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# USATRECOM TECHNICAL REPORT 64-69

# EFFECTS OF TASK LOADING ON PILOT PERFORMANCE DURING SIMULATED LOW-ALTITUDE HIGH-SPEED FLIGHT

BY

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FEBRUARY 1965

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FORT EUSTIS, VIRGINIA

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# EFFECTS OF TASK LOADING ON PILOT PERFORMANCE DURING SIMULATED LOW-ALTITUDE HIGH-SPEED FLIGHT

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# ABSTRACT

The effects of task loading on pilot performance during simulated low-altitude, high-speed flight were studied. Approximately 210 hours of flight were made by experienced pilots in a moving-base simulator that had a total vertical travel of 12 feet and an acceleration capability of ± 6G. The flights were made over several types of terrain at several airspeeds under different conditions of navigation task and emergency task loading. Medium-heavy turbulence was simulated for all flights. Data were analyzed in terms of human performance aspects of the missions.

# PREFACE

This study is part of an Army investigation of man-machine compatibility under low-altitude, high-speed (LAHS) flight conditions. It was sponsored by the U. S. Army transportation Research Command, (USATRECOM), Fort Eustis, Virginia, under Contract DA 44-177-AMC-66(T), with Mr. Joseph McGarvey serving as USATRECOM Project Engineer.

The study was conducted by the Human Factors Group, Crew Systems Section of North American Aviation, Inc., Columbus, Ohio, under the technical direction of Dr. Stanley M. Soliday.

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## LIST OF SYMBOLS

| Symbol | Definition | Unit |
|---|---|---|
| $g$ | acceleration of gravity | ft/sec |
| $G$ | multiple of normal force of gravity | |
| $K_{n/\delta}$ | load factor to stick deflection gain | g/in |
| $\Delta N_z$ | incremental vertical load factor | g |
| $w_g$ | vertical gust velocity | ft/sec |
| $\zeta_N$ | airplane damping | |
| $\omega_N$ | undamped natural frequency of airplane (longitudinal) | rad/sec |
| $\delta$ | longitudinal stick deflection | inches |
| $\delta_L$ | lateral stick deflection | inches |
| $S$ | Laplace transform variable | |
| $\phi$ | bank angle | rad/sec |
| $\psi$ | yaw angle | radians |
| $\dot{\psi}$ | yaw rate | rad/sec |
| $h_e$ | altitude error | feet |
| $h_e^2$ | mean square altitude error | feet$^2$ |
| $g^2$ | mean square g | ft/sec2 |
| $\dot{\psi}^2$ | yaw rate$^2$ | rad/sec$^2$ |
| RMS | root mean square | |
| $\sigma$ | standard deviation | |
| df | degrees of freedom | |

## LIST OF SYMBOLS (CONT'D)

| Symbol | |
|---|---|
| SS | sum of squares in analysis of variance |
| MS | mean squares in analysis of variance |
| F | F-ratio; ratio of two sample variances |
| P | proportion of a population possessing a given characteristic |
| CRT | cathode ray tube |
| AAI | all-attitude indicator |
| M | Mach number |
| K | knots |
| PPH | pounds per hour |
| PPM | pounds per minute |
| CPS | cycles per second |
| ECM | electronic countermeasures |

# SUMMARY

The purpose of this study was to investigate the effects of task loading on pilot performance during simulated low-altitude high-speed terrain-following flight. To make the necessary tests, experienced pilots flew simulated missions in a flight simulator that consisted of a vertically moving cockpit having a total travel of approximately twelve feet and an acceleration capability of ±6G. The simulator had a functional control system and an associated analog computer for obtaining solutions to the equations of motion of a mechanized aircraft. A jet aircraft in the light fighter or attack category was mechanized on the computer.

Experimental flights were made under varying conditions of airspeed, type of terrain, navigation task loading, and emergency task loading. All flights were made under medium-heavy turbulence conditions and all lasted one hour. System performance measurements were continually recorded, and pilot reaction times were measured in several situations during the flights.

Average altitude maintained throughout the flights did not vary with any of the experimental conditions, but the pilots always flew too high going up terrain slopes and too low going down them. Deviations about the required clearance altitude increased with increasing airspeed and with increasing steepness of slopes, but were unaffected by navigation or emergency task procedures. Heading maintenance was equally good under all experimental conditions.

Pilots' reaction times did not change under the different experimental conditions, indicating that they were equally alert and could perform physical and mental tasks equally well under all conditions. There was no evidence of fatigue under any condition. Several measures showed that learning continued throughout the experiment.

Experimental control flights established limits to the time that a pilot can be inattentive to the flight control display.

## CONCLUSIONS AND RECOMMENDATIONS

The general conclusion of this study is that pilots can fly LAHS terrain-following missions throughout a wide spectrum of task loadings without crashing or exceeding a 1000-foot altitude in a jet aircraft of the light fighter or attack category. The missions can be flown in turbulence high enough to produce acceleration loadings as high as .4 RMS G on the pilot. Specific results lead to the conclusions, recommendations, and future study needs discussed below.

### TERRAIN

1. Average clearance altitudes were the same when flights were made over rolling, hilly, and mountainous terrain, the slopes of which averaged ±8, ±16, and ±24 degrees, respectively.

2. Deviations or oscillations about a required clearance altitude increased in direct proportion to the steepness of terrain slopes through a range of slopes extending from an average of ±8 degrees to an average of ±24 degrees.

3. In the study, pilots usually were above the required clearance altitude when going up hillsides and were below it when going down. This may be due to differences in pilot response patterns or to aircraft and/or display characteristics.

### AIRSPEED

1. Average clearance altitudes are the same at airspeeds of .4M, .7M, and .9M in the type of aircraft studied.

2. Deviations about the required clearance altitude were the same at .4M and .7M, but increased greatly at .9M. The amount of deviation increase at .9M was relatively greater over mountainous and hilly terrain than over rolling terrain.

3. Theoretical minimum possible clearance altitudes were determined for the different terrain and airspeed combinations studied.

### NAVIGATION

1. Turning the aircraft to make heading changes did not affect altitude holding (based on average clearance altitude and deviations about this average) over any type of terrain or any airspeed. This

might not hold true in certain situations such as those demanding sudden course corrections.

2. Heading changes were made equally well at different degrees of navigation task loading.

3. Heading changes were made equally well over all types of terrain and at all airspeeds studied.

## EMERGENCY TASK PERFORMANCE

1. Performance of emergency tasks did not in itself affect altitude holding over any type of terrain, at any airspeed, or at any degree of navigation task loading. As in the case of navigation, this might not hold true in certain situations, e.g. those in which several malfunctions occur at the same time.

2. Emergency tasks were performed with equal facility when flights were made over all types of terrain, at all airspeeds, and at all different degrees of navigation task loadings.

3. Emergency tasks were performed equally well at the several different levels of emergency task loading.

## PILOTS' REACTIONS

1. Pilot alertness or vigilance was very high and was unaffected throughout the range of task loads studied.

2. Performance of learned responses such as those made in emergency situations was quick and reliable under the different task loads.

3. Mental computation ability was unaffected under the different task loads studied. However, results indicated that problems such as fuel computation should be kept as simple as possible.

4. Uncertainty or lack of confidence in the aircraft will cause pilots to increase the average clearance altitude greatly. The need for pilot confidence in the machine is thus stressed, especially when maintenance of lowest possible clearance altitudes is desirable.

## BASE-LINE DATA

1. Deviations about the required clearance altitude increased regularly as pilot inattentiveness to the primary control task of altitude holding increased. The rate of increase in the study was constant at all airspeeds and terrain types tested. The rate was great enough to place stringent limits on the amount of time that a pilot can devote exclusively to any activity other than altitude holding.

## FATIGUE

1. There was no evidence of fatigue throughout the range of conditions studied. This, along with evidence from other studies, indicates that vertical acceleration and tracking do not in themselves induce sufficient fatigue to affect performance for periods up to 3 hours in fairly severe acceleration environments. However, fear, high temperatures, noise, etc., may contribute to fatigue in the operational situation.

## LEARNING

1. The importance of learning was firmly established in this study. It is therefore recommended that pilots be given initial and follow-up periodic simulator training to prepare and maintain proficiency in LAHS flight.

## FUTURE STUDIES

Research should be undertaken to:

1. Investigate different methods of visual display of terrain-following information.

2. Investigate the presentation of supplementary terrain-following information through human sense modes other than visual; i.e. auditory, tactile, or kinesthetic. The purpose here would be to unburden the overloaded visual sense mode.

3. Study the influence of anxiety on terrain-following performance.

# DISCUSSION

## INTRODUCTION

A previous study conducted for USATRECOM (ref. 9) concluded that terrain-following under low-altitude high-speed (LAHS) conditions is a full-time job and that the pilot should be assigned the tasks of terrain-following and aircraft operation only. However, pilots were subjected to a constant task load in the previous study; e.g. terrain representative of low, hilly, desert terrain was the only type tracked, and numbers of heading changes were held constant from mission to mission.

The pilot's task load will of course vary in the real world due to flight over different types of terrain, various navigation requirements, and responses to equipment malfunctions. The present simulator study of pilot performance under different degrees of task loading was undertaken to help answer the question of what pilots can and cannot do in this flight regime, and will thus provide data for aircraft design and mission planning.

## ANALYSIS OF PROBLEM

The pilot's primary task in LAHS terrain-following is continuous maintenance of a particular clearance altitude. Continuous attention must be devoted to this task because desirable clearance altitudes are generally so low that slight deviations downward may immediately result in a crash, while any upward deviation greatly increases the probability of detection by enemy radar. LAHS terrain-following is therefore difficult, and this difficulty is greatly increased when the flights are made up and down increasingly steep slopes and at increasingly fast airspeeds. The terrain-following task loading will thus fluctuate over a wide range of types of terrain and airspeeds. In the present study, different degrees of loading on this task are produced by having LAHS missions flown over simulated rolling country, hills, and mountains, at airspeeds compatible with the speeds of future Army surveillance aircraft.*

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* Atmospheric turbulence also affects altitude holding. Since its effects have previously been investigated (refs. 2, 7, 9, and 10), it is unnecessary to study them here. In this connection, it should be noted that aircraft characteristics such as control stick forces, damping ratios, etc. also produce different pilot task loads when varied (refs. 1 and 9). However, consideration of the latter class of variables is beyond the scope of the present study.

In addition to terrain-following in the LAHS mission, heading must also be maintained. Although relatively small deviations from a desired heading do not as inevitably lead to disaster as deviations in altitude do, maintenance of correct heading is obviously a critical factor in mission success. In terms of the navigation task itself, courses to be flown can vary in the average amplitude of the required heading changes or in the number of heading changes to be made.* The size or amplitude variable probably has very little effect on task difficulty since the real problem of controlling in azimuth occurs as the pilot completes his turn and assumes a new heading. Thus, increasing the number or frequency of turns to be made within a given period of time should increase navigation task difficulty due to the increased number of turn completions and new headings to be assumed. In the present study, missions of different numbers of turns are flown under the assumption that task loading varies with numbers of turns, increasing as the number of turns increases within a given period of time.

Corrections of equipment malfunctions and activities such as responding to electronic countermeasures (ECM) warnings constitute a third type of task performed by a pilot during a mission. In LAHS flight, performance of these tasks may interfere with altitude holding to the extent that adequate control cannot be maintained during the periods of emergency (see ref. 9). Since emergency events can arise at any time, it is important to determine how fast they can be detected, how well they can be performed within the mission context, and what the effects of their performance on flight control are.

Different levels of emergency task loadings are used in the present study to make this determination. The levels are produced by varying the numbers of emergency events that occur within given missions. If performance of such tasks interferes with flight control, there will be greater altitude deviations in missions with more emergency events.

Analysis of reasons for the possible interference of emergency task performance with flight control reveals that it may occur simply because the pilot is temporarily inattentive to flight control due to the distraction caused by the emergency and not by the physical movements or work needed to correct the emergency. If it is shown that altitude deviations in a given period of "distraction" time equal the deviations in the same amount of time that it takes to perform an emergency task, the hypothesis

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* Visibility and type of navigation system also affect the efficiency with which turns are made; however, a study of these variables is beyond the scope of the present study.

that distraction or inattention to flight control is the principal factor causing the increased error would be strengthened. If the altitude deviations in a given period of "distraction" time are less than those made during the same amount of time taken to perform an emergency task, this would indicate that the emergency task response itself somehow interferes with altitude holding. If there is greater deviation during the distraction period than during the time taken to perform an emergency task, this would indicate that emergency task performance in itself probably does not interfere with altitude holding, and that distraction was not complete during performance of the task.

A special series of flights in which distractions of various time intervals were simulated was made at the end of the experiment to determine whether the expected degradation of altitude holding by emergency task performance is greater than, equal to, or less than that caused by distractions themselves. This run series is reported in the section "Control Flights", p 24, since these runs actually provided a control for the emergency tasks.

Finally, a comparison of pertinent aspects of the present study and a former study conducted by NAA for USATRECOM (ref. 9) is given as Appendix I, pp 37 and 38.

## METHOD

### Subjects

Three pilots participated in the experiment. Their ages ranged from 30 to 41, their heights from 65 inches to 72 inches, and their weights from 150 pounds to 180 pounds. Flying experience varied from jets to helicopters, with total flying hours ranging from 1800 to 5000. The subjects had previously had from 30 to 250 hours of simulator experience.

### The Dynamic Flight Simulator (G-Seat)

The dynamic flight simulator, or G-seat, was a vertically moving cockpit having a total travel of approximately 12 feet and the capability of accelerating up to ± 6G. It had a functional control system and cockpit display and an analog computer for obtaining solutions to equations of motion (ref. 6).

Longitudinal control system feel characteristics such as bob weight forces, viscous damping, and bungee rate were approximated with a feel simulator which was a hydraulic actuator with feedback from stick rate and displacement, aircraft load factor, and pitch acceleration. Safety and limiting circuits were used to modify the input command to the G-seat servo. The seat is actually a position servo with a ± 6-foot travel. Therefore, a ± 20-volt limiter was incorporated as an electrical seat travel stop.

The simulator was equipped with a modified A-5A seat which used the integrated torso harness system of the F9F-8T. Since the G-seat system does not incorporate an inertia reel, the operator's shoulders were held rigidly against the back of the seat.

## The Mechanized Aircraft

A jet airplane in the light fighter or attack category was simulated on the analog computer. The simulation provided physical motion of the G-seat in the vertical axis. Rotational positions in pitch, roll, and yaw were displayed on an all-attitude indicator (AAI). A description of the airplane characteristics is given on pp 39 and 40 of Appendix II, and in Figure 1, p 41.

## Displays

Information forflight control and navigation was provided by four functional instruments: a cathode-ray tube (CRT), radar altimeter, rate-of-climb indicator, and the AAI.

For terrain-following, the CRT provided a command error display through movements of one of two luminous horizontal lines on the tube face. One line represented the aircraft and was stationary; the other represented the horizon, and was movable. Displayed error was a combination of pitch error and altitude error. Pitch error was the angle between the instantaneous pitch attitude of the aircraft and the terrain slope 2.5 seconds ahead. (Due to this 2.5 second lead time, the pitch error actually represents a projected pitch error.) Altitude error was the deviation from a base altitude of 500 feet above the terrain, and was measured directly beneath the aircraft. Summation of the two errors provided, in one error signal, information about oncoming terrain slopes and present altitude. As long as the correct pitch angle was maintained, the aircraft was at, or converging on, a 500-foot altitude. A displacement of 1 inch between the movingterrain trace and the fixed aircraft reference was equivalent to 10 degrees of projected pitch error or 400 feet of altitude error. (See Figure 2, p 42 , for a block diagram describing the signal flow for aircraft altitude and pitch control.) All flights were made with this terrain-following display system; thus, all flights were simulated IFR.

The AAI was a standard instrument driven by the computer. As previously noted, it showed all aircraft rotational positions, i.e. pitch, roll, and heading. Although most of the flight information concerning the dynamic behavior of the aircraft was displayed, it was used primarily to obtain heading information. The radar altimeter presented height directly under the aircraft. Instantaneous rate of climb, computed from attitude angle and airspeed, was displayed on the rate-of-climb indicator.

Other functional instruments included an airspeed indicator, fuel gage selector and switch, fuel quantity indicator, oil pressure indicator, tachometer, two hydraulic pressure indicators, exhaust temperature indicator, fuel flow indicator, and an oil pressure indicator. A master warning light, a panel of individual warning and caution lights, and ECM warning lights were used to signal emergency situations. Use of these displays in performance of the emergency tasks is discussed in the section Experimental (Independent) Variables, below. An accelerometer and a clock were also provided. Figure 3, p 43, illustrates the instrument panel layout.

## Controls

A center-stick controller functional in lateral and longitudinal modes was used. It was a standard type, with a curved shaft and an offset grip. It had a longitudinal trim button and an emergency "kill" button which stopped seat motion if pressed. A graph of both lateral and longitudinal control stick forces is given as Figure 4, p 44.

Left and right consoles adjacent to the pilot's seat and just aft of the instrument panel were also used for controls placement. The left console, shown in detail in Figure 5, p 45, contained switches for the electrical system, engine fire, hydraulic system, pitch augmentation, yaw augmentation, and gust alleviator. The right console, shown in Figure 6, p 46, contained switches for ramp control, pitot heat, and ECM.

A ram air handle (lower left corner; see Figure 3) and a master warning light reset switch (left of center near the bottom of the panel; see Figure 3) were incorporated into the instrument panel. Adjustable dummy rudder pedals were also used. A microphone switch was located on the throttle. There was a direct correlation between throttle and RPM and fuel flow indications.

## Experimental (Independent Variables)

Terrain was generated by adding the outputs of six sinusoid generators and recording the output sums on magnetic tape. Three basic terrain tapes, each an hour long, were made to simulate airspeeds of .4, .7, and .9M. All of these basic terrains represented rolling country in which the average slopes are ±8° with a standard deviation of ±4°. To simulate hilly country, the amplitudes of the basic terrains were doubled in playback, thus producing average slopes of ±16° with a standard deviation of ±7°. Amplitudes of the basic terrains were trebeled to produce "mountains" in playback; here, average slopes were ±24° with a standard deviation of ±9°. The three different airspeeds and three amplitude levels produce nine different terrain profiles. Complete statistical descriptions of all profiles, including peak heights and distances, are given in Table 1, p 47. Samples of each profile are given as Figure 7, p 51. Terrain amplitudes are coded in Table 1 and Figure 7 in the following way: terrain I is the rolling country, terrain II the hilly, and terrain III the mountainous. The same code is used throughout the report. Task difficulty is assumed to increase with increasing airspeed and with terrain amplitude (rolling country through mountains).

At various times during each flight, the experimenter, acting as navigator, requested heading changes. The pilot made lateral stick inputs to simulate the requested turns. Two levels of navigation difficulty were used. In the first or "easy" level, five turns were required in a given flight, and in the second or "difficult" level, 15 were required. The total number of degrees turned was the same for all flights at a given difficulty level; e.g. all flights with five turns had the same total degrees turned per mission. Average turns were 25 degrees. Average bank angles were 5-10 degrees, with a maximum of 30 degrees.

Several emergency situations of the kind that might arise in actual flight were simulated. The emergencies required specific responses from the pilot, but there were no changes in aircraft flying and/or handling qualities associated with them. Emergencies were initiated by the experimenter at various times during a flight; time of occurrence and type of emergency were previously unknown to the pilot. (A detailed discussion of these tasks is given in the section <u>Pilots' Tasks</u>, p 11).

Three levels of emergency task difficulty were used. In the easiest level, six emergencies occurred within a mission; in the medium difficulty level, 12 occurred; and in the most difficult level, 24 occurred. Although these latter numbers are perhaps unrealistic from an operational standpoint, they are justified from an experimental standpoint since the purpose is to determine how well the pilot can cope with situations of this type during LAHS terrain-following flight, and not to determine if or when a mission should be aborted because of equipment failure.

## Experimental Design

The three types of terrain, three airspeeds, two navigation levels and three emergency task levels were combined into a 3x3x2x3 factorial design. Each pilot flew each of the 54 conditions of the design, thus producing a total of 162 experimental missions. The conditions were presented randomly to control order effects such as learning and fatigue. The RMS* gust level was held constant throughout the study at 8 feet per second, thus representing what is generally held to be medium to heavy turbulence. It produced an RMS G of about 0.4. (The output of a gaussian white noise generator was recorded on an hour-long magnetic tape to provide the gust input. This tape was actually the one on which the terrains were recorded.)

## Pilots' Tasks

The experimental flights were organized into simulated missions during which the pilot's primary task was terrain-following. The moving line on the face of the CRT simulated a horizon line as it would appear to move during LAHS terrain-following flight. If the moving line was above the fixed or aircraft line, the aircraft was pitched too low, while if the moving line was below the fixed line, the aircraft was pitched too high. His task was to superimpose the two lines, i.e. to null the displayed error by appropriate longitudinal control stick movements.

Heading was determined from the AAI. At various times during a mission, the experimenter, acting as navigator, requested heading changes over the intercommunication system. Upon receipt of a heading change request, the pilot verbally repeated the requested heading, made lateral stick inputs to turn the AAI to the new heading, and, when the turn was completed, stated the fact over the intercom.

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* RMS is an assumed standard deviation, or $\sigma$; one RMS = one $\sigma$. In a normal distribution, 68% of sample values fall within $\pm 1 \sigma$, or RMS, from the mean; 95% within $\pm 2 \sigma$; and 99.7% within $\pm 3 \sigma$.

Emergencies were initiated by the experimenter at various times during the missions. Indications of an emergency appeared in the cockpit as a simultaneous illumination of the master warning light and the appropriate panel warning light. As soon as the pilot saw the master warning light, he reset it. He then determined the nature of the emergency by looking at the panel of individual warning lights, scanned the instruments to detect the source of "trouble", and, finally, took "corrective" action. Since flying and/or handling qualities were not affected by the emergencies, all appropriate corrective actions were assumed to produce successful results. A detailed list of the emergencies and procedures associated with them is given in Appendix I on pages 47 - 50. Figure 8, p 52, shows the console from which the experimenter initiated emergencies (including ECM warnings).

In addition to routine emergency tasks, the pilot had to solve computational problems near the beginning and end of every mission. The problem was called out by the experimenter at various times within 5 to 30 minutes after the flight began and within 30 to 55 minutes before the flight ended. Exact times were varied randomly from mission to mission so that the pilot never knew exactly when a problem would be required. The task was always to calculate (mentally) how much fuel would remain after 5, 10, 15, 20, 25, 30 or 35 minutes. As with the times of problem insertion, these consumption periods varied randomly from problem to problem within a mission, and from mission to mission. (Assumed consumption rates were 80 PPM at .4M, 90 PPM at .7M, and 100 PPM at .9M.) After the pilot determined how much fuel would be used up in a given period, he subtracted this amount from the amount showing on the fuel indicator and reported the final answer to the experimenter.

## Recorded Data (Dependent Variables)

Pilot Performance Measurements - Performance data were recorded by two six-channel pen recorders. Deviations from the required clearance altitude of 500 feet were continuously recorded as an error trace, and averaged to give the average altitude error (AE) for each minute. Average altitude error was also determined for positive and for negative slopes to determine whether the pilots flew higher or lower than 500 feet when going up or down the hillsides. All scoring equations are given in Table 2, p 50.

Mean square altitude deviations were also recorded each minute. Mean square (MS) rather than root mean square (RMS) measurements were recorded because the analog computer gives more accurate mean squares. Standard deviations ($\sigma$) of altitude error were determined from all mean squares by the formula $\sigma = \sqrt{MS - AE^2}$ (ref. 8). MS altitude deviations were also determined for positive and negative slopes.

Heading errors were recorded as average and mean square yaw rates, listed as $\dot{\psi}$ and $\dot{\psi}^2$ in Table 2. Position measurements such as number of degrees turned were not used because recorder channel widths are not great enough to include all of the headings on a scale large enough to be read. These measures were made to determine if numbers of turns affected the total navigation error, and, if so, how much; and to determine if turn errors were affected by terrain, airspeed, or emergency tasks.

Vertical accelerations were recorded continuously and as mean squares each minute from an accelerometer attached to the G-seat. RMS G was obtained from the mean squares by taking the square root of the mean square values.

Continuous terrain traces were recorded so that performance at any point over the terrain could be studied.

Mean square longitudinal stick movements were recorded each minute. These records were not studied in detail, however, after preliminary examination revealed that the stick movements were almost perfectly positively correlated with the deviation altitude error scores and, hence, that detailed study would provide no additional knowledge.

Figure 9, shown on p53, is a sample of the terrain traces. Measures on each channel are identified on the records. They were taken from about 3½ minutes of one of the flights, and are read from right to left.

Pilots' Reactions - The time between onset of illumination of the master warning light and the instant that it was reset was measured with a timing clock on the experimenter's console. This was to determine the pilot's alertness or vigilance. The time between the resetting of the master warning light and completion of the emergency procedure was also measured with a timing clock on the experimenter's console to determine efficiency of performance of these relatively short, routine tasks.

Fuel computation problems were scored in terms of time required to solve them. Accuracy scores were not used; answers were right nearly 100 percent of the time because the problems were fairly easy.

Pilots' Opinions - A program critique was held at the conclusion of the experiment with all personnel involved in the study participating. A summary of the pilots' comments, as expressed in the critique, is presented in Appendix IV, pp 76 and 77.

## Procedure

Seat belt and torso harness were securely fastened before a mission began. At the start, flight instruments were turned on in the cockpit, a metal hood fastened in place over the cockpit, the seat was raised to mid-position, and the room lights were turned out. Terrain inputs were introduced into the CRT and the pilot began tracking. Gust inputs were then introduced, first at low intensity then building up within a minute to the 8 ft/sec value. Pilot, experimenter, computer operator, and G-seat operator were in contact over the intercommunication system at all times. However, discussion was limited to heading requests and their acknowledgments, and to other comments pertinent to the mission.

Each mission was pre-programmed as to type of terrain and airspeed; to times, amplitudes, and directions of heading changes; and to times and types of emergencies. All of these events were indicated on an experimenter's mission schedule sheet prepared for each mission; e.g. one mission called for a turn to 025 degrees at 08 minutes after the mission began, an ECM warning in sector 4 at 12 minutes, etc. Insertions of turns and emergencies were made according to times indicated on the mission schedule. These times were regulated by a time clock on the experimenter's console and were unknown to the pilot. No turns, emergencies, or fuel computations were given during the first or last 5 minutes of the mission so that beginning-end scores could be compared across conditions to determine if fatigue had occurred during the mission.

Each mission lasted 1 hour. Since there were no turns, emergencies, or fuel computations in the first or last 5 minutes, each mission had 50 minutes in which these events could occur. In the most heavily task-loaded condition, there was a turn, emergency, or fuel computation nearly every minute while the flight was being made at .9M over terrain with average slopes of ±24 degrees.

There was a total of 54 missions, each corresponding to one of the 54 experimental conditions. Thus, for example, one mission at .4M over type I (rolling) terrain, had 15 turns and six emergency events, while another at .7M over the same terrain had the same number of turns and emergency events. Airspeed and terrain type were held constant within a mission, but times, amplitudes, and directions of turns varied from mission to mission to prevent memorization; and times of occurrence and types of emergencies were also varied to simulate reality as closely as possible. (Emergencies did not occur at random; inasmuch as possible, series of malfunctions were used. The pilots could thus make general predictions regarding upcoming emergencies from their knowledge of trouble patterns. However, this predictive ability was somewhat attenuated since they did not have prior knowledge of how many emergencies were scheduled to occur in a given mission.) Order of presentation of each of the 54 missions was randomized by use of a table of random numbers. A master mission schedule was prepared for each pilot before the experiment began.

Each pilot received approximately 6 hours' training which included experience with the typical experimental conditions. However, due to reassignments of several pilots shortly after the study began, the three pilots who completed the experiment received an additional week's training, or about 10 extra hours of simulator time, with the result that all three had approximately 16 hours in the simulator that were classed as training time. Each of the three completed the necessary 54 hours (54 experimental conditions) plus 2 hours of control runs.

The testing period was about 8 weeks for each of the three pilots who completed the experiment. During this period, a given man flew two missions in 1 day, two the next, one the next, and then the cycle repeated itself. Two flights per day at the RMS G level (.4) used did not produce excessive fatigue. (However, in the preliminary phases of the study, one pilot who was given 3 hours per day felt that it was too much stress in one day.) Times of day that missions were flown were balanced among the subjects as much as possible so that each had approximately the same number of missions the first thing in the morning, last thing in the afternoon, etc. No other attempts were made to control their activities.

## RESULTS

### Measured Acceleration Environment

Average RMS G's were determined for each of the 162 missions (54 different missions x three pilots). Averages were then calculated across pilots to yield a combined average for each of the 54 conditions. This procedure of obtaining averages first for individual conditions and then across pilots is followed throughout this report.

An analysis of variance was performed on the 54 combined averages. This analysis, summarized in Table 3, p 54, revealed no significant differences among the levels of the four variables of terrain, airspeed, navigation, and emergency task. Values for the levels of each variable are listed in Table 4, p 54. These values were determined by obtaining means for all missions at a given airspeed or at a given terrain type, etc. Thus, there are three means for the terrain variable, each corresponding to a type of terrain; three means for the airspeed variable, each corresponding to one of the three airspeeds, etc. This procedure for obtaining values for the levels of the variables is also followed throughout the report.

Although there are no significant main effects, there is one significant interaction, terrain type by navigation ($P < .05$). In this interaction, shown in Figure 10, p 55, RMS G decreased from missions with five turns to missions with 15 turns in the flights over terrains I (rolling) and III (mountains), but increased from five to 15 over terrain II (hills).

The grand average of all the RMS G's was 0.4, i.e. RMS G was generally .4 throughout the experiment. This value includes the effects of pilot stick inputs as well as computer or gust inputs. At the end of the experiment, a 180-pound weight was fastened to the G-seat, the control stick was made immovable, and the seat was run without pilot inputs. When measured this way, it was 0.331, a value only 83 percent of the average obtained with control inputs. G-loadings were thus increased by about 17 percent by the pilots.

### Pilot Performance

Average Altitude Error - This measure, which is the average number of feet that the pilots were above or below the required clearance altitude, was determined for each of the 162 missions and again across pilots to obtain the combined averages. An analysis of variance, summarized in Table 5, p 55, was performed on the combined averages. There were no significant main effects or interactions which leads to the conclusion that the same average altitude was maintained throughout all conditions.

Table 6, p 56, shows average altitude errors for the levels of each experimental variable. Note that, although as stated there are no differences among conditions, all of these average errors are positive, indicating that the pilots were always slightly above the required altitude.

The scores for each of the 162 missions were then divided into two groups, one group representing error as a function of positive slopes and the other representing error as a function of negative slopes, i.e. average error when going "up" and "down" hillsides. This showed that the pilots were nearly always above 500 feet when going up slopes, and below when going down.

The positive and negative slope scores were then segregated into groups representing the three airspeeds and three terrain types, as shown in Table 7, p 56. The scores were not segregated into groups representing navigation and emergency task variables because there was no reason to expect slope error to vary with either of these variables. (Examination of the data showed that it did not.) An analysis of variance, summarized in Table 8, p 57, was performed on the scores representing the two slopes, three terrains, and three airspeeds. As expected, there were highly significant main effects in the slope variable ($P < .01$). There were also two significant interactions, terrain type by slope ($P < .01$) and airspeed by slope ($P < .01$).

Individual means were then tested for significance of differences with Duncan's Multiple Range Test (ref. 4). Results of the Duncan test, summarized in Table 9, p 57, show that the mean differences between positive and negative slopes are significantly different in every case ($P < .001$). Performance was thus always different on the two types of slope. As Table 9 shows, errors were always positive on positive slopes and negative on negative slopes; the pilots were always high going up hills and low going down them. In addition to these direction errors, there was about 30 percent more error on positive than on negative slopes. A graph of the terrain-slope interaction, shown in Figure 11, p 58, shows that error increases with increasing slope. The interaction is due to the fact that the errors on different slopes go in opposite directions. Note again that errors on positive slopes are generally much greater than on negative slopes. A graph of the airspeed-slope interaction, Figure 12, p 58, shows that errors on both slopes increase greatly from .4 and .7M, where there are no differences, to .9M. The interaction is due to the fact that the increases are in opposite directions.

<u>Deviation Altitude Error</u> - The pilots did not crash or exceed a 1000-foot altitude at any time during the study. Standard deviations ($\sigma$) of altitude error were computed for each individual mission and again across pilots to yield combined averages. The averages ranged from 25.2 feet (.4M over rolling terrain) to 77.8

feet (.9M over mountainous terrain), a wide dispersion of scores across the terrain and airspeed conditions.

An analysis of variance, summarized in Table 10, p 59, shows significant main effects in the airspeed and terrain variables, but none in the navigation and emergency task variables. That is, $\sigma$ altitude error varied with speed and terrain type, but was unaffected by either the navigation or the emergency tasks. Although the latter two findings were unexpected, the implications are clear: turning the aircraft and performing emergency tasks did not affect altitude holding. Examination of the flight path traces did not reveal any evidence of brief spurts of altitude error that could be associated with a turn or emergency task.

Duncan's tests were then applied to the levels of each experimental variable. Results of these tests are shown in Table 11, p 59. Terrain type was by far the most important factor affecting altitude holding; it accounted for most of the observed variance. Performance deteriorated markedly from the rolling country (±8° slopes) to hills (±16° slopes) to mountains (±24 slopes). Differences between each of these levels were significant beyond the .001 level. Figure 13, p 60, shows $\sigma$ altitude error plotted against terrain type. Rate of error increase was about 9 percent per degree of slope increase.

Airspeed differences were not as straightforward as terrain type differences. The pilots tracked as well at .4M as they did at .7M, but their errors increased greatly (27 percent) at .9M; differences between .4 and .7M were not significant, while differences between .4M and .9M and .7M and .9M were significant at the .001 level. Figure 14, p 60, shows $\sigma$ altitude error as a function of airspeed.

There is one significant interaction in the $\sigma$ altitude error analysis of variance. This is airspeed and terrain, and it is shown in Figure 15, p 61. It is due to the fact that the amount of altitude error increase from .4M and .7M to .9M was disproportionately greater over the steepest than over the less steep terrains, e.g. the amount of error increase from .4M and .7M to .9M was greater over hilly than over rolling terrain. The apparent differences between .4M and .7M at terrain types II and III are not real; a Duncan test showed that there were no differences between these two airspeeds at any terrain type. The same Duncan test showed differences significant beyond the .05 level between .4M and .7M and .9M at all terrain types. To summarize, altitude deviations from .4M and .7M to .9M increase more rapidly over the steepest than over the less steep terrain.

Standard deviation altitude error scores were next studied as a function of terrain slope, airspeed, and terrain type. Means for the levels of each variable are listed in Table 12, p 61. An analysis of variance of these three variables, summarized in Table 13, p 62, shows significant main effects for airspeed beyond the .01 level, terrain type beyond the .01 level, and slope beyond the .05 level. Figure 16, p 62, shows $\sigma$ altitude error as a function of terrain type and slope, while Figure 17, p 63, shows the same error as a function of airspeed and slope. The mean difference analyses considered error as a function of terrain type and slope, and as a function of airspeed and slope. Results of these analyses are given in Table 14, p 63, and Table 15, p 64. The analyses show that there are no significant differences between errors on positive and negative slopes at any of the three types of terrain or airspeed. Therefore, deviations from the required clearance altitude are the same whether the aircraft goes up or down hillsides.

Heading (Yaw Rate) - Mean square yaw rate was determined for each of the 162 missions, and again across pilots to yield combined averages for each of the 54 missions. These rates, expressed in degrees turned per second, are summarized for the different levels of each of the four experimental variables in Table 16, p 64. There are virtually no differences among any of the levels, indicating that heading maintenance was unaffected by any of the conditions. However, to make certain, an analysis of variance, summarized in Table 17, p 65, was performed. It revealed that there were no significant main effects and no significant interactions. Therefore, it is concluded that there are no differences in heading performance due to the experimental variables. These findings parallel the findings that the navigation variable did not affect altitude holding.

### Pilot Reactions

Reaction to Master Warning Light - Average time taken to turn off or reset the master warning light was determined for each of the 162 missions, and again across pilots to yield combined averages for each of the 54 different missions. For illustrative purposes, the reaction times are shown for the levels of each variable in Table 18, p 65. Note that all of these values are about .9 second and that there are apparently no differences among any of them.

An analysis of variance, summarized in Table 19, p 66, was performed on the 54 basic scores. There were no significant main effects, showing that there were no differences in reaction time as a direct function of any of the four variables. However, there were two significant interactions, airspeed by turns ($P < .05$) and emergency tasks by turns ($P < .05$).

The emergency task-turn interaction, shown in Figure 18, p 66, reveals that, with five heading changes required, reaction time increased as the number of emergencies increased, rapidly at first and slower after that. With 15 heading changes required, reaction time increased when six emergency tasks were required, decreased slightly with 12 tasks required, and decreased much more when 24 tasks were required. These patterns suggest that the experimenter's called-out heading changes affected the alertness of the pilots. In the mission with the greater number of heading requests, the probability that the pilot would have been previously stimulated or alerted by the request when an emergency occurred would have been increased, and hence the probability of a quick response to the master warning light would have been increased.

In the airspeed by turn interaction (Figure 19, p 67), reaction time at .4 and .9M decreases from five to 15 turns, while reaction time at .7M increases from five to 15.

Emergency Task Performance Time - Average time to perform emergency tasks was determined for each mission, and again across pilots to yield combined averages for the 54 different missions. Values for the various levels of each variable are presented in Table 20, p 67, for illustrative purposes. The table shows that the tasks each required about 1.5 second to perform, and that, as was the case with reactions to the master warning light, there were apparently no differences among the various mission conditions. An analysis of variance, summarized in Table 21, p 68, reveals that there were no significant main effects or interactions. Therefore, time to perform these short, routine tasks did not vary with any of the experimental conditions. These findings parallel the finding that emergency task performance did not affect altitude holding, as was the case with the navigation variable.

Fuel Computation Time - Average times to compute pounds of remaining fuel were determined for each individual mission, and then across pilots to yield combined averages for each of the 54 different missions. Values for the levels of each experimental variable are presented for illustrative purposes in Table 22, p 68. The pilots generally required about 12 seconds to compute their fuel reserves, and there is more variation among the values at each variable level than was the case with the two preceding pilot reaction measures.

An analysis of variance, summarized in Table 23, p 69, was performed on the scores. There were significant differences among the levels of the airspeed variable ($P < .01$), but no other significant main effects or interactions. A Duncan test was made among the three airspeed levels. It revealed that computation times were significantly longer at .7 than at either .4 or .9M ($P < .001$) and that there were no differences between .4 and .9M.

The greater times taken at .7M can probably be explained by the following: consumption rates were assumed to be 80 PPM at .4M, 90 PPM at .7M, and 100 PPM at .9M. Computations were made for periods of 5, 10, 20, 25, 30, or 35 minutes. At 80 and 100 PPM consumption rates, all answers are in even hundreds; e.g. 400, 800, and 1200 pounds would be used at .4M at 5, 10, and 15 minutes. However, every other answer at .7M contains a fifty; e.g. 450, 900, and 1350 pounds would be used in 5, 10, and 15 minutes. The fifties made both computation and subtraction from present amounts more difficult than the hundreds, and consequently increased problem-solving time.

Fatigue

RMS G - Flights over type III (mountainous) terrain were used to determine whether RMS G changes with time because the amount of aircraft maneuvering was greatest over this terrain. For one set of comparisons, RMS G averages of the three pilots were first determined for the first and last 5 minutes of the six flights made at .4M over the most difficult, or type III terrain. The six "first" and six "last" averages were then compared using a Mann-Whitney U-Test. There were no significant differences ($P = .197$). The same procedure was followed with the six flights at .7M and the six at .9M over type III terrain. RMS G was significantly higher during the last 5 minutes than during the first 5 minutes in the .7M flights ($P = .032$), but there were no beginning-end differences in the .9M flights ($P = .197$). The apparent change in G at .7M is regarded as an artifact, however, since the performance records show that the flights at .9M were much more difficult. It is concluded that maneuver-induced G did not change with time and hence did not indicate the presence of fatigue.

Average Altitude Error - Average (of the three pilots) values of this measure were determined for the first and last 5 minutes of flights over type I terrain (rolling) at both .4 and .9M, and in flights over type III terrain (mountainous) at both .4 and .9M. Four comparisons were made using U-tests: beginning-end measures for the flights at .4M over type I terrain; at .9M over type I terrain; at .4M over type III; and at .9M over type III. There were no significant differences. Therefore it is concluded that average altitude error did not change with time and hence did not indicate the presence of fatigue.

Standard Deviation of Altitude Error - Values of $\sigma$ altitude error were determined for the first and last 5 minutes of all flights. Averages for the three pilots were obtained as above for each mission condition, and the mission conditions segregated into three groups, one containing all flights over type I terrain, one with all flights over type II terrain, and one with all type III terrain flights. U-tests were then used to compare the beginning-end scores. There were no significant differences in any of the three groups.

It is thus concluded that $\sigma$ altitude error, which measures deviations from the required clearance altitude, did not change with time and hence did not indicate the presence of fatigue.

When the first-last RMS G, average altitude error, and standard deviation of altitude error comparions are all considered, the conclusion is that there were essentially no changes in the measurements over time and that, therefore, fatigue did not occur during the missions.

## Learning

Although precise statements about any learning that may have occurred throughout the study cannot be made because the experimental conditions were presented at random, estimates can be made by comparing groups that have approximately equal numbers of the experimental conditions. As in any learning study, the comparions are made between measurements taken at various stages of the study, from beginning to end.

It was found that groups of 18 fulfill the requirements of equal numbers of conditions in each group; e.g. there are approximately equal numbers of flights at .4M in the first, second, and third sets of 18 flights, and there are also equal numbers of flights over type II terrain, etc. The exact procedure was to take a particular score or measure for each pilot's first flight and calculate an average across pilots, take the same score or measure for the second flights and calculate an average across all three pilots, continuing this procedure through the fifty-fourth and last flight. The averages were then segregated into the three groups of 18, and statistical comparisons were made among these groups with Mann-Whitney U-tests. Discussion of the scores and measures studied to determine the extent of learning follows.

Time to Reset Master Warning Light - Differences between the first and second groups of 18 scores were significant at the .002 level, and differences between the second and third were significant at the .025 level. An arithmetic average of this reaction time was then obtained for each of the three groups. The averages are plotted in Figure 20, p 69. Note that there was a consistent decrease in reaction time from the first through the last 18 flights. The amount of decrease was about 22 percent, indicating marked improvement with practice.

Time to Perform Emergency Tasks - Differences between the first and second groups of 18 were significant at the .001 level, and those between the second and third were also significant at the .001 level. Arithmetic group averages are plotted in Figure 21, p 70. The amount of decrease was consistent, the total reduction being about 37 percent. This represents very great improvement with practice. It should be noted here that at the beginning of training, when the pilots did not know the emergency procedures or navigation tasks well, performance of either one of them would greatly disrupt altitude holding. After a few hours of training, these obvious, marked effects disappeared.

RMS G - Differences between the first and second groups of 18 were not significant, while those between first and third and second and third were ($P = .001$ in both cases). Arithmetic group averages are plotted in Figure 22, p 70. Although there is an apparent increase in RMS G from first to second groups, the "increase" is not real because the differences between these two groups are not significant. However, there is about an 11 percent decrease from the first two groups of 18 to the last one. Apparently, pilots learn to reduce the maneuver-induced G-loading, but only after rather extensive practice, which took, in the present experiment, an estimated 40 to 50 hours (formal training time included).

Average Altitude Error - Differences between the first and second groups of 18 were significant ($P = .05$), but those between the second and third were not. Arithmetic group averages are plotted in Figure 23, p 71. Note that average altitude error increases rather than decreases from beginning to end of the experiment. The increase is very small, however, and probably of little practical importance.

Standard Deviation of Altitude Error - No inter-group differences were significant even though the arithmetic group averages, as shown in Figure 24, p 71, show a slight but consistent decrease from beginning to end of the experiment. In this connection, note that those measures reflecting constant conditions in the experiment show the best learning curves, i.e. reaction time to the master warning light, time to perform emergency tasks, and RMS G.

The most definite learning effects are thus shown for those measures that did not vary with the experimental conditions, i.e. time to reset master warning light, time to perform emergency tasks, and RMS G. Average altitude error, the measure that showed only a slight response to the experimental conditions, also showed a slight learning effect. Standard deviation of altitude error, which showed the greatest response to the experimental conditions, showed the least learning effects.

## CONTROL FLIGHTS

The purpose of these flights was, as stated in the problem analysis section, to provide control or baseline data to compare with the expected degradation of altitude holding by emergency task performance.

### Procedure

Subjects and apparatus were the same as those previously used. Distraction intervals were simulated by removing all flight control information for short periods. The periods were initiated and their length controlled by the experimenter from a control on the computer which, when actuated, turned off or reset to zero all the instruments used for flight control (CRT, AAI, radar altimeter, and rate of climb indicator). Timing of the length of the distraction period was automatic; when the instruments were turned off with the computer control, they were turned on again automatically after a predetermined period.

Distraction intervals of 0, 2.5, and 5.0 seconds were used. The zero interval served as a control or baseline condition. This was necessary because all of these runs were made after the main series was finished. Two speeds, .4 and .9M, were used to provide data over the entire speed range of the study, and three terrains, I (rolling), II (hills), and III (mountainous) were used so that the entire terrain range could be studied in detail. The three distraction intervals, two speeds, and three terrains were combined into a 3x2x3 factorial to produce 18 different experimental conditions (missions), each of which was experienced by each of three pilots. Total number of flights was thus 54.

Each flight or experimental condition lasted 10 minutes. Sample periods of this duration were used because the pilots were very proficient after their main run series was completed. The conditions were presented randomly to control order effects. The only task was altitude holding; no turns or emergency tasks were required. RMS gust level was the same as in the main run series.

At the beginning of a flight, a pilot began tracking one terrain at one speed. The flight control instruments were turned off at various times during the 10-minute flight at an average of once a minute. The pilot knew that the instruments would be turned off several times during the flight, but did not know when or whether the period was to be 2.5 or 5 seconds. Distraction intervals were not initiated unless the pilot had full control of the simulated aircraft, as could readily be determined from the oscillograph records. Distractions were not, of course, initiated during the 0-interval or control condition.

Since the flights were relatively short, six flights were made in a given session. During all of the runs, segments with no distraction, i.e. the 0-interval conditions, were interspersed at random among the segments with distractions. Thus, at times there might be a minute interval with two distractions followed by one or two minutes with none, etc. Care was taken to prevent overlapping of a distraction and/or its effects from one minute to the next. The same kinds of data that were recorded in the main series of runs were recorded in the control flights. All 54 flights required by the design were completed (three intervals x three terrains x two airspeeds x three pilots).

## Results

Average Altitude Error - This measure was determined for each of the 54 missions actually flown and again across pilots to yield combined averages for each of the 18 experimental conditions. Means for the different levels of each of the three variables are presented in Table 24, p 72. These average errors are all positive as they were in the main run series, but they are 300 percent greater than they were previously. The pilots consciously or unconsciously avoided the ground more in the control runs, probably because they never knew when the instruments would fail, i.e. when they would be "distracted". However, crashes were never observed, and there were only occasional excursions above 1000 feet (during the 5-second distraction interval).

An analysis of variance, summarized in Table 25, p 72, was performed on the scores. There were no significant main effects or interactions, as was the case in the main series of runs.

As indicated above, distraction raises average altitude error. The lack of significant main effects or interactions shows that these effects are the same for airspeed and terrain. Otherwise there would have been significant main effects and possibly interactions.

Standard Deviation of Altitude Error - Standard deviation of altitude error was determined for each of the 54 flights, and then across pilots to obtain averages for the 18 experimental conditions. Means for the levels of each variable are given in Table 26, p 73. The means as shown for the control runs in this table are slightly higher than the same means in the main run series; the pilots not only generally flew higher in the control runs but also, probably because of their uncertainty about times of instrument failure, deviated from the required altitude more than they did in the main series.

An analysis of variance was performed on the averages for the 18 different conditions. As summary Table 27, p 73, shows, there were main effects in all three variables, with a significance level of .01 in all three, and no significant interaction.

As Table 26 shows, the $\sigma$ altitude error increases from 0 to 2.5 to 5.0 seconds of distraction. Significance between the levels was determined with a Duncan test, which revealed that all levels (0, 2.5, and 5.0) differ at the .01 level of confidence. Figure 25, p 74, presents this data in graphic form. The function is a straight line in which the rate of error increase is 10.4 percent per second of distraction.

Figure 26, p 74, shows $\sigma$ altitude error by terrain type and distraction interval. Differences between the distraction intervals are significant at all three terrain types ($P < .05$). The rates of error increase are about the same for all three terrains and all of these are, in turn, the same as the combined rate, or 10.4 percent. Figure 27, p 75, shows $\sigma$ altitude error by airspeed and distraction interval. Differences between the distraction intervals are significant at both airspeeds ($P < .05$). Error increase rates are about the same for the two airspeeds and both of these in turn are the same as the combined rate. Consistency of terrain-distraction interval and airspeed-distraction interval effects reflects the lack of interaction.

In summary, deviations about the required clearance altitude increase at the rate of about 10.4 percent for each second of distraction. The function is a straight line from 0 to 5 seconds. The rate is the same over all kinds of terrain tested, and for all airspeeds tested.

# EVALUATION

Pilots flew simulated LAHS terrain-following missions in a series of experimental conditions in which their task loads varied widely. They flew over terrain which ranged from rolling to hilly to mountainous at airspeeds as low as .4M and as high as .9M. Navigation task difficulty ranged from missions with one heading change every 10 minutes to missions with one every 3 minutes. Emergency situations and ECM warnings occurred every 9 minutes in some missions, every 4 minutes in others, and every 2 minutes in still others.

The pilots did not crash or exceed a 1000-foot altitude at any time in any of the experimental conditions, which leads to the general conclusion that LAHS missions can be successfully flown throughout the spectra of task loadings imposed in the study. However, pilot performance and reactions were greatly influenced by some of the experimental variables. These variables and their effects must therefore be considered when LAHS terrain-following missions are flown. They are discussed below.

Of all the variables studied, the steepness of the terrain slopes had the greatest influence on terrain-following performance. Difficulty in maintaining the required clearance altitude of 500 feet increased in direct proportion to increasing slope steepness. This was shown by the fact that $\sigma$ altitude error, or the standard deviation of oscillations about the required clearance altitude, increased at a constant rate of about 9 percent per degree of slope increase throughout the range of terrains studied. No other variable showed such a consistent and powerful effect.

Although slope steepness influenced altitude deviations, it did not affect the averages of the deviations. Deviations above the required clearance altitude were approximately equal to those below it over all kinds of terrain, and thus cancelled each other out to yield an average of approximately zero for the entire mission. However, the sign of slopes did influence altitude holding, i.e. performance was different on positive (uphill) than on negative (downhill) slopes. The pilots always exceeded 500 feet when going uphill and were below 500 feet going downhill. In addition, this average error was 30 percent greater on positive than on negative slopes; the pilots were thus higher going uphill than they were going down. Different uphill and downhill performance may reflect the different directions of control stick movement needed to pitch the aircraft down and up, or it may reflect a tendency to avoid terrain more when it rises ahead of the aircraft than when it falls away. A third possible explanation is that the command signal lead time of 2.5 seconds was not quite optimal, with the result that responses of the pilot-aircraft system were slightly out of phase with the terrain.

Airspeed also affected performance, but not to the degree that terrain slope did, and not as consistently. The data indicate that pilots can track as well at .7M as at .4M but that their tracking deteriorates rapidly when airspeed is increased to .9M.

Examination of a large number of altitude error traces revealed that the maximum excursions of the simulated aircraft upwards from 500 feet were approximately equal to the maximum excursions downward from 500 feet, and that the excursions in both directions were nearly always within 4 $\sigma$'s of the 500-foot mean. The maxima were larger than 5 $\sigma$'s but smaller than 6 $\sigma$'s in three of the flights; in each of these flights there was one excursion that exceeded 5 $\sigma$'s. The boundaries within which the pilots always flew were thus ±6 $\sigma$ of the 500-foot clearance altitude.

If the lower excursion boundary in the simulated flights is set as the ground or a 0-foot altitude, the pilots could have flown at a clearance altitude of 6 $\sigma$'s without crashing because they never exceeded 6 $\sigma$ limits. For example, the $\sigma$ altitude error in the flights at .4M over rolling terrain averaged about 25.2 feet. Multiplying this figure by 6 produces 151.2 feet, which is the range of excursions either above or below a clearance altitude. If the required clearance had been 151.2 feet, the pilots would never have crashed because they would not have exceeded the 6 $\sigma$ limits below it; and, conversely, would never have risen above 302.4 feet, which is the 6 $\sigma$ limit above 151.2 feet. Clearance altitudes determined by 6 $\sigma$ ranges are here called "minimum safe altitudes".

Figure 28, p 75, shows minimum safe altitudes that could have been flown under the various airspeed and terrain conditions of the present study. As expected, the figure shows no essential differences between .4M and .7M when the flights are made over all terrain types. At these speeds, it would have been possible to fly missions as low as about 155 feet above rolling terrain and slightly less than 400 feet above mountains. It was possible to fly missions at .9M as low as about 190 feet over the rolling terrain, or about 470 feet over the mountainous terrain. Note that the minimum safe altitudes vary quite regularly with terrain slope.

All missions of the present study were flown in a medium-heavy gust environment in an aircraft with a fairly high gust sensitivity (.042). Even in this aircraft, in which vertical accelerations of .4 RMS were produced, performance was actually quite good. Gust alleviation techniques could only enhance the observed performance. One study (ref. 10) showed that deviations about a required clearance altitude increase or decrease by 25 percent for each .1 RMS G increment or decrement. By applying this finding, minimum safe altitudes could be reduced in less gusty environments. For example, if the gusts were about RMS 4 ft/sec, the RMS G would be about .168 from the gust input alone, or probably about .200 with pilot control stick inputs added*. This would represent a decrease of .2 RMS G from the .4 RMS level of the present study and a corresponding altitude deviation reduction of about 50 percent. The minimum safe altitudes could also be reduced by 50 percent since the error magnitudes which establish them are reduced. Of course, all extrapolations leading to the establishment of minimum clearance altitudes assume that the pilot is without fear. The extent to which fear or anxiety (learned fear) influence this kind of performance should be investigated.

Detection and resetting of a master warning signal light placed at the top of the instrument panel was very rapid, about .9 second, and did not vary among the various mission conditions. Alertness or vigilance of the pilots thus was unaffected by the different task loads. Similarly, the performance of short, straightforward emergency procedures such as those that might be encountered in emergency situations was very rapid, averaging about 1.5 seconds, and also did not vary among the various mission conditions, indicating that performance of habitual acts of this type is reliable under different task loads. Performance of the emergency tasks did not affect terrain-following or navigation under any experimental condition, even when the pilots performed tasks involving as many as three responses or acts nearly every minute.

Average times to respond to the master warning light and to perform the emergency tasks total slightly over 2 seconds. If the pilot's attention was completely removed from altitude holding during the 2 seconds, i.e. if distraction were complete during that time, altitude deviations would have increased by about 25 percent (see Figure 25, p 74). This increase would probably have produced significant differences between the runs with few emergency tasks and the runs with many. Since it did not produce these differences, it may be assumed that distraction when responding to the master

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* Gust Sensitivity = $\frac{\text{RMS } \Delta N_Z}{\text{RMS } w_g}$

warning light and performing the associated emergency tasks was not complete, and that many tasks of the same kind can be performed without effect on altitude holding. The pilots did say that they manipulated the emergency switches without looking at them after some practice, and they recommended that switches be large and easy to locate without looking.

As noted in the discussion of experimental results, the pilots did not crash or exceed a 1,000-foot altitude with up to 5 seconds of complete loss of flight control information. Rather, altitude holding deteriorated steadily as time of information loss increased. This would mean that, if a given activity took two successive seconds of a pilot's time, his altitude deviations would increase about 20 percent if he had no flight control information during the 2 seconds. This increase could easily be fatal if the flight were made at a minimum safe altitude. The only solutions would be to increase the clearance altitude 20 percent if the activity happened to be a necessary one, or to provide altitude holding information over other sensory channels during the activity period. A recent study indicated that auditory signals could be used as an additional sensory channel to provide altitude holding information (ref. 5). Other senses, such as tactile (skin) or kinesthetic (muscle) might also be used.

Average clearance altitudes during missions with brief "distractions" or periods of complete altitude holding information loss were 300 percent higher than normal. The best explanation for this finding is that if pilots are uncertain about the status of instruments, and probably controls, they will fly higher and thus avoid the ground to a greater than normal extent. If this hypothesis is true, it points up the necessity for complete pilot confidence in the machine, especially in this flight regime where permissible error margins are so small.

The rate of increase of altitude deviations with distraction time should be constant under all flight conditions because the present study showed that the rate, about 10 percent error increase for each successive second of distraction, was the same at all airspeeds and terrain types tested. The distraction concept thus places stringent limits on the amount of time during which a pilot can be completely inattentive to his primary control task. Any pilot activity other than altitude holding must take these limits into account.

Times taken by the pilots to solve fuel computation problems changed only with airspeed. Times taken to compute the amount of fuel that would remain after certain flight times were higher when the flights were made at .7M than when they were made at .4 or .9M. In the discussion of this point on page 21 of this report, it is hypothesized that the difference is due to the fact that the problem was more difficult at .7 than at .4 or .9M, with the conclusion being that computational or mental ability does not change over a wide range of task loading conditions. However, problems of this type should be kept as simple and as easy as possible to obtain the speedy solutions that might be necessary under actual flight conditions.

The importance of training was demonstrated by several measures. The first of these, reaction time to reset the master warning light, decreased 22 percent from the beginning to the end of the study, probably indicating increased proficiency in making the response that reset the light, and, to a lesser extent, indicating that the flight control task became less demanding as time went on, thus permitting quicker signal detection.

Time to perform emergency tasks decreased 37 percent throughout the course of the experiment, again probably indicating increased task performance proficiency as the locations of controls became more familiar and corrective procedures became more firmly established. Thus, learning occurred continuously throughout the experimental runs.

RMS G decreased by 11 percent from the first to the last parts of the study. The pilots probably learned to decrease the maneuver-induced G-loading, making more appropriate control stick movements as time went on. They remarked on several occasions that postural adaptations to the acceleration environment were constantly being made. One of them said that it was like learning to ride a horse; one stops fighting the animal as one becomes better.

Fatigue was not a problem in the study even though the flights lasted for an hour at 0.4 RMS G. These findings are consistent with a previous G-seat study in which pilots tracked simulated hilly terrain up to 3 hours in an RMS G environment averaging about .19 over the entire mission (ref. 9). Altitude deviations did not increase over the 3 hours. Still another G-seat study yielded similar results (ref. 10). In that study, pilots tracked simulated flat and contour terrain at different airspeeds for 1 1/2 hour periods in RMS G environments as high as .29, and, again, there were no effective performance decrements over time. The general conclusion from these simulator studies is that fatigue is not important in LAHS missions lasting up to 1 1/2 hours with fairly severe buffeting producing RMS G perhaps as high as 0.3 or 0.4, nor is it important in missions lasting up to 3 hours in an acceleration environment with RMS G of about 0.2 This conclusion does not, of course, take fear into account. Fear could increase the pilot's task load in actual flight to the extent that performance decrements might occur before they do in a simulator.

Increasingly steep terrain slopes and increasingly fast airspeeds exerted a positive influence on altitude holding in the present study, while turning the aircraft and performing emergency tasks did not affect it. The terrain and airspeed variables were thus, in the context of the study, the most important of the four experimental variables in terms of their influence on the primary task of altitude holding. The study context was one in which each turn was requested according to a previously determined plan, with sufficient time allowed for initiation and completion of the turn; and in which emergencies that occurred required definite responses that inevitably "corrected" the particular malfunction. However, if a pilot were in a situation where he had to turn suddenly, as to take evasive action, he might crash if the turn were too abrupt at very low altitudes under any terrain-airspeed situation, or especially if it were made when flying over certain types of terrain at certain airspeeds. If several emergencies occurred at the same time, and/or if the pilot had no assurance that corrective procedures would be successful, he might abort his mission or climb to a higher altitude and thereby become more vulnerable to missiles.

Of course, the hypothetical situations of evasive actions and emergencies represent task-loading extremes where either of these two types of tasks may exert a profound influence on altitude holding. As indicated above, the problem is further complicated by the fact that the tasks will be performed in one of many possible configurations of altitude, type of terrain, airspeed, etc. Even though the extremes probably occur rarely because they are extremes, they should be studied so that the pilot's performance limits can be established. These limits will, in turn, determine the probabilities of mission success in abnormal as well as normal situations.

The use of the relatively small number (N) of subjects in the present study may be questioned since large N's usually give greater confidence in results than small N's. Two previous NAA G-Seat studies of simulated LAHS flight used, e.g. an N of 6 (ref. 9) and an N of 8 (ref. 10). Now, when the subjects themselves are considered in these groups of 6 and 8, it is a truism to say that they varied with respect to "personal' factors such as ability, previous experience, and attitudes. It is equally true that the pilots in the present study varied with respect to the same factors. It was observed by personnel connected with each of the three studies that the pilots in the present study, even though only three, varied at least as much in regard to personal factors as they did in the previous studies, with the result that all three groups were equal on this basis. However, a comparison of performance variabilities revealed that both intra- and inter-subject variability in the present study were actually less in the previous studies. (This decreased variability is probably due to the greater amount of training experienced by the subjects in the present study, an amount that was approximately that recommended by the ref. 9 study). Finally, appropriate statistical tests were used to examine all data in the present study; any statements regarding differences or similarities have significance at least at the .05 level of confidence attached to them. For all of these reasons, it is concluded that results of the present study have as much validity and reliability as those of studies with larger N's.

Appendix I presents a comparison of this study and a previous one conducted for TRECOM (ref. 9). In both studies, the same simulator and highly similar aircraft equations were used; some of the flights in each study were made under similar terrain, airspeed, and turbulence conditions; and similar groups of pilots were used. However, there was one major difference between the two. In the present study, movements of the command signal used to follow terrain were determined by the slopes of terrain ahead of the aircraft and by present altitude, whereas, in the previous study, the command signal movements were determined only by present altitude*. Thus, even though the pilots saw the same kinds of command signal movements in the two studies, the signals were generated differently. Since altitude deviations were 6 times less in the present than in the previous study, and since the major difference in the terrain-following task between the two studies was the anticipatory information, it was concluded that the reduced deviations were due to this display variable.

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* Anticipatory information was not needed in that study.

Future studies should investigate ways of displaying terrain-following information visually because of the apparent great control of the terrain-following task exerted by the information content of the signal being tracked. For example, different methods of presenting the anticipatory information could be investigated to determine efficiency and reliability of the methods. Some methods could possibly lead to even greater efficiency than that found in the present study, but could also be prohibitive because of complexity and costs. Pilots might have greater reliability of the preferred method. There are obviously many trade-offs to be made in terms of equipment costs, efficiency, reliability, and maintainability.

The possibility of unburdening the visual sense mode during LAHS flight should be explored. There are times when the pilot's attention to the terrain-following display will undoubtedly be removed for relatively long periods, perhaps for several seconds. During these times, proper clearance altitudes might be maintained and crashes or excessive heights prevented if supplementary terrain-following information from other senses such as auditory, tactile, or kinesthetic were available.

The influence of fear or anxiety on terrain-following performance should also be determined. Estimates of the effects of this important psychophysiological variable are absolutely necessary in predicting behavior in the real world from behavior in a flight simulator. A study of this kind would probably involve actual as well as simulated flights, and would, therefore, provide data which would help answer the all-important question of to what degree can simulator findings be extrapolated to the real world situation.

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## APPENDIX I

## COMPARISON OF PRESENT AND FORMER STUDIES

Mean RMS altitude error in the dash portion of the former study, hereafter called Study I, was about 173 feet (ref. 9, p 14). In the present study, hereafter called Study II, the mean $\sigma$ ($\simeq$ RMS) altitude error was about 28 feet in the flights over comparable terrain (Terrain I).* Altitude deviations were thus about six times as great in Study I as in Study II. In addition, crashes and excursions over 1,000 feet were frequently observed in Study I, but never in Study II. Although the pilots in Study II had more training than those in Study I, this cannot account for the observed differences since altitude deviations did not decrease over time in Study II. Aircraft characteristics were nearly identical in the two studies so these factors cannot account for the differences. Although the out-of-cockpit visual tasks in Study I were reported to increase deviations about the required clearance altitude, there were not enough of them to inflate the RMS error to a figure 6 times that of Study II. In any event this effect would undoubtedly be counteracted by the greater difficulty of tracking in the higher RMS G environment of Study II.

The performance differences are probably due to the type of display used. The terrain-following display used in Study II provided anticipatory information in that the displayed error -- the pitch command -- was partly determined by the terrain slope 2.5 seconds ahead of the aircraft. The display of Study I showed deviations from 500 feet as measured directly below the aircraft; as used, it was essentially radar altimeter information displayed on a CRT. The Study II display was evidently more efficient in reducing altitude deviations than the Study I display due to the anticipatory information.

Altitude deviation differences as a function of airspeed were found in both studies. It should be noted that, in Study I, only aircraft response characteristics varied with airspeed; frequency of movement of the command signal, which would be associated with airspeed changes in the real world, was not varied. The reverse was true in Study II; frequency of command signal movement showed an error increase of about 21 percent from .4M to .9M, while

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* RMS G in the dash portion of the Study I missions was about .25, a value more similar to the RMS G of .4 in Study II than the G in the cruise portion of Study I. For this reasons, dash portion error scores are used when comparing the two studies.

Study II showed an error increase of about 27 percent from .4 to .9M. In Study II, greater command signal movement frequency led to error increases since frequency was the only factor changed between the two airspeeds. In Study I, however, several aircraft characteristics changed from .4 to .9M, e.g. airplane undamped natural frquency, damping ratio, stick force per g, etc. (p 50). Determination of the relative contributions of each of these factors to error should be made through experimentation.

In Study I, altitude holding deteriorated when the pilot looked out of the cockpit, changed heading, or responded to ECM warning. Although there were no out-of-cockpit tasks in Study II, heading changes and response to ECM warning did not affect altitude holding. In Study I, the pilots had to perform the navigation tasks without assistance; they were required to call out checkpoint acquisition, make heading changes, and announce new heading changes. The greater distractions in conjunction with the navigation task could have degraded altitude holding quite markedly. Similarly, the relatively long ECM reaction times in Study I of 3.63 seconds could have provided sufficient distraction and consequent loss of control to markedly deteriorate altitude holding. In Study II, however, the pilot had assistance in navigating (the experimenter called out heading changes), and a more efficient warning system (ECM reaction time was about 2 seconds).

No performance decrements ascribable to fatigue were found in either Study I or Study II. Fatigue does not seem to pose a problem for LAHS missions lasting up to an hour in a very stressful acceleration environment (average RMS G = .19). Both studies also show definite learning effects even though the experimental conditions were not selected to demonstrate learning. Learning is thus a powerful variable. The possibility of pre-LAHS flight simulator training should definitely be explored to determine exactly what gains it will provide in terms of time, money, and, possibly, lives saved.

One of the Study I conclusions is that pilots learn "tricks of the trade" in restraint system adjustment as time goes on, and that they make postural adaptations which increase their tolerance to these environments. These conclusions are supported by Study II results, both in terms of RMS G decrease during the course of the experiment and pilots' statements that postural adaptations continue even over many weeks.

# APPENDIX II

## EXPERIMENTAL PROCEDURES

### Simulated Aircraft Characteristics

The aircraft dynamics were chosen to give satisfactory flying qualities so that the primary study objectives would not be affected by undesirable flight characteristics. Figure 1, p 41, shows frequency and damping of the simulated aircraft and presents a comparison of this aircraft with satisfactory flying qualities regions established by North American Aviation and by Cornell Aeronautical Laboratory (ref. 3). By either criterion, the dynamics used are satisfactory. The dynamics are also typical of many current airplanes.

The control characteristics employed were:

$$\frac{\text{STICK DEFLECTION}}{g} = .5 \text{ in}/g$$

$$\frac{\text{STICK FORCE}}{g} = 5 \text{ lb}/g$$

These characteristics were chosen to give satisfactory handling qualities and are also typical values of many current airplanes.

The airplane transfer function which describes the load factor response to longitudinal stick deflection is

$$\frac{\Delta n}{\delta}(s) = \frac{K_{n/\delta}}{\frac{s^2}{\omega_N^2} + \frac{2\zeta_N}{\omega_N} s + 1}$$

where

$K_{n/\delta}$ = 2.0 g/in.
$\omega_N$ = 4.08 rad/sec = 65 CPS
$\zeta_N$ = .546
$s$ = Laplace transform variable

Gust effects were introduced as disturbances to the airplane load factor. The gust response of the simulated airplane is given by the ratio of the root-mean-square load factor induced by gusts to the root-mean-square gust velocity and was:

$$\frac{\text{RMS } (\Delta n_z)}{\text{RMS } w_g} = .042 \qquad \frac{1}{\text{Ft./Sec.}}$$

This value of gust sensitivity is common among many currently flying airplanes.

The lateral-directional simulation was provided by an extremely simple representation since the intent was to provide capability for changing heading; the aircraft lateral-directional characteristics were not of interest.

The form used was:

$$\frac{\phi}{\delta} = \frac{K}{s}$$

$$\frac{\psi}{\delta_L} = \frac{K}{.8\,s+1} = \frac{1}{s^2}$$

where:

$\phi$ = bank angle
$\psi$ = heading angle
$\delta_L$ - lateral stick deflection

The values of the K's in the above were adjusted at the start of the investigation to give realistic bank and heading change rates.

Dynamic characteristics used for all airspeeds were those of the aircraft at .7M. One set of characteristics were used to prevent simultaneous variation of more than the frequency factor at the different airspeeds. A point approximately midway between the extremes of .4 and .9M was chosen because it represented an average.

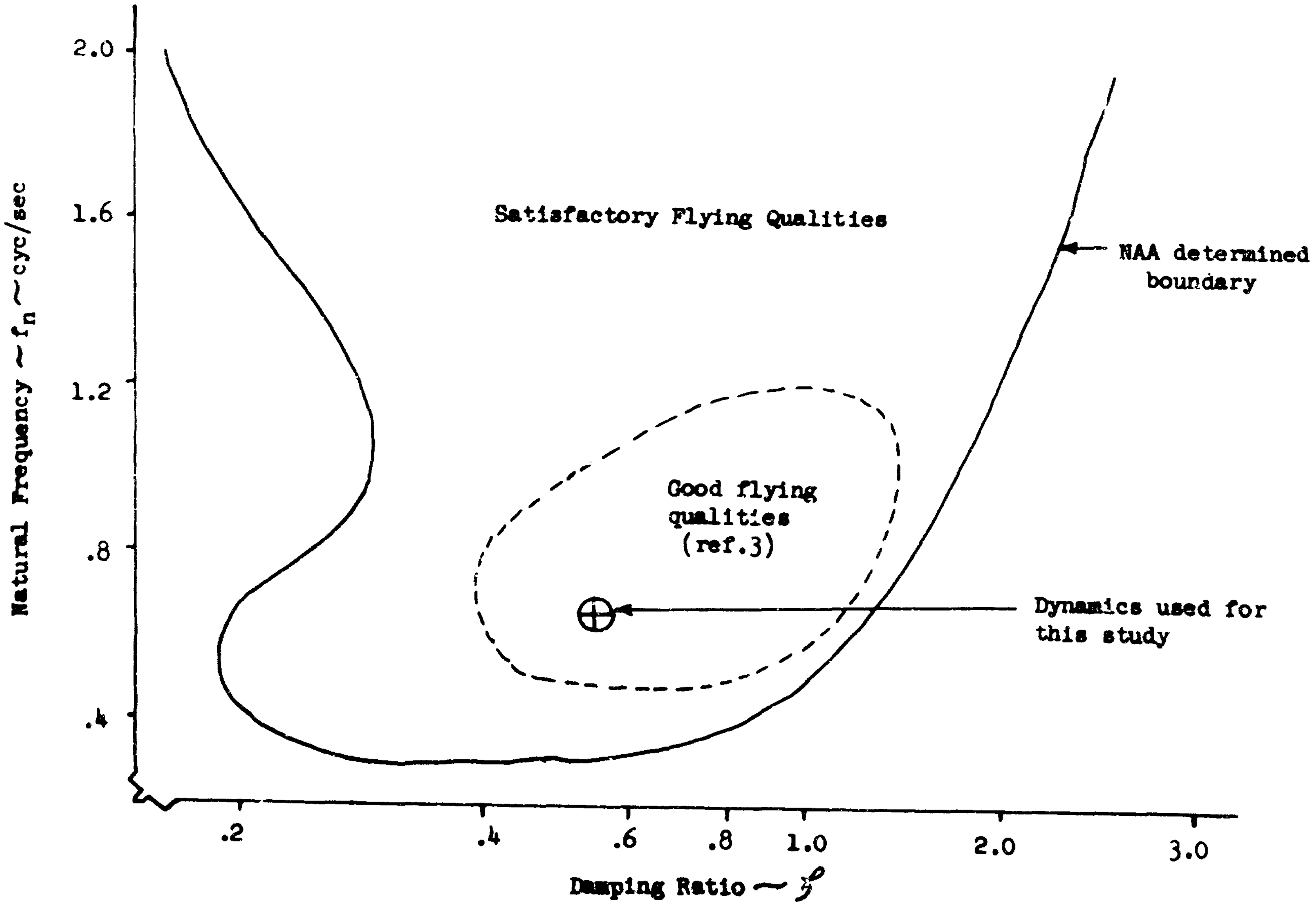
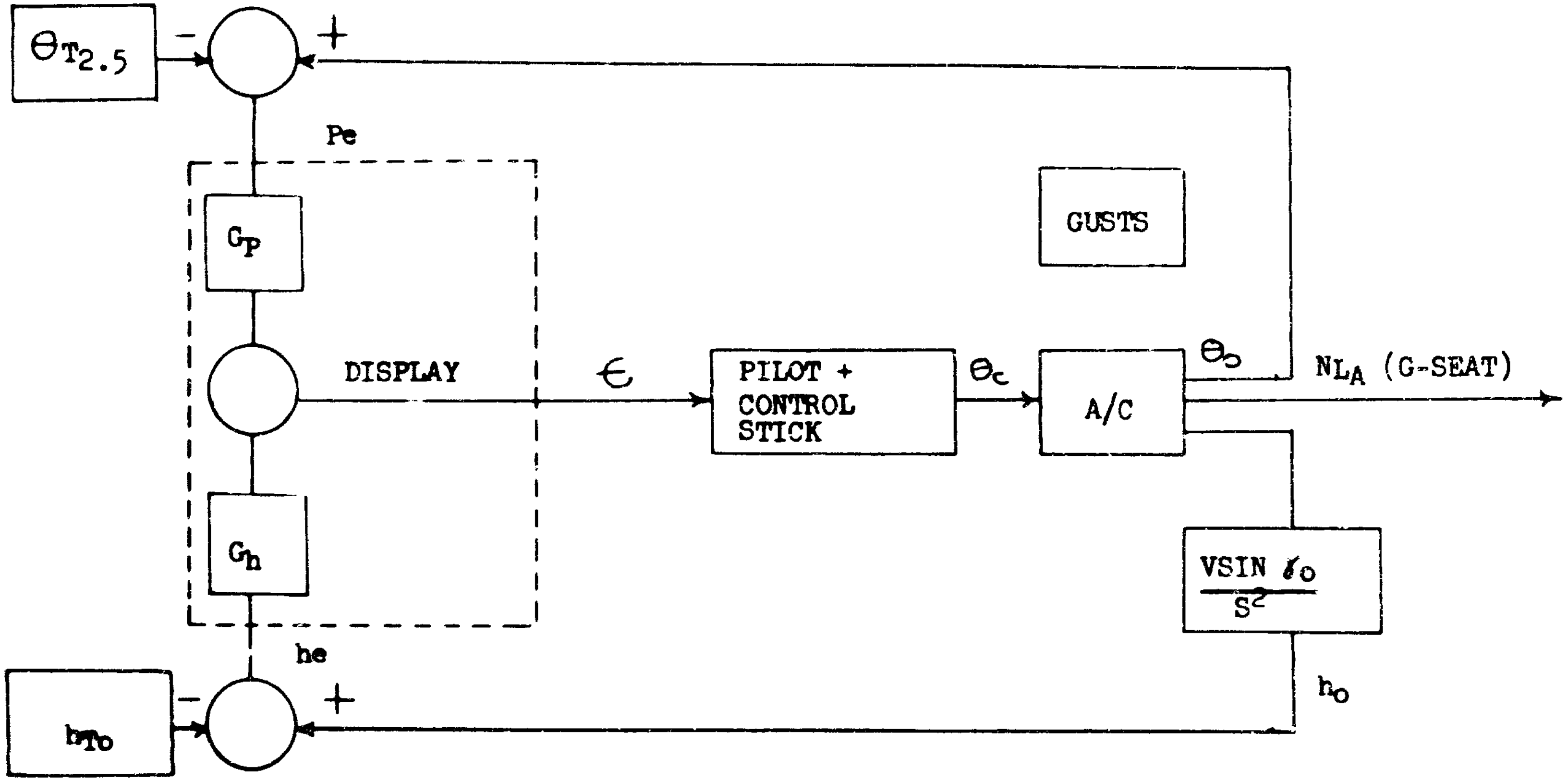


Figure 1 - Simulated Aircraft Dynamic Characteristics



○ : Summer

$\theta_{T2.5}$ : Slope of Terrain in Degrees (2.5 Sec. Lead)

$h_{To}$ : Terrain Altitude Plus 500 Feet

Gp: Scope Gain - Pitch Error (Pe) (0.1 inches per degree)

Gh: Scope Gain - Altitude Error (He) ($25 \times 10^{-4}$ inches per foot)

$\in$: Displayed Error

$\Theta_c$ : Pilot Pitch Command

$\Theta_o$ : A/C Pitch Response

$\gamma_o$ : A/C Velocity Vector Angle

V : A/C Velocity

Figure 2 - Block Diagram of Signal Flow for Aircraft Altitude and Pitch Control

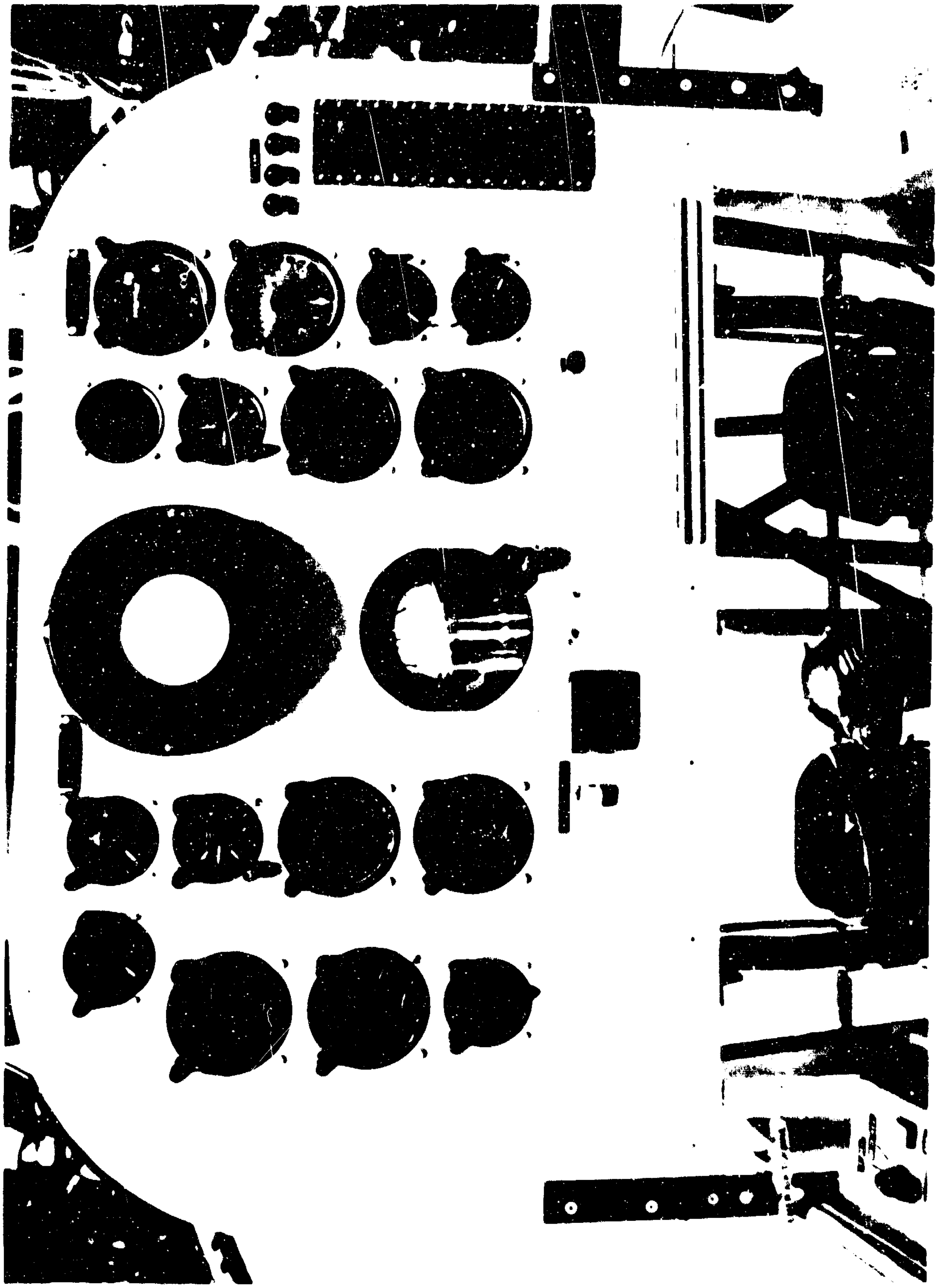


Figure 3. Instrument Panel Layout

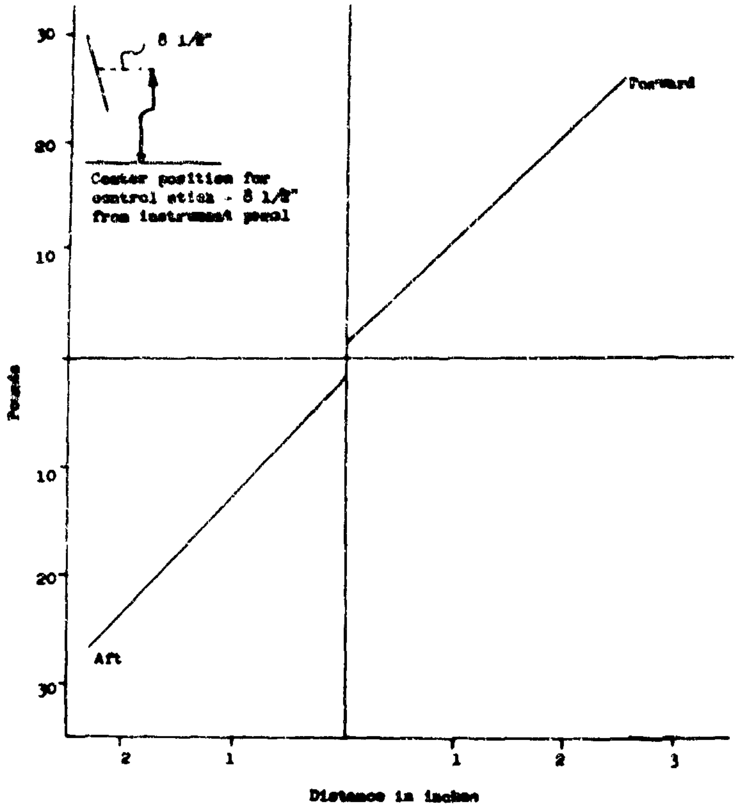


Figure 4. Control Stick Forces; Longitudinal.

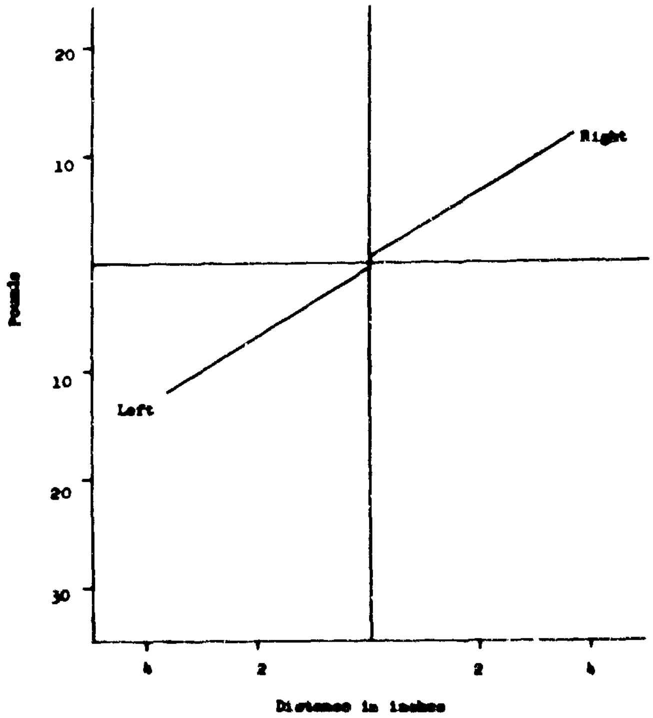


Figure 4. Control Stick Forces: Lateral.

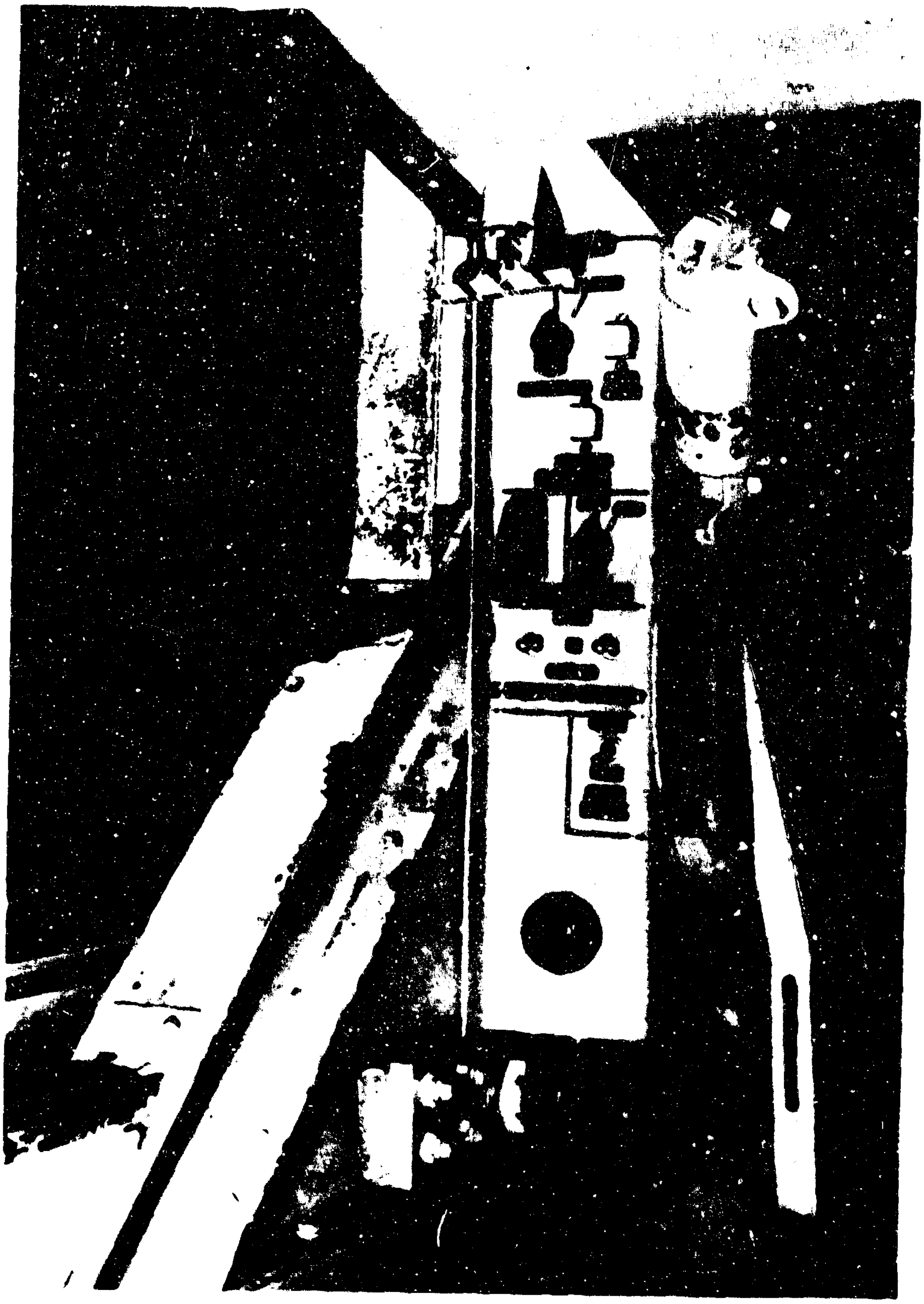


Figure 5. Left-Hand Console

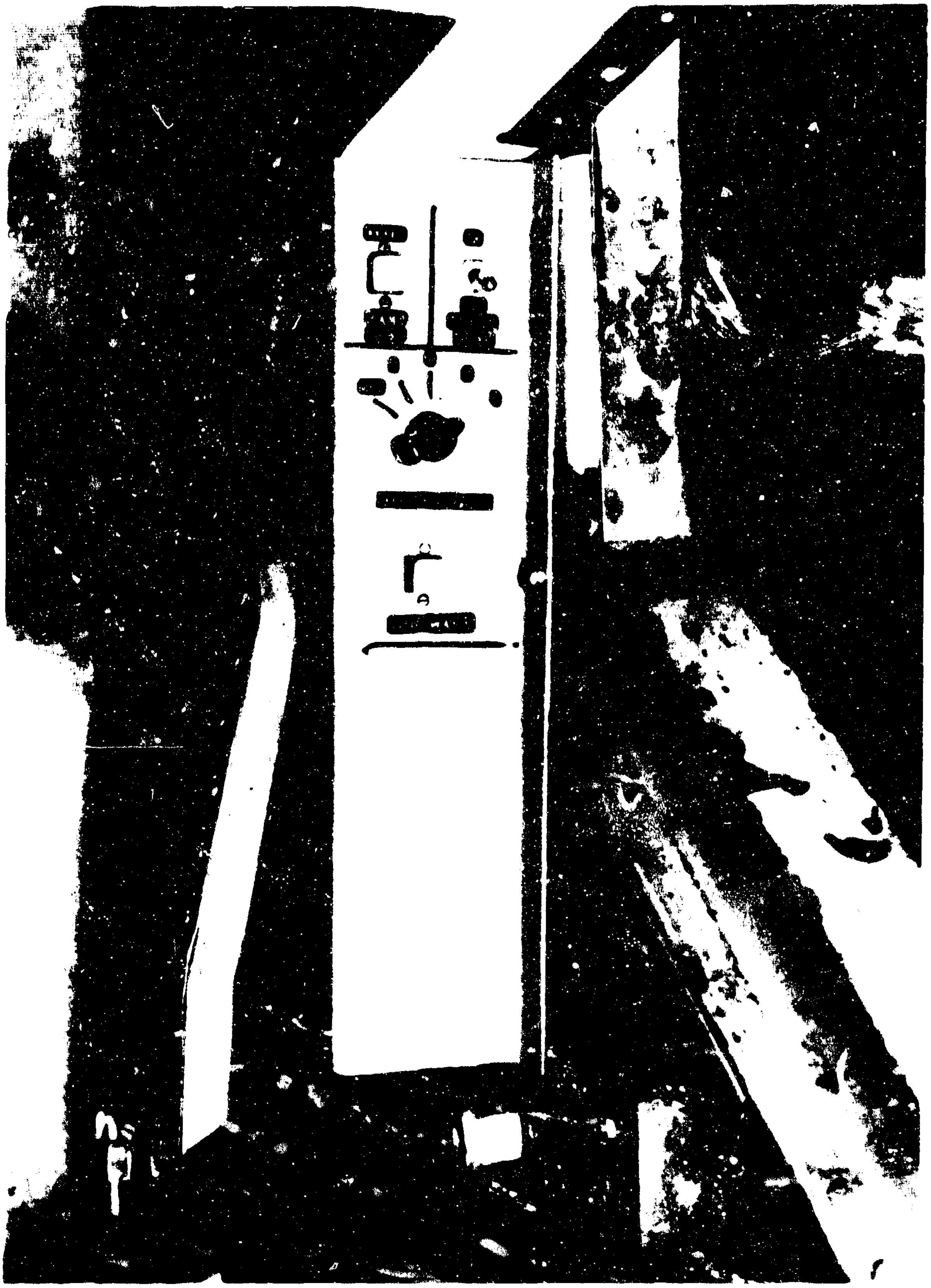


Figure 6. Right-Hand Console

TABLE 1
TERRAIN CHARACTERISTICS

| Terrain Type | Average Slopes | σ Slopes | Average Peaks | σ Peaks |
|---|---|---|---|---|
| I | ± 8° | ± 4° | ± 300' | ± 118' |
| II | ± 16° | ± 7° | ± 600' | ± 289' |
| III | ± 24° | ± 9° | ± 900' | ± 438' |

| Airspeed | Slopes per Minute | Average Slope Duration | σ Slope Duration | Peak to Peak Length |
|---|---|---|---|---|
| .4M | 2.1 | 28 sec. | 12 sec. | 2.77 mi. |
| .7M | 3.9 | 16 sec. | 5 sec. | 2.77 mi. |
| .9M | 5.0 | 12 sec. | 4 sec. | 2.77 mi. |

Emergency Tasks

The following emergency situations and associated corrective procedures were used in the simulated flights. They were presented in logical sequences, i.e. the series of emergency events in a particular mission were as closely related as possible.

Fuel Leak - Assuming 7500 lbs. of fuel per tank and flow rates of 4800, 5400, 6000 PPH at .4M, .7M, and .9M, respectively, the fuel consumption for the particular Mach no. is a computer-driven function. To simulate a fuel leak, the computer, at a signal from the experimenter, changed to a fast integration and depleted the fuel in the selected tank within 1 min. 15 secs. When the needle indicated 2000 lbs, the computer sent a signal to light the master warning and fuel low lights. After the pilot reset the master warning system and switched to another tank, the computer reverted to the initial condition which was identical for all tanks. This allowed a simulated fuel leak in Tanks #1 and #2.

Hydraulic System Failure - There were two hydraulic systems, each indicating 3000 psi. Each system could be failed by the experimenter. When the particular fail switch and problem start switch were activated, the indicator reverted to a zero indication within 5 seconds and the warning and HYD.PRESS lights went on. After the warning light was reset, the selector switch was then positioned at the remaining operable system. If the second system was then failed with the appropriate indications following, the pilot then had to revert to the ram (emergency) air turbine. By pulling the handle out, the number one hydraulic indicator (left hand) then reverted to the normal operating pressure of 3000 psi. Also, after 5 seconds the HYD.EPU and ELEC.EPU lights went on. With both systems failed and the ram air unit operating, the HYD.PRESS caution lights remained on.

Electrical System Failure - The electrical system was composed of a generator selector switch, a generator reset switch, and a DC reset switch. If the experimenter activated the #1 GEN fail switch and problem start switch, the master warning and #1 GEN caution light went on. After resetting the warning light, the pilot pressed the GEN RESET switch. This action shut off the #1 GEN caution light. The experimenter could then activate both the #1 GEN fail switch and #1 GEN RESET fail switch and problem start switch. The pilot used the same sequence of action as previously stated except that since the reset was failed, the #1 GEN caution light would not go out. The pilot then had to place the GEN selector switch at #2 GEN position. The same sequence of failure could be accomplished for the #2 generator. If both generators were failed, the pilot reverted to the ram air turbine. With the handle pulled, the EPU lights went on and the #1 and #2 GEN caution lights remained on. Activation of the DC PWR fail switch and problem start switch by the experimenter caused the master warning and DC PWR caution lights to go on. After the warning light was reset, the pilot depressed the DC RESET switch. This action shut off the DC PWR caution light. It should be noted that DC PWR could be failed only prior to failure of both generators since with both generators inoperative the emergency power unit was in operation and supplied electrical power as required.

Engine Fire - The normal operating EGT was 580°C. When the experimenter depressed the fire switch and problem start switch, the EGT was driven up to 880°C in 20 seconds. When the indicator read 780°C, the warning and engine fire lights went on. After warning light reset, the throttle was retarded to the idle position. After 4 seconds, the EGT started back down and returned to the normal EGT of 580°C. The throttle could then be advanced to the scheduled RPM. The RPM and fuel flow indicators functioned linearally with throttle movement. A limited speed degradation was also incorporated with throttle retardation. If the pilot initiated the fire exiting switch, the only indication was a light at the experimenter's console.

Pitch Augmentation Failure - When the PITCH AUG fail switch and problem start switch were activated, the master warning light and pitch augmentation caution light went on. After warning light reset, the pilot scanned the #2 hydraulic indicator for normal pressures. With normal pressure, the PITCH AUG switch was held in reset position. If the caution light went out, the switch was released back to the normal ON position. The sequence could be repeated with the experimenter depressing both PITCH AUG fail and PITCH AUG RESET fail and problem start switch. The pilot went through the same routine except that the caution light did not go out. The pilot then had to place the PITCH AUG switch in STANDBY position. The caution light then went out. It should be noted that if the #2 hydraulic system was previously failed, the system could not be reset and the PITCH AUG switch had to be placed in the STANDBY position.

Yaw Augmentation Failure - The sequence of operation was identical to the pitch augmentation system operation with one addition. The pilot also had to scan the #1 and #2 generator caution lights to be sure they were out. If the #2 hydraulic system was inoperative and the #1 and #2 generator caution lights were on, the system could not be reset. The system switch had to be placed in standby position and then the caution light went out.

Gust Alleviation Failure - When the experimenter depressed the fail switch and problem start switch, the master warning and GUST ALLEV caution lights went on. After warning light reset, the pilot switched to the emergency position. The caution light then went out.

Plugged Pitot Tube - When the monitor depressed the plugged pitot tube switch and problem start switch, the airspeed gradually dropped off. There were no master warning-light or caution-light indications of trouble. The airspeed was allowed to drop off 130K in 15 secs. When the pilot recognized the situation, the pitot heat switch was placed in the ON position. After approximately 15 seconds, the airspeed increased to the original scheduled indication.

Ramp Control Failure - The master warning light and RAMP CONT light went on when the experimenter depressed the RAMP CONT fail switch and problem start switch. After warning light reset, the pilot had to press the ramp control reset switch. The caution light then went out and the system was in normal operating condition.

ECM Warning - There were four switches at the experimenter's console with each switch simulating a 90° quadrant of the compass. When one of these was depressed along with the problem start switch, the master warning light and appropriate sector caution light went on. After warning light reset, the knob on the right-hand console was rotated to the position corresponding to the light which was on, and then the ECM WARN switch was pressed. This extinguished the light and stopped the emergency timer.

TABLE 2
SCORING EQUATIONS

1. $$\sum h_e = \alpha \cdot \sigma \int_{t_i}^{t_i + 60} h_e(t)\,dt$$

2. $$\sum h_e^2 = \alpha \cdot \sigma \int_{t_i}^{t_i + 60} h_e^2(t)\,dt$$

3. $$\sum_{g} = \alpha \int_{t_i}^{t_i + 60} g^2(t)\,dt$$

4. $$\sum \dot\psi = \alpha \int_{t_i}^{t_i + 60} \dot\psi(t)\,dt$$

5. $$\sum \dot\psi^2 = \alpha \int_{t_i}^{t_i + 60} \dot\psi^2(t)\,dt$$

6. $$\sum \delta = \alpha\,\gamma \int_{t_i}^{t_i + 60} \delta(t)\,dt$$

where:

(a) $t_i = 0,\ 60 + \Delta t,\ 120 + \Delta t,\ \ldots M(60 + \Delta t)$

(b) $\Delta t = 3$ sec (to recycle scoring circuit)

(c) $M = 0, 1, 2, 3, \ldots N$

(d) If $\dot h_T \leq 0$ then $\sigma = -1$, or if $\dot h_T > 0$ then $\sigma = +1$

(e) If $\delta \leq 0$ then $\gamma = -1$, or if $\delta > 0$ then $\gamma = +1$

(f) when $60M + \Delta t(M-1) \leq t_i < M(60 + \Delta t)$, then $\alpha = 0$

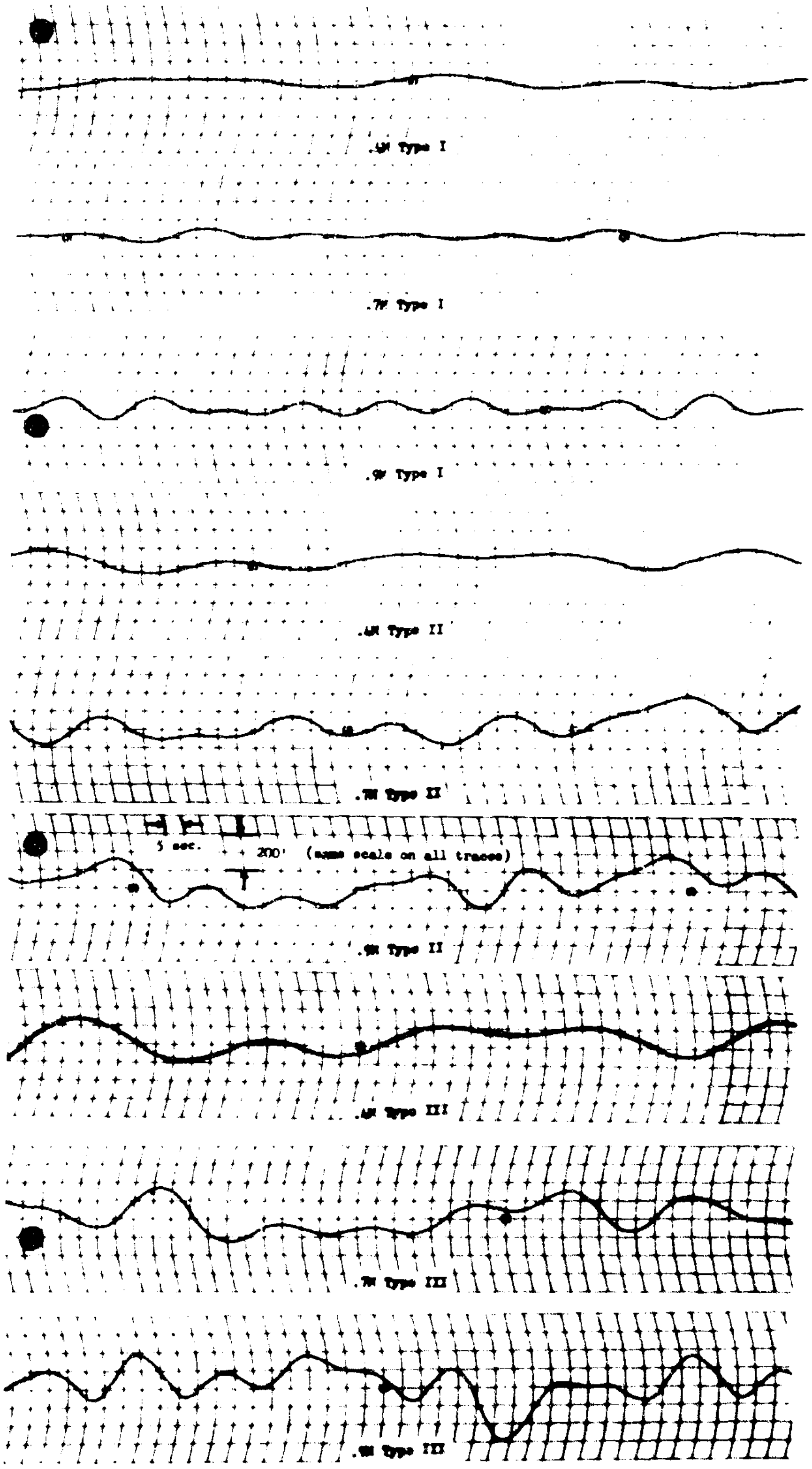


Figure 7. Terrain Profiles

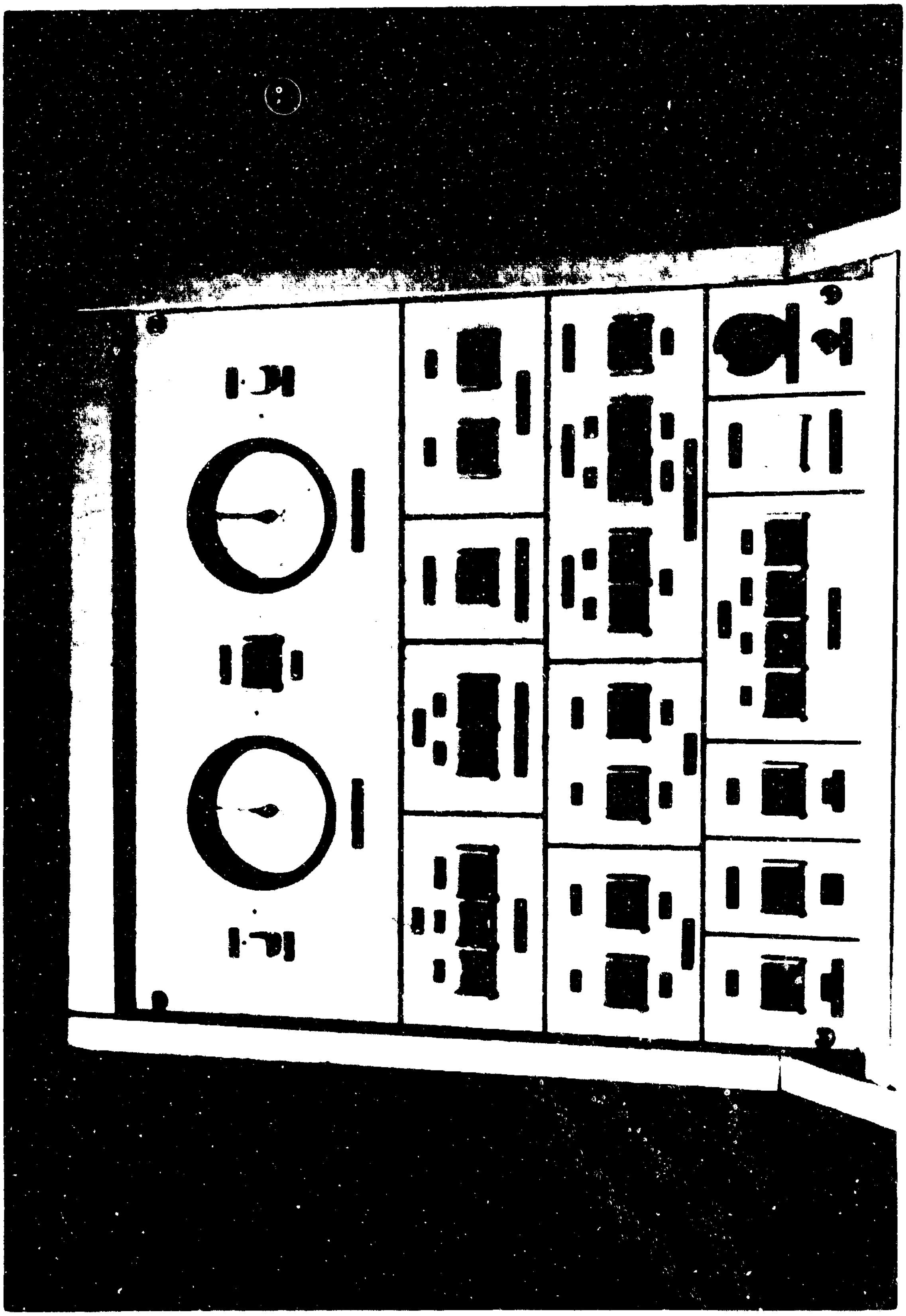


Figure 8. Experimenter's Console

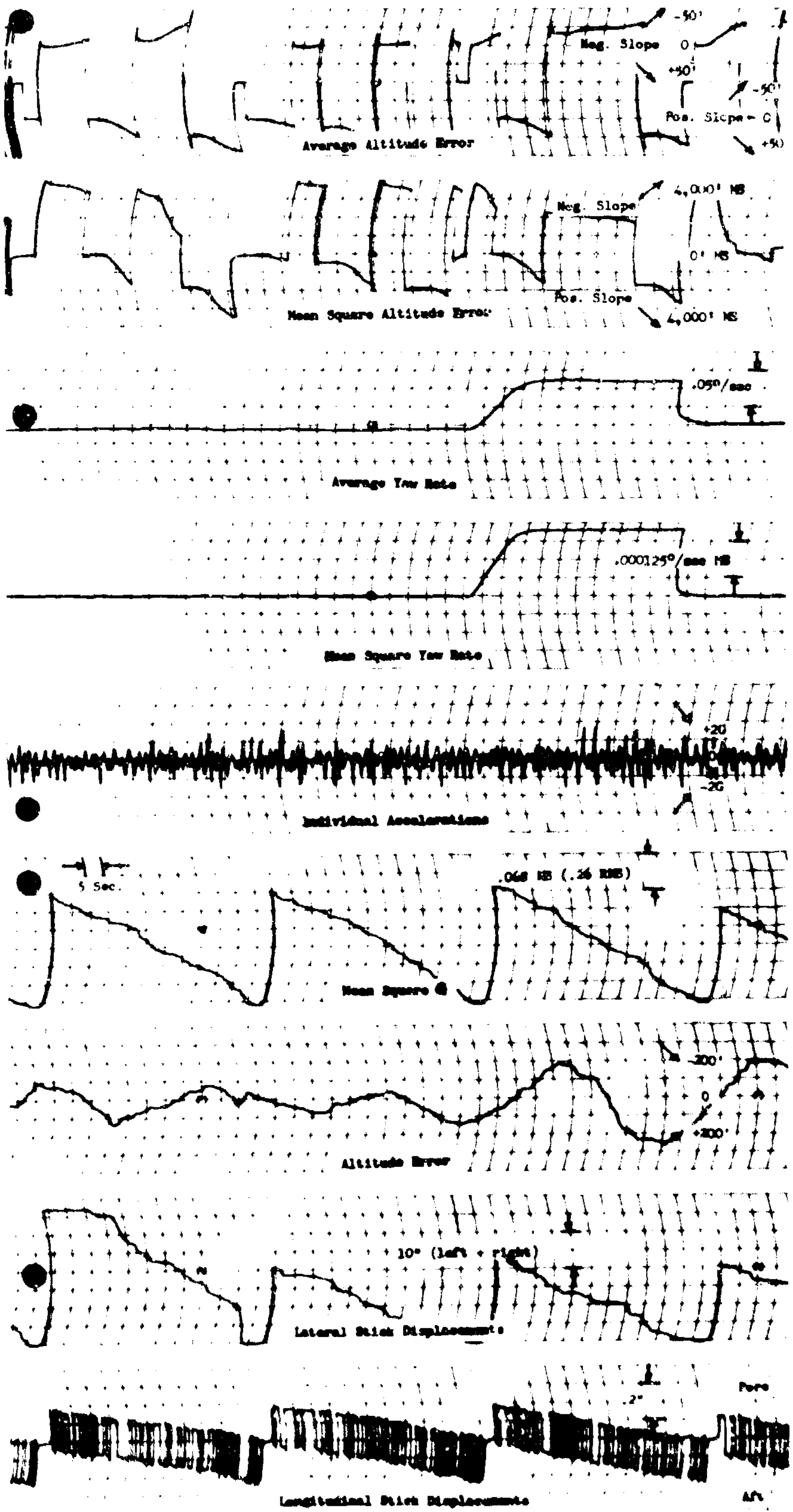


Figure 9. Performance Records

# APPENDIX III

## EXPERIMENTAL RESULTS

TABLE 3
SUMMARY OF VARIANCE: RMS G

| SOURCE | SS | df | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 27 | 2 | 13.5 | 1.14 |
| B (Terrain) | 42 | 2 | 21.0 | 1.77 |
| C (Em. Tasks) | 2 | 2 | 1.0 | |
| D (Turns) | 16 | 1 | 16.0 | 1.35 |
| AB | 110 | 4 | 27.5 | 2.33 |
| AC | 45 | 4 | 11.2 | |
| AD | 19 | 2 | 9.5 | |
| BC | 47 | 4 | 11.7 | |
| BD | 86 | 2 | 43.0 | 3.64* |
| CD | 34 | 2 | 17.0 | 1.44 |
| ABC | 49 | 8 | 6.1 | |
| ABD | 99 | 4 | 24.7 | 2.09 |
| ACD | 0 | 4 | 0.0 | |
| BCD | 9 | 4 | 2.2 | |
| ABCD | 62 | 8 | 7.7 | |
| Within | 1275 | 108 | 11.8 | |
| Total | 1922 | 161 | | |

*Significant at the .05 level.

TABLE 4
MEANS FOR THE LEVELS OF EACH VARIABLE

| VARIABLE | RMS G |
|---|---|
| Airspeed | |
| .4M | .396 |
| .7M | .404 |
| .9M | .396 |
| Terrain | |
| I | .396 |
| II | .391 |
| III | .403 |
| Tasks | |
| 6 | .397 |
| 12 | .400 |
| 24 | .399 |
| Turns | |
| 5 | .402 |
| 15 | .395 |

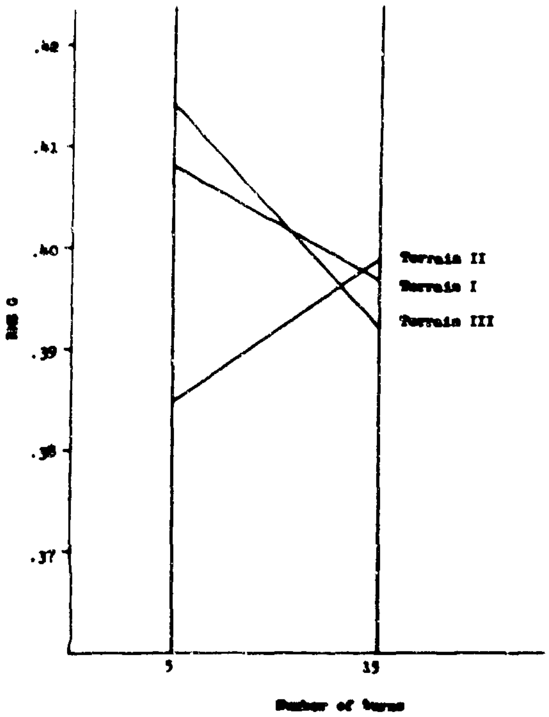


Figure 10. Terrain by Turns Interaction of RMS G

TABLE 5
SUMMARY OF VARIANCE: AVERAGE ALTITUDE ERROR

| SOURCE | SS | df | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 107.43 | 2 | 53.7 | 1.43 |
| B (Terrain) | 43.69 | 2 | 21.8 | |
| C (Em. Tasks) | 6.21 | 2 | 3.1 | |
| D (Turns) | 4.08 | 1 | 4.1 | |
| AB | 43.73 | 4 | 10.9 | |
| AC | 27.50 | 4 | 6.9 | |
| AD | 0.00 | 2 | 0.0 | |
| BC | 17.46 | 4 | 4.4 | |
| BD | 8.47 | 2 | 4.3 | |
| CD | 6.92 | 2 | 3.4 | |
| ABC | 26.88 | 8 | 3.4 | |
| ABD | 11.72 | 4 | 2.9 | |
| ACD | 3.81 | 4 | 1.0 | |
| BCD | 11.33 | 4 | 2.8 | |
| ABCD | 11.43 | 8 | 1.4 | |
| Within | 4018.54 | 108 | 37.2 | |
| Total | 4349.20 | 161 | | |

TABLE 6

AVERAGE ALTITUDE ERROR: MEANS FOR THE LEVELS OF EACH VARIABLE

| | ERROR, FEET |
|---|---|
| **Airspeed** | |
| .4M | 3.4 |
| .7M | 2.4 |
| .9M | 2.8 |
| **Terrain** | |
| I | 2.2 |
| II | 3.1 |
| III | 3.8 |
| **Tasks** | |
| 6 | 3.0 |
| 12 | 3.0 |
| 24 | 3.0 |
| **Turns** | |
| 5 | 3.0 |
| 15 | 3.0 |

TABLE 7

AVERAGE ALTITUDE ERROR AS A FUNCTION OF SLOPE

| | ERROR, FEET | | |
|---|---|---|---|
| | NEG. SLOPE | POS. SLOPE | AVERAGE |
| **Airspeed** | | | |
| .4M | -13.4 | 22.0 | 3.4 |
| .7M | -15.3 | 20.0 | 2.4 |
| .9M | -18.7 | 24.3 | 2.8 |
| **Terrain** | | | |
| I | -6.8 | 11.1 | 2.2 |
| II | -15.6 | 21.7 | 3.1 |
| III | -25.1 | 32.7 | 3.8 |

## TABLE 8
## AVERAGE ALTITUDE ERROR, AS A FUNCTION OF SLOPE
## SUMMARY OF VARIANCE

| SOURCE | SS | df | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 37 | 2 | 18.5 | 2.43 |
| B (Terrain) | 13 | 2 | 6.5 | |
| C (Slope) | 19,418 | 1 | 19,418.0 | 2,555.00 ** |
| AB | 17 | 4 | 4.3 | |
| AC | 174 | 2 | 87.0 | 11.44 ** |
| BC | 3,425 | 2 | 1,712.5 | 225.32 ** |
| ABC | 75 | 4 | 18.8 | 2.47 |
| Within | 274 | 36 | 7.6 | |
| Total | 23,433 | 53 | | |

Pos 22.1' 39.9% inc
neg -15.8'

** Significant beyond the .01 level

## TABLE 9
## DUNCAN'S MULTIPLE RANGE TEST
## FOR MAIN EFFECTS OF AVERAGE ALTITUDE ERROR
## ON POSITIVE AND NEGATIVE SLOPES

| | AIRSPEED* | | |
|---|---|---|---|
| | .4M | .7M | .9M |
| Negative Slopes | -13.4' | -15.3' | -18.7' |
| Positive Slopes | 22.0' | 20.0' | 24.3' |
| | **TERRAIN**** | | |
| | I | II | III |
| Negative Slopes | -6.8 | -15.6 | -25.1 |
| Positive Slopes | 11.1 | 21.7 | 32.7 |

* Underlined means are not significantly different. Means not underlined are significant at the .05 level.

** All mean differences are significant at the .001 level.

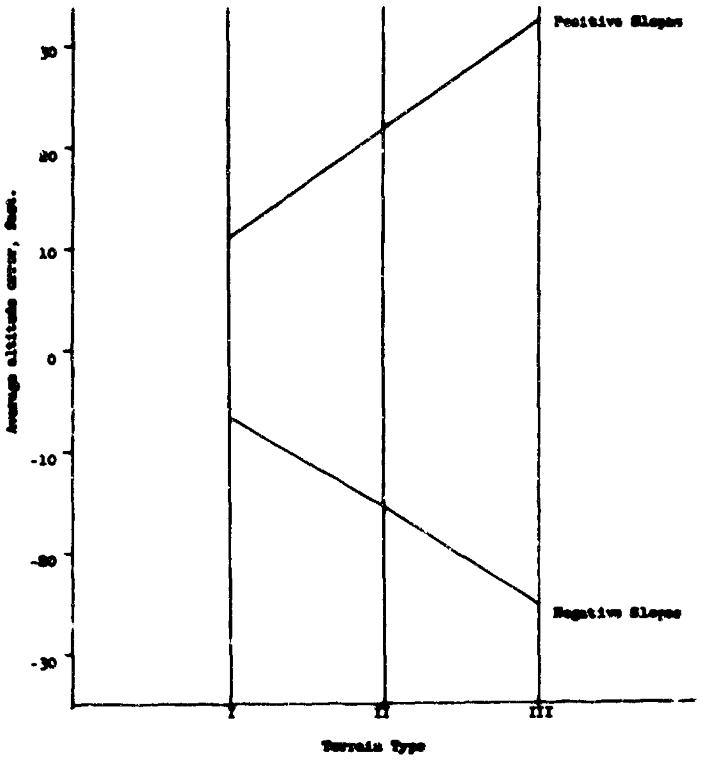


Figure 11. Terrain by Slope Interaction of Average Altitude Error

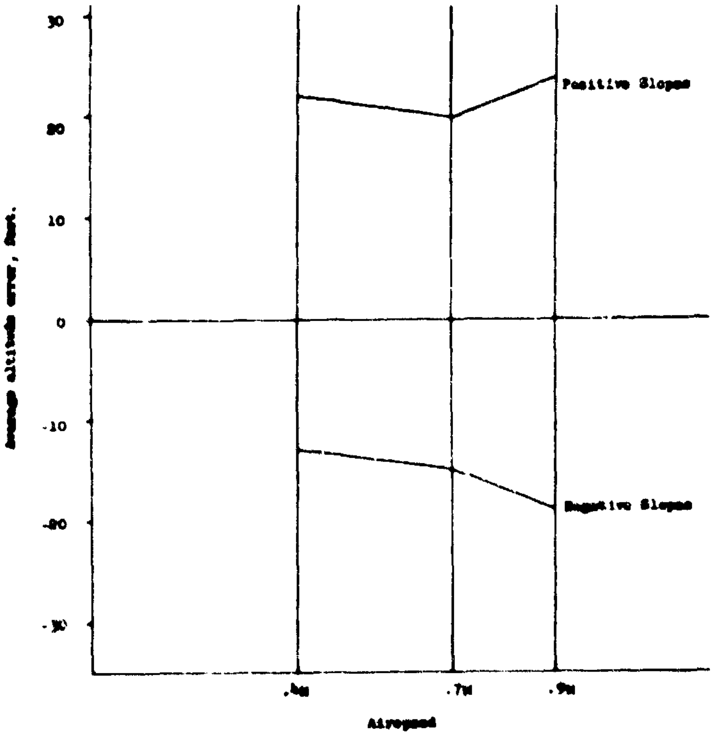


Figure 12. Airspeed by Slope Interaction of Average Altitude Error

## TABLE 10
## SUMMARY OF VARIANCE: $\sigma$ ALTITUDE ERROR

| SOURCE | SS | $d_f$ | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 5,088.3 | 2 | 2,544.2 | 35.68 ** |
| B (Terrain) | 44,601.6 | 2 | 22,300.8 | 312.77 ** |
| C (Em. Tasks) | 157.7 | 2 | 78.9 | |
| D (Turns) | 0 | 1 | 0 | - |
| AB | 1,048.8 | 4 | 262.2 | 3.68 ** |
| AC | 46.3 | 4 | 11.6 | |
| AD | 45.8 | 2 | 22.9 | |
| BC | 63.1 | 4 | 15.8 | |
| BD | 49.0 | 2 | 24.5 | |
| CD | 82.0 | 2 | 41.0 | |
| ABC | 132.5 | 8 | 16.6 | |
| ABD | 60.7 | 4 | 15.2 | |
| ACD | 9.5 | 4 | 2.4 | |
| BCD | 158.0 | 4 | 39.5 | |
| ABCD | 299.1 | 8 | 37.4 | |
| Within | 7,697.6 | 108 | 71.3 | |
| Total | 59,540.0 | 161 | | |

** Significant at the .01 level.

## TABLE 11
## DUNCAN'S MULTIPLE RANGE TEST APPLIED TO MAIN EFFECTS OF $\sigma$ ALTITUDE ERROR

| | | | |
|---|---|---|---|
| Airspeed | .4(43.2') | .7(43.6') | .9(55.3') |
| Terrain | I(27.6') | II(46.3') | III(68.3') |
| Em. Tasks | 6(46.5') | 12(47.0') | 24(48.8') |
| Turns | 5(47.4') | 15(47.4') | |

* Any two treatment means not underscored by the same line are significantly different (at the .001 level). Any two treatment means underscored by the same line are not significantly different.

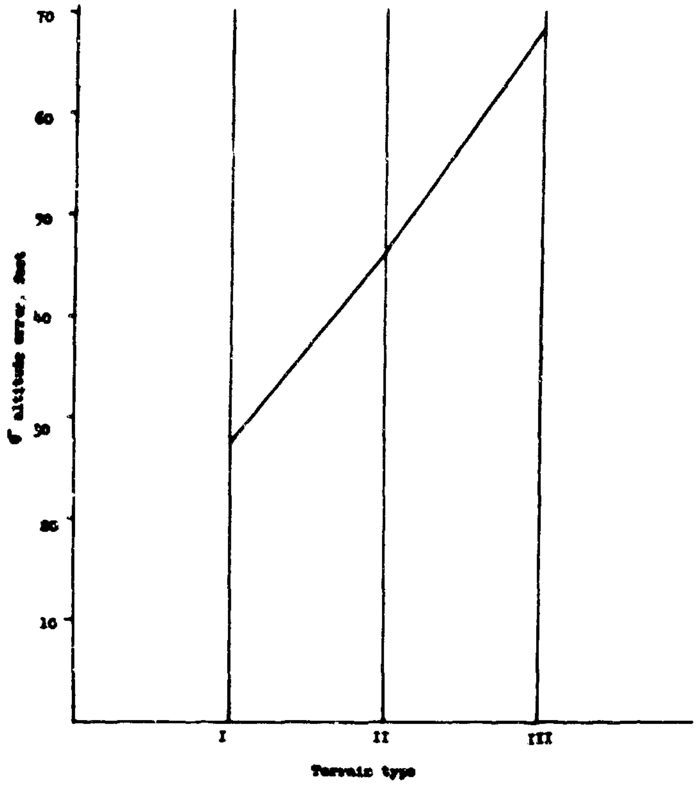


Figure 13. $\sigma$ Altitude Error as a Function of Terrain Type

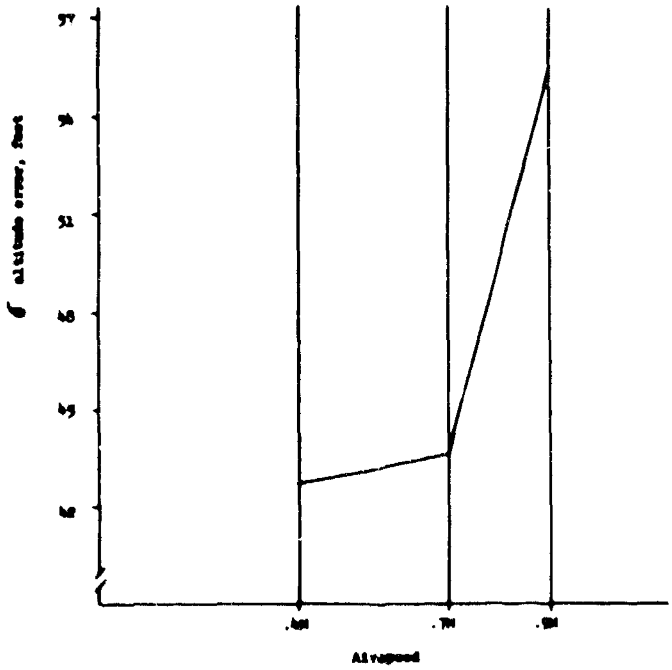


Figure 14. $\sigma$ Altitude Error as a Function of Airspeed

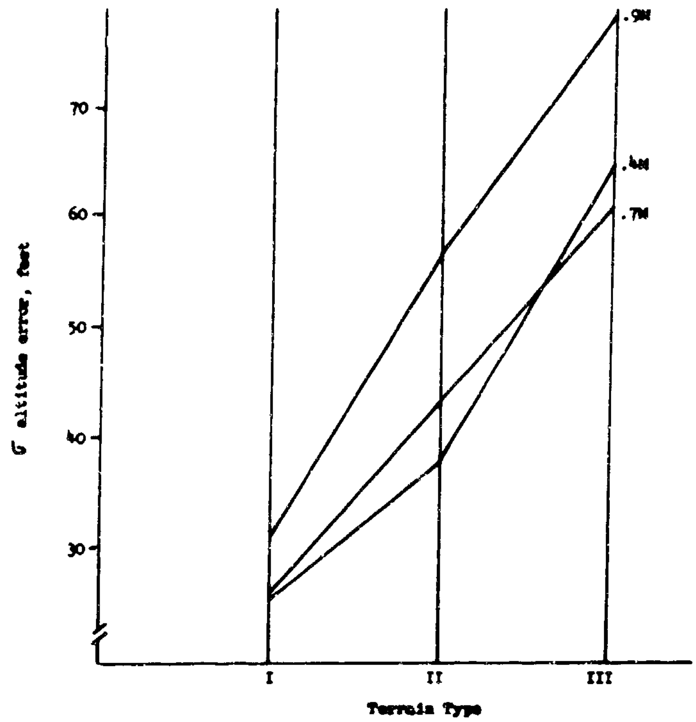


Figure 15. Terrain by Airspeed Interaction of $\sigma$ Altitude Error

TABLE 12
$\sigma$ ALTITUDE ERROR AS A FUNCTION OF TERRAIN SLOPE

| | ERROR, FEET | |
|---|---|---|
| | NEG. SLOPE | POS. SLOPE |
| AIRSPEED | | |
| .4M | 40.9 | 37.4 |
| .7M | 42.3 | 37.3 |
| .9M | 53.1 | 48.6 |
| TERRAIN | | |
| I | 28.1 | 23.7 |
| II | 44.6 | 40.1 |
| III | 63.7 | 59.6 |

## TABLE 13
## SUMMARY OF VARIANCE:
## σ ALTITUDE ERROR WITH SLOPE AS A VARIABLE

| SOURCE | SS | $d_f$ | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 1,547 | 2 | 773.5 | 14.27 ** |
| B (Terrain) | 11,509 | 2 | 5,754.5 | 106.17 ** |
| C (Slope) | 253 | 1 | 253.0 | 4.67 * |
| AB | 312 | 4 | 78.0 | 1.44 |
| AC | 5 | 2 | 2.5 | |
| BD | 1 | 2 | .5 | |
| ABC | 2 | 4 | .5 | |
| Within | 1,952 | 36 | 54.2 | |
| Total | 15,581 | 53 | | |

* Significant at the .05 level.

** Significant at the .01 level.

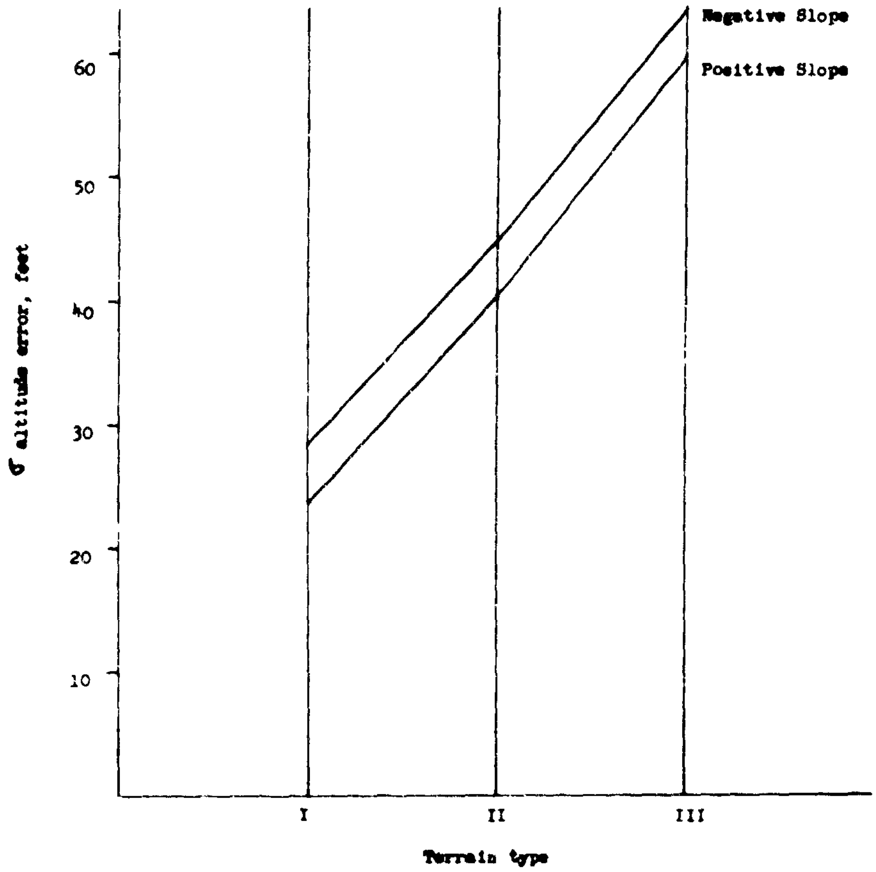


Figure 16. σ Altitude Error as a Function of Terrain Type and Slope

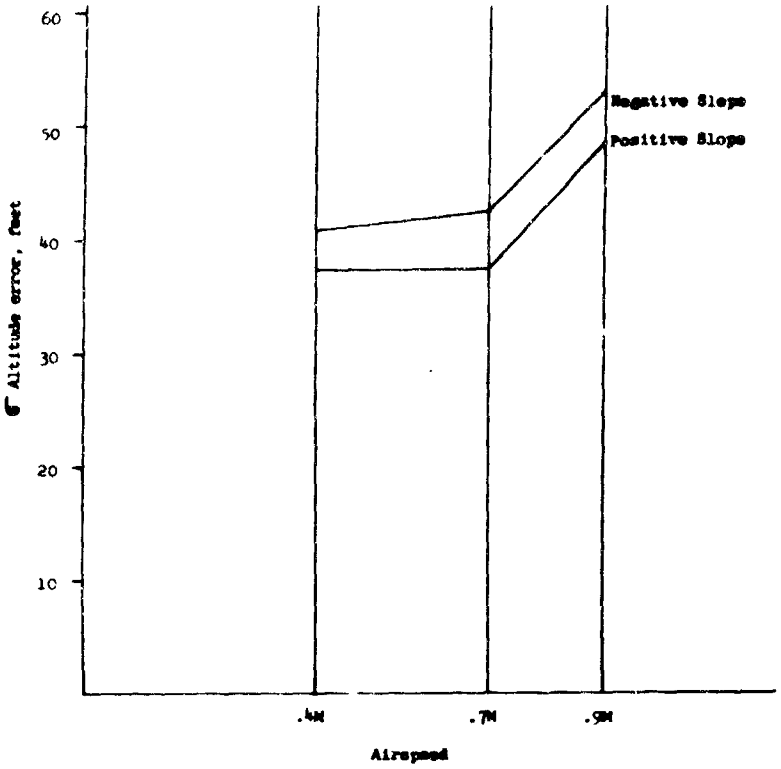


Figure 17. σ Altitude Error as a Function of Airspeed and Terrain Slope

### TABLE 14
### MEAN DIFFERENCE TESTS ON DIFFERENT SLOPES AND TYPES OF TERRAIN*

| Error Means | 23.7' | 28.1' | 40.1' | 44.6' | 59.6' | 63.7' |
|---|---|---|---|---|---|---|
| Condition | IP | IN | IIP | IIN | IIIP | IIIN |

* P = positive slopes; N = negative slopes. Any two treatment means not underscored by the same line are significant at the .001 level. Any two treatment means underscored by the same line are not significant at any level.

## TABLE 15

## MEAN DIFFERENCE TESTS ON DIFFERENT SLOPES AND AIRSPEEDS*

| Error Means | 37.3' | 37.4' | 40.9' | 42.3' | 48.6' | 53.1' |
|---|---|---|---|---|---|---|
| Condition | .7P | .4P | .4N | .7N | .9P | .9N |

---

* P = positive slopes; N = negative slopes. Any two treatment means not underscored by the same line are significant at the .05 level. Any two treatment means underscored by the same line are not significantly different.

## TABLE 16

## YAW RATE: MEANS FOR THE LEVELS OF EACH EXPERIMENTAL VARIABLE

| VARIABLE | RATE (DEGREES PER SECOND) |
|---|---|
| AIRSPEED | |
| .4M | 2.50 |
| .7M | 2.52 |
| .9M | 2.54 |
| TERRAIN | |
| I | 2.48 |
| II | 2.55 |
| III | 2.52 |
| EM. TASKS | |
| 6 | 2.52 |
| 12 | 2.54 |
| 24 | 2.50 |
| TURNS | |
| 5 | 2.54 |
| 15 | 2.50 |

## TABLE 17

## SUMMARY OF VARIANCE: YAW RATE

| SOURCE | SS | $d_f$ | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 0.2 | 2 | 0.10 | |
| B (Terrain) | 0.3 | 2 | 0.15 | 1.36 |
| C (Em. Tasks) | 0.2 | 2 | 0.10 | |
| D (Turns) | 0.1 | 1 | 0.10 | |
| AB | 0.3 | 4 | 0.08 | |
| AC | 0.4 | 4 | 0.10 | |
| AD | 0.1 | 2 | 0.05 | |
| BC | 0.3 | 4 | 0.08 | |
| BD | 0.1 | 2 | 0.05 | |
| CD | 0.3 | 2 | 0.15 | 1.36 |
| ABC | 0.5 | 8 | 0.06 | |
| ABD | 0.3 | 4 | 0.08 | |
| ACD | 0.1 | 4 | 0.03 | |
| BCD | 0.4 | 4 | 0.10 | |
| ABCD | 1.6 | 8 | 0.20 | 1.82 |
| Within | 12.1 | 108 | 0.11 | |
| Total | 17.3 | 161 | | |

## TABLE 18

## REACTION TIME TO MASTER WARNING LIGHT: MEANS FOR LEVELS OF EACH EXPERIMENTAL VARIABLE

| VARIABLE | TIME, SECONDS |
|---|---|
| AIRSPEED | |
| .4M | .91 |
| .7M | .92 |
| .9M | .92 |
| TERRAIN | |
| I | .93 |
| II | .94 |
| III | .89 |
| EM. TASKS | |
| 6 | .88 |
| 12 | .94 |
| 24 | .94 |
| TURNS | |
| 5 | .94 |
| 15 | .90 |

TABLE 19
SUMMARY OF VARIANCE:
REACTION TIME TO MASTER WARNING LIGHT

| SOURCE | SS | df | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 2 | 2 | 1.0 | |
| B (Terrain) | 20 | 2 | 10.0 | 1.25 |
| C (Em. Tasks) | 26 | 2 | 13.0 | 1.63 |
| D (Turns) | 14 | 1 | 14.0 | 1.75 |
| AB | 29 | 4 | 7.3 | |
| AC | 18 | 4 | 4.5 | |
| AD | 59 | 2 | 29.5 | 3.69 * |
| BC | 24 | 4 | 6.0 | |
| BD | 10 | 2 | 5.0 | |
| CD | 52 | 2 | 26.0 | 3.25 * |
| ABC | 37 | 8 | 4.6 | |
| ABD | 20 | 4 | 5.0 | |
| ACD | 14 | 4 | 3.5 | |
| BCD | 2 | 4 | .5 | |
| ABCD | 36 | 8 | 4.0 | |
| Within | 869 | 108 | 8.0 | |
| Total | 1232 | 161 | | |

*P = .05

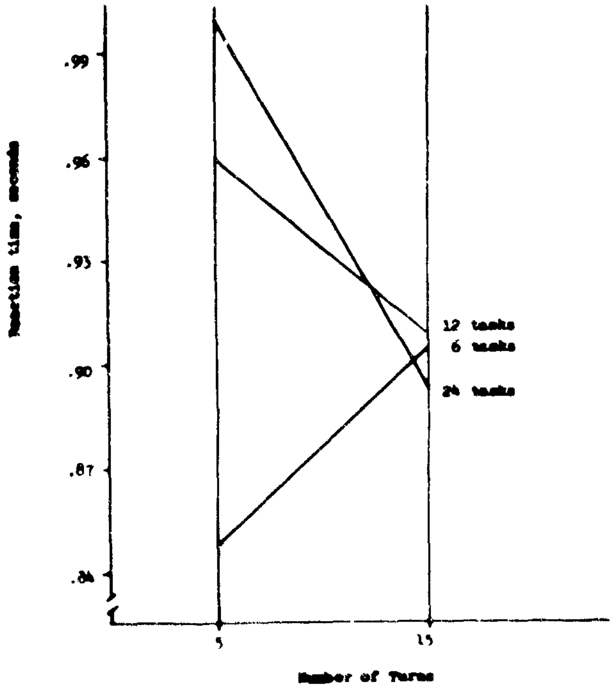


Figure 18. Emergency Task by Turn Interaction of Reaction Time to Master Warning Light

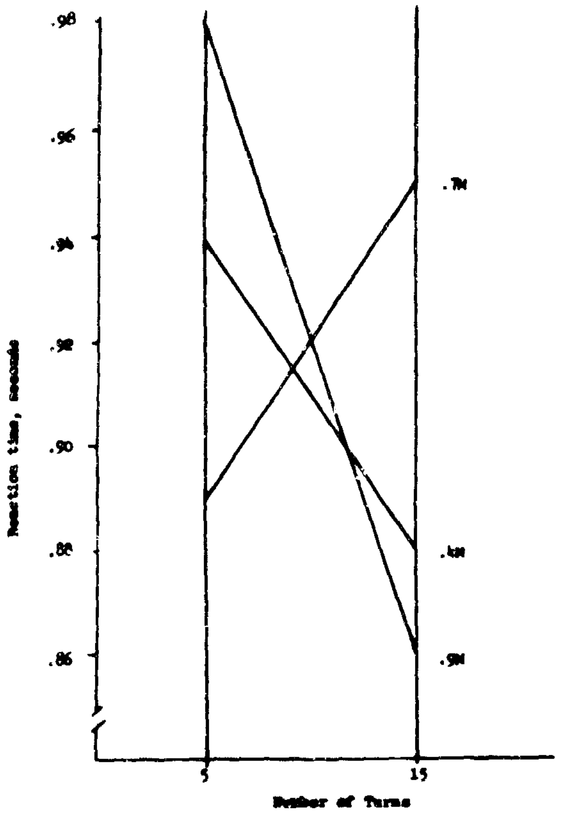


Figure 19. Airspeed by Turns Interaction of Reaction Time to Master Warning Light

TABLE 20
EMERGENCY TASK PERFORMANCE TIME:
MEANS FOR LEVELS OF EACH EXPERIMENTAL VARIABLE

| VARIABLE | TIME, SECONDS |
|---|---|
| AIRSPEED | |
| .4 M | 1.49 |
| .7 M | 1.49 |
| .9 M | 1.41 |
| TERRAIN | |
| I | 1.48 |
| II | 1.45 |
| III | 1.46 |
| EM. TASKS | |
| 6 | 1.48 |
| 12 | 1.66 |
| 24 | 1.25 |
| TURNS | |
| 5 | 1.49 |
| 15 | 1.43 |

## TABLE 21
## SUMMARY OF VARIANCE: EMERGENCY TASK PERFORMANCE TIME

| SOURCE | SS | $d_f$ | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 72 | 2 | 36.0 | |
| B (Terrain) | 6 | 2 | 3.0 | |
| C (Em. Tasks) | 8 | 2 | 4.0 | |
| D (Turns) | 42 | 1 | 42.0 | |
| AB | 78 | 4 | 19.5 | |
| AC | 144 | 4 | 36.0 | |
| AD | 180 | 2 | 90.0 | 1.62 |
| BC | 64 | 4 | 16.0 | |
| BD | 92 | 2 | 46.0 | |
| CD | 305 | 2 | 152.5 | 2.74 |
| ABC | 700 | 8 | 87.5 | 1.57 |
| ABD | 124 | 4 | 31.0 | |
| ACD | 89 | 4 | 22.3 | |
| BCD | 68 | 4 | 17.0 | |
| ABCD | 328 | 8 | 41.0 | |
| Within | 5999 | 108 | 55.5 | |
| Total | 8299 | 161 | | |

## TABLE 22
## FUEL COMPUTATION: MEAN TIME AT THE LEVELS OF EACH EXPERIMENTAL VARIABLE

| VARIABLE | TIME, SECONDS |
|---|---|
| AIRSPEED | |
| .4M | 11.0 |
| .7M | 15.5 |
| .9M | 10.3 |
| TERRAIN | |
| I | 12.3 |
| II | 12.8 |
| III | 11.8 |
| EM. TASKS | |
| 6 | 12.3 |
| 12 | 12.2 |
| 24 | 12.4 |
| TURNS | |
| 5 | 11.6 |
| 15 | 12.9 |

TABLE 23
SUMMARY OF VARIANCE:
FUEL COMPUTATION TIME

| SOURCE | SS | df | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 810 | 2 | 405.0 | 9.22 ** |
| B (Terrain) | 33 | 2 | 16.5 | |
| C (Em. Tasks) | 3 | 2 | 1.5 | |
| D (Turns) | 53 | 1 | 53.0 | 1.20 |
| AB | 293 | 4 | 73.3 | 1.66 |
| AC | 211 | 4 | 52.8 | 1.20 |
| AD | 150 | 2 | 75.0 | 1.70 |
| BC | 92 | 4 | 23.0 | |
| BD | 257 | 2 | 128.5 | 2.92 |
| CD | 94 | 2 | 47.0 | 1.07 |
| ABC | 234 | 8 | 29.3 | |
| ABD | 330 | 4 | 82.5 | 1.87 |
| ACD | 74 | 4 | 18.5 | |
| BCD | 183 | 4 | 45.8 | 1.04 |
| ABCD | 320 | 8 | 40.0 | |
| Within | 4736 | 108 | 43.9 | |
| Total | 7873 | 161 | | |

**Significant at the .01 level of confidence.

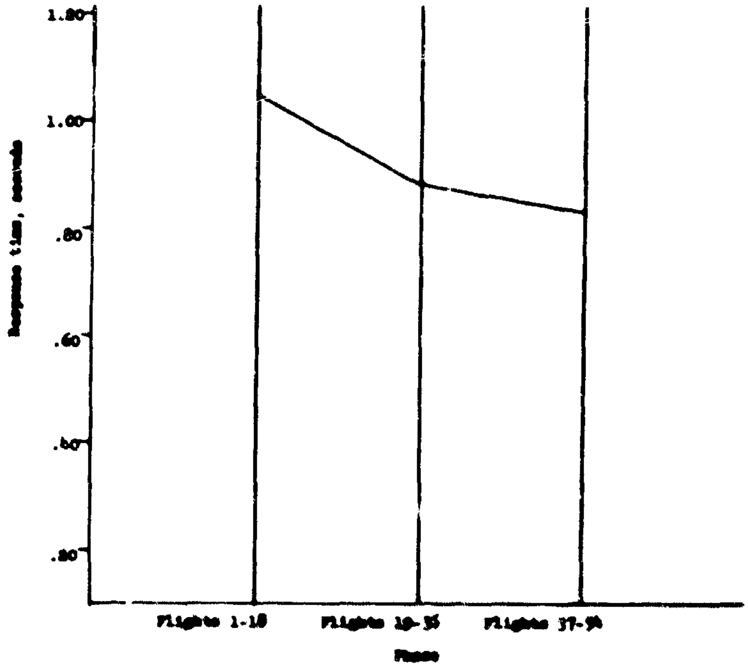


Figure 20. Response to the Master Warning Light at the Three Phases of the Experiment

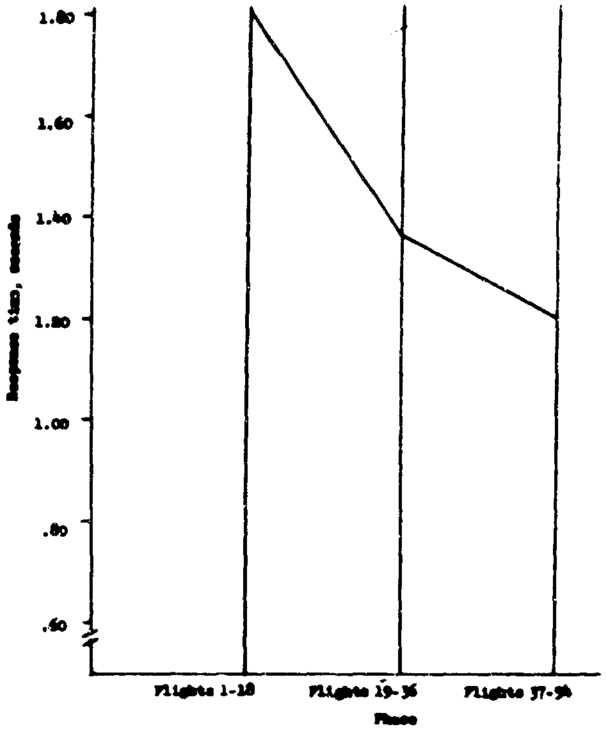


Figure 21. Response Time to Perform Emergency Tasks at the Three Phases of the Experiment

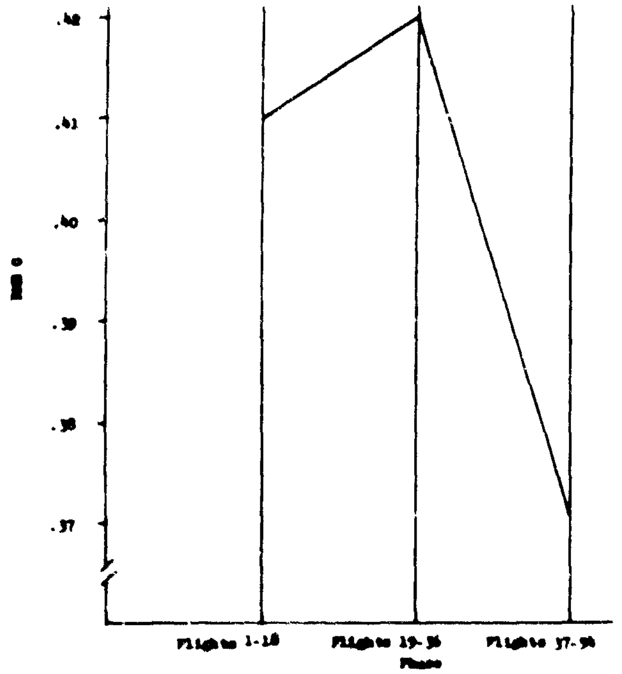


Figure 22. RMS G at the Three Phases of the Experiment

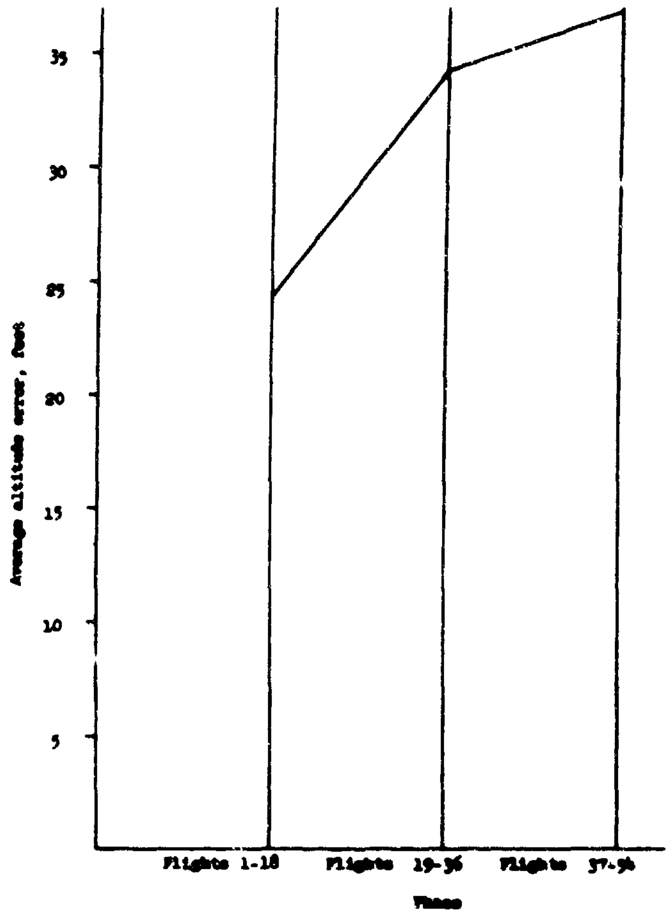


Figure 23. Average Altitude Error at the Three Phases of the Experiment

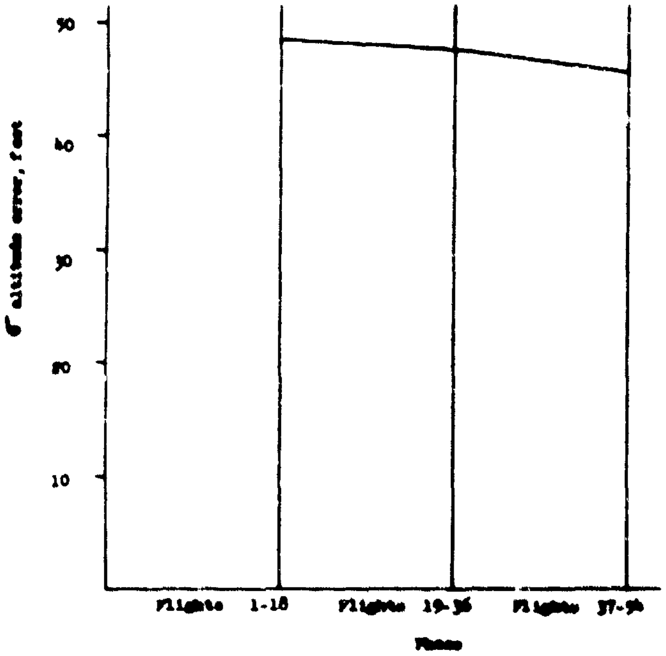


Figure 24. σ Altitude Error at the Three Phases of the Experiment

## TABLE 24
## CONTROL RUN AVERAGE ALTITUDE ERROR: MEANS FOR THE LEVELS OF EACH EXPERIMENTAL VARIABLE

| VARIABLE | ERROR, FEET |
|---|---|
| AIRSPEED | |
| .4M | 12.7 |
| .9M | 14.3 |
| TERRAIN | |
| I | 12.9 |
| II | 15.1 |
| III | 12.4 |
| INTERVAL | |
| 0 sec. | 12.6 |
| 2.5 sec. | 14.5 |
| 5 sec. | 13.3 |

## TABLE 25
## SUMMARY OF VARIANCE: CONTROL RUN AVERAGE ALTITUDE ERROR

| SOURCE | SS | df | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 34 | 1 | 34.0 | |
| B (Terrain) | 70 | 2 | 35.0 | |
| C (Interval) | 33 | 2 | 16.5 | |
| AB | 675 | 2 | 338.5 | 3.23 |
| AC | 114 | 2 | 57.0 | |
| BC | 153 | 4 | 38.3 | |
| ABC | 1321 | 4 | 330.3 | 3.16 |
| Within | 3761 | 36 | 104.5 | |
| Total | 6161 | 53 | | |

## TABLE 26

## CONTROL RUN 6 ALTITUDE ERROR:
## MEANS FOR THE LEVELS OF EACH EXPERIMENTAL VARIABLE

| VARIABLE | ERROR, FEET |
|---|---|
| **AIRSPEED** | |
| .4 M | 63.7 |
| .9 M | 86.0 |
| **TERRAIN** | |
| I | 51.5 |
| II | 72.4 |
| III | 100.7 |
| **INTERVAL** | |
| 0 sec. | 59.6 |
| 2.5 sec. | 74.5 |
| 5 sec. | 90.6 |

## TABLE 27

## SUMMARY OF VARIANCE: CONTROL RUN 6 ALTITUDE ERROR

| SOURCE | SS | df | MS | F |
|---|---|---|---|---|
| A (Airspeed) | 6711 | 1 | 6711.0 | 25.90 ** |
| B (Terrain) | 21967 | 2 | 10984.0 | 42.39 ** |
| C (Interval) | 8685 | 2 | 4342.5 | 16.75 ** |
| AB | 95 | 2 | 47.5 | |
| AC | 68 | 2 | 34.0 | |
| BC | 732 | 4 | 183.0 | |
| ABC | 313 | 4 | 78.3 | |
| Within | 9326 | 36 | 259.1 | |
| Total | 47897 | | | |

**Significant at the .01 level.

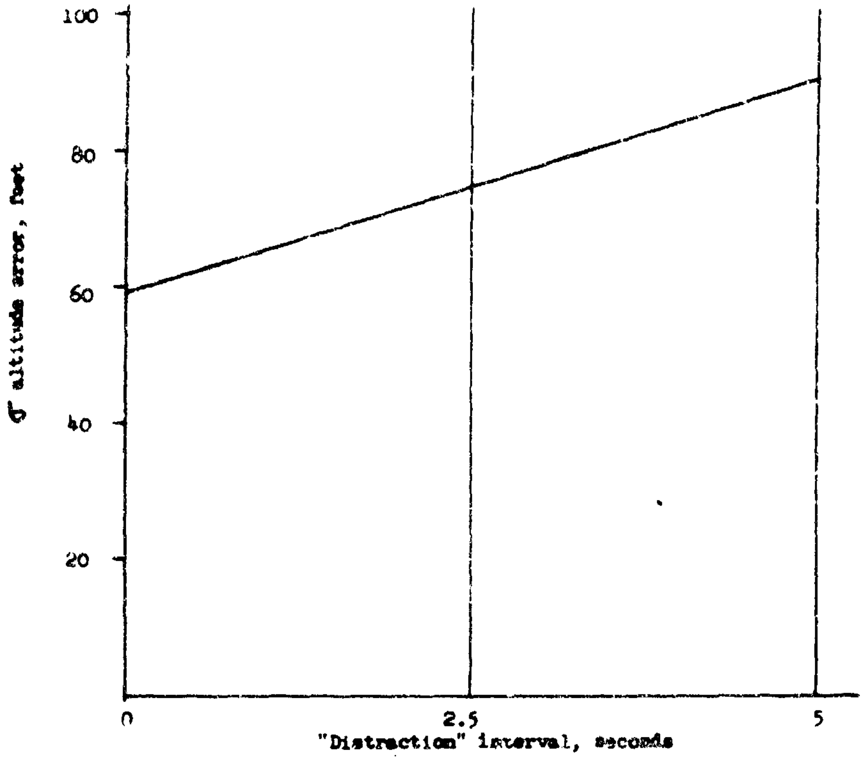


Figure 25. σ Altitude Error as a Function of "Distraction" Interval

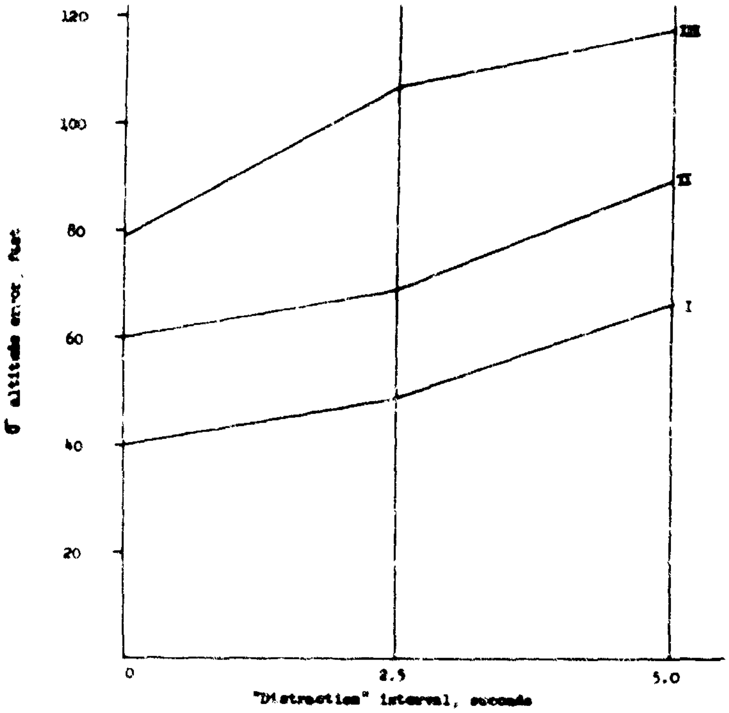


Figure 26. σ Altitude Error by Terrain Type as a Function of "Distraction" Interval

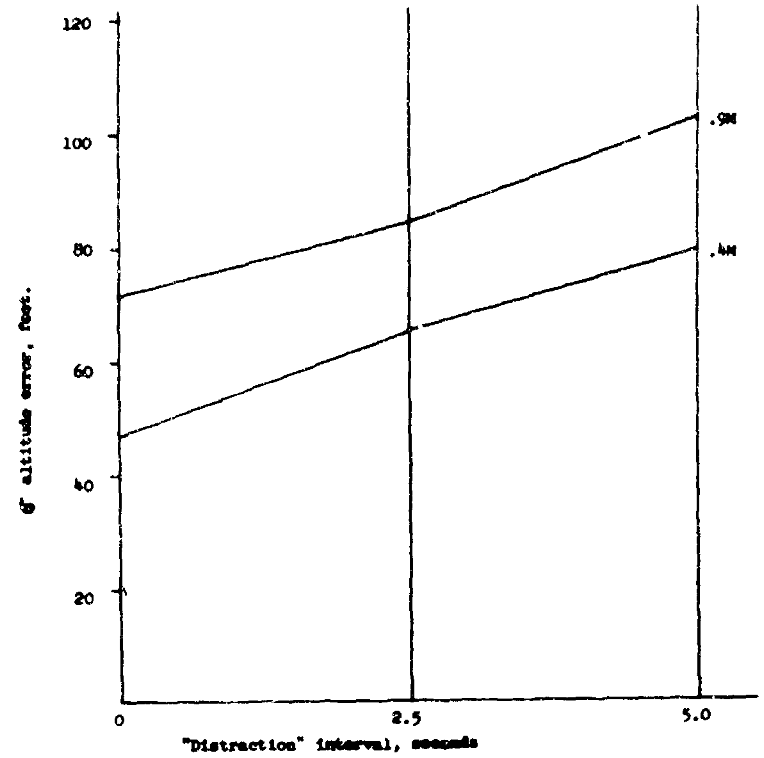


Figure 27. σ Altitude Error by Airspeed as a Function of "Distraction" Interval

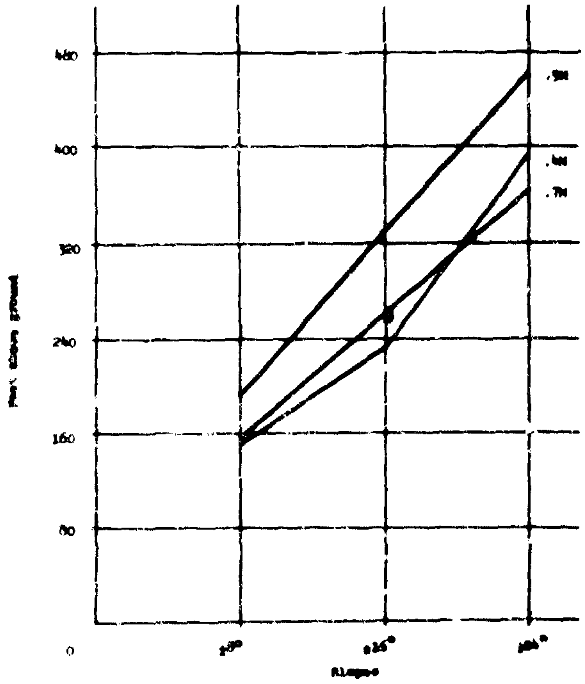


Figure 28. Minimum Safe Altitude at Different Terrain Slopes and Airspeeds

# APPENDIX IV

## PILOTS' COMMENTS

A program critique was held after the experiment was completed. It was primarily a question and answer session to obtain the views, opinions, suggestions, etc., of the USATRECOM Project Engineer, and all NAA employees directly concerned with the study. A summary of the pilots' thoughts as expressed in the meeting is presented below.

### LEARNING

The consensus of pilot opinion was that learning continued throughout the study, both with respect to flying the simulated aircraft and to adapting body posture to the acceleration environment.

### TASK DIFFICULTY

The pilots did not feel "overloaded" or overburdened with tasks in any of the experimental conditions. They did not feel that performance of emergency procedures affected altitude holding. Two of them stated that complex emergencies requiring several simultaneous decisions might affect altitude holding, and suggested a study of decision-making processes in LAHS flight.

### GUST INTENSITY

All pilots agreed that the gust intensity used in the study could be described as moderate to severe. The accelerations caused them to err occasionally when making emergency corrections.

### FLYING TECHNIQUE

Different proportions of time were spent on different flight control instruments (CRT, AAI, radar altimeter, rate-of-climb indicator) by the different pilots. For example, one used the radar altimeter only occasionally to cross check the accuracy of the CRT command signal, while another used the radar altimeter constantly as an altitude reference. (In spite of these differences, performance variability among the subjects was very small compared to that observed in other studies, e.g., ref. 9 and 10).

## PILOT REACTIONS

The experimental flights were unexciting, even boring much of the time. Interest increased when there were more things to be done during the missions, e.g. when there were more heading changes to be made.

## RESTRAINT SYSTEM

A more efficient restraint system than the Navy integrated torso harness and lap belt were thought to be desirable for LAHS flight.

## FATIGUE

The pilots felt that the 1-hour flights did not produce fatigue and that two flights per day were satisfactory.

## SIMULATOR TRAINING

It was unanimously agreed that G-seat training would help prepare the pilot for both operational terrain-following and adaptation to the LAHS acceleration environment.

## INSTRUMENTS AND THEIR ARRANGEMENT

Five-inch instruments were recommended instead of the 3-inch ones used, with the stipulation that the numbers be large enough to be read. Color coding of instruments was suggested. The possibility of using a larger CRT and displaying integrated information such as heading, pitch, roll, etc. in addition to terrain-following information was suggested. Cockpit layout studies were also suggested.

## CONTROLS

It was felt that side-arm control could be very effective in LAHS terrain-following (this has been shown to be true in the ref. 10 study).

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4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
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5 AUTHOR(S) *(Last name, first name, initial)*
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13 ABSTRACT

The effects of task loading on pilot performance during simulated low-altitude, high-speed flight were studied. Approximately 210 hours of flight were made by experienced pilots in a moving-base simulator that had a total vertical travel of 12 feet and an acceleration capability of ± 6G. Ghe flights were made over several types of terrain at several airspeeds under different conditions of navigation task and emergency task loading. Medium-heavy turbulence waw simulated for all flights. Data were analyzed in terms of human performance aspects of the missions.

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