .165                    | 2.426          |
| C (frequencies)                  | .133                   | 4         | .033                    | 1.727          |
| P (subjects)                     | .947                   | 5         | .189                    | <1             |
| AB                               | .058                   | 2         | .029                    | <1             |
| AC                               | .187                   | 4         | .047                    | <1             |
| AP                               | 1.190                  | 5         | .238                    | 4.491**        |
| BC                               | .481                   | 8         | .060                    | <1             |
| BP                               | .731                   | 10        | .073                    | 2.147          |
| CP                               | 1.913                  | 20        | .096                    | <1             |
| ABC                              | .573                   | 8         | .072                    | 1.358          |
| ABP                              | .335                   | 10        | .034                    | <1             |
| ACP                              | 4.271                  | 20        | .214                    | 4.038***       |
| BCP                              | 1.696                  | 40        | .042                    | <1             |
| ABCP                             | 2.102                  | 40        | .053                    |                |

ANALYSIS II

TABLE XXVIII CONTROL FORCE ANALYSES  
VIBRATION TIME SCORES, LARGE KNOB

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'   |
|-----------------------|-------------|-----|--------------|-----------|
| A (levels)            | 2.676       | 2   | 1.338        | 13.653    |
| B (forces)            | 10.186      | 2   | 5.093        | 15.361**  |
| C (frequencies)       | 3.287       | 8   | .411         | <1        |
| F (subjects)          | 78.115      | 5   | 15.623       | 30.875*** |
| AB                    | 1.136       | 4   | .284         | <1        |
| AC                    | 8.806       | 16  | .550         | <1        |
| AP                    | 1.910       | 10  | .191         | <1        |
| BC                    | 2.315       | 16  | .145         | <1        |
| BP                    | 2.040       | 10  | .204         | <1        |
| CP                    | 20.223      | 40  | .506         | 1.902**   |
| ABC                   | 14.477      | 32  | .452         | 1.699*    |
| ABP                   | 5.214       | 20  | .261         | <1        |
| ACP                   | 51.448      | 80  | .643         | 2.417***  |
| BCP                   | 21.473      | 80  | .268         | 1.008     |
| ABCP                  | 42.594      | 160 | .266         |           |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F'  |
|-----------------------|-------------|----|--------------|----------|
| A (levels)            | .319        | 1  | .319         | <1       |
| B (forces)            | 3.299       | 2  | 1.649        | 2.529    |
| C (frequencies)       | .879        | 4  | .220         | <1       |
| P (subjects)          | 39.253      | 5  | 7.851        | 17.966** |
| AB                    | 1.090       | 2  | .549         | 7.521*   |
| AC                    | 2.109       | 4  | .527         | <1       |
| AP                    | 2.185       | 5  | .437         | 3.035*   |
| BC                    | 3.303       | 8  | .413         | 1.000    |
| BP                    | 1.706       | 10 | .170         | 2.411    |
| CP                    | 8.956       | 20 | .448         | <1       |
| ABC                   | 2.420       | 8  | .302         | 2.097    |
| ABP                   | .727        | 10 | .073         | .1       |
| ACP                   | 11.547      | 20 | .577         | 4.007*** |
| BCP                   | 10.113      | 40 | .253         | 1.757*   |
| ABCP                  | 5.742       | 40 | .144         |          |

#### ANALYSIS II

TABLE XXIX CONTROL FORCE ANALYSES  
VIBRATION TIME SCORES, SMALL KNOB

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'   |
|--------------------------|----------------|-----|-----------------|-----------|
| A (levels)               | .551           | 2   | .276            | 1.211     |
| B (forces)               | 9.399          | 2   | 4.700           | 16.968**  |
| C (frequencies)          | 4.139          | 8   | .517            | 1.200     |
| P (subjects)             | 46.398         | 5   | 9.280           | 21.531*** |
| AB                       | .968           | 4   | .217            | <1        |
| AC                       | 8.124          | 16  | .508            | <1        |
| AP                       | 3.317          | 10  | .332            | <1        |
| BC                       | 3.478          | 16  | .217            | 1.064     |
| BP                       | 2.644          | 10  | .264            | 1.294     |
| CP                       | 17.233         | 40  | .431            | 2.280***  |
| ABC                      | 9.310          | 32  | .291            | 1.540*    |
| ABP                      | 6.554          | 20  | .328            | 1.735*    |
| ACP                      | 48.998         | 80  | .612            | 3.238***  |
| BCP                      | 16.317         | 80  | .204            | 1.079     |
| ABCP                     | 30.193         | 160 | .189            |           |

#### ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | 1.035          | 1  | 1.035           | <1      |
| B (forces)               | .377           | 2  | .188            | <1      |
| C (frequencies)          | 4.962          | 4  | 1.240           | 2.719   |
| P (subjects)             | 18.48          | 5  | 3.697           | 2.873   |
| AB                       | 1.199          | 2  | .600            | 1.626   |
| AC                       | .555           | 4  | .139            | <1      |
| AP                       | 6.437          | 5  | 1.287           | 4.857** |
| BC                       | 2.152          | 8  | .269            | 6.405   |
| BP                       | 1.307          | 10 | .131            | <1      |
| CP                       | 12.662         | 20 | .633            | 2.003   |
| ABC                      | .738           | 8  | .092            | <1      |
| ABP                      | 3.691          | 10 | .369            | 1.392   |
| ACP                      | 6.317          | 20 | .316            | 1.192   |
| BCP                      | 8.605          | 40 | .215            | <1      |
| ABCP                     | 10.594         | 40 | .265            |         |

#### ANALYSIS II

TABLE XXX CONTROL FORCE ANALYSES  
VIBRATION TIME SCORES, HORIZONTAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'   |
|-----------------------|-------------|-----|--------------|-----------|
| A (Levels)            | 2.172       | 2   | 1.086        | 3.103     |
| B (Forces)            | 3.678       | 2   | 1.839        | 9.782*    |
| C (Frequencies)       | 6.742       | 8   | .843         | 2.087     |
| P (Subjects)          | 29.636      | 5   | 5.927        | 14.671*** |
| AB                    | 2.002       | 4   | .500         | 3.247     |
| AC                    | 9.128       | 16  | .508         | 1.114     |
| AP                    | 2.978       | 10  | .298         | < 1       |
| BC                    | 3.873       | 16  | .242         | 1.169     |
| BP                    | 1.533       | 10  | .153         | < 1       |
| CP                    | 16.151      | 40  | .404         | 2.061***  |
| ABC                   | 6.450       | 32  | .202         | 1.031     |
| ABP                   | 2.970       | 20  | .148         | < 1       |
| ACP                   | 36.495      | 80  | .456         | 2.327***  |
| BCP                   | 16.533      | 80  | .207         | 1.056     |
| ABCP                  | 31.392      | 160 | .196         |           |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (Levels)            | .325        | 1  | .325         | < 1     |
| B (Forces)            | .495        | 2  | .248         | < 1     |
| C (Frequencies)       | 2.822       | 4  | .706         | < 1     |
| P (Subjects)          | 12.074      | 5  | 2.415        | 7.166*  |
| AB                    | .443        | 2  | .222         | 1.247   |
| AC                    | 2.978       | 4  | .744         | 1.746   |
| AP                    | 1.684       | 5  | .337         | 1.546   |
| BC                    | 1.073       | 8  | .134         | < 1     |
| BP                    | 2.161       | 10 | .216         | 1.213   |
| CP                    | 16.396      | 20 | .820         | 1.925   |
| APC                   | 1.155       | 8  | .144         | < 1     |
| ABP                   | 1.778       | 10 | .178         | < 1     |
| ACP                   | 8.512       | 20 | .426         | 1.954*  |
| BCP                   | 9.195       | 40 | .230         | 1.055   |
| ABCP                  | 8.749       | 40 | .218         |         |

#### ANALYSIS II

TABLE XXXI CONTROL FORCE ANALYSES  
VIBRATION TIME SCORES, VERTICAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'   |
|-----------------------|-------------|-----|--------------|-----------|
| A (Levels)            | 2.388       | 2   | 1.194        | 4.131     |
| B (Forces)            | 10.545      | 2   | 5.272        | 20.921*** |
| C (Frequencies)       | 6.334       | 8   | .792         | 1.760     |
| P (Subjects)          | 33.586      | 5   | 6.717        | 14.927*** |
| AB                    | .206        | 4   | .052         | < 1       |
| AC                    | 3.682       | 16  | .230         | < 1       |
| AP                    | 5.369       | 10  | .537         | 1.123     |
| BC                    | 2.688       | 16  | .168         | < 1       |
| BP                    | 2.545       | 10  | .254         | 1.494     |
| CP                    | 17.984      | 40  | .450         | 2.133***  |
| ABC                   | 7.278       | 32  | .227         | 1.076     |
| ABP                   | 3.851       | 20  | .193         | < 1       |
| ACP                   | 38.211      | 80  | .478         | 2.265***  |
| BCP                   | 13.628      | 80  | .170         | < 1       |
| ABCP                  | 33.763      | 160 | .211         |           |

ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (Levels)            | .798        | 1  | .798         | < 1     |
| B (Forces)            | 5.370       | 2  | 2.685        | 6.334   |
| C (Frequencies)       | 3.197       | 4  | .799         | 1.278   |
| P (Subjects)          | 20.843      | 5  | 4.169        | 4.622   |
| AB                    | 1.142       | 2  | .571         | 1.627   |
| AC                    | 2.401       | 4  | .600         | 1.396   |
| AP                    | 4.510       | 5  | .902         | 3.774*  |
| BC                    | .947        | 8  | .118         | < 1     |
| BP                    | 2.036       | 10 | .204         | < 1     |
| CP                    | 9.159       | 20 | .458         | 1.058   |
| ABC                   | 3.261       | 9  | .408         | 1.707   |
| ABP                   | 3.510       | 10 | .351         | 1.469   |
| ACP                   | 8.658       | 20 | .433         | 1.812   |
| BCP                   | 7.530       | 40 | .188         | < 1     |
| ABCP                  | 9.546       | 40 | .239         |         |

ANALYSIS II

TABLE XXXII CONTROL FORCE ANALYSES  
VIBRATION TIME SCORES, HORIZONTAL THUMBWHEEL

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'   |
|--------------------------|----------------|-----|-----------------|-----------|
| A (Levels)               | 1.815          | 2   | .908            | 1.327     |
| B (Forces)               | 42.010         | 2   | 21.005          | 93.356**  |
| C (Frequencies)          | 2.342          | 8   | .293            | < 1       |
| P (Subjects)             | 34.243         | 5   | 6.849           | 10.222*** |
| AB                       | .806           | 4   | .202            | < 1       |
| AC                       | 12.155         | 16  | .760            | 1.484     |
| AP                       | 4.365          | 10  | .436            | < 1       |
| BC                       | 2.486          | 16  | .155            | < 1       |
| BP                       | 3.707          | 10  | .371            | 1.233     |
| CP                       | 25.806         | 40  | .645            | 3.059***  |
| ABC                      | 11.268         | 32  | .352            | 1.607*    |
| ABP                      | 2.026          | 20  | .101            | < 1       |
| ACP                      | 40.995         | 80  | .512            | 2.338***  |
| BCP                      | 24.102         | 80  | .301            | 1.374*    |
| ABCP                     | 35.099         | 160 | .219            |           |

ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'  |
|--------------------------|----------------|----|-----------------|----------|
| A (Levels)               | .596           | 1  | .596            | 2.463    |
| B (Forces)               | 20.740         | 2  | 10.370          | 25.170** |
| C (Frequencies)          | 2.657          | 4  | .664            | 1.309    |
| P (Subjects)             | 18.405         | 5  | 3.681           | 15.211** |
| AB                       | .322           | 2  | .161            | < 1      |
| AC                       | .387           | 4  | .097            | < 1      |
| AP                       | 1.210          | 5  | .242            | 1.061    |
| BC                       | 4.074          | 8  | .509            | 1.631    |
| BP                       | 4.185          | 10 | .418            | 2.523    |
| CP                       | 14.926         | 20 | .746            | 1.567    |
| ABC                      | 2.796          | 8  | .350            | 1.535    |
| ABP                      | 1.670          | 10 | .167            | < 1      |
| ACP                      | 9.514          | 20 | .476            | 2.138*   |
| BCP                      | 7.611          | 40 | .190            | < 1      |
| ABCP                     | 9.139          | 40 | .228            |          |

ANALYSIS II

TABLE XXXIII CONTROL FORCE ANALYSES  
VIBRATION TIME SCORES, VERTICAL THUMBWHEEL

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F'   |
|--------------------------|----------------|-----|-----------------|-----------|
| A (levels)               | 4.477          | 2   | 2.238           | 2.270     |
| B (forces)               | 12.057         | 2   | 6.028           | 22.409**  |
| C (frequencies)          | 12.713         | 8   | 1.587           | 4.187**   |
| P (subjects)             | 57.156         | 5   | 11.431          | 30.161*** |
| AB                       | .382           | 4   | .096            | < 1       |
| AC                       | 14.154         | 16  | .885            | 1.536     |
| AP                       | 6.772          | 10  | .677            | 1.175     |
| BC                       | 3.662          | 16  | .229            | < 1       |
| BP                       | 3.222          | 10  | .322            | 1.142     |
| CP                       | 15.146         | 40  | .379            | 1.354     |
| ABC                      | 9.915          | 32  | .310            | 1.107     |
| ABP                      | 5.788          | 20  | .289            | 1.032     |
| ACP                      | 46.049         | 80  | .576            | 2.057***  |
| BCP                      | 22.595         | 80  | .282            | 1.007     |
| ABCP                     | 44.755         | 160 | .280            |           |

ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | .061           | 1  | .061            | < 1     |
| B (forces)               | 5.371          | 2  | 2.936           | 2.619   |
| C (frequencies)          | 5.857          | 4  | 1.464           | < 1     |
| P (subjects)             | 20.921         | 5  | 4.184           | 9.776*  |
| AB                       | 1.932          | 2  | .566            | 3.275   |
| AC                       | 7.431          | 4  | 1.858           | 4.466** |
| AP                       | 2.139          | 5  | .423            | 2.834*  |
| BC                       | 1.888          | 8  | .236            | < 1     |
| BP                       | 4.500          | 10 | .450            | 1.525   |
| CP                       | 9.787          | 20 | .489            | 1.175   |
| ABC                      | 4.477          | 8  | .560            | 3.709** |
| ABP                      | 2.951          | 10 | .295            | 1.954   |
| ACP                      | 8.325          | 20 | .416            | 2.755** |
| BCP                      | 7.014          | 40 | .175            | 1.159   |
| ABCP                     | 6.043          | 40 | .151            |         |

ANALYSIS II

TABLE XXXIV CONTROL FORCE ANALYSES  
TIME DIFFERENCE SCORES, LARGE KNOB

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F' |
|--------------------------|----------------|-----|-----------------|---------|
| A (levels)               | .442           | 2   | .221            | < 1     |
| B (forces)               | 2.432          | 2   | 1.216           | 4.208   |
| C (frequencies)          | 4.397          | 8   | .550            | 1.036   |
| P (subjects)             | 9.021          | 5   | 1.804           | 3.397*  |
| AB                       | 1.328          | 4   | .332            | < 1     |
| AC                       | 5.375          | 16  | .336            | < 1     |
| AP                       | 4.283          | 10  | .428            | < 1     |
| BC                       | 3.561          | 16  | .223            | < 1     |
| BF                       | 4.088          | 10  | .409            | 1.192   |
| CP                       | 21.237         | 40  | .531            | 1.654*  |
| ABC                      | 14.335         | 32  | .448            | 1.396   |
| ABP                      | 6.105          | 20  | .305            | < 1     |
| ACP                      | 36.716         | 80  | .459            | 1.430*  |
| BCP                      | 27.439         | 80  | .343            | 1.069   |
| ABCP                     | 51.398         | 160 | .321            |         |

#### ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'  |
|--------------------------|----------------|----|-----------------|----------|
| A (levels)               | .800           | 1  | .800            | 2.010    |
| B (forces)               | .944           | 2  | .472            | < 1      |
| C (frequencies)          | 1.163          | 4  | .291            | < 1      |
| P (subjects)             | 3.990          | 5  | .798            | 2.005    |
| AB                       | 2.135          | 2  | 1.068           | 12.867** |
| AC                       | 3.062          | 4  | .766            | 1.733    |
| AP                       | 1.391          | 5  | .278            | 1.733    |
| BC                       | 3.770          | 8  | .472            | < 1      |
| BP                       | 4.208          | 10 | .421            | 5.072**  |
| CP                       | 6.675          | 20 | .334            | < 1      |
| ABC                      | 3.163          | 8  | .395            | 1.725    |
| ABP                      | .833           | 10 | .083            | < 1      |
| ACP                      | 8.838          | 20 | .442            | 1.930*   |
| BCP                      | 17.770         | 40 | .444            | 1.939*   |
| ABCP                     | 9.155          | 40 | .229            |          |

#### ANALYSIS II

TABLE XXXV CONTROL FORCE ANALYSES  
TIME DIFFERENCE SCORES, SMALL KNOB

| Source of<br>Variability | Sum<br>Squares | df  | Mean<br>Squares | F or F' |
|--------------------------|----------------|-----|-----------------|---------|
| A (levels)               | .419           | 2   | .210            | <1      |
| B (forces)               | 3.223          | 2   | 1.611           | 4.942*  |
| C (frequencies)          | 3.999          | 8   | .500            | 1.126   |
| P (subjects)             | 2.728          | 5   | .546            | 1.230   |
| AB                       | .714           | 4   | .178            | <1      |
| AC                       | 5.456          | 16  | .341            | <1      |
| AP                       | 2.554          | 10  | .255            | <1      |
| BC                       | 4.556          | 16  | .285            | 1.067   |
| BP                       | 3.085          | 10  | .308            | 1.154   |
| CP                       | 17.745         | 40  | .444            | 1.922** |
| ABC                      | 11.328         | 32  | .354            | 1.532*  |
| ABP                      | 6.900          | 20  | .345            | 1.494   |
| ACP                      | 28.670         | 80  | .358            | 1.550*  |
| BCP                      | 21.394         | 80  | .267            | 1.156   |
| ABCP                     | 36.978         | 160 | .231            |         |

ANALYSIS I

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | 1.823          | 1  | 1.823           | 1.475   |
| B (forces)               | .694           | 2  | .347            | 1.770   |
| C (frequencies)          | 2.997          | 4  | .749            | 3.147   |
| P (subjects)             | .829           | 5  | .166            | <1      |
| AB                       | .783           | 2  | .392            | <1      |
| AC                       | 1.700          | 4  | .425            | <1      |
| AP                       | 6.180          | 5  | 1.236           | 3.700** |
| BC                       | 3.981          | 8  | .498            | 2.658** |
| BP                       | 2.994          | 10 | .299            | <1      |
| CP                       | 6.177          | 20 | .309            | <1      |
| ABC                      | .771           | 8  | .096            | <1      |
| ABP                      | 4.947          | 10 | .495            | 1.482   |
| ACP                      | 9.910          | 20 | .496            | 1.485   |
| BCP                      | 8.672          | 40 | .217            | <1      |
| ABCP                     | 13.345         | 40 | .334            |         |

ANALYSIS II

TABLE XXXVI CONTROL FORCE ANALYSES  
TIME DIFFERENCE SCORES, HORIZONTAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F' |
|-----------------------|-------------|-----|--------------|---------|
| A (Levels)            | .415        | 2   | .208         | < 1     |
| B (Forces)            | 1.198       | 2   | .599         | 1.060   |
| C (Frequencies)       | 2.386       | 8   | .298         | < 1     |
| P (Subjects)          | 5.520       | 5   | 1.104        | 2.928*  |
| AB                    | 2.0         | 4   | .502         | 2.773   |
| AC                    | 6.965       | 16  | .435         | 1.605   |
| AP                    | 1.577       | 10  | .158         | < 1     |
| BC                    | 4.405       | 16  | .275         | 1.087   |
| BP                    | 5.427       | 10  | .543         | 2.146*  |
| CP                    | 15.097      | 40  | .377         | 1.484*  |
| ABC                   | 8.012       | 32  | .250         | < 1     |
| ABP                   | 3.699       | 20  | .185         | < 1     |
| ACP                   | 21.716      | 80  | .271         | 1.067   |
| BCP                   | 20.264      | 80  | .253         | < 1     |
| ABCP                  | 40.588      | 160 | .254         |         |

ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (Levels)            | .369        | 1  | .369         | 1.425   |
| B (Forces)            | .382        | 2  | .191         | < 1     |
| C (Frequencies)       | 1.061       | 4  | .265         | < 1     |
| P (Subjects)          | 2.223       | 5  | .445         | 1.718   |
| AB                    | 1.032       | 2  | .516         | 2.335   |
| AC                    | 2.431       | 4  | .608         | 1.865   |
| AP                    | 1.293       | 5  | .259         | < 1     |
| BC                    | 1.875       | 8  | .234         | 1.225   |
| BP                    | 2.296       | 10 | .230         | 1.041   |
| CP                    | 12.250      | 20 | .612         | 1.877   |
| ABC                   | 1.521       | 8  | .190         | < 1     |
| ABP                   | 2.212       | 10 | .221         | < 1     |
| ACP                   | 6.524       | 20 | .326         | 1.076   |
| BCP                   | 12.142      | 40 | .304         | 1.003   |
| ABCP                  | 12.126      | 40 | .303         |         |

ANALYSIS II

TABLE XXXVII CONTROL FORCE ANALYSES  
TIME DIFFERENCE SCORES, VERTICAL LEVER

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (Levels)            | 2.320       | 2   | 1.160        | 1.993    |
| B (Forces)            | 6.531       | 2   | 3.266        | 3.413    |
| C (Frequencies)       | 5.652       | 8   | .706         | 1.677    |
| P (Subjects)          | 2.598       | 5   | .520         | 1.235    |
| AB                    | .676        | 4   | .169         | < 1      |
| AC                    | 4.695       | 16  | .293         | 1.003    |
| AP                    | 5.814       | 10  | .581         | 1.990    |
| BC                    | 3.762       | 16  | .235         | 1.103    |
| BP                    | 9.349       | 10  | .935         | 4.390*** |
| CP                    | 16.825      | 40  | .421         | 1.320    |
| ABC                   | 12.500      | 32  | .391         | 1.226    |
| ABP                   | 5.297       | 20  | .265         | < 1      |
| ACP                   | 23.331      | 80  | .292         | < 1      |
| BCP                   | 17.048      | 80  | .213         | < 1      |
| ABCP                  | 51.089      | 160 | .319         |          |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (Levels)            | .985        | 1  | .985         | < 1     |
| B (Forces)            | 3.008       | 2  | 1.504        | 2.705   |
| C (Frequencies)       | 2.134       | 1  | .534         | 2.472   |
| P (Subjects)          | 4.673       | 5  | .935         | < 1     |
| AB                    | .743        | 2  | .371         | 1.421   |
| AC                    | .924        | 4  | .231         | < 1     |
| AP                    | 5.264       | 5  | 1.053        | 2.569** |
| BC                    | 1.951       | 8  | .244         | < 1     |
| BP                    | 4.463       | 10 | .446         | 1.709   |
| CP                    | 9.359       | 20 | .468         | < 1     |
| ABC                   | 4.887       | 8  | .611         | 2.129   |
| ABP                   | 2.610       | 10 | .261         | < 1     |
| ACP                   | 9.666       | 20 | .483         | 1.683   |
| BCP                   | 9.512       | 40 | .238         | < 1     |
| ABCP                  | 11.479      | 40 | .287         |         |

#### ANALYSIS II

TABLE XXXVIII CONTROL FORCE ANALYSIS  
TIME DIFFERENCE SCORES, HORIZONTAL THUMBWHEEL

| Source of Variability | Sum Squares | df  | Mean Squares | F or F'  |
|-----------------------|-------------|-----|--------------|----------|
| A (Levels)            | .051        | 2   | .026         | < 1      |
| B (Forces)            | 1.459       | 2   | .730         | < 1      |
| C (Frequencies)       | 2.951       | 8   | .369         | < 1      |
| P (Subjects)          | 5.155       | 5   | 1.031        | 1.305    |
| AB                    | 1.276       | 4   | .319         | 1        |
| AC                    | 9.576       | 16  | .598         | 1.541    |
| AP                    | 3.874       | 10  | .387         | < 1      |
| BC                    | 3.655       | 16  | .228         | < 1      |
| BP                    | 10.787      | 10  | 1.079        | 2.613**  |
| CP                    | 31.595      | 40  | .790         | 2.416*** |
| ABC                   | 19.854      | 32  | .620         | 1.896**  |
| ABP                   | 2.771       | 20  | .139         | < 1      |
| ACP                   | 31.004      | 80  | .388         | 1.187    |
| BCP                   | 33.032      | 80  | .413         | 1.263    |
| ABCP                  | 52.289      | 160 | .327         |          |

#### ANALYSIS I

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (Levels)            | .462        | 1  | .462         | 3.581   |
| B (Forces)            | 1.250       | 2  | .625         | < 1     |
| C (Frequencies)       | .569        | 4  | .142         | < 1     |
| P (Subjects)          | 5.358       | 5  | 1.071        | 8.302*  |
| AB                    | 1.247       | 2  | .624         | 2.457   |
| AC                    | 2.351       | 4  | .588         | 2.210   |
| AP                    | .646        | 5  | .129         | < 1     |
| BC                    | 4.884       | 8  | .610         | 1.456   |
| BP                    | 3.517       | 10 | .352         | 1.386   |
| CP                    | 4.685       | 20 | .234         | < 1     |
| ABC                   | 3.264       | 8  | .408         | 1.103   |
| ABP                   | 2.536       | 10 | .254         | < 1     |
| ACP                   | 5.322       | 20 | .266         | < 1     |
| BCP                   | 15.249      | 40 | .381         | 1.030   |
| ABCP                  | 14.782      | 40 | .370         |         |

#### ANALYSIS II

TABLE XXXIX CONTROL FORCE ANALYSES  
TIME DIFFERENCE SCORES, VERTICAL THUMBWHEEL

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | 1.310                  | 2         | .655                    | < 1            |
| B (forces)                       | 9.038                  | 2         | 4.519                   | 4.649*         |
| C (frequencies)                  | 5.483                  | 8         | .685                    | 2.095          |
| P (subjects)                     | 5.439                  | 5         | 1.088                   | 3.083*         |
| AB                               | .234                   | 4         | .058                    | < 1            |
| AC                               | 12.258                 | 16        | .766                    | 1.599          |
| AP                               | 7.613                  | 10        | .761                    | 1.589          |
| BC                               | 5.008                  | 16        | .313                    | 1.016          |
| BP                               | 9.670                  | 10        | .967                    | 3.140**        |
| CP                               | 13.086                 | 40        | .327                    | < 1            |
| ABC                              | 12.423                 | 32        | .388                    | 1.152          |
| ABP                              | 6.567                  | 20        | .328                    | < 1            |
| ACP                              | 39.358                 | 80        | .479                    | 1.434*         |
| BCP                              | 24.633                 | 80        | .308                    | < 1            |
| ABCP                             | 53.472                 | 160       | .334                    |                |

#### ANALYSIS I

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .033                   | 1         | .033                    | < 1            |
| B (forces)                       | 1.469                  | 2         | .734                    | < 1            |
| C (frequencies)                  | 2.958                  | 4         | .740                    | < 1            |
| P (subjects)                     | 1.969                  | 5         | .394                    | < 1            |
| AB                               | 2.016                  | 2         | 1.008                   | 4.000          |
| AC                               | 5.397                  | 4         | 1.099                   | 3.392*         |
| AP                               | 2.700                  | 5         | .540                    | 2.660*         |
| BC                               | 1.846                  | 8         | .231                    | < 1            |
| BP                               | 6.435                  | 10        | .644                    | 2.556          |
| CP                               | 9.253                  | 20        | .463                    | 1.429          |
| ABC                              | 5.024                  | 8         | .628                    | 3.094**        |
| ABP                              | 2.523                  | 10        | .252                    | 1.241          |
| ACP                              | 5.481                  | 20        | .274                    | 1.596          |
| BCP                              | 8.297                  | 40        | .207                    | 1.020          |
| ABCP                             | 8.126                  | 40        | .203                    |                |

#### ANALYSIS II

TABLE XL WORK LOAD ANALYSES  
ERROR SCORES, LARGE KNOB

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | 1.126                  | 2         | .563                    | < 1            |
| B (conditions)                   | 53.189                 | 1         | 53.189                  | 38.655**       |
| C (frequencies)                  | 1.617                  | 4         | .404                    | 1.239          |
| P (subjects)                     | 3.465                  | 4         | .866                    | 2.656          |
| AB                               | .856                   | 2         | .428                    | < 1            |
| AC                               | 4.757                  | 8         | .595                    | 1.621          |
| AP                               | 3.246                  | 8         | .406                    | 1.106          |
| BC                               | 1.781                  | 4         | .445                    | 1.279          |
| BP                               | 5.116                  | 4         | 1.279                   | 3.675*         |
| CP                               | 5.211                  | 16        | .326                    | < 1            |
| ABC                              | 5.515                  | 8         | .689                    | 1.178          |
| ABP                              | 3.287                  | 8         | .411                    | < 1            |
| ACP                              | 11.746                 | 32        | .367                    | < 1            |
| BCP                              | 5.573                  | 16        | .348                    | < 1            |
| ABCP                             | 18.708                 | 32        | .585                    |                |

VIBRATION SCORES

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .545                   | 2         | .272                    | < 1            |
| B (conditions)                   | .081                   | 1         | .081                    | < 1            |
| C (frequencies)                  | 5.327                  | 4         | 1.332                   | 6.110**        |
| P (subjects)                     | 2.047                  | 4         | .509                    | 2.335          |
| AP                               | 1.678                  | 2         | .839                    | 1.040          |
| AC                               | 5.245                  | 8         | .656                    | 1.778          |
| AP                               | 2.200                  | 8         | .275                    | < 1            |
| BC                               | 3.543                  | 4         | .886                    | 2.100          |
| BP                               | 6.426                  | 4         | 1.606                   | 3.806*         |
| CP                               | 3.487                  | 16        | .218                    | < 1            |
| ABC                              | 6.536                  | 8         | .817                    | 2.468*         |
| ABP                              | 2.565                  | 8         | .321                    | < 1            |
| ACP                              | 11.806                 | 32        | .369                    | 1.115          |
| BCP                              | 6.756                  | 16        | .422                    | 1.275          |
| ABCP                             | 10.600                 | 32        | .331                    |                |

DIFFERENCE SCORES

TABLE XLI WORK LOAD ANALYSES  
ERROR SCORES, SMALL KNOB

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'  |
|--------------------------|----------------|----|-----------------|----------|
| A (levels)               | 1.042          | 2  | .521            | 2.499    |
| B (conditions)           | 47.810         | 1  | 47.810          | 48.244** |
| C (frequencies)          | .754           | 4  | .188            | < 1      |
| P (subjects)             | 3.634          | 4  | .908            | 2.447    |
| AB                       | .792           | 2  | .396            | 11.647   |
| AC                       | 1.791          | 3  | .224            | < 1      |
| AP                       | 1.301          | 5  | .163            | < 1      |
| BC                       | .962           | 4  | .240            | < 1      |
| BP                       | 4.055          | 4  | 1.014           | 3.856*   |
| CP                       | 5.943          | 16 | .371            | < 1      |
| ABC                      | 3.882          | 8  | .485            | < 1      |
| ABP                      | 1.372          | 8  | .172            | < 1      |
| ACP                      | 14.282         | 32 | .446            | < 1      |
| BCP                      | 4.207          | 16 | .263            | < 1      |
| ABCP                     | 19.927         | 32 | .623            |          |

VIBRATION SCORES

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | 1.634          | 2  | .817            | 3.714   |
| B (conditions)           | .450           | 1  | .450            | < 1     |
| C (frequencies)          | .667           | 4  | .142            | < 1     |
| P (subjects)             | .754           | 4  | .188            | < 1     |
| AB                       | 1.576          | 2  | .788            | 4.987   |
| AC                       | 2.856          | 8  | .357            | 1.361   |
| AP                       | .954           | 8  | .124            | < 1     |
| BC                       | .782           | 4  | .196            | < 1     |
| BP                       | 3.173          | 4  | .793            | 3.945*  |
| CP                       | 5.494          | 16 | .343            | < 1     |
| ABC                      | 3.188          | 8  | .398            | 1.042   |
| ABP                      | 1.140          | 8  | .142            | < 1     |
| ACP                      | 8.514          | 32 | .266            | < 1     |
| BCP                      | 3.219          | 16 | .201            | < 1     |
| ABCP                     | 12.239         | 32 | .382            |         |

DIFFERENCE SCORES

TABLE XLII WORK LOAD ANALYSES  
ERROR SCORES, HORIZONTAL LEVER

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'    |
|--------------------------|----------------|----|-----------------|------------|
| A (levels)               | .327           | 2  | .164            | < 1        |
| B (conditions)           | 47.581         | 1  | 47.581          | 131.279*** |
| C (frequencies)          | .784           | 4  | .196            | < 1        |
| P (subjects)             | 1.421          | 4  | .355            | < 1        |
| AB                       | 1.065          | 2  | .532            | < 1        |
| AC                       | 4.582          | 8  | .573            | 1.169      |
| AP                       | 5.217          | 8  | .652            | 1.331      |
| BC                       | .357           | 4  | .089            | < 1        |
| BP                       | 1.107          | 4  | .277            | < 1        |
| CP                       | 6.705          | 16 | .419            | < 1        |
| ABC                      | 4.426          | 8  | .553            | < 1        |
| ABP                      | 7.682          | 8  | .960            | 1.693      |
| ACP                      | 15.688         | 32 | .490            | < 1        |
| BCP                      | 7.470          | 16 | .467            | < 1        |
| ABCP                     | 18.113         | 32 | .567            |            |

#### VIBRATION SCORES

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | .331           | 2  | .166            | < 1     |
| B (conditions)           | .100           | 1  | .100            | < 1     |
| C (frequencies)          | 2.011          | 4  | .503            | < 1     |
| P (subjects)             | 3.493          | 4  | .873            | 1.529   |
| AB                       | .672           | 2  | .336            | < 1     |
| AC                       | 3.091          | 8  | .386            | 1.300   |
| AP                       | 2.876          | 8  | .359            | 1.380   |
| BC                       | 2.437          | 4  | .609            | 1.321   |
| BP                       | .670           | 4  | .168            | < 1     |
| CP                       | 9.140          | 16 | .571            | 1.807   |
| ABC                      | 3.884          | 8  | .486            | 1.538   |
| ABP                      | 5.580          | 8  | .698            | 2.209   |
| ACP                      | 9.519          | 32 | .297            | < 1     |
| BCP                      | 7.374          | 16 | .461            | 1.459   |
| ABCP                     | 10.101         | 32 | .316            |         |

#### DIFFERENCE SCORES

TABLE XLIII WORK LOAD ANALYSES  
ERROR SCORES, VERTICAL LEVER

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .551                   | 2         | .276                    | < 1            |
| B (conditions)                   | 46.151                 | 1         | 46.151                  | 33.083**       |
| C (frequencies)                  | 1.964                  | 4         | .491                    | < 1            |
| P (subjects)                     | 5.125                  | 4         | 1.281                   | 2.459          |
| AB                               | .731                   | 2         | .366                    | < 1            |
| AC                               | 3.778                  | 8         | .472                    | 1.272          |
| AP                               | 2.934                  | 8         | .367                    | < 1            |
| BC                               | 2.466                  | 4         | .616                    | 1.339          |
| BP                               | 4.955                  | 4         | 1.239                   | 2.693          |
| CP                               | 8.338                  | 16        | .521                    | 1.143          |
| ABC                              | 4.959                  | 8         | .620                    | 1.360          |
| ABP                              | 1.986                  | 8         | .248                    | < 1            |
| ACP                              | 11.870                 | 32        | .371                    | < 1            |
| BCP                              | 7.362                  | 16        | .460                    | 1.009          |
| ABCP                             | 14.584                 | 32        | .456                    |                |

VIBRATION SCORES

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .101                   | 2         | .050                    | < 1            |
| B (conditions)                   | 3.015                  | 1         | 3.015                   | 1.938          |
| C (frequencies)                  | 3.117                  | 4         | .779                    | 2.353          |
| P (subjects)                     | 3.537                  | 4         | .884                    | 2.671          |
| AB                               | .211                   | 2         | .106                    | 1.963          |
| AC                               | 1.655                  | 8         | .207                    | < 1            |
| AP                               | 2.529                  | 8         | .316                    | < 1            |
| BC                               | 2.605                  | 4         | .651                    | 1.543          |
| BP                               | 5.307                  | 4         | 1.327                   | 3.145*         |
| CP                               | 5.291                  | 16        | .331                    | < 1            |
| APC                              | 2.181                  | 8         | .273                    | < 1            |
| ABP                              | 2.060                  | 8         | .258                    | < 1            |
| ACP                              | 12.293                 | 32        | .384                    | < 1            |
| BCP                              | 6.757                  | 16        | .422                    | < 1            |
| ABCP                             | 15.267                 | 32        | .477                    |                |

DIFFERENCE SCORES

TABLE XLIV WORK LOAD ANALYSES  
ERROR SCORES, HORIZONTAL THUMBWHEEL

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'  |
|--------------------------|----------------|----|-----------------|----------|
| A (levels)               | 1.716          | 2  | .858            | 1.360    |
| B (conditions)           | 59.804         | 1  | 59.804          | 39.139** |
| C (frequencies)          | .437           | 4  | .109            | < 1      |
| P (subjects)             | 4.721          | 4  | 1.180           | 2.516    |
| AB                       | 2.213          | 2  | 1.106           | 1.653    |
| AC                       | 3.566          | 8  | .446            | 1.364    |
| AP                       | 4.099          | 8  | .512            | 1.566    |
| BC                       | 1.263          | 4  | .316            | < 1      |
| BP                       | 6.518          | 4  | 1.630           | 3.900*   |
| CP                       | 7.507          | 16 | .469            | 1.144    |
| ABC                      | 4.362          | 8  | .545            | 1.329    |
| ABP                      | 4.269          | 8  | .534            | 1.302    |
| ACP                      | 10.450         | 32 | .327            | < 1      |
| BCP                      | 6.688          | 16 | .418            | 1.030    |
| ABCP                     | 13.122         | 32 | .410            |          |

VIBRATION SCORES

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | .250           | 2  | .125            | < 1     |
| B (conditions)           | .007           | 1  | .007            | < 1     |
| C (frequencies)          | .928           | 4  | .232            | < 1     |
| P (subjects)             | 2.158          | 4  | .540            | 1.693   |
| AB                       | 1.244          | 2  | .622            | 4.065   |
| AC                       | 2.150          | 8  | .269            | 1.257   |
| AP                       | 2.253          | 8  | .282            | 1.318   |
| BC                       | 1.506          | 4  | .376            | 1.126   |
| BP                       | 2.233          | 4  | .558            | 1.671   |
| CP                       | 5.097          | 16 | .317            | 1.164   |
| ABC                      | 1.173          | 8  | .147            | < 1     |
| ABP                      | 2.239          | 8  | .280            | 1.022   |
| ACP                      | 6.844          | 32 | .214            | < 1     |
| BCP                      | 5.344          | 16 | .334            | 1.219   |
| ABCP                     | 8.783          | 32 | .274            |         |

DIFFERENCE SCORES

TABLE XLV WORK LOAD ANALYSES  
ERROR SCORES, VERTICAL THUMBWHEEL

| Source of Variability | Sum Squares | df | Mean Squares | F or F'  |
|-----------------------|-------------|----|--------------|----------|
| A (levels)            | 1.081       | 2  | .540         | 3.344*   |
| B (conditions)        | 60.566      | 1  | 60.566       | 43.169** |
| C (frequencies)       | .963        | 4  | .241         | < 1      |
| P (subjects)          | 4.063       | 4  | 1.016        | 1.773    |
| AB                    | 1.050       | 2  | .525         | 1.617    |
| AC                    | 2.036       | 8  | .254         | < 1      |
| AP                    | 1.066       | 8  | .133         | < 1      |
| BC                    | 2.393       | 4  | .597         | 1.012    |
| BP                    | 5.582       | 4  | 1.396        | 2.366    |
| CP                    | 9.161       | 16 | .573         | < 1      |
| ABC                   | 5.890       | 8  | .736         | < 1      |
| ABP                   | .632        | 8  | .079         | < 1      |
| ACP                   | 24.129      | 32 | .754         | < 1      |
| BCP                   | 9.442       | 16 | .590         | < 1      |
| ABCP                  | 25.364      | 32 | .793         |          |

VIBRATION SCORES

| Source of Variability | Sum Squares | df | Mean Squares | F or F' |
|-----------------------|-------------|----|--------------|---------|
| A (levels)            | .137        | 2  | .068         | 2.096   |
| B (conditions)        | 1.577       | 1  | 1.577        | 6.089   |
| C (frequencies)       | 1.490       | 4  | .372         | < 1     |
| P (subjects)          | .562        | 4  | .140         | < 1     |
| AB                    | .027        | 2  | .014         | 1.198   |
| AC                    | .790        | 8  | .099         | < 1     |
| AP                    | .701        | 8  | .088         | < 1     |
| BC                    | 1.782       | 4  | .446         | < 1     |
| BP                    | 1.073       | 4  | .268         | < 1     |
| CP                    | 7.603       | 16 | .475         | 1.116   |
| ABC                   | 2.333       | 8  | .292         | < 1     |
| ABP                   | .650        | 8  | .082         | < 1     |
| ACP                   | 10.363      | 32 | .324         | < 1     |
| BCP                   | 7.273       | 16 | .455         | 1.48    |
| ABCP                  | 13.892      | 32 | .434         |         |

DIFFERENCE SCORES

**TABLE XLVI WORK LOAD ANALYSES  
TIME SCORES, LARGE KNOB**

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .193                   | 2         | .096                    | <1             |
| B (conditions)                   | 187.627                | 1         | 187.627                 | 51.902**       |
| C (frequencies)                  | 1.598                  | 4         | .400                    | 1.117          |
| P (subjects)                     | 34.087                 | 4         | 8.522                   | 23.804***      |
| AB                               | .096                   | 2         | .048                    | 1.371          |
| AC                               | 2.592                  | 8         | .324                    | 1.266          |
| AP                               | 1.204                  | 3         | .150                    | <1             |
| BC                               | 1.236                  | 4         | .309                    | <1             |
| BP                               | 14.518                 | 4         | 3.629                   | 11.235***      |
| CP                               | 5.721                  | 16        | .358                    | <1             |
| ABC                              | 3.062                  | 8         | .383                    | <1             |
| ABP                              | .662                   | 8         | .083                    | <1             |
| ACP                              | 8.203                  | 32        | .256                    | <1             |
| BCP                              | 5.170                  | 16        | .323                    | <1             |
| ABCP                             | 13.800                 | 32        | .431                    |                |

**VIBRATION SCORES**

| <u>Source of<br/>Variability</u> | <u>Sum<br/>Squares</u> | <u>df</u> | <u>Mean<br/>Squares</u> | <u>F or F'</u> |
|----------------------------------|------------------------|-----------|-------------------------|----------------|
| A (levels)                       | .060                   | 2         | .030                    | <1             |
| B (conditions)                   | 1.166                  | 1         | 1.166                   | 1.151          |
| C (frequencies)                  | 1.772                  | 4         | .443                    | <1             |
| P (subjects)                     | 6.538                  | 4         | 1.634                   | 3.591*         |
| AB                               | .206                   | 2         | .103                    | <1             |
| AC                               | 3.185                  | 8         | .373                    | 2.144          |
| AP                               | 1.327                  | 8         | .166                    | <1             |
| BC                               | 2.568                  | 4         | .642                    | 2.253          |
| BP                               | 2.623                  | 4         | .656                    | 2.302          |
| CP                               | 7.281                  | 16        | .455                    | <1             |
| ABC                              | 4.213                  | 8         | .527                    | <1             |
| ABP                              | 1.733                  | 8         | .217                    | <1             |
| ACP                              | 5.575                  | 32        | .174                    | <1             |
| BCP                              | 4.553                  | 16        | .285                    | <1             |
| ABCP                             | 17.832                 | 32        | .557                    |                |

**DIFFERENCE SCORES**

TABLE XLVII WORK LOAD ANALYSES  
TIME SCORES, SMALL KNOB

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'   |
|--------------------------|----------------|----|-----------------|-----------|
| A (levels)               | .409           | 2  | .204            | < 1       |
| B (conditions)           | 210.124        | 1  | 210.124         | 63.405**  |
| C (frequencies)          | .955           | 4  | .239            | 1.096     |
| P (subjects)             | 38.324         | 4  | 9.581           | 43.950*** |
| AB                       | .202           | 2  | .101            | 1.262     |
| AC                       | 2.168          | 8  | .271            | 1.522     |
| AP                       | 1.308          | 8  | .164            | < 1       |
| BC                       | 1.282          | 4  | .320            | < 1       |
| BP                       | 13.475         | 4  | 3.369           | 8.984***  |
| CP                       | 3.489          | 16 | .218            | < 1       |
| ABC                      | 2.770          | 8  | .346            | 1.116     |
| ABP                      | .353           | 8  | .044            | < 1       |
| ACP                      | 15.681         | 32 | .178            | < 1       |
| BCP                      | 6.005          | 16 | .375            | 1.210     |
| ABCP                     | 9.923          | 32 | .310            |           |

VIBRATION SCORES

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | .076           | 2  | .038            | < 1     |
| B (conditions)           | .104           | 1  | .104            | < 1     |
| C (frequencies)          | .212           | 4  | .053            | < 1     |
| P (subjects)             | 1.290          | 4  | .322            | 1.293   |
| AB                       | 1.127          | 2  | .564            | 9.097   |
| AC                       | 2.589          | 8  | .324            | < 1     |
| AP                       | 1.528          | 8  | .191            | < 1     |
| BC                       | .152           | 4  | .038            | < 1     |
| BP                       | 1.685          | 4  | .421            | 1.272   |
| CP                       | 3.977          | 16 | .249            | < 1     |
| ABC                      | 1.496          | 8  | .187            | < 1     |
| ABP                      | 1.451          | 8  | .181            | < 1     |
| ACP                      | 13.851         | 32 | .433            | 1.415   |
| BCP                      | 5.292          | 16 | .331            | 1.082   |
| ABCP                     | 9.776          | 32 | .306            |         |

DIFFERENCE SCORES

TABLE XLVIII WORK LOAD ANALYSES  
TIME SCORES, HORIZONTAL LEVER

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'    |
|--------------------------|----------------|----|-----------------|------------|
| A (levels)               | .248           | 2  | .124            | <1         |
| B (conditions)           | 185.661        | 1  | 185.661         | 172.068*** |
| C (frequencies)          | 4.545          | 4  | 1.136           | 2.123      |
| P (subjects)             | 23.355         | 4  | 5.839           | 10.914***  |
| AB                       | 4.291          | 2  | 2.146           | 11.600     |
| AC                       | 2.319          | 8  | .290            | 1.551      |
| AP                       | .374           | 8  | .047            | <1         |
| BC                       | .503           | 4  | .126            | <1         |
| BP                       | 5.013          | 4  | 1.253           | 4.177*     |
| CP                       | 8.559          | 16 | .535            | 2.248*     |
| ABC                      | 2.162          | 8  | .270            | 1.134      |
| ABP                      | 1.227          | 8  | .153            | <1         |
| ACP                      | 5.975          | 32 | .187            | <1         |
| BCP                      | 4.805          | 16 | .300            | 1.260      |
| ABCP                     | 7.602          | 32 | .238            |            |

#### VIBRATION SCORES

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | .247           | 2  | .124            | <1      |
| B (conditions)           | .356           | 1  | .356            | <1      |
| C (frequencies)          | 6.190          | 4  | 1.548           | 3.550*  |
| P (subjects)             | 1.526          | 4  | .382            | <1      |
| AB                       | 4.249          | 2  | 2.124           | 6.417   |
| AC                       | 2.638          | 8  | .330            | 1.294   |
| AP                       | .481           | 8  | .060            | <1      |
| BC                       | .490           | 4  | .122            | <1      |
| BP                       | 4.529          | 4  | 1.132           | 4.510*  |
| CP                       | 6.969          | 16 | .436            | 1.633   |
| ABC                      | 2.321          | 8  | .290            | 1.086   |
| ABP                      | 2.461          | 8  | .308            | 1.154   |
| ACP                      | 8.147          | 32 | .255            | <1      |
| BCP                      | 4.023          | 16 | .251            | <1      |
| ABCP                     | 8.557          | 32 | .267            |         |

#### DIFFERENCE SCORES

TABLE XLIX WORK LOAD ANALYSES  
TIME SCORES, VERTICAL LEVER

| <u>Source of Variability</u> | <u>Sum Squares</u> | <u>df</u> | <u>Mean Squares</u> | <u>F or F'</u> |
|------------------------------|--------------------|-----------|---------------------|----------------|
| A (levels)                   | .143               | 2         | .071                | < 1            |
| B (conditions)               | 196.479            | 1         | 196.479             | 136.824***     |
| C (frequencies)              | 2.697              | 4         | .674                | 2.217          |
| P (subjects)                 | 24.055             | 4         | 5.014               | 19.783***      |
| AB                           | .286               | 2         | .143                | 1.021          |
| AC                           | 1.792              | 8         | .224                | < 1            |
| AP                           | 3.111              | 9         | .378                | 1.400          |
| BC                           | 1.913              | 4         | .478                | 1.282          |
| BP                           | 5.324              | 4         | 1.331               | 3.568*         |
| CP                           | 4.865              | 16        | .304                | 1.236          |
| ABC                          | 1.380              | 8         | .172                | < 1            |
| ABP                          | 1.714              | 8         | .214                | < 1            |
| ACP                          | 8.645              | 32        | .270                | 1.098          |
| BCP                          | 5.962              | 16        | .373                | 1.516          |
| ABCP                         | 7.866              | 32        | .246                |                |

VIBRATION SCORES

| <u>Source of Variability</u> | <u>Sum Squares</u> | <u>df</u> | <u>Mean Squares</u> | <u>F or F'</u> |
|------------------------------|--------------------|-----------|---------------------|----------------|
| A (levels)                   | .321               | 2         | .160                | < 1            |
| B (conditions)               | .626               | 1         | .626                | 1.605          |
| C (frequencies)              | 1.631              | 4         | .408                | 1.365          |
| P (subjects)                 | 5.152              | 4         | 1.288               | 4.308*         |
| AB                           | .872               | 2         | .436                | 2.236          |
| AC                           | 2.737              | 8         | .342                | 1.396          |
| AP                           | 2.106              | 8         | .263                | 1.073          |
| BC                           | 2.099              | 4         | .525                | 1.141          |
| BP                           | 1.299              | 4         | .325                | < 1            |
| CP                           | 4.786              | 16        | .299                | 1.020          |
| ABC                          | 1.502              | 8         | .188                | < 1            |
| ABP                          | 2.404              | 8         | .300                | 1.024          |
| ACP                          | 7.828              | 32        | .245                | < 1            |
| BCP                          | 7.360              | 16        | .460                | 1.570          |
| ABCP                         | 9.387              | 32        | .293                |                |

DIFFERENCE SCORES

TABLE L WORK LOAD ANALYSES  
TIME SCORES, HORIZONTAL THUMBWHEEL

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'   |
|--------------------------|----------------|----|-----------------|-----------|
| A (levels)               | .068           | 2  | .034            | 1.109     |
| B (conditions)           | 217.624        | 1  | 217.624         | 196.058** |
| C (frequencies)          | 1.368          | 4  | .342            | 1.090     |
| P (subjects)             | 31.127         | 4  | 7.782           | 24.783*** |
| AB                       | .042           | 2  | .021            | < 1       |
| AC                       | 1.738          | 8  | .217            | < 1       |
| AP                       | .760           | 8  | .095            | < 1       |
| BC                       | .837           | 4  | .209            | < 1       |
| BP                       | 5.721          | 4  | 1.430           | 2.703     |
| CP                       | 5.025          | 16 | .314            | < 1       |
| ABC                      | 5.325          | 8  | .666            | 1.897     |
| ABP                      | 2.307          | 8  | .288            | < 1       |
| ACP                      | 9.981          | 32 | .312            | < 1       |
| BCP                      | 8.466          | 16 | .529            | 1.507     |
| ABCP                     | 11.228         | 32 | .351            |           |

VIBRATION SCORES

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | .585           | 2  | .292            | 2.026   |
| B (conditions)           | .105           | 1  | .105            | 1.248   |
| C (frequencies)          | 1.172          | 4  | .293            | < 1     |
| P (subjects)             | 7.257          | 4  | 1.814           | 5.025** |
| AB                       | .661           | 2  | .330            | < 1     |
| AC                       | 1.077          | 8  | .135            | < 1     |
| AP                       | 1.709          | 8  | .214            | < 1     |
| BC                       | 1.305          | 4  | .321            | < 1     |
| BP                       | 1.036          | 4  | .259            | < 1     |
| CP                       | 5.777          | 16 | .361            | 1.180   |
| ABC                      | 8.214          | 8  | 1.027           | 3.356** |
| ABP                      | 3.007          | 8  | .376            | 1.229   |
| ACP                      | 13.294         | 32 | .415            | 1.356   |
| BCP                      | 9.910          | 16 | .619            | 2.023*  |
| ABCP                     | 9.792          | 32 | .306            |         |

DIFFERENCE SCORES

TABLE LI WORK LOAD ANALYSES  
TIME SCORES, VERTICAL THUMBWHEEL

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F'    |
|--------------------------|----------------|----|-----------------|------------|
| A (levels)               | 2.034          | 2  | 1.017           | 2.296      |
| B (conditions)           | 215.388        | 1  | 215.388         | 156.988*** |
| C (frequencies)          | 1.704          | 4  | .426            | 1.340      |
| P (subjects)             | 36.706         | 4  | 9.176           | 28.855***  |
| AB                       | 2.173          | 2  | 1.086           | 7.490      |
| AC                       | 4.066          | 8  | .508            | 1.881      |
| AP                       | 1.637          | 8  | .205            | <1         |
| BC                       | 2.269          | 4  | .567            | 1.800      |
| BP                       | 4.480          | 4  | 1.120           | 3.556*     |
| CP                       | 5.095          | 16 | .318            | <1         |
| ABC                      | 2.057          | 8  | .257            | <1         |
| ABP                      | 2.548          | 8  | .318            | <1         |
| ACP                      | 8.606          | 32 | .270            | <1         |
| BCP                      | 5.034          | 16 | .315            | <1         |
| ABCP                     | 13.763         | 32 | .430            |            |

# VIBRATION SCORES

| Source of<br>Variability | Sum<br>Squares | df | Mean<br>Squares | F or F' |
|--------------------------|----------------|----|-----------------|---------|
| A (levels)               | .393           | 2  | .196            | 2.390   |
| B (conditions)           | .736           | 1  | .736            | <1      |
| C (frequencies)          | 1.646          | 4  | .412            | 1.724   |
| P (subjects)             | .368           | 4  | .092            | <1      |
| AB                       | 1.023          | 2  | .512            | 3.391   |
| AC                       | 1.487          | 8  | .186            | <1      |
| AP                       | 2.042          | 8  | .255            | <1      |
| BC                       | .572           | 4  | .143            | <1      |
| BP                       | 4.971          | 4  | 1.243           | 5.404** |
| CP                       | 3.824          | 16 | .239            | <1      |
| ABC                      | 1.762          | 8  | .220            | <1      |
| ABP                      | 2.899          | 8  | .362            | <1      |
| ACP                      | 11.498         | 32 | .359            | <1      |
| BCP                      | 3.686          | 16 | .230            | <1      |
| ABCP                     | 13.786         | 32 | .431            |         |

# DIFFERENCE SCORES

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