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FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 63-52

FLIGHT SIMULATOR STUDY OF HUMAN PERFORMANCE DURING LOW-ALTITUDE, HIGH-SPEED FLIGHT

Project 1D131201D159
(Formerly Task 9R38-10-005-04)
Contract DA 44-177-TC-803

November 1963

prepared by:

NORTH AMERICAN AVIATION, INC.
Columbus, Ohio

HEADQUARTERS
U S ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

This report has been reviewed by the U. S. Army Transportation Research Command and is considered to be technically sound. The report is published for the exchange of information and stimulation of ideas.

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PREFACE

This study is part of a continuing 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, Fort Eustis, Virginia, under Contract DA-44-177-TC-803, with Messrs. Martin Copp and Robert Brugh serving as TRECOM Project Engineers.

The study was conducted by the Behavioral Sciences Group, Life Sciences Section of North American Aviation, Inc., Columbus, Ohio, under the technical direction of Dr. Harve E. Rawson, Principal Investigator.

Acknowledgement and appreciation is hereby extended to the following Army personnel who served most cooperatively as subjects in the experimental phases of the study:

> Majors D. King, J. A. Barrett, W. E. Crouch, Jr., and L. F. Jackson; Captain S. Wroten, and CWO B. W. Hutchinson of the U.S. Army Aviation Board, Fort Rucker, Alabama; Major J. Cranford, Army Liaison Officer, Wright-Patterson Air Force Base, Wright Field, Ohio; Captains B. W. Addy and B. Mixter, and First Lieutenants E. S. Rebhotz and D. Farris of the Aviation Division, Fort Eustis, Virginia.

Appreciation and acknowledgement is also extended to Dr. Robert Wright, Army Aviation Human Research Unit, Fort Rucker, Alabama, for his valuable advice and for loan of visual stimulus materials.

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LIST OF SYMBOLS

Symbol		Unit
A	time constant in load factor due to gust transfer function	seconds
f_n	undamped natural frequency of airplane	cycles per second
F_s	control stick force	pounds
g	acceleration of gravity	32.2 feet per second^2
h	altitude	feet
h_e	altitude error	feet
h_t	terrain altitude	feet
K_{ϵ}/w_g	gain of pitch to gust velocity equation	1/foot per second
$K_1 K_2$	yaw to lateral stick gain	
$K_{n_z/\delta}$	gain of load factor to control equation	1/inch
$K_{q/\delta}$	gain of pitch to control equation	inch/second
M_n	Mach number	
M_q	pitch damping dimensional derivative	1/second
M_δ	pitch control dimensional derivative	1/second^2
ΔN_i	incremental load factor	
$\sigma_{\Delta N_i}$	root-mean-square load factor	
σ_{w_q}	root-mean-square vertical gust velocity	feet per second

LIST OF SYMBOLS (Continued)

Symbol		Unit
δ/g	control stick deflection per g	inches/g
δ	control stick deflection	inches
$\sigma^2 w_g$	mean square vertical gust velocity	feet^2/second^2
R/C	rate of climb	feet/minute
RMS	root mean square	
σh_e	RMS altitude error	feet
$\sigma n_{z_{gust}}$	RMS gust load factor	
ζ	damping ratio	
$\Phi(w)/\sigma^2_{w_g}$	normalized power spectral density of vertical gust velocity	1/radian/second
$\sigma n_z/\sigma w_g$	gust sensitivity factor	g/foot/second
W	frequency	radians/second
W_g	vertical gust velocity	feet per second
W_n	undamped natural frequency of airplane	radians/second
W_{n_d}	lateral-directional undamped natural frequency	radians/second
U	forward velocity	feet/second
Z'_α	lift curves slope dimensional derivative	1/second
G	multiple of normal force of gravity	nondimensional
d_f	degrees of freedom	
ss	sum of squares	

LIST OF SYMBOLS (Continued)

Symbol		Unit
ms	mean squares	
F	F-ratio	

SUMMARY

Responses of experienced pilots and aerial observers were studied in simulated low-altitude, high-speed (LAHS) flight. Tests were made in a dynamic flight simulator that consisted of a moving cockpit having a total travel of approximately 12 feet and an acceleration capability of $\pm$ 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.

Pilots' tasks consisted of terrain-tracking over a variable terrain using an altitude command display, out-of-cockpit target identification, ECM monitoring, and in-cockpit electronic sensor monitoring. Vertical accelerations were produced by a summation of cockpit movements due to simulated gusts and to movements of the control stick. The observers performed their tasks while experiencing acceleration time-histories recorded from the pilots' flights. Their tasks consisted of out-of-cockpit surveillance, ECM monitoring. fuel consumption computations, navigation, and in-cockpit electronic sensor monitoring.

All but two of the pilots and all of the observers flew approximately seven 3-hour missions following briefing and practice runs. In addition, a few endurance runs were made in which pilots and observers were asked to fly up to three hours under severe turbulence conditions.

Results indicated that pilots could follow satisfactorily a contoured terrain at only 500 feet altitude at the lower airspeed of 0.4 Mach, despite gust intensity. Terrain-following at 0.9 Mach resulted in large error margins and numerous crashes.

The intensity of vertical-gust-acceleration time-histories imposed on the pilots did not seem to affect their flying ability except at the most severe levels.

The pilots had considerable difficulty in performing adequately any tasks in addition to terrain-following.

Observers performed their surveillance tasks approximately 25 percent better than pilots. Observers could not perform navigational tasks, using manual computers and plotters, at the higher turbulence levels.

Human adaptation to heavy turbulence seems to be very high. This

consists of the reduction of fear, learning "tricks of the trade" in dial reading and restraint system adjustment, and muscular adaptations. Consequently, marked learning effects occurred under LAHS flight conditions.

Pilots can tolerate three hours of continuous heavy buffeting, but the risk of incurring severe, incapacitating fatigue is quite high.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of data gathered during both the pilot and observer studies, conclusions and recommendations can be categorized and discussed as follows:

OPERATOR PERFORMANCE

Terrain-following under LAHS conditions is a full-time job. Performance on this task is satisfactory at 0.4 Mach, but falls off at the higher airspeed of 0.9 Mach. More specifically, at 0.9 Mach, the pilots incurred a large number of "missile kills" and crashes, and the altitude error records indicate a marginal degree of aircraft control at high-turbulence levels. Based on the results of this study, it is recommended that LAHS flights at 0.9 Mach or higher be considered only under conditions of rather mild turbulence. Higher speeds or flights in heavy turbulence should be considered only if gust alleviation devices can reduce significantly total G-loadings.

Since the pilot is fully occupied with terrain-following, two operators are essential to conduct this type of mission satisfactorily. The pilot should be assigned the tasks of terrain-following and aircraft operation only. Results indicated that any additional tasks tended to degrade his performance in these essential operations. The observer should handle all other tasks such as navigation, in-cockpit electronic sensor surveillance, out-of-cockpit visual surveillance, and ECM monitoring and jamming operations. Results obtained in this study supported this allocation of tasks. The pilot can perform pilotage tasks quite well except at high turbulence levels during subsonic speeds. Under these latter conditions, missions should probably be aborted except in emergencies unless gust alleviation devices provide significant relief in jostling. When tasks in addition to pilotage were imposed on pilots, the results were erratic pilotage and poor performance on the additional tasks. Observers, relieved of the heavy pilot load, completed their assigned tasks in a satisfactory manner despite total G-loads imposed in this study. Increased speed, with its shorter viewing time, did affect their surveillance performance, however, as would be expected. Navigational tasks performed on a manual computer proved, in general, to be less than satisfactory. Observers were slow and often inaccurate in their calculations; this would result in "being lost" a good deal of the time. Furthermore, these computers could not be held in the observer's hands at higher turbulence levels. It is strongly indicated that some new type of navigational aid which is quick and accurate and which does not have to be held in the observer's hands should be employed.

Therefore, an inboard computer, preferably electronic for speed and accuracy, seems to be indicated. Out-of-cockpit surveillance and in-cockpit electronic sensor surveillance was handled satisfactorily, at least to the level of proficiency that this study measured. More complex task requirements for the observer might lead to deterioration of performance under severe conditions. It should be pointed out, however, that all four observers flew one continuous three-hour mission at the highest turbulence levels used in the study with no noticeable performance decrements or physiological ill effects. This seems to indicate that observers could handle fairly heavy task-loadings with no serious effect on mission effectiveness. Therefore, it appears feasible that task allocation should center around assigning the observer more tasks to perform and assigning the pilot as few tasks as possible, other than terrain-following.

CREW TRAINING

The results of this study demonstrated marked adaptation to the acceleration environments prevalent in LAHS conditions. This adaptation seems to center around three phenomena: (a) a decrease in anxiety as the operator becomes psychologically conditioned to an unusual environment; (b) a quick learning of new control, visual reading, and comfort techniques, which greatly enhances performance; and (c) a physiological conditioning in which muscles used in tensing the body under high turbulence become effective in enabling the operator to perform his tasks with greater ease.

Results indicated that some intensive, short-term, specialized training under dynamic buffeting conditions would greatly enhance performance on the LAHS mission. This training program should include proper restraint system adjustment, visual scanning techniques, control responses under heavy turbulence, relaxation techniques, and physiological conditioning. In such a program, the operator should be instructed to use fine motor movements rather than gross motor movements in instrument and/or control adjustments.

RESTRAINT SYSTEMS

For long-duration LAHS missions, new restraint systems must be developed which offer adequate restraint but which are, at the same time, comfortable to wear. The operational Navy restraint system used in this study occasioned many complaints after the pilot and/or observer had been exposed to turbulent conditions continuously for approximately one hour. Complaints centered about levels of discomfort rather than about adequacy of restraint. Some observers loosened their restraint system after an hour so that they could twist and bend into a more comfortable position. This practice, although undoubtedly allowing more comfort, is extremely dangerous from a physiological safety viewpoint. The fact that observers who know the dangers involved loosened their restraint system points to the gravity of the problem. A program to develop a special LAHS restraint system which allows the operator a high degree of comfort is imperative if long duration LAHS missions are to be undertaken.

COCKPIT DESIGN

Cockpit displays should be specifically designed for this flight mode. All cockpit displays and controls should be as vibration-free as possible in order to avoid large readout errors. A damped cockpit panel should be investigated for this purpose. Dial faces should be larger than usual to aid in the quick information-processing necessary under LAHS conditions. Multimode displays (displays which can be "switched" to special low-altitude calibrations) should be investigated. Controls should be designed to operate by fine motor movements rather than gross motor movements. In this connection, a pencil-stick or ball-type side-arm controller should be investigated in lieu of center-stick control. Manual navigational aids (discussed previously) will probably have to be built into the cockpit. Electronic navigational aids which require little manual adjustment should be investigated.

FUTURE STUDIES

Further work should explore the maximum amount of task loading which each crew member can adequately handle under varying terrain conditions experienced in the LAHS flight regime, the effects of specialized LAHS training on performance, and possible improvement of operator performance by specialized restraint, display, and control systems.

DISCUSSION

INTRODUCTION

In order to minimize the probability of detection and thus enhance the chance for survival, the mission of the projected U.S. Army Surveillance Aircraft is presently defined in terms of flying at very low altitudes and at relatively high equivalent airspeeds for extended durations. This type of mission raises the possibility of human operator performance decrements due to the buffeting experienced in low-altitude, high-speed (LAHS) conditions. Two distinct problems may arise: the problem of accomplishing the system's primary mission (surveillance, reconnaissance, etc) and the problem of maintaining the vehicle's flight path (specifically altitude) within a set of restricted bounds. This study investigated pilot and observer performance in pilot, navigational and surveillance-type tasks under simulated LAHS conditions, utilizing the North American Aviation (NAA) Dynamic Flight Simulator (G-seat).

At the beginning, a typical surveillance mission was defined and then analyzed in terms of task components and time of essential task performance.

From this analysis, tasks essential for successful completion of a typical LAHS surveillance mission were determined so that human performance measurements could be made under various buffeting conditions experienced in LAHS flight.

To simulate realistic LAHS buffeting, the aerodynamic and control characteristics of an advanced-type surveillance aircraft were defined. Gust data obtained from the Douglas RB-66 flights were then used to determine acceleration time histories of rms gust velocities of 2, 4, 6, 8, and 10 ft/sec at velocities of 0.4 Mach and 0.9 Mach. These acceleration time histories were programmed for the G-seat. The equations of motion of the vehicle were set in an analog computer for the flight simulation. Thus, the simulator and its supporting computer complex enabled the pilot to experience a closed-loop simulation. The simulated missions were three hours long, consisting of an 80-minute cruise to target at 0.4 Mach, a 20-minute dash at 0.9 Mach, followed by an 80-minute cruise at 0.4 Mach.

Six Army pilots and four Army observers "flew" approximately 278 hours on simulated three-hour missions involving the five gust intensity levels at each of the two airspeeds. All data collected was then analyzed in terms of the human performance aspects of this mission. The results of this analysis as well as a complete description of the simulation employed are contained in this report.

SIMULATION DEVELOPMENT

Task Simulation

A simulated LAHS "mission" was designed for the study. This mission incorporated most of the operator tasks suggested by the gross mission/task analysis completed prior to this analysis and shown in Appendix XIII. Tasks included altitude maintenance, heading changes, out-of-cockpit surveillance tasks, in-cockpit surveillance tasks, and instrument monitoring. These mission-oriented task presentations were designed to add realism to the simulation and to offer some means of measuring performance decrements under controlled conditions. The mission was comprised of three segments: an 80-minute "cruise to target" at 0.4 Mach; a 20-minute "dash" at 0.9 Mach; and an 80-minute return cruise at 0.4 Mach. These segments combined to yield a continuous three-hour mission which was flown in its entirety at 500 feet altitude over a variable (level-contour) terrain. RMS gust intensities encountered in each segment varied over a range of 2 ft/sec to 10 ft/sec according to a randomly arranged schedule of presentation. As a result, terrain-tracking performance and the other performance tasks elicited during each mission could be measured under five levels of gust intensity for each of the two airspeeds. The simulation of these acceleration time histories is discussed under separate headings.

The Dynamic Flight Simulator (G-seat)

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

In order to simulate adequately an aircraft approximating characteristics of an advanced-type surveillance aircraft, it was necessary to modify the existing cockpit hardware. Longitudinal control system feel-characteristics such as bob-weight forces, viscous damping, and bungee rate were simulated by utilizing a feel simulator, which was simply a hydraulic actuator with feedback from stick rate and displacement, and aircraft load factor and pitch acceleration.

Safety and limiting circuits were used to modify the input command to the G-seat servo. The G-seat is actually a position servo with a ± 6 G-foot travel. Therefore, a ± 20 volt limiter was incorporated as an electrical stop on seat travel.

The simulator was equipped with a Martin-Baker Mark V seat which utilized the integrated torso harness restraint system used in the F9F-8T. Since the system used in the G-seat does not incorporate an inertial reel, the operator's shoulders were held rigidly against the back of the seat. This was done to avoid possible injury to the spine and viscera under the high turbulence conditions simulated in the study.

The G-seat room was darkened during all runs to avoid the peripheral distractions of a stationary room. Two blue fluorescent "sky-lights" (totaling 40 watts output) were the only light source in the room. These lights were located behind a large Polocoat screen mounted in front of the G-seat so that the light was diffused over the entire out-of-cockpit visual field of the subject.

Cockpit Displays

A computer-driven, terrain-tracking task was presented to the operator on a cathode ray tube (CRT) mounted in the instrument panel. On the CRT, a line (terrain height plus 500 feet clearance altitude) moved vertically to simulate the terrain variation at airspeeds of 0.4 and 0.9 Mach. The relative position of this line and a fixed "airplane" on the scope face ("inside-out" presentation) provided the pilot with an altitude error indication in which one-inch displacement on the scope was equal to 250 feet of altitude error. An integral part of the terrain-following display was the instantaneous rate-of-climb indicator, which was a distinct aid to the pilots in providing the lead compensation required to track an altitude error signal.

Other computer-driven instruments were the all-attitude indicator (AAI), a radar altimeter, and accelerometer. Other functional instruments (but not computer-driven) were a 24-hour clock, seat accelerometer, a servo-driven compass, an infrared (IR)-television (TV)-radar display, and a servo-driven electronic countermeasure (ECM) display. The arrangements of these displays in the cockpit are shown in Appendix V.

In order to simulate in-cockpit sensor surveillance tasks, three 16mm films were prepared, utilizing U.S. Air Force IR, TV, and radar sensor photography borrowed from Wright-Patterson Air Force Base, Ohio. Each of these films incorporated sections of each sensor input along a given flight path. In addition, final editing of these films produced a consecutive display of all three sensors along a given flight path for the two airspeeds required by the study.

The IR, TV, and radar target imagery on 16mm film was rear-projected onto an 8 x 10 inch Polocoat screen mounted on the cockpit instrument panel. A reinforced movie projector was mounted behind this panel for this purpose.

The compass and ECM display were servo-driven by an experimenter located in front and to one side of the G-seat itself. Thus, dial readings could be set according to a preset experimental procedure.

Cockpit lights, adjustable in intensity, were installed on either side of the operator's head for illumination needed in navigational computations. In addition, a sound generator simulating jet noise was installed on the rear of the G-seat itself. A nonfunctional throttle was also provided.

Out-of-cockpit visual target recognition tasks were simulated by a rear-projection system involving 35mm color slides, an automatic remote-controlled slide projector, a large Polocoat screen, and a three-axis stand. Specifically, the projector was mounted on a three-axis stand, which in turn was "slaved" into the G-seat hydraulic system. A 12 x 18 foot Polocoat screen was installed between this projector and the G-seat at a point six feet ahead of the cockpit. Consequently, the projected image always appeared before the pilot at any point in the G-seat's vertical travel.

The slides were photographs of approximately 50 representative Army targets filmed on an H-0 scale terrain model. These targets consisted of missile launchers, tanks, trucks, aircraft, and self-propelled guns of various types. Three slides were prepared for each target: the first slide represented the target as it first appeared in the pilot's visual range; the second slide was of the same target but at half this range and at a somewhat sharper angle; the third slide was filmed as if the pilot were almost directly over the target. To effect some realism using static (still) photographics, these slides were presented to the subject in a timed sequence corresponding to the airspeed at which he was purportedly traveling. Thus, at 0.4 Mach, a given set of three slides was presented in a 6-, 4-, and 2-second sequence. This successively shorter viewing time gave the subject glimpses of an approaching target, but prevented his experiencing disorientation due to improper viewing angles. At 0.9 Mach, the three slides in each set were presented sequentially for 3.5, 2.0 and 0.5 seconds, respectively. Camouflage difficulty levels for each target were ascertained, and each series of slides had an equal number of targets from each difficulty level.

Acceleration Time Histories

To simulate realistic LAHS buffeting, the aerodynamic and control characteristics of an advanced-type surveillance aircraft were defined. Gust data obtained from the Douglas RB-66 flights were then used to determine acceleration time histories of root-mean-square (RMS) gust velocities of 2, 4, 6, 8, and 10 ft/sec at velocities of 0.4 Mach and 0.9 Mach. A description of the aerodynamic and control characteristics utilized in this study is detailed in Appendix I, while a description of the atmospheric gust characteristics used is given in Appendix II.

These acceleration time histories were programmed for the North American Aviation, Inc., Dynamic Flight Simulator (G-seat). The equations of motion of the vehicle were set up on an analog computer for the flight simulation. Thus, the simulator and its supporting computer complex enabled the pilot to experience a closed-loop simulation of acceleration time histories over a specified range. In addition, the acceleration environment was modified by the pilot's control responses. These control responses added to the vertical G-load factor experienced by the pilot. Appendix III describes in detail the mechanization of the analog computer - G-seat complex.

These simulated gust environments are best represented by the RMS G-load factors below, which approximate a mean value of all vertical gusts for a given acceleration time history. The RMS G-load factors, without maneuvering error (pilot inputs) included, are given in Appendix I. The total RMS G-load factors (including maneuvering error), averaged across all pilots in the study, are shown in Table I.

Without exception, the values in Table I are considerably higher than the RMS load factors due to turbulence alone. This is due to the fact that the total G-load factor includes the effects of voluntary pilot control inputs required to follow the terrain and involuntary movements induced by the jostling of the pilot's arms and body.

TABLE I
TOTAL RMS G-LOADS AVERAGED ACROSS ALL PILOTS

Gust Intensity Level (ft/sec)	Airspeed	Average Total RMS Load Factor Expressed in G's
2	0.4 Mach	.050
4	0.4 Mach	.075
6	0.4 Mach	.150
8	0.4 Mach	.175
10	0.4 Mach	.195
2	0.9 Mach	.140
4	0.9 Mach	.145
6	0.9 Mach	.240
8	0.9 Mach	.310
10	0.9 Mach	.405

A comparison of the total RMS G-load levels experienced at the two airspeeds with aircraft turbulence G-loads alone (without pilot induced oscillations) is shown in Figure 1, page 34 .

Peak positive and negative accelerations at each gust level and airspeed are shown in Figure 2, page 35 . Reference acceleration values are zero; these zero values were recorded when the G-seat was at rest. The peaks or top values were reached only infrequently since gust inputs were presented randomly on a probability of occurrence basis.

THE PILOT STUDY

Pilot Background

The six pilots participating in this first phase were from the U.S. Army Aviation Board, Fort Rucker, Alabama. Pilot experience varied from jet-qualified to helicopter experience. Three of the six pilots had had previous experience in flight simulators.

Pilot Indoctrination

Each pilot in this study was familiarized with the purpose of the program, G-seat hardware and displays, and operating procedures and safety features. A briefing manual, shown in Appendix IX, was prepared for this purpose. The first few runs always consisted of orientation flights in which the subject was briefly exposed to each of the turbulence levels at each airspeed. After the subject was familiar with the tracking task and operating procedures, the G-seat was placed in motion with the pilot flying a constant altitude tracking-task at the lowest turbulence level. As the pilot became experienced in using the available instruments and equipment, atmospheric gusts were included in increasing amounts along with the terrain-following task. The usual procedure was to start at 0.4 Mach, and briefly expose the subject to gust environments at 2, 4, 6, 8, and 10 ft/sec levels at this airspeed before switching to 0.9 Mach, where again the subject was exposed to 2, 4, 6, 8, and 10 ft/sec gust environments. Orientation flights were usually concluded at the end of the second day of the pilots' 14-day stay at NAA.

Experimental Procedure

The runs schedule for each pilot is shown in Appendix IV. Each pilot was exposed to a series of runs in which the first 80-minute cruise segment (0.4 Mach) was at a given RMS gust level, and the final 80-minute cruise segment (0.4 Mach) was at yet another gust level. Each pilot then proceeded to "fly" his mission for a three-hour period over a combination of three gust levels. Consequently, each pilot was to fly all five gust levels (2, 4, 6, 8, and 10 ft/sec) at each of the two airspeeds (0.4 and 0.9 Mach) and at both the initial and final cruises. Checkpoint acquisition, in-cockpit and out-of-cockpit surveillance, and ECM tasks were presented to the pilot during each gust environment so that an equal number of equivalent tasks were presented for each 20-minute segment of the mission.

Two pilots were utilized during each series of runs. Normally, pilot A would fly one three-hour mission in the afternoon and another three-hour mission the following morning. Then pilot B would fly this same schedule, thereby counterbalancing effects due to morning or afternoon flights. No attempt was made to control pilot activity during nonflying hours. Consequently, it is possible that activity before and after the flights could influence the pilot performance measured. All pilots in the sample were experienced and well-qualified, but they varied in age and type of experience rather widely. This diversity of background could heavily influence the performance measured.

Other restrictions in the experimental procedure were concerned with mechanical and electronic simulation problems which sometimes forced the abandonment of a given mission. Since the pilots were available for limited periods only, not all of the pilots flew all of the programmed missions. However, enough data were collected over a wide enough range of pilots that all conclusions reached were considered representative of pilot performance under the experimental conditions studied.

Prior to each run, the pilot was strapped into the seat; the cockpit lighting was adjusted to the pilot's preferred level, and the terrain-following display was adjusted.

Each pilot could converse over an intercom system (pilot helmet mike) with the experimenter, G-seat operator, or computer personnel at any point of the mission.

In the initial 80-minute cruise-to-target segment of this three-hour mission, the pilot had to reach seven checkpoints and make seven course changes. In addition, he had to detect three electronic countermeasure (ECM) warnings, and proceed with appropriate action; he had to identify nine out-of-cockpit targets, and identify three targets during six minutes of electronic sensor (infrared, radar, and television) display presentations.

In the 20-minute dash segment, three navigational checkpoints had to be reached, each one indicating a heading change. Two ECM warnings were presented to the pilot in close sequence, and at this time the pilot was required to report verbally the megacycle frequencies of jamming for surveillance purposes. Five visual targets were presented out-of-cockpit. A total of three in-cockpit target identification tasks was presented, utilizing the simulated electronic sensor displays.

The return-cruise segment presented the pilot with the same tasks as in the cruise-to-target segment, but different ECM megacycle frequencies were given; different out-of-cockpit targets were presented; and different IR-Radar-TV displays were presented. Again, seven navigational checkpoints had to be reached, with heading changes required at each checkpoint.

As an additional task, the pilot was required to announce when he wanted the airspeed to change (at the end of 80 and 100 minutes).

Throughout each mission segment, at each checkpoint acquisition (5 to 20 minutes) the pilot was required to call out the acquisition of that checkpoint and to announce his heading change to reach the new checkpoint. In addition, pilots were required to give all target information possible over the intercom system following each slide's presentation. For example, after one of the slide presentations, the pilot would be expected to announce something like "two tanks pointing north, a river east-west, with bridge crossing." TV-IR-radar was turned on periodically, and again the pilot had to report verbally on prebriefed checkpoints and targets using these sensor displays. ECM warnings had to be reported as to megacycle reading. The pilot then had to turn a dial so that the dial reading was at zero or null position. A list of all required tasks and their order of presentation is given in Appendix VII.

The pilot could stop G-seat movements at any time in case of emergency by pushing a "kill-button" located on the center stick.

Analysis and Results

Each of the performance criteria utilized in the pilot study is discussed below in relation to the experimental variables of vertical gust acceleration environment, airspeed, and length of pilot exposure to the gust environment.

1. RMS Altitude Error

Altitude error was defined as any departure from the criterion altitude of 500 feet. RMS altitude error was computed each minute throughout all flights. The RMS values were then averaged for each 10-minute period and again averaged across all six subjects. Figure 3, page 36, shows this mean altitude error at the 10-minute intervals. Note the great error increase at minutes 90 and 100. These points represent the altitude error made during the two 10-minute periods of the dash segment of the mission. Maximum and minimum error scores of individual subjects during each of the 10-minute intervals are given in Figure 4, page 37. Note that error variability is much greater during the dash segment than in either cruise segment.

For more gross comparisons, a mean RMS value was then computed for each mission segment; i.e., initial cruise, dash, and final cruise. Comparisons can thus be made for each acceleration environment introduced in the study. The average RMS altitude error for each segment is presented below in Table 2 by vertical gust acceleration environments.

TABLE 2
MEAN RMS ALTITUDE ERROR AS A FUNCTION OF TOTAL RMS VERTICAL GUST ACCELERATION ONLY

RMS Gust Velocity	Cruise (0.4 Mach)	Mission Segment Dash (0.9 Mach)	Final Cruise (0.4 Mach)
2 ft/sec	*M = 149.12; **S = 21.13	M = 109.50; S = 12.27	M = 110.62; S = 9.96
4 ft/sec	M = 108.62; S = 18.59	M = 132.00; S = 24.86	M = 162.00; S = 10.70
6 ft/sec	M = 99.50; S = 8.86	M = 121.50; S = 46.44	M = 127.00; S = 19.02
8 ft/sec	M = 132.88; S = 12.90	M = 348.00; S = 106.68	M = 104.87; S = 11.66
10 ft/sec	M = 134.75 S = 9.52	M = 152.50; S = 152.50	M = 101.38 S = 14.92

*M represents the mean RMS altitude error.
**S represents the standard deviation of RMS altitude error.

An analysis of variance was conducted for each mission segment to determine differences in mean RMS altitude error due to vertical gust intensity (for details of the analysis of variance technique, see, e.g., Lindquist, E. F., Design and Analysis of Experiments in Psychology and Education, Houghton Mifflin Company, Cambridge, Massachusetts, 1935). The mean squares are presented in Tables 3 through 5.

TABLE 3
SUMMARY OF VARIANCE, RMS ALTITUDE ERROR IN INITIAL CRUISE (0.4 MACH)

	df	ss	ms
Gust Intensity Levels	4	19757.14	4939.28
Within-levels	35	7476.64	213.62
Total	39	27233.78	-
			$F = 23.12$

TABLE 4
SUMMARY OF VARIANCE, RMS ALTITUDE ERROR IN DASH (0.9 MACH)

	df	ss	ms
Gust Intensity Levels	4	78820.6	19705.15
Within-Levels	5	129.5	25.9
Total	9	78950.1	-
			$F = 760.8$

TABLE 5
SUMMARY OF VARIANCE, RMS ALTITUDE ERROR IN FINAL CRUISE (0.4 MACH)

	df	ss	ms
Gust Intensity Levels	4	13259.84	3314.96
Within-Levels	35	9023.14	257.80
Total	39	22282.98	-
			F = 12.86

In all segments of the mission, altitude error was significantly different due to vertical gust intensity. These differences would not be expected to occur by chance, except one time in a thousand. It should be noted, however, that these differences are not always in the expected direction; i.e., the higher the gust, the more altitude error. This is probably explained by training effects, discussed later, which tend to confound the results of gust intensity per se.

Mean RMS altitude error was then analyzed in terms of elapsed time. Computations were made using 10-minute samples across all subjects at 30, 60, 90, 120, 150 and 180 minutes. The results of this analysis are presented in Table 6.

TABLE 6
MEAN RMS ALTITUDE ERROR
AS A FUNCTION OF ELAPSED TIME ONLY

Gust Intensity Level	ELAPSED TIME IN MINUTES					
	30	60	90	120	150	180
2 ft/sec	114	163	116	116	127	101
4 ft/sec	102	136	128	140	167	154
6 ft/sec	109	113	123	120	132	94
8 ft/sec	132	113	346	101	90	120
10 ft/sec	116	139	153	116	108	80
Total	573	664	866	593	624	549

Since this analysis consisted of time intervals throughout the mission, the data above are compounded by the 20-minute dash occurring between 100 and 120 minutes of the total mission. Consequently, gust intensity levels for both airspeeds have been grouped together.

These results do not seem to indicate any pronounced differences in altitude error due to the effects of elapsed flight time. It appears that flight duration does not influence pilot performance as much as was commonly suspected. As a gross statistical check on this observation, the mean RMS altitude error was computed for the initial and final cruise segments (0.4 Mach) of the mission. These two means were then compared for differences with a t-test. The resultant t is insignificant. Thus, altitude error differences due to the effects of flight duration are not significant.

RMS altitude error due to airspeed was next computed. This data is presented in Table 7.

TABLE 7
MEAN RMS ALTITUDE ERROR
AS A FUNCTION OF AIRSPEED ONLY

0.4 Mach		0.9 Mach
Initial Cruise	Final Cruise	Dash
Mean = 119.02	Mean = 121.17	Mean = 172.7
s = 29.11	s = 26.09	s = 88.85
Combined Initial and Final Cruise		
Mean = 120.10		
s = 27.67		

A statistical test of difference between the means of flight at 0.4 Mach and 0.9 Mach (t-test) revealed differences significant beyond the 0.4 level of confidence. A difference this great would occur by chance only four times out of a hundred.

2. Number of Crashes and "Missile Kills"

The obtained data were then inspected for the number of times when pilots exceeded 1000 feet altitude or crashed (below 0 feet) during the simulated missions. As each pilot was told in the briefing, exceeding 1000 feet altitude was construed as a "missile kill," while going below 0 feet was construed as a crash. Other than noting his radar altimeter reading for himself, each pilot was not specifically warned each time he exceeded these limits.

TABLE 8

MEDIAN NUMBER OF CRASHES (6 SUBJECTS)

	MISSION SEGMENT		
Gust Intensity Level	Initial Cruise 0.4 Mach	Dash 0.9 Mach	Final Cruise 0.4 Mach
2 ft/sec - 0.4 Mach	4	-	1
4 ft/sec - 0.4 Mach	1	-	3
6 ft/sec - 0.4 Mach	0	-	0
8 ft/sec - 0.4 Mach	0	-	4
10 ft/sec - 0.4 Mach	0	-	2
2 ft/sec - 0.9 Mach	-	0	-
4 ft/sec - 0.9 Mach	-	0	-
6 ft/sec - 0.9 Mach	-	0	-
8 ft/sec - 0.9 Mach	-	4	-
10 ft/sec - 0.9 Mach	-	1	-
Total	5	5	10

Since the two cruise segments were 80 minutes each and since the dash portion was only 20 minutes long, a percentage of crashes per amount of exposure time was computed. This yields 5/80 or 6-1/4 percent for the initial cruise, 5/20 or 25 percent for the dash and 10/80 or 12-1/2 percent for the final cruise. Adjusted for time intervals, there were twice as many crashes in the final cruise as in the initial cruise; thus suggesting a fatigue effect which did not show up in altitude error, probably due to the fact that the coefficients are in effect averages and thus tend to cancel out extreme reactions.

The dash segment had considerably more crashes (considering the shorter time interval) than either cruise segment (25 percent vs 6-1/4 percent and 12-1/4 percent). It appears that the higher airspeed leads to far more frequent crashes.

Differences in number of crashes due to the effects of vertical-gust acceleration levels alone do not appear to be significant. Higher airspeed, rather than higher atmospheric gusts, per se, seems to affect pilot performance.

The number of missile kills per mission segment and for each gust intensity was also determined. Results of this analysis appear in Table 9 below. Differences in missile kills among gust levels in the mission segments are probably due to training effects rather than gusts, as is the case with altitude error (see the discussion of training effects). Therefore, the study of patterns of missile kills is restricted to a comparison of the total number of kills in one mission segment with the total number in another.

As can be seen in Table 9, considerably more missile kills occurred in the dash segment than in either cruise segment. It is also interesting to note that kills in the final cruise segment were slightly higher than in the initial cruise segment. This again seems to indicate a fatigue factor. The performance variability indicated by S^2 shows that pilots vary markedly in performance under dash conditions.

Differences due to gust intensity levels alone are not significant at the lower airspeeds of the cruise segments. In the dash portion, however, the higher gust intensity leads to significantly more missile kills.

3. Effects of Training

In the inspection of the data, it became apparent that order of experimental runs might have an effect on pilot performance measures due to the effects of learning. The order of presentation was not randomized across all subjects due to the exploratory nature of the effects of various gust intensities on performance. Consequently, although gust intensity levels were randomized across the entire mission for the initial cruise, dash, and final cruise, pilots were always run in the same order of presentation.

The data were re-arranged in order of three-hour missions for each subject. This, of course, disregards the effects of the various gust intensity levels involved in each mission. Nevertheless, learning effects could be grossly examined, since effects due to gust alone were not marked, especially at the lower airspeeds. The results of this inspection are presented in Table 10. Gust levels associated with cruise segments are listed in this table as 2, 4, 6, 8, or 10 ft/sec.

TABLE 9
AVERAGE NUMBER OF MISSILE KILLS (6 SUBJECTS)

Gust Intensity Level	MISSION SEGMENT Initial Cruise 0.4 Mach	Dash 0.9 Mach	Final Cruise 0.4 Mach
2 ft/sec - 0.4 Mach	9.99	-	3.69
4 ft/sec - 0.4 Mach	2.81	-	13.00
6 ft/sec - 0.4 Mach	1.67	-	5.31
8 ft/sec - 0.4 Mach	5.24	-	3.54
10 ft/sec - 0.4 Mach	5.25	-	2.08
2 ft/sec - 0.9 Mach	-	1.25	-
4 ft/sec - 0.9 Mach	-	3.75	-
6 ft/sec - 0.9 Mach	-	4.17	-
8 ft/sec - 0.9 Mach	-	38.75	-
10 ft/sec - 0.9 Mach	-	13.33	-
Total =	24.96	61.25	27.62
Mean =	4.99	12.25	5.52
S^2 =	8.18	192.40	15.01

TABLE 10
MEAN RMS ALTITUDE ERROR DURING EACH MISSION

	Initial Cruise 0.4 Mach	Dash 0.9 Mach	Final Cruise 0.4 Mach
Session I	M = 110.62	M = 348.12	M = 108.62
(2 ft/sec)	= 9.96	(8 ft/sec) = 106.68	(4 ft/sec) = 18.59
Session II	M = 104.87	M = 152.33	M = 132.88
(4 ft/sec)	= 11.66	(10 ft/sec) = 55.44	(8 ft/sec) = 12.90
Session III	M = 162.00	M = 121.83	M = 149.12
(8 ft/sec)	= 10.70	(6 ft/sec) = 46.44	(2 ft/sec) = 21.13
Session IV	M = 101.38	M = 132.12	M = 99.50
(10 ft/sec)	= 14.92	(4 ft/sec) = 24.86	(6 ft/sec) = 8.86
Session V	M = 127.00	M = 109.50	M = 134.75
(6 ft/sec)	= 19.02	(2 ft/sec) = 12.27	(10 ft/sec) = 9.52

The combined RMS altitude error for each mission was computed and yielded the following results:

	MEAN	STANDARD DEVIATION
Mission I	136.11	76.23
Mission II	122.61	20.50
Mission III	151.78	20.02
Mission IV	103.94	15.33
Mission V	128.50	16.25

The mean altitude error does not systematically decrease as a function of number of missions as might be expected if training effects are very pronounced. The variability of performance, as reflected by the standard deviations, is quite indicative of training effects. The steady decrease in variability with each mission strongly suggests that training effects are taking place; the pilots are becoming more and more consistent in their performance. By Mission IV, this decrease seems to have leveled off, indicating that even 10 to 12 hours of specialized LAHS training under dynamic buffeting conditions could help elicit consistent performance under actual LAHS conditions.

These training effects, although undoubtedly contaminating the results to a certain degree in the measurement of acceleration environment effects, are clearly evident and constitute one of the most important results of the study. A test of the difference between the standard deviations (variability) was significant at the .001 level; i.e., the observed differences would only happen by chance one time out of a thousand.

4. Target Identification

Each target presented to the pilot throughout each mission was scored by using the following system:

0 = no response or less than 25 percent correct

1 = 25 to 50 percent correct

2 = 50 to 75 percent correct

3 = 75 to 100 percent correct

Identification of military vehicles and weapons only was scored, although for purposes of realism each pilot was asked to "identify all objects of military significance". These scores were then added to yield a total score for each segment of the mission. Since the same slides were used for each mission in the pilot study, the learning curve of target recognition was computed by order of mission presentation. The results were then adjusted in view of this learning curve. The results of this analysis, adjusted for learning effects, are shown for each segment in Figures 5, 6, and 7, pages 38, 39, 40.

There were no significant target identification differences among any of the mission segments; i.e., there were not more or less correct responses in any one segment as compared with the others. Also, there were no significant performance differences in any of the segments as a function of gust intensity levels. Increased numbers of targets to be identified, or increased numbers of slides to be viewed, might lead to various differential mission segment and gust effects (see results of the target identification tests in the observer study, page 35).

It should be pointed out that all the pilots used in the study were highly trained in surveillance tasks and had had considerable experience in this area.

5. ECM Monitoring

The number of seconds that it takes a pilot to respond to an ECM warning light constituted another performance measure. The average number of seconds for each warning across all subjects was determined and plotted for each mission segment. The results are shown in Figure 8, page 41 .

Reactions experienced during the higher airspeed and more severe vertical gusts in the dash segment of the mission were considerably slower than those of either cruise segment. It is also apparent that only at the higher gust levels does the increased airspeed of the dash segment markedly affect ECM reaction time.

6. Task-Sharing

One interesting result of this pilot study was that whenever two tasks were presented simultaneously, the pilot was usually unable to perform both tasks adequately. He was forced to choose one task or the other, based on the immediate priority of the task. For example, if a target identification task and an ECM warning were presented at the same time, the ECM warning was usually not seen. Furthermore, if it was seen, target identification suffered as a result. It appeared in this study that the pilot, who has the continual task of flying the aircraft, cannot handle more than one task at a time, although task-sharing and task-time allocation should be investigated further.

7. Special Endurance Runs

Three of the pilots were asked to fly missions at the highest vertical acceleration time history utilized in the study. These missions were flown at 0.9 Mach consistently. One pilot flew for one hour, 30 minutes; one pilot flew one hour, 50 minutes; and one pilot flew three hours under these severe conditions. Performance under these conditions did not differ significantly from performance under less severe conditions.

The pilots flying for less than three hours duration felt that the mission was fatiguing. The pilot flying for a full three hours actually improved (as measured by RMS altitude error) and at the end of this mission did not feel abnormally tired. A record of this pilot's mean altitude error is shown in Figure 9, page 42 . It was learned later, however, that this pilot felt dizzy for about 24 hours and experienced extreme fatigue (kept falling asleep) for about 48 hours after experiencing this endurance run. This seems to indicate that three hour missions at high speed under heavy turbulence would be extremely hazardous and very fatiguing to the pilot. The chances of repeating successfully such a mission soon after the first one would be low.

It should be noted that pilots actually performed slightly better under these severe conditions than during normal missions. This can probably be attributed to the high level of motivation and competition surrounding these special flights.

8. Pilot Maneuvering Load Factor

The mean RMS total G-loading was computed for each 20-minute period throughout each mission and averaged across pilots. The results are shown in Figure 10, page 43.

A Mann-Whitney "U" Test was made to determine any significant differences between G-loadings in the initial and final cruise segments of the mission. It was hypothesized that fatigue effects might reveal themselves in an increase in pilot maneuvering error; however, no significant differences were present.

There was a significant difference in G-loadings between airspeeds, of course. At 0.9 Mach, maneuvering error was considerably higher. At the higher vertical-gust acceleration levels of 0.9 Mach, maneuvering error was proportionately far greater than the aircraft G-loadings, indicating a higher increase in pilot maneuvering error at the higher turbulence levels.

THE OBSERVER STUDY

Observer Background

The four observers participating in this second phase of the study were from the Aviation Division, Fort Eustis, Virginia. They were also trained pilots, although their experience was limited to O-1A operation.

Experimental Procedure

Each subject was exposed to the same G-seat environments as in the pilot study. Thus, the same airspeeds and gust intensity levels were used in this phase of the experimental program. Stick inputs (pilotage) were provided by the taped performance of two Army pilots in order to effect a closed loop operation. For this purpose, tapes were made during the pilot study. By the variation of pilot tapes during the course of the observer runs, any observer performance variations due to pilot control variations could be ascertained.

The tasks imposed on the observer were centered around out-of-cockpit and in-cockpit surveillance and basic navigational skills. Three separate missions were developed. Each mission incorporated a given flight path with numerous heading changes. For example, on Mission A, the "flight" started at Conroe, Texas, and terminated three hours later at Sioux City, Iowa. At intervals, the pilot (a role played by the experimenter) reported "visual checkpoints" and requested new headings and time estimates for arrival at the next checkpoint. During this "flight", 108 targets were presented to the observer on a large screen mounted in front of the G-seat (previously described). The observer verbally reported on the targets as they were presented. These targets were of varying degrees of camouflage, representing Army weapons and installations. Half of the target scenes were obtained from the U.S. Army Aviation Board, Fort Rucker, Alabama; the other half were the same slides used in the pilot study; they were prepared at NAA, Columbus using an H-0 scale terrain model. Observers were scored on completeness of report and accuracy of detection. In addition, television, infrared, and side-viewing radar electronic sensor inputs were presented in the cockpit at various points along the "flight". These displays coincided with geographical location, and several navigational checkpoints were presented with the targets for identification. Electronic countermeasure (ECM) monitoring was also required at numerous intervals throughout the mission. Appendix VIII chronologically lists all tasks imposed on the observer during typical missions. A diagram of the cockpit display arrangement for this study is shown in Appendix VI.

The runs schedule for the observer was identical to the pilot's schedule, with the exception that the two pilot tapes were alternated so that any effects of pilot control variation could be determined. The same three-hour missions were again utilized. However, instead of using the same mission each time, three missions judged comparable in difficulty were utilized. Thus, each observer would not become too familiar (or bored) with the tasks required during each mission. These missions had an equal number of all tasks at various difficulty levels.

Prior to the experiment, each observer was briefed for each of the three missions and given brief exposure to each of the gust intensity levels.

The observer's tasks consisted of navigation, in- and out-of-cockpit target and checkpoint identification, ECM monitoring and jamming operations, and fuel consumption problems. An equal number of these tasks was present in each initial cruise, dash, and final cruise segment of each of the three missions. As in the pilot study, each observer was asked to give as much target information as possible for each out-of-cockpit surveillance task. With the exception of piloting, all tasks presented in the pilot study were required in the observer study also. These tasks were at a more difficult level and more numerous than in the pilot study, however. Additional tasks of navigation and fuel consumption were also presented; these were not present in the pilot study. A "kill button" to stop G-seat movement was provided on the left side of the cockpit in case of emergency.

Analysis and Results

Performance on various navigational and surveillance tasks was measured throughout all missions in the observer study. In addition to the four Army pilots used for the majority of runs, four NAA-furnished navigators were also used for a few runs so that comparisons of untrained (NAA) observers could be made with trained (Army) observers. Performance of the untrained observers was four times worse than that of the trained observers. Results of the observer study given below are for the trained observers only.

1. Navigation

A total "navigational" score was assigned to all observers for every segment of each mission. This score, assigned by an expert navigator, consisted of an estimate from 1 (excellent) to 6 (unacceptable) based on performance in determining wind direction, wind velocity, ground speed, new headings, and estimating times of arrival at various checkpoints. The scoring system used appears in Table 11. These scores were then averaged for all subjects under all experimental conditions. The results of this analysis appear in Table 12.

No navigational tasks were presented during the dash segment of the mission. An F-test (statistical test) revealed no significant differences in navigational performance under the conditions in the various acceleration environments. It should be noted that none of the observers scored excellent or good on the navigational tasks; they all were in the average to fair range. This could be interpreted to mean that many crews would be lost some of the time if they depended solely on the observer-navigator for course direction. It appears that some additional training would be necessary before personnel of this type could cope with the higher-speed navigational problems inherent in the LAHS mission.

2. Infrared-Radar-Television Tasks

Tasks associated with all three modes of electronic sensor inputs were scored on a 0 (failed to identify checkpoint or target) or 1 (identified checkpoint or target) basis. The percentages of correct responses for all four subjects are shown in Table 13.

No significant differences were detected in correct responses as a function of either vertical-gust-intensity levels or speed levels. Apparently, no problems will be encountered in this task as long as the task itself remains a simple identification process rather than one of continuous scanning and interpretation.

3. ECM Monitoring

Reaction time to cockpit ECM warnings was divided into two classes: those responses made in three seconds or less and those responses made after three seconds had elapsed. The results of this analysis appear in Table 14.

TABLE 11
NAVIGATIONAL SCORING SYSTEM

		DEVIATION		GRADE		RATING
Wind Direction		5°	=	1	=	Excellent
		15°	=	2	=	Good
		25°	=	3	=	Average
		40°	=	4	=	Fair
		55°	=	5	=	Poor
	Above	55°	=	6	=	Unacceptable
Wind Velocity		2 Kts	=	1	=	Excellent
		5 Kts	=	2	=	Good
		9 Kts	=	3	=	Average
		14 Kts	=	4	=	Fair
		20 Kts	=	5	=	Poor
	Above	20 Kts	=	6	=	Unacceptable
Ground Speed		2 Kts	=	1	=	Excellent
		4 Kts	=	2	=	Good
		7 Kts	=	3	=	Average
		11 Kts	=	4	=	Fair
		16 Kts	=	5	=	Poor
	Above	16 Kts	=	6	=	Unacceptable
Heading		1°	=	1	=	Excellent
		2°	=	2	=	Good
		4°	=	3	=	Average
		7°	=	4	=	Fair
		11°	=	5	=	Poor
	Above	11°	=	6	=	Unacceptable
Estimated Time of Arrival		1'	=	1		Excellent
		2'	=	2		Good
		3'	=	3		Average
		4'	=	4		Fair
		5'	=	5		Poor
		5'	=	6		Unacceptable

(All problems not answered = 6)

TABLE 12
MEAN NAVIGATION SCORES

Gust Intensity Levels	Initial Cruise	Final Cruise
2 ft/sec	3.83	3.55
4 ft/sec	3.41	3.30
6 ft/sec	3.77	3.10
8 ft/sec	3.88	4.31
10 ft/sec	3.92	3.40

TABLE 13
CORRECT RESPONSES TO IR-RADAR-TV PRESENTATIONS

	MISSION SEGMENT		
Gust Intensity Levels	Initial Cruise (0.4 Mach)	Dash (0.9 Mach)	Final Cruise (0.4 Mach)
2 ft/sec	83%	-	75%
4 ft/sec	83%	-	89%
6 ft/sec	78%	-	75%
8 ft/sec	92%	-	86%
10 ft/sec	100%	-	92%
2 ft/sec	-	92%	-
4 ft/sec	-	100%	-
6 ft/sec	-	100%	-
8 ft/sec	-	89%	-
10 ft/sec	-	100%	-
Average Percent	87.2%	96.2%	83.4%

TABLE 14
PERCENT OF INSTANTANEOUS AND DELAYED REACTIONS TO ECM WARNINGS

Gust Intensity Levels		Initial Cruise (0.4 Mach)	Dash (0.9 Mach)	Final Cruise (0.4 Mach)
Under 3 sec	(2 ft/sec)	82%	-	78%
Over 3 sec		18%	-	22%
Under 3 sec	(4 ft/sec)	73%	-	74%
Over 3 sec		27%	-	26%
Under 3 sec	(6 ft/sec)	67%	-	98%
Over 3 sec		33%	-	2%
Under 3 sec	(8 ft/sec)	66%	-	82%
Over 3 sec		34%	-	18%
Under 3 sec	(8 ft/sec)	75%	-	79%
Over 3 sec		25%	-	21%
Under 3 sec	(2 ft/sec)	-	73%	-
Over 3 sec		-	27%	-
Under 3 sec	(4 ft/sec)	-	88%	-
Over 3 sec		-	12%	-
Under 3 sec	(6 ft/sec)	-	85%	-
Over 3 sec		-	15%	-
Under 3 sec	(8 ft/sec)	-	74%	-
Over 3 sec		-	26%	-
Under 3 sec	(10 ft/sec)	-	76%	-
Over 3 sec		-	24%	-

An F-test of significant differences among percentages revealed that vertical gust intensity levels did not significantly affect ECM reaction time. Increasing gust intensity seemed to lead to a greater proportion of reaction times only during the initial cruise segment of the mission. This was not true during the dash and final cruise segments of the mission. The average number of seconds required to respond to the ECM warnings was then computed across all four subjects. These results are shown in Table 15.

TABLE 15
AVERAGE ECM REACTION TIME
(IN SECONDS)

Gust Intensity Levels	Initial Cruise (0.4 Mach)	Dash (0.9 Mach)	Final Cruise (0.4 Mach)
2 ft/sec	4.89	-	3.76
4 ft/sec	4.22	-	4.74
6 ft/sec	4.73	-	3.48
8 ft/sec	4.85	-	3.74
10 ft/sec	3.88	-	3.40
2 ft/sec	-	3.73	-
4 ft/sec	-	3.28	-
6 ft/sec	-	3.77	-
8 ft/sec	-	4.12	-
10 ft/sec	-	3.29	-
Average	4.51	3.63	3.82

There were no significant differences in any mission segment due to vertical gust intensity levels. There was a somewhat faster average reaction time in the dash segment of the mission despite the higher gust intensities. This can probably be attributed to a higher level of anxiety and alertness present during the dash segment, which supposedly was through hostile territory.

4. Target Identification

Target identification was scored in a fashion identical to that employed in the pilot study. The averaged scores (representing percentages of target contents correctly identified) are presented in Table 16.

TABLE 16
AVERAGE PERCENTAGE OF TARGETS CORRECTLY IDENTIFIED

Gust Intensity Levels	Initial Cruise (0.4 Mach)	Dash (0.9 Mach)	Final Cruise (0.4 Mach)
2 ft/sec	76.4	-	73.0
4 ft/sec	77.0	-	70.6
6 ft/sec	71.7	-	70.5
8 ft/sec	76.4	-	78.7
10 ft/sec	82.2	-	81.3
2 ft/sec	-	58.7	-
4 ft/sec	-	75.2	-
6 ft/sec	-	69.0	-
8 ft/sec	-	60.0	-
10 ft/sec	-	76.6	-
Average Percent	76.74	67.90	74.8

Statistical t-tests of differences between overall means obtained during the initial-cruise, dash, and final segments of the mission revealed that: (1) there was no significant difference in target identification as a result of varying gust intensities; (2) there was a significant difference in target identification when overall performance during the cruise segments was compared with overall performance during the dash segment. Identification during the dash portion was significantly lower at the .02 level of probability. Consequently, the only real differences in target identification seemed to be a result of increased speed which led to shorter viewing times. Whether this decrement is due to the higher total G-load factors at higher speeds or due to the shorter target viewing time cannot be determined from this data.

5. Difference Due to Pilotage

Navigational scores were compared under missions "piloted" by the taped performance of the two pilots scored highest and lowest in total RMS altitude error. No differences were detected in the performance of observers as a function of these pilot differences. It should be noted, however, that the observers could always identify their "pilots" after a short period due to the difference in "gustiness" and smoothness of ride. They strongly preferred the smooth ride offered by the pilot with the highest RMS altitude error record; i.e., flew peak to peak.

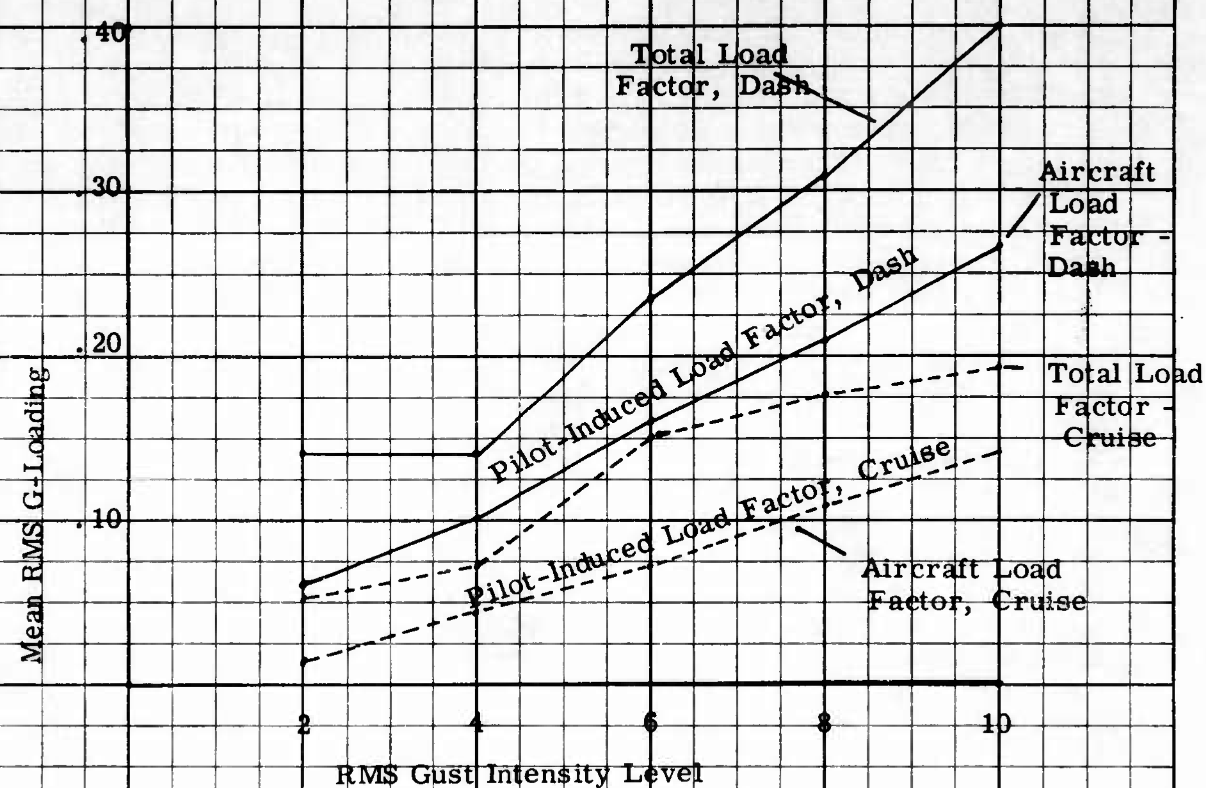

Figure 1

Pilot-Induced RMS G-Loadings. Solid Lines represent the dash segment; dotted lines, the cruise segments. The pilot-induced RMS G is the difference between total load factor and aircraft load factor in both dash and cruise.

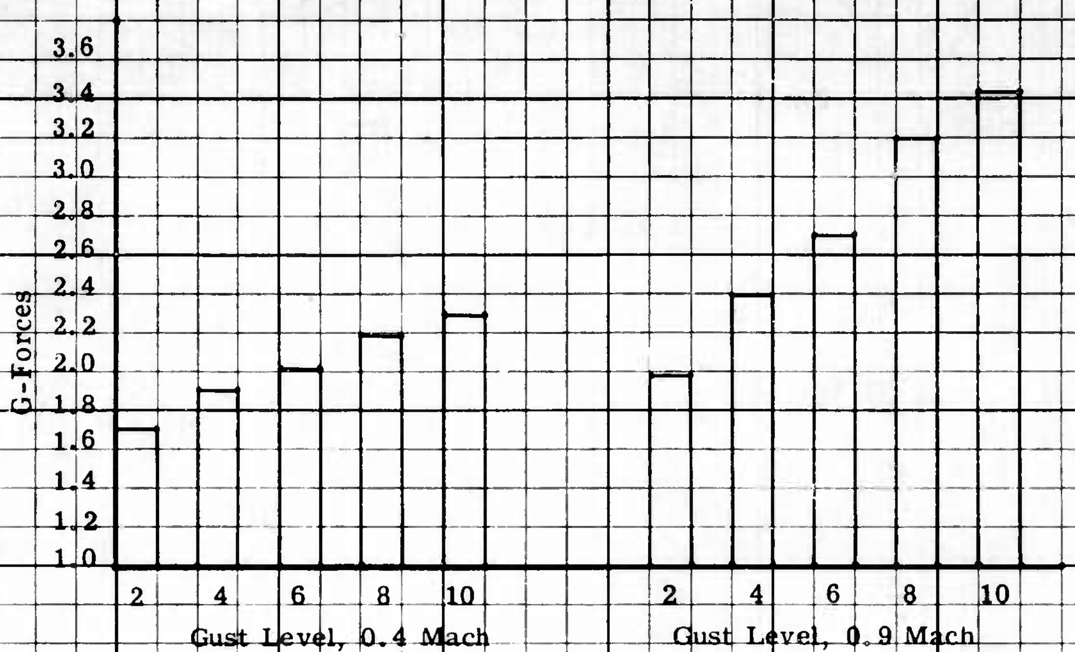

Figure 2

Range of total G-forces at each gust level. Heights of the bars represent peak positive and negative accelerations from a zero reference, or from the G-seat at rest.

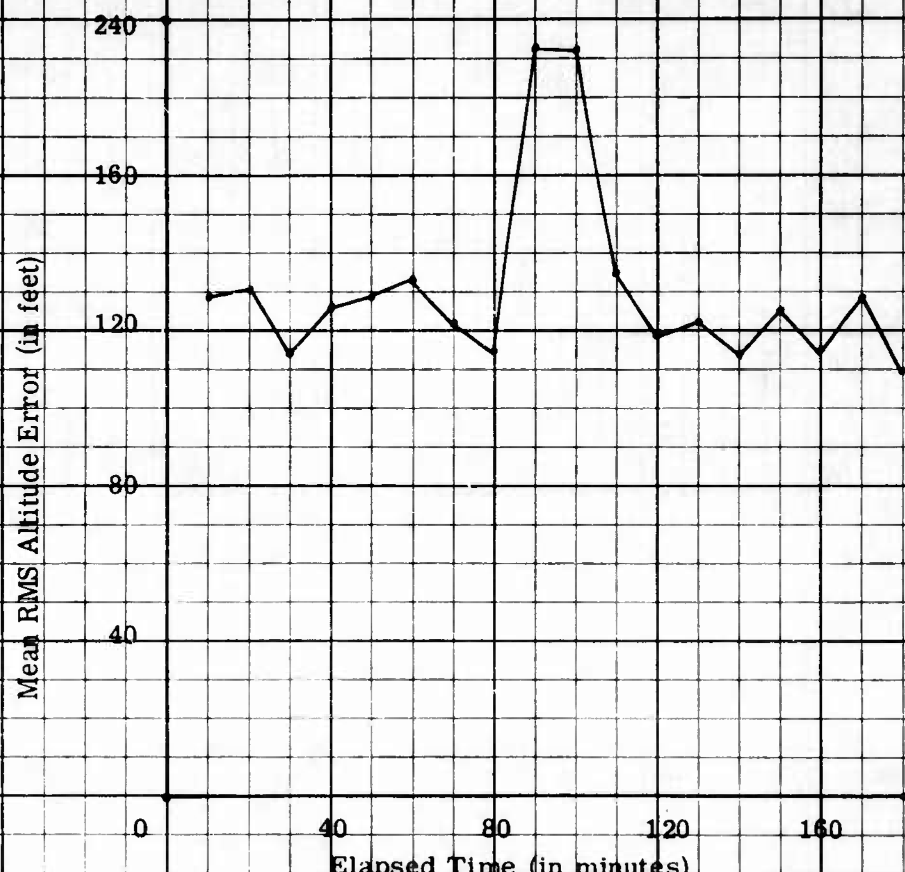

Figure 3

Mean RMS altitude error. Altitude errors averaged across all pilots at 10-minute intervals throughout the three-hour mission.

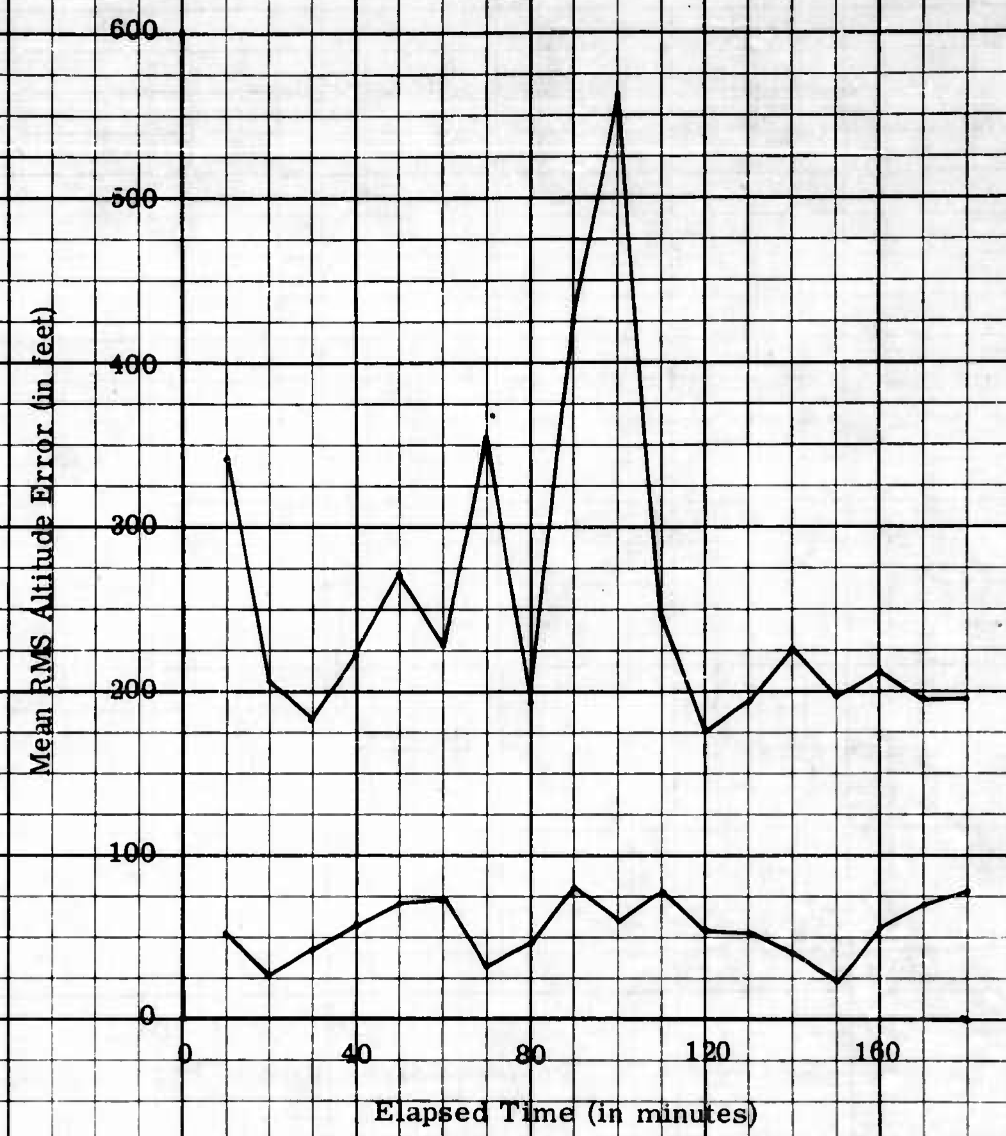

Figure 4

Range of individual RMS altitude error scores. Minimum and maximum scores are shown at 10-minute intervals throughout the mission.

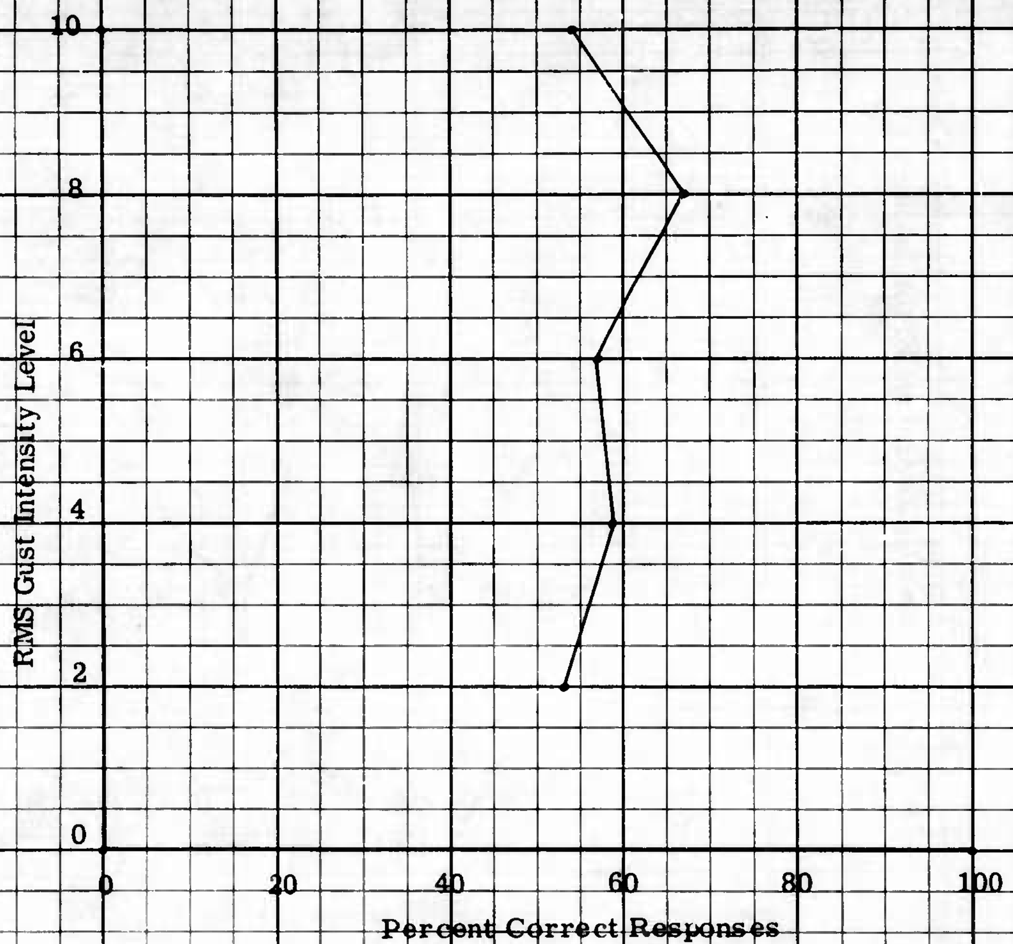

Figure 5
Adjusted Correct Responses to Target Identification Tasks - Initial Cruise Segment at 0.4 Mach

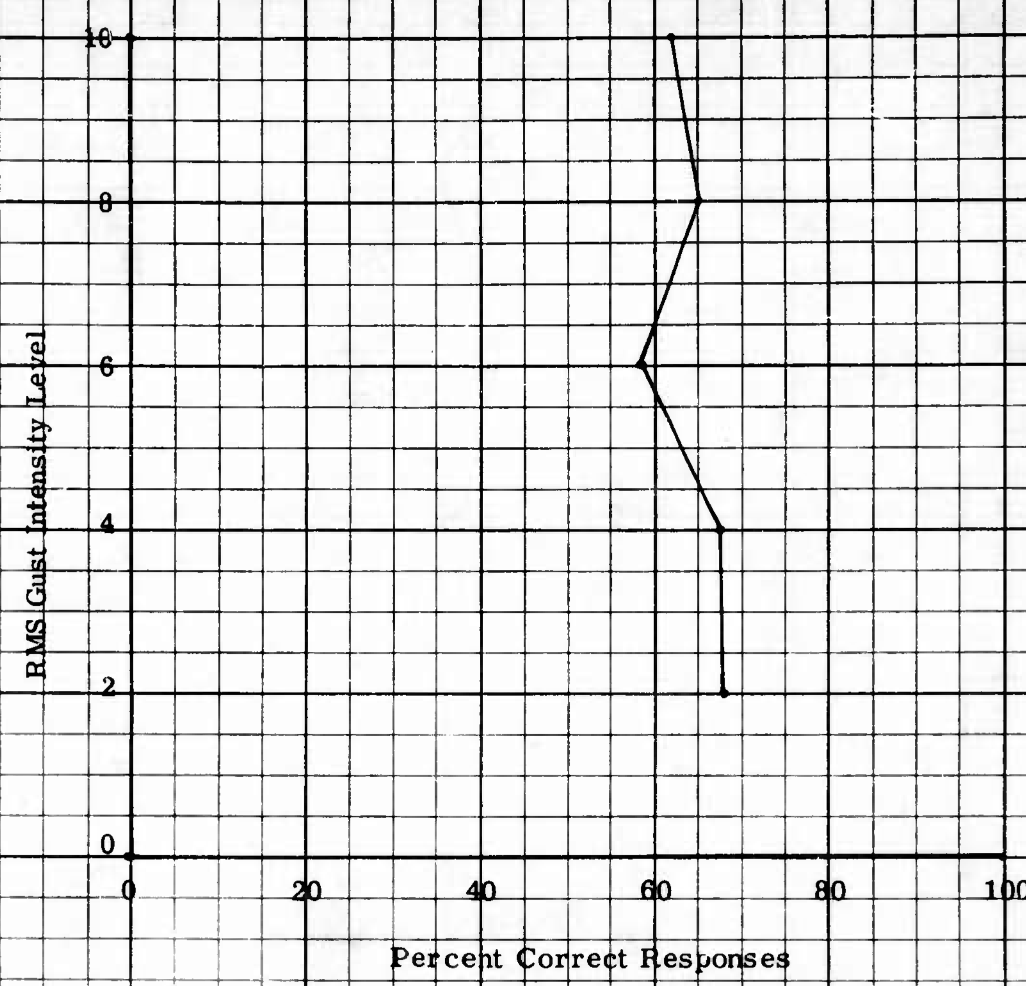

Figure 6

Adjusted Correct Responses to Target Identification Tasks - Dash Segment at 0.9 M.

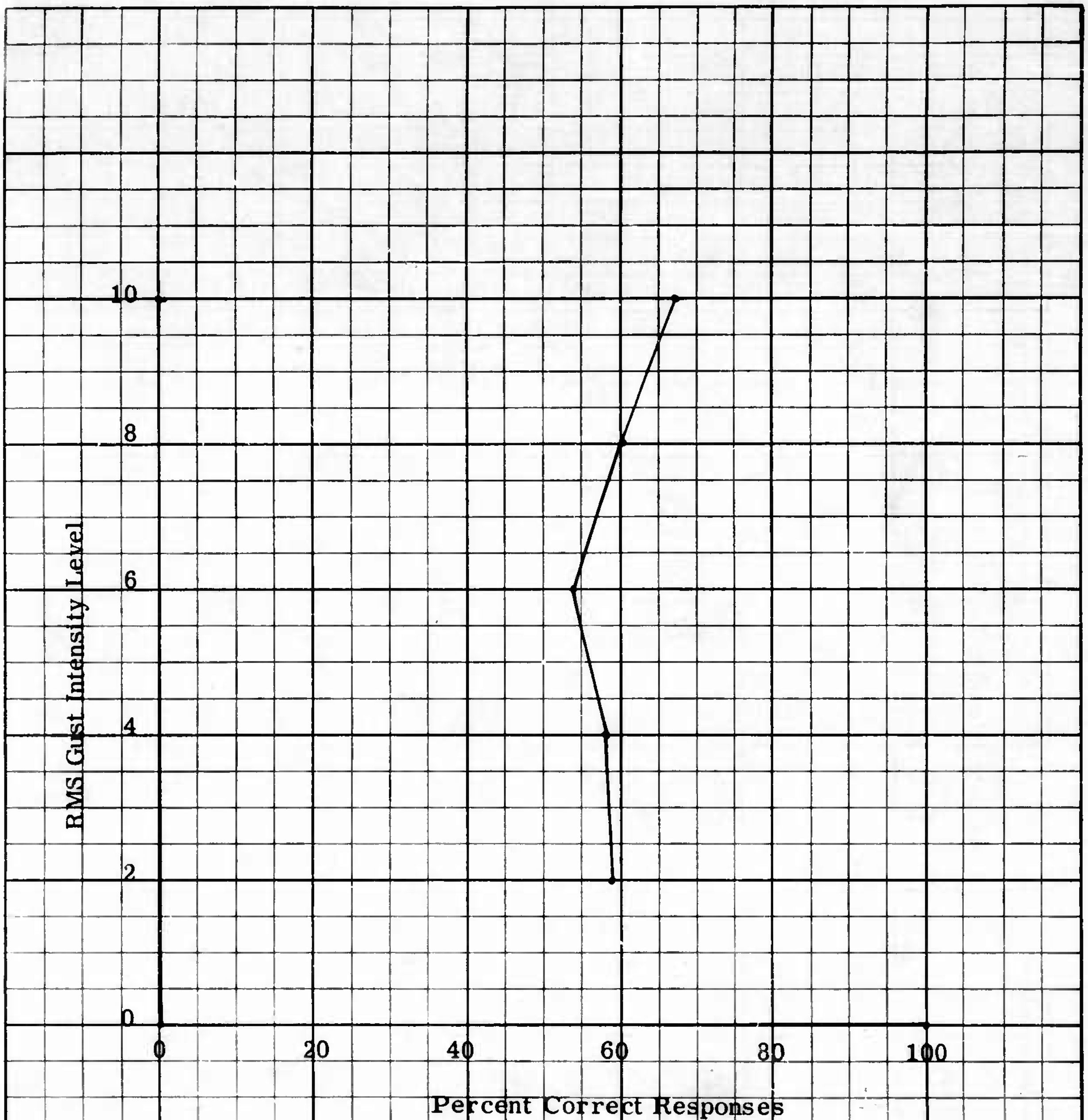

Figure 7
Adjusted Correct Responses to Target Identification Tasks - Final Cruise Segment at 0.4 M.

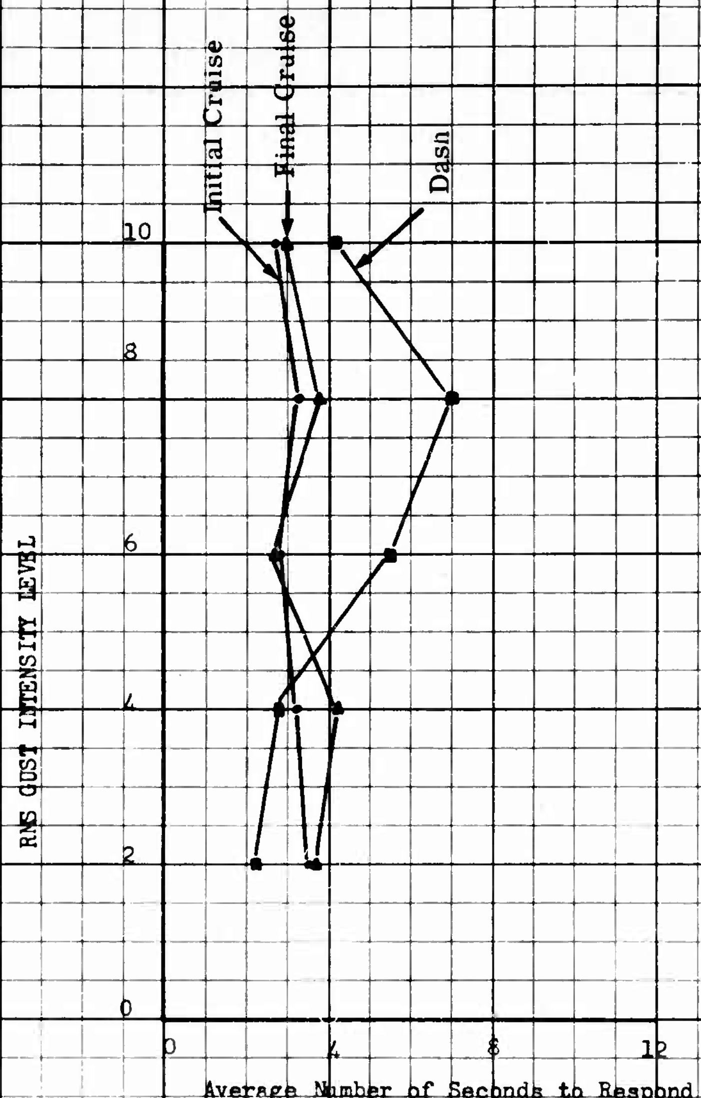

Figure 8
ECM Reaction Time:
Comparison of Mission Segments

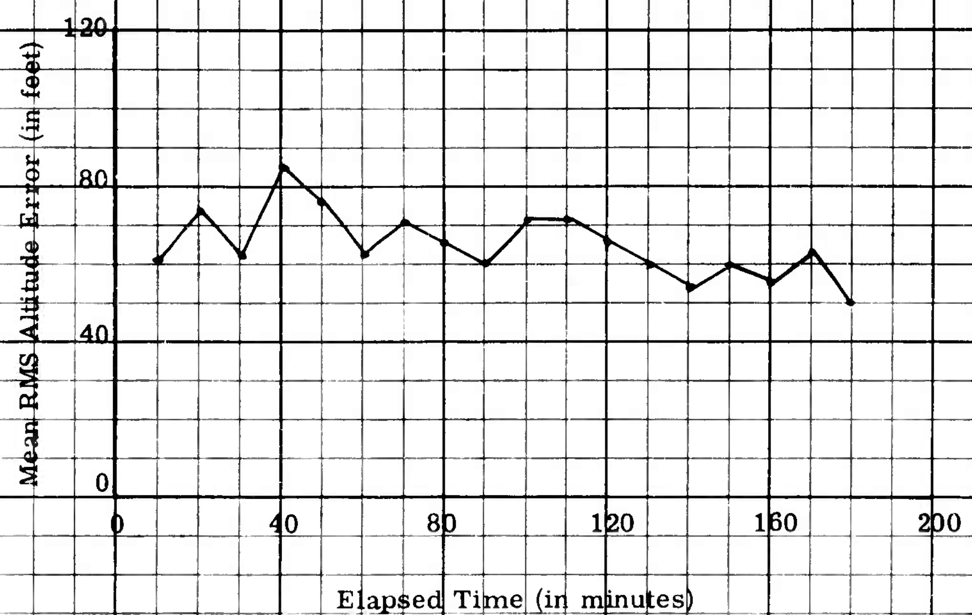

Figure 9

Mean RMS Altitude Error - Special Endurance Run (10 feet per second; 0.9 Mach)

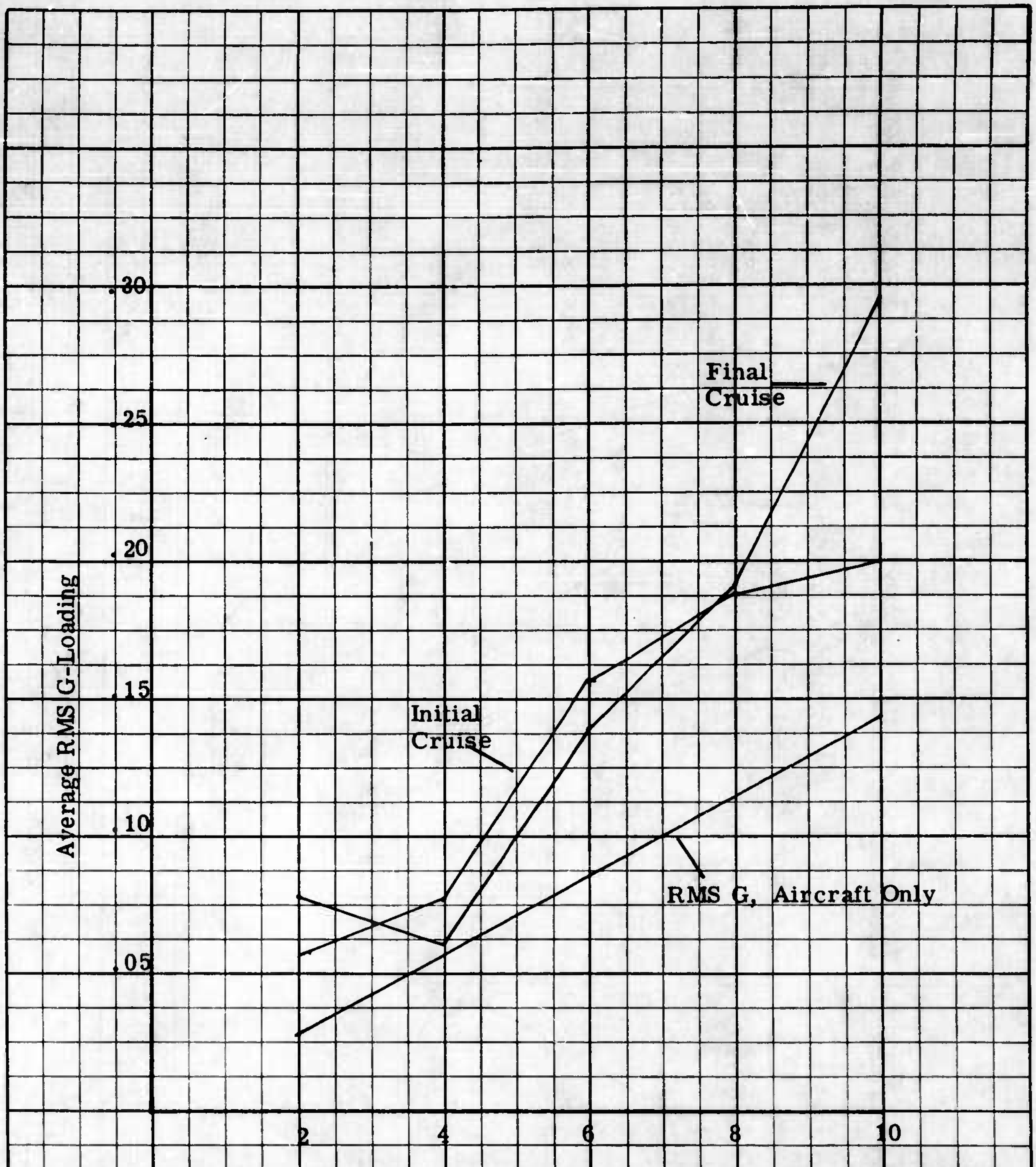

Figure 10
Total G-Loading at Each Gust Intensity Level

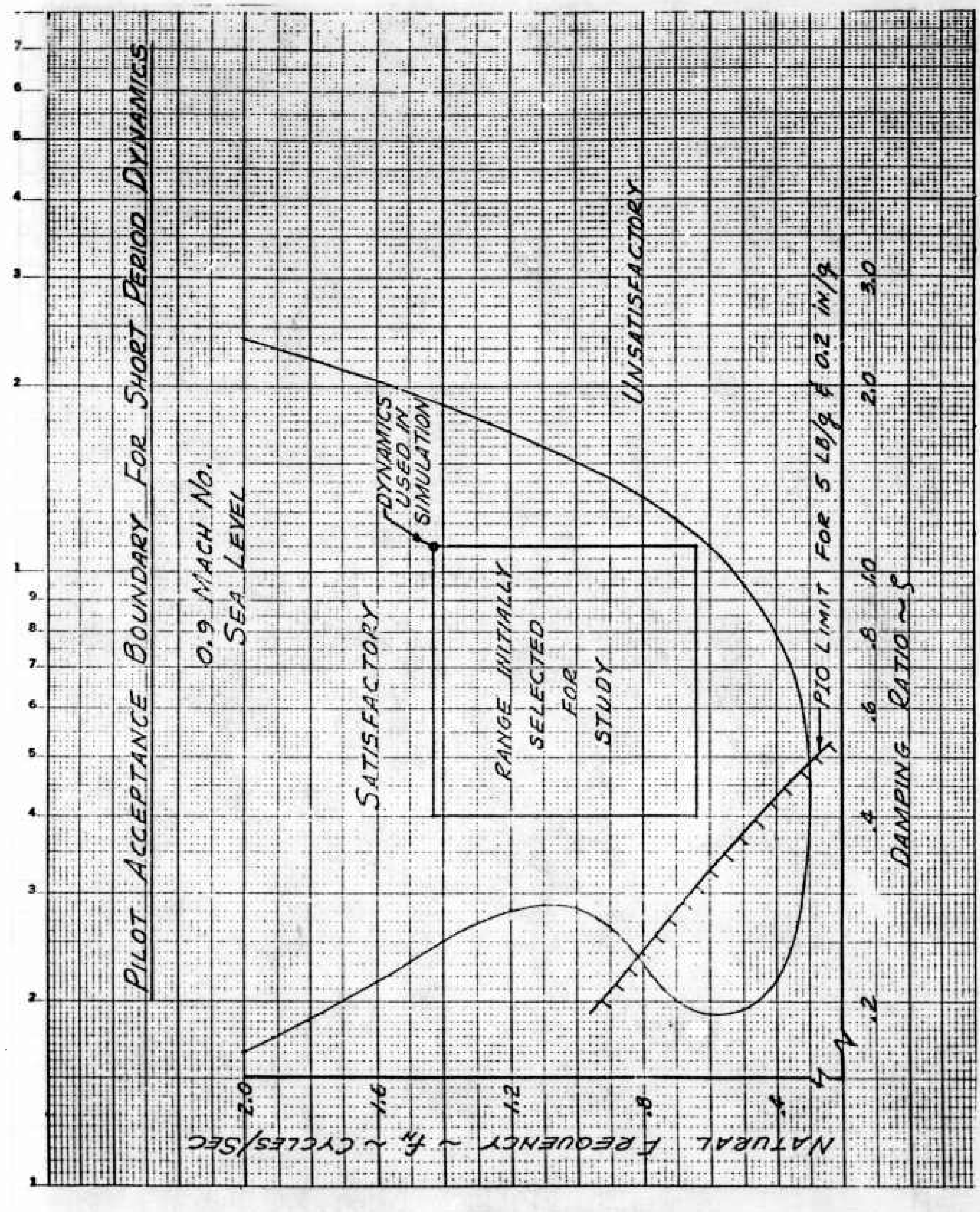

Figure 11
Pilot Acceptance Boundary for Short Period Dynamics

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APPENDIX I

DESCRIPTION OF SIMULATED AIRCRAFT

Handling Qualities

Because the emphasis of this study was to be placed on defining the effects of riding qualities on the pilot and observer performance, the aircraft handling qualities characteristics were chosen to be satisfactory for the flight regime of interest. The range of satisfactory airplane dynamic characteristics was based upon a recent study of low-altitude, high-speed handling and riding qualities.* The range of characteristics is shown in Figure 11 and generally includes the damping and frequency characteristics of many current high-speed aircraft as well as anticipated future aircraft specifically designed for the LAHS mission. Care was taken to avoid the pilot-induced oscillation boundary as determined in reference (*) and shown in Figure 11 so as not to confound the results of this study.

The initial simulator flights indicated that the objectives of the study could be obtained by use of a single simulated aircraft configuration. Based upon the contractor's and Army pilots' evaluation, the dynamic characteristics chosen for the simulator runs at 0.9 Mach number were airplane short-period natural frequency, $FN = 1.434 \frac{cyc}{sec}$, and airplane short-period damping ratio, $S = 1.1$, which corresponds to the upper right-hand corner of the range of characteristics shown in Figure 11.

Consistent with the airplane dynamic characteristics, the control system characteristics were also chosen to produce satisfactory flying qualities. A range of stick force per g values from 1.5 to 6 lbs/g was selected at 0.9 Mach number with a control stick sensitivity of .3 inches stick deflection per g. The stick force per g value finally selected by the pilots in the initial simulator runs was 6 lbs per g with the above sensitivity. These values are typical of many current fighter, trainer, and light attack aircraft in the LAHS regime.

*An Investigation of Low-Altitude, High-Speed Flying and Riding Qualities of Aircraft, North American Aviation, Inc., Report No. NA62H-397, Columbus Division, Columbus, Ohio, February 1963.

The airplane dynamic and control system characteristics were selected for the most critical flight condition of 0.9 Mach number. The characteristics at 0.4 Mach number were based upon those at 0.9 Mach number, accounting for the change in velocity and typical variations of the stability derivatives with Mach number. The characteristics used in the simulated mission runs are shown below in Table 17.

TABLE 17
AIRCRAFT AND CONTROL CHARACTERISTICS

Characteristic	0.4 Mach No.	0.9 Mach No.
Airplane Undamped Natural Frequency ~ F_n ~ $\frac{cyc}{sec}$	.561	1.434
Damping Ratio ~ ζ	1.044	1.1
Stick Force Per g ~ F_s/g ~ $\frac{Lb}{g}$	10	6
Stick Sensitivity ~ $\frac{S}{g}$ ~ $\frac{In.}{g}$	.5	.3

It is noted that the flying quality parameters for satisfactory characteristics assumes that the longitudinal stick deadband (stick motion for no electrical output) and friction are very low. The majority of the simulator flights in this study were performed with a total stick deadband of 5/8 inch (3/8 inch fwd and 1/4 inch aft) and a breakout force of approximately four pounds. The deadband and breakout force for the BuWeps study was 0.1 inch and less than one pound, respectively. The higher deadband and breakout force for this study was probably responsible for the pilots' choice of the higher value of stick force per g from the range of values evaluated in the initial simulator flights.

Riding Qualities

Since the turbulence tapes used in the study were generated according to the normalized, power-spectral density for low-altitude turbulence, the gust sensitivity can be calculated from

$$\frac{\text{RMS } \Delta N_L}{\text{RMS } wg} = \frac{\sigma \Delta N_L}{\sigma wg} = \left[\int_0^{\infty} \frac{\Phi(w)}{\sigma^2_{wg}} \left| \frac{\Delta N_L}{w_g} (w) \right|^2 dw \right]^{1/2}$$

where

$\Phi(w)/\sigma^2 wg$ is the normalized, power-spectral density of low-altitude turbulence, and

$\left| \frac{\Delta N_L}{wg} (w) \right|^2$ is the modulus squared of the frequency-response function of the airplane to gusts.

By the use of the coefficients from Table 19 to evaluate the modulus squared of the frequency-response function for each Mach number, the computed gust sensitivities at the pilot location are

$$M = 0.4, \sigma \Delta N_L / \sigma_{w_g} = .0142$$

$$M = 0.9, \sigma \Delta N_L / \sigma_{w_g} = .0273$$

It is noted that the above gust sensitivities are relatively low due primarily to the dynamic characteristics of the simulated airplane. Contractor studies have shown that the dynamic characteristics of the rigid airplane can have a great influence on the gust sensitivity, especially at the pilot location. Without dynamic considerations the airplane would have a sensitivity of 0.1 at .9 Mach number.

The root-mean-square load factor $\delta\Delta N_L$ due to gusts for various root-mean-square vertical gust velocities is shown below in Table 18 for each Mach number.

TABLE 18
RMS LOAD FACTORS DUE TO GUSTS

σw_g - Ft/Sec	$\sigma \Delta N_L$ 0.4 Mach No.	$\sigma \Delta N_L$ 0.9 Mach No.
2	.0284	.0546
4	.0568	.1092
6	.0852	.1638
8	.1136	.2184
10	.142	.273

The RMS load factors shown above are due only to the turbulence. The total RMS load factors as obtained for this study are appreciably larger because the maneuvering load factor has been included in the recorded data. It should be noted that the maneuvering load factor includes the effects of voluntary pilot control inputs required to follow the terrain and involuntary movements induced by the jostling of the pilot's arm and body.

Airplane Transfer Functions

The airplane longitudinal transfer functions simulated on the analog computer are based on two degrees of freedom; namely, vertical translation or heavy degree of freedom and rotation about the airplane Y-axis or pitch degree of freedom.

The transfer functions for the load factor at the pilot location for control stick inputs and inputs due to gusts are given by

$$\frac{\Delta N_L}{g} = \frac{K_N/\delta + \frac{l_p}{g} K_q/\delta S\,(S/-2\alpha' + 1)}{S^2/W_m^2 + \frac{2S}{w_m} S + 1} \qquad (1)$$

$$\frac{\Delta N_L}{w_g} = \frac{-Z'\alpha / gW_m^2 (S^2 - 2M_q S) + \frac{l_p}{g} K \,{}^{\theta}/_{w_g} S^2 (AS-1)}{S^2/W_m^2 + \frac{2S}{w_m} S + 1} \tag{2}$$

where the first term in each equation accounts for the load factor produced at the airplane center of gravity, and the second term in the numerator accounts for the incremental load factor at the pilot's location produced by the pitching acceleration. Since the speed was changed discretely, two-degrees-of-freedom equations are permissible. The effect of the discrete change in speed was produced by changing the parameters of equation 1 and 2. The parameters in equation 1 for each Mach number are shown in Table 19 below.

TABLE 19
EQUATIONS OF MOTION PARAMETERS, I

Parameter	0.4 Mach No.	0.9 Mach No.
$K_{N_L/\delta} \sim$ g/in.	-2.0	-3.33
$\frac{l_p}{g} K_{q/\delta} \sim \frac{sec}{in.}$	-.0184	-.0414
$-Z'_\alpha \sim \frac{1}{sec}$	1.43	3.22
$W_m^2 \sim \frac{1}{sec^2}$	12.4	81
$\frac{2S}{w_m} \sim$ sec	.594	.2445

In equation 2, the effects of the gusts are treated as first reacting on the wing and a short time later as reacting on the tail. The parameters used in equation 2 for each Mach number are shown below in Table 20.

TABLE 20
EQUATIONS OF MOTION PARAMETERS, II

Parameter	0.4 Mach No.	0.9 Mach No.
$\frac{-Z\alpha}{g w_m^2} \sim \frac{sec^2}{ft}$	.00358	.001235
$-2M_q \sim \frac{1}{sec}$	1.32	4
$\frac{l_p}{g} K \cdot / w_g \sim \frac{sec^3}{ft}$	.000436	.000194
$A \sim sec$	.152	.05
$W_m^2 \sim \frac{1}{sec}$	12.4	81
$\frac{2^5}{w_m} \sim sec$	.594	.2445

The total incremental load factor at the pilot location due to gusts and pilot control inputs is then

$$(\Delta N_L)\ \text{Total} = (\Delta N_L)\ \text{Gusts} + (\Delta N_L)\ \text{Control}.$$

In order to provide the ability to change heading with lateral stick displacement, a simplified lateral-directional transfer function was employed of the form

$$\frac{\psi}{S_L} \qquad \frac{K_1 K_2}{S\,(S^2 + 25\,W_{N_D} S + W^2_{N_D}} \cdot \qquad (3)$$

The values of the gains and coefficient in equation 3 are shown below in Table 21 for each Mach number.

TABLE 21
LATERAL-DIRECTIONAL TRANSFER FUNCTION VALUES

Constants	0.4 Mach No.	0.9 Mach No.
$K_1 \sim \frac{1}{\text{in-sec}^2}$	.052	.08
$K_2 \sim \frac{1}{\text{sec}}$	.4	.16
$25\ W_{n_d} \sim \frac{1}{\text{sec}}$	.698	.698
$W_{n_d}^2 \sim \frac{1}{\text{sec}^2}$	.244	.244

APPENDIX II
ATMOSPHERIC TURBULENCE AND TERRAIN SIMULATION

The traces of altitude error and terrain altitude are shown in Figure 13. The error trace, in this case, shows that the actual error never exceeded 165 feet.

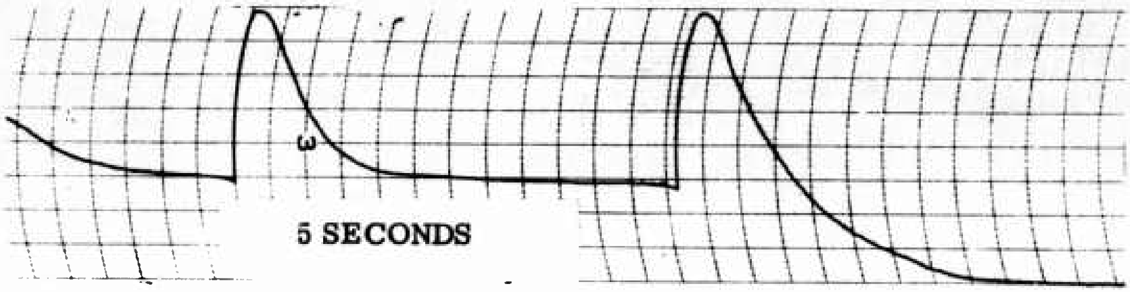
Figure 12 presents sample time histories for all the remaining pilot parameters recorded. Total G-output and RMS total G-output represents the sum of the maneuvering load factor and the total gust-induced load factor.

The characteristics of the terrain structure used in this study are shown in Figures 14 and 15. Figure 14 gives the amplitude-frequency distribution of peaks and valleys from a base level which lies below the valleys. For example, a 500-foot peak may occur prior to a depression or valley which is 100 feet lower than the peak. This valley would be recorded as 400 feet above the base level.

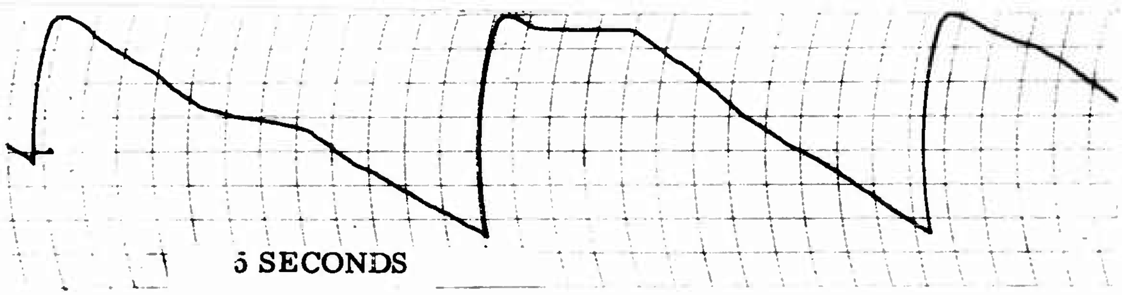
The slopes of the hillsides, both ascending and descending, are given in Figure 15. The maximum rate of climb is 80 ft/sec at Mach 0.9, while the maximum rate of descent is -85 ft/sec. The maximum frequency of 1.68 slopes/minute occurs for positive slopes between five and 10 feet per second.

Atmospheric turbulence was inserted into the G-seat runs as a change in vertical velocity, Wg. These gusts were recorded on magnetic tapes, and by the use of known gain settings, the RMS gust intensity could be set at 2, 4, 6, 8 or 10 ft/sec for each run. The probability distribution used is shown in Figure 16.

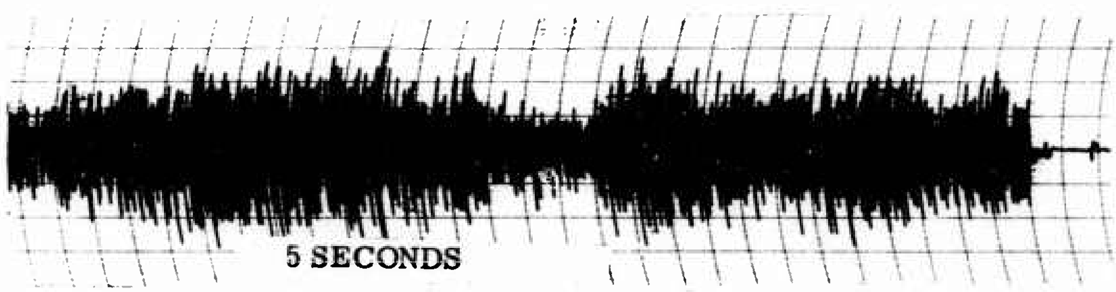
The distribution of the gust levels was randomized, according to a random numbers table, and sampled at a rate which varied inversely with the Mach number. The nominal rate was six seconds per sample for $M_n = 0.9$.



RMS Altitude Error 125 ft/cm



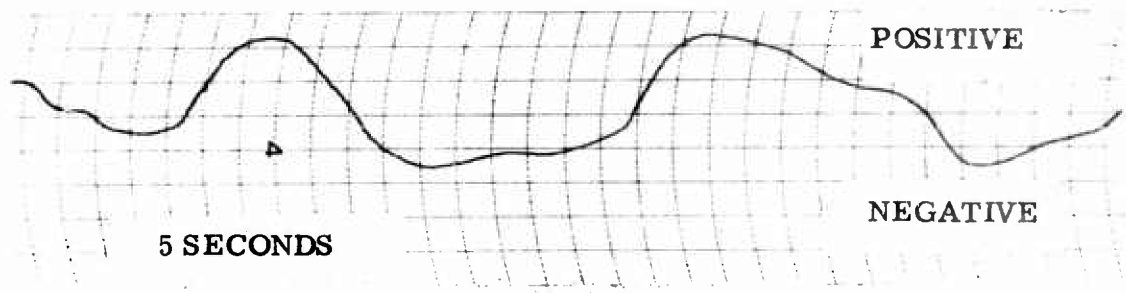
Total G Outputs 1 G /cm



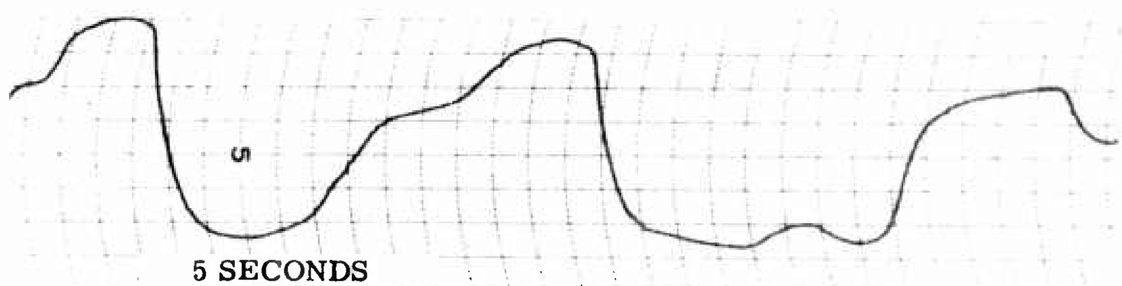
RMS Total G Outputs 0.11 G/cm

Figure 12
Typical Pilot Performance Recordings

Gust Level: 10 ft/sec 0.9 Mach



Aircraft Altitude Error 100 ft/cm $\pm$ 500 ft



Terrain Altitude 250 ft/cm

Figure 13
Terrain Tracking Records

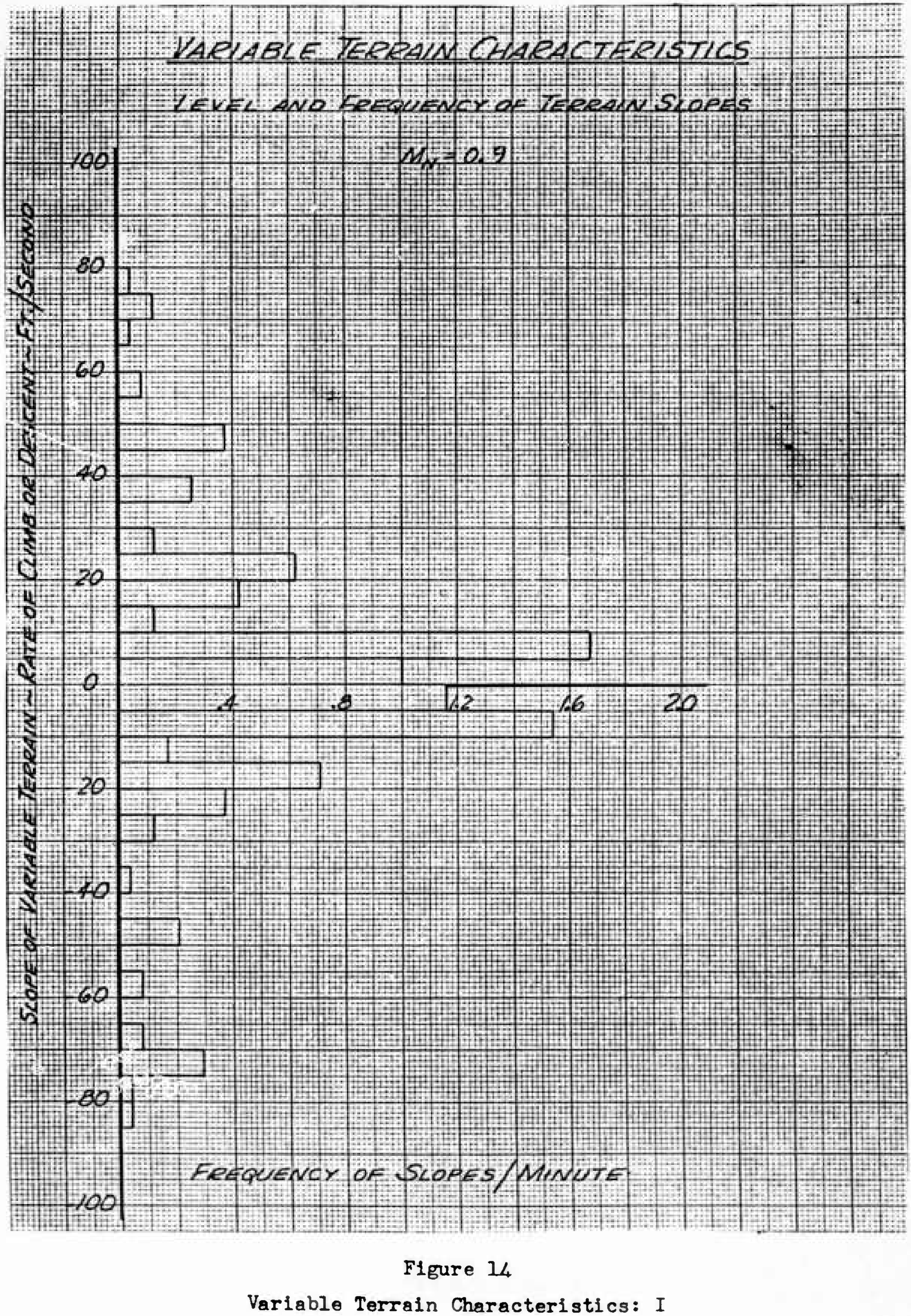


Figure 14

Variable Terrain Characteristics: I

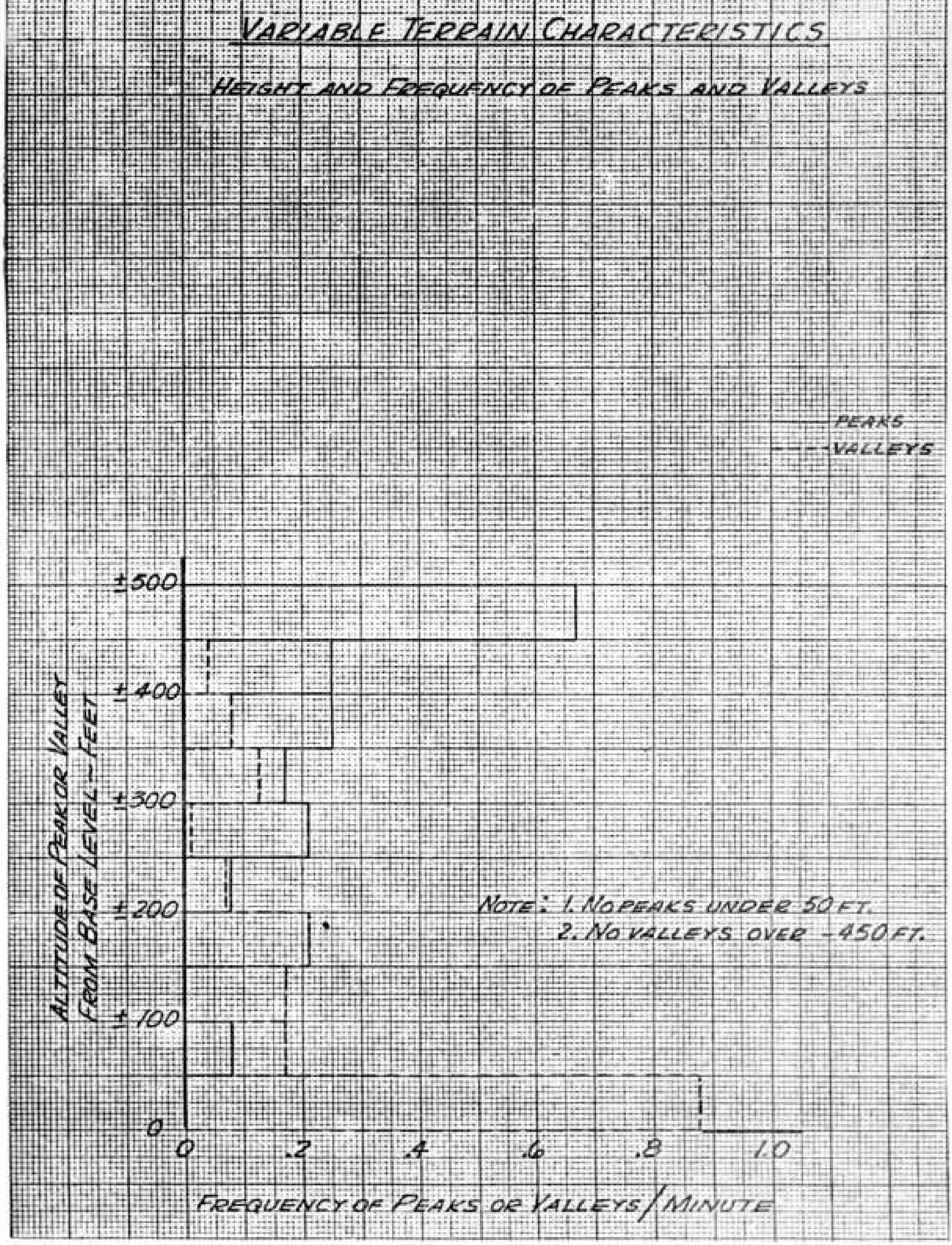


Figure 15
Variable Terrain Characteristics: II

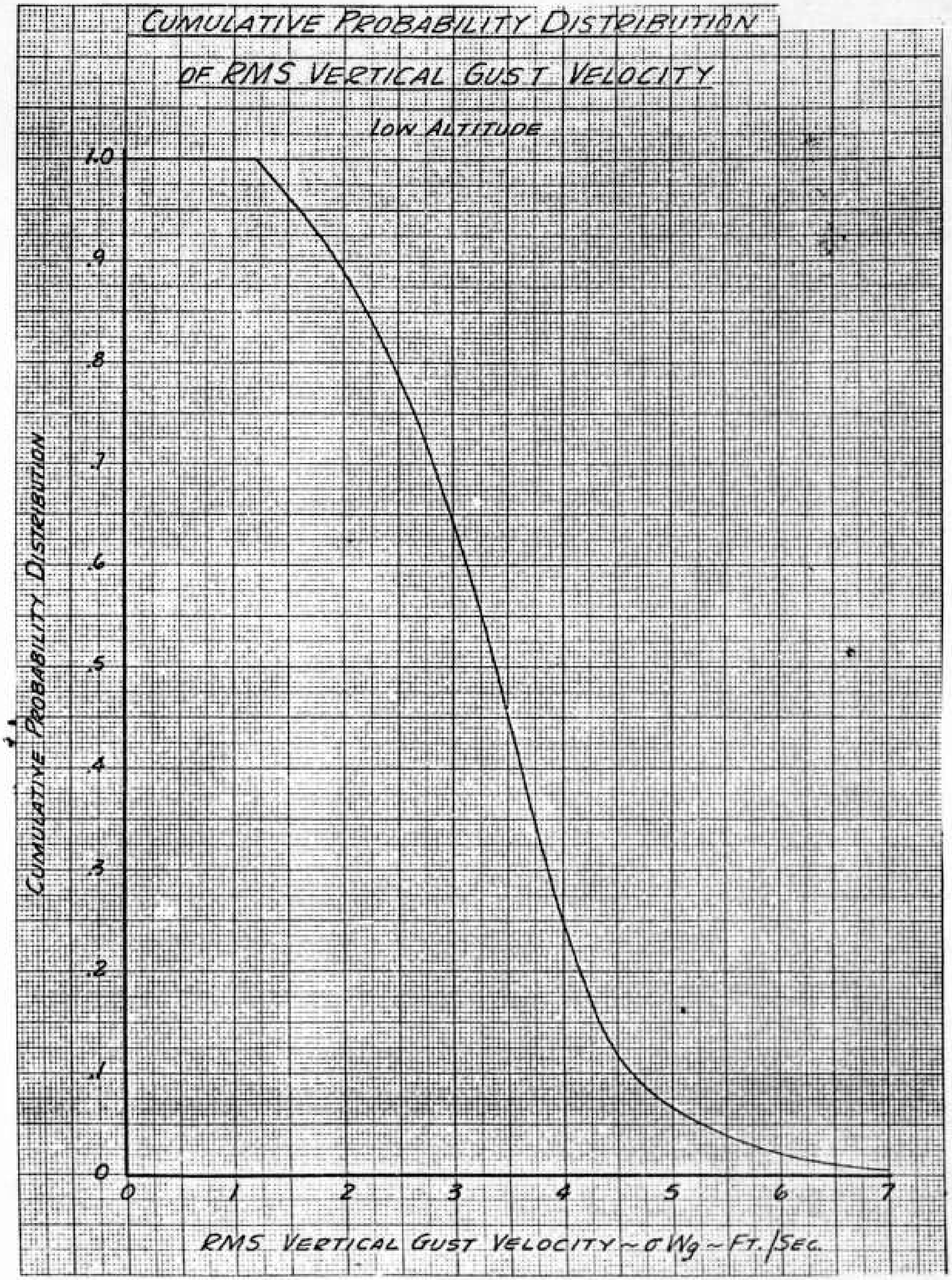


Figure 16
Cumulative Probability Distribution of
RMS Vertical Gust Velocity

APPENDIX III
ANALOG COMPUTER MECHANIZATION

Two degrees of freedom were mechanized to provide commands to the seat servovalve as functions of control stick and wind gust inputs. Euler angles were also computed to drive the AAI, to provide for heading indication, and to provide a more realistic simulation in general.

The equipment necessary for the program included a 131-R console, a portable TR-10 console, one six-channel oscillograph, one magnetic tape machine, and the G-seat and its associated equipment.

Two airspeeds (0.4 Mach and 0.9 Mach) and five gust levels (2, 4, 6, 8, and 10 feet per second RMS) were simulated during the program.

All coefficients that were functions of airspeed were set on potentiometers for both airspeeds. A multiple-pole transfer switch facilitated changing airspeeds without interrupting the mission.

THE PILOT STUDY

The following data were recorded during the pilot phases of the program: pilot acceleration (from seat), RMS pilot acceleration (computed), compass heading (computed), altitude error (computed), RMS altitude error (computed), and terrain. The following instruments were computer-operated during this phase of the program: oscilloscope, rate of climb meter, radar altimeter, accelerometer, and AAI. Wind gusts and terrain were prerecorded on magnetic tape and played into the mechanization on command. Stick inputs were commanded by the pilot from the seat. Computer outputs were used to drive the seat servovalve, the previously-mentioned cockpit instruments, and the oscillograph.

A Pace TR-10 computer was used in conjunction with the 131-R computer for operation of the All-Altitude Indicator (AAI).

THE OBSERVER STUDY

Longitudinal stick inputs which had been recorded during two missions of the pilot study were played into the mechanization during the observer study. The modifications of the mechanization consisted of disconnecting the stick inputs from the seat and inserting the recorded stick inputs just downstream from the dead space circuit. Lateral stick inputs were commanded by the computer operator. All computer-operated instruments except the AAI were disabled. The terrain signal was not used during this phase. The following data were recorded during the observer study: pilot acceleration (from seat), compass heading (computed), longitudinal stick displacement (computed), and RMS pilot acceleration (from seat).

APPENDIX IV
EXPERIMENTAL RUNS SCHEDULE

THE PILOT STUDY

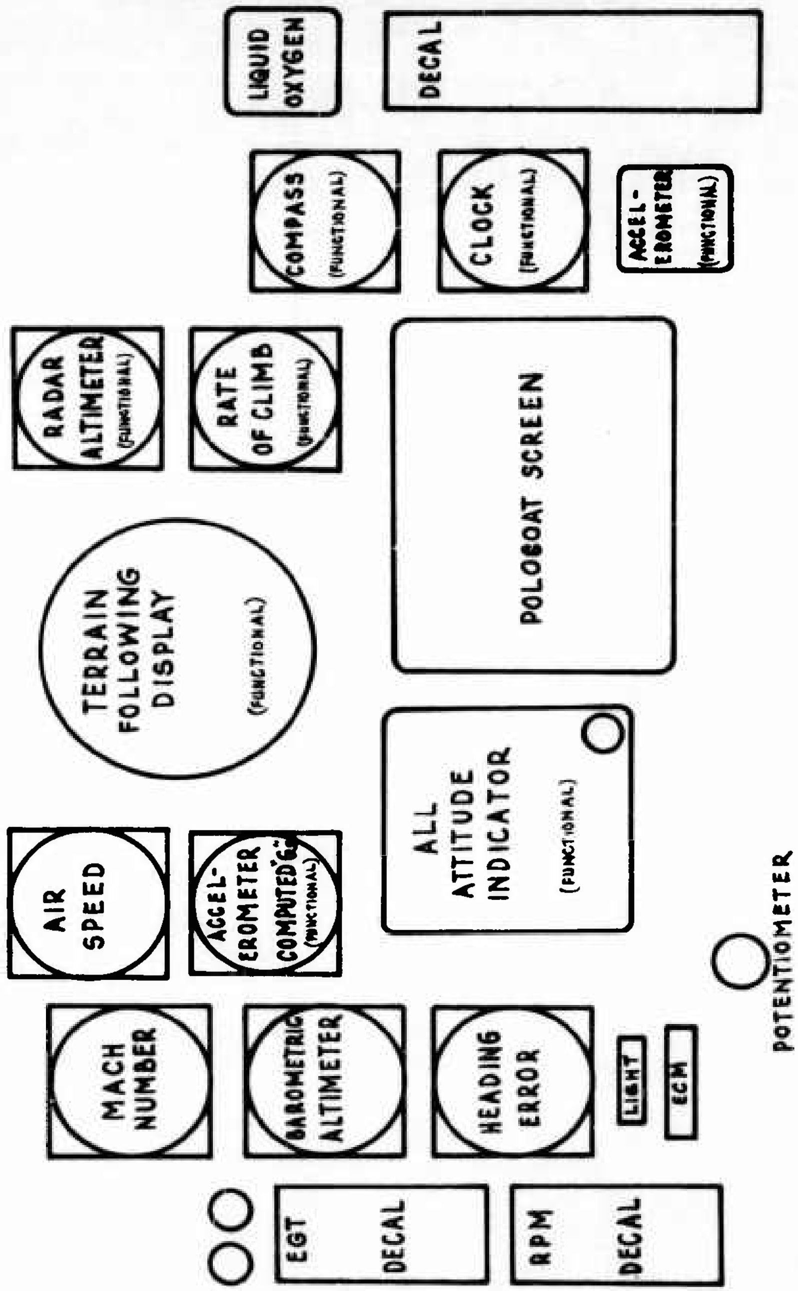
RMS TURBULENCE LEVELS

Series	Initial Cruise 0.4 Mach	Dash 0.9 Mach	Final Cruise 0.4 Mach
1	2 ft/sec	8 ft/sec	4 ft/sec
2	4 ft/sec	6 ft/sec	8 ft/sec
3	8 ft/sec	10 ft/sec	2 ft/sec
4	10 ft/sec	4 ft/sec	6 ft/sec
5	6 ft/sec	2 ft/sec	10 ft/sec
6	2 ft/sec	8 ft/sec	4 ft/sec
7	4 ft/sec	6 ft/sec	8 ft/sec
8	8 ft/sec	10 ft/sec	2 ft/sec
9	10 ft/sec	4 ft/sec	6 ft/sec
10	6 ft/sec	2 ft/sec	10 ft/sec

THE OBSERVER STUDY

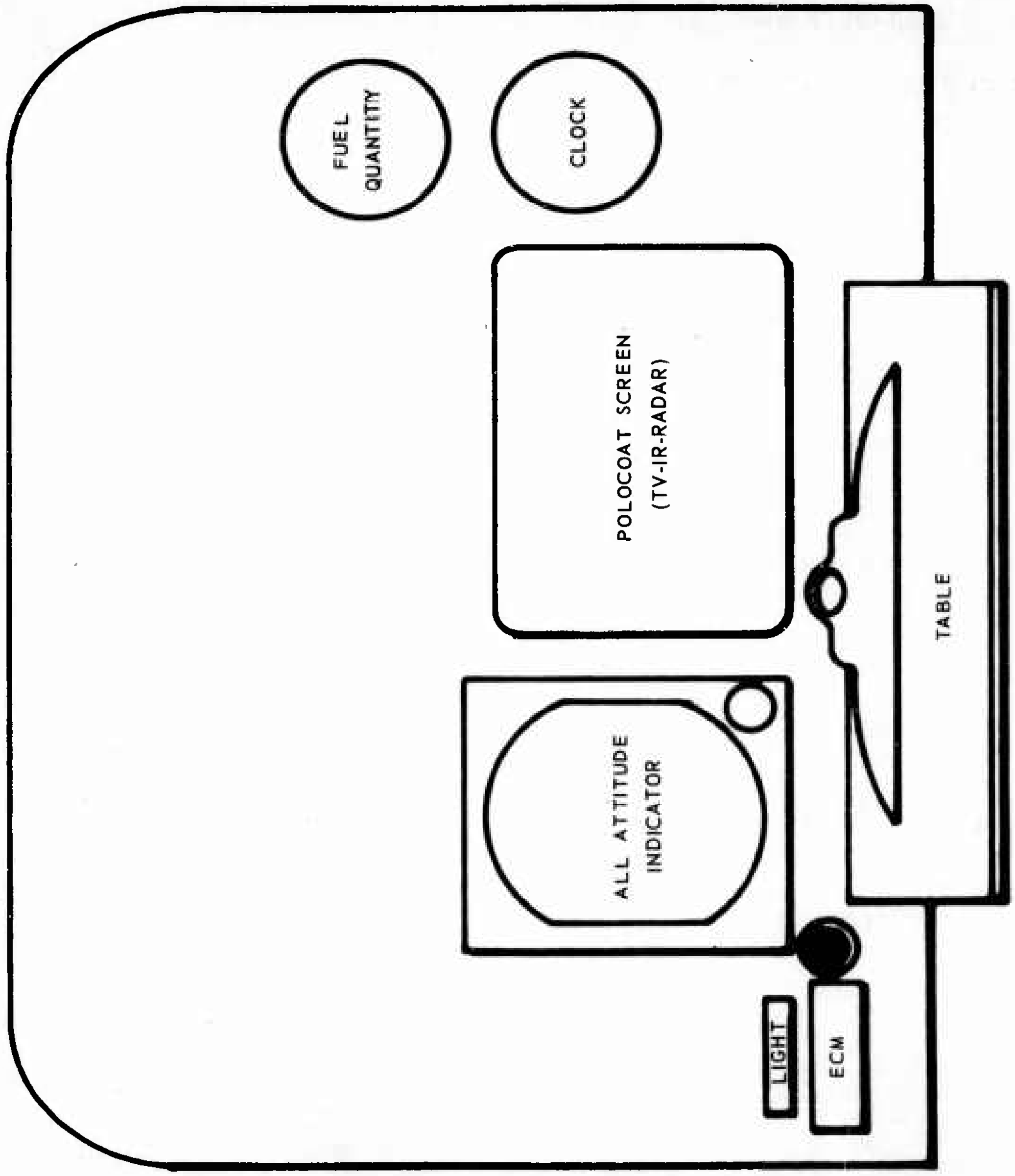
Series	RMS Turbulence Levels: Initial Cruise 0.4 Mach	Dash 0.9 Mach	Final Cruise 0.4 Mach	Pilotage	Mission Plan
1	2 ft/sec	8 ft/sec	4 ft/sec	A	A
2	4 ft/sec	6 ft/sec	8 ft/sec	B	B
3	8 ft/sec	10 ft/sec	2 ft/sec	A	C
4	10 ft/sec	4 ft/sec	6 ft/sec	B	A
5	6 ft/sec	2 ft/sec	10 ft/sec	A	B
6	2 ft/sec	8 ft/sec	4 ft/sec	B	C
7	4 ft/sec	6 ft/sec	8 ft/sec	A	A
8	8 ft/sec	10 ft/sec	2 ft/sec	B	B
9	10 ft/sec	4 ft/sec	6 ft/sec	A	C
10	6 ft/sec	2 ft/sec	10 ft/sec	B	A

APPENDIX V
PILOT STUDY COCKPIT DISPLAY



APPENDIX VI

OBSERVER STUDY COCKPIT DISPLAY



APPENDIX VII
CHRONOLOGICAL LIST OF TASKS, PILOT STUDY

Elapsed Time	Task
Initial Cruise - .4 Mach	
05 minutes	ECM jamming operation
10	Heading change
	Out-of-cockpit surveillance
15	Heading change
	Out-of-cockpit surveillance
20	Out-of-cockpit surveillance
25	Out-of-cockpit surveillance
30	ECM jamming operation
	Heading change
50	Out-of-cockpit surveillance
55	Heading change
	Heading change
	Out-of-cockpit surveillance
60	Out-of-cockpit surveillance
	ECM jamming operation
	Out-of-cockpit surveillance
65	Out-of-cockpit surveillance
	Heading change
70	Out-of-cockpit surveillance
80	Heading change
	Out-of-cockpit surveillance
Dash - .9 Mach	
85	Out-of-cockpit surveillance
	Heading change
90	ECM jamming operation
	Out-of-cockpit surveillance
95	Out-of-cockpit surveillance
	Heading change
	ECM jamming operation
100	Heading change
	Out-of-cockpit surveillance

Final Cruise - .4 Mach

105	ECM jamming operation
110	Out-of-cockpit surveillance
115	Heading change
120	Out-of-cockpit surveillance
125	Heading change
130	Heading change
	ECM jamming operation
	Out-of-cockpit surveillance
140	Out-of-cockpit surveillance
150	Out-of-cockpit surveillance
	Heading change
160	ECM jamming operation
	Out-of-cockpit surveillance
165	Heading change
170	Heading change
175	Out-of-cockpit surveillance
180	ECM jamming operation
	Heading change
	End of mission

APPENDIX VIII
CHRONOLOGICAL LIST OF TASKS, OBSERVER STUDY

Elapsed Time	Task
Initial Cruise - .4 Mach	
04 minutes	Out-of-cockpit surveillance
08	Out-of-cockpit surveillance
09	ECM jamming operation
11	Out-of-cockpit surveillance
15	ECM jamming operation
16	Navigational information charting
17	Out-of-cockpit surveillance
19	Out-of-cockpit surveillance
20	ECM jamming operation
23	Out-of-cockpit surveillance
28	Out-of-cockpit surveillance
31	Navigation: new heading, estimated time to arrival (ETA), current ground speed and wind velocity required
32	ECM jamming operation
33	Out-of-cockpit surveillance
34	Out-of-cockpit surveillance
35	Out-of-cockpit surveillance
37	ECM jamming operation
39	Out-of-cockpit surveillance
41	Navigation: new heading and ETA required
42	Out-of-cockpit surveillance
45	Out-of-cockpit surveillance
47	Out-of-cockpit surveillance
50	Out-of-cockpit surveillance
52	Navigation: new heading, ETA, current ground speed and wind velocity required
54	Out-of-cockpit surveillance
55	Out-of-cockpit surveillance
57	ECM jamming operation

60	Out-of-cockpit surveillance
62	Out-of-cockpit surveillance
63	Navigation: new heading and ETA required
66	ECM jamming operation
68	Out-of-cockpit surveillance
70	Navigation: new heading and ETA required
72	TV in-cockpit surveillance tasks (2 min)
77	IR and radar in-cockpit surveillance tasks (4 min)
78	ECM jamming operation
80	Navigation: new heading and ETA required

<u>Dash - .9 Mach</u>

81	Out-of-cockpit surveillance
82	Out-of-cockpit surveillance
82	ECM jamming operation
83	ECM jamming operation
84	Out-of-cockpit surveillance
85	ECM jamming operation
86	ECM jamming operation
87	Navigation: new heading and ETA required
87	TV and IR in-cockpit surveillance tasks (2 min)
88	Out-of-cockpit surveillance
89	ECM jamming operation
90	Out-of-cockpit surveillance
92	ECM jamming operation
93	ECM jamming operation
94	Navigation: new heading and ETA required
95	Out-of-cockpit surveillance
96	Out-of-cockpit surveillance
97	ECM jamming operation
98	Out-of-cockpit surveillance
99	ECM jamming operation

100	ECM jamming operation

Final Cruise - .4 Mach

101	Out-of-cockpit surveillance
102	Navigation: new heading and ETA required
107	Out-of-cockpit surveillance
108	ECM jamming operation
109	ECM jamming operation
110	Out-of-cockpit surveillance
111	Out-of-cockpit surveillance
112	Navigation: new heading and ETA required
114	Out-of-cockpit surveillance
115	Out-of-cockpit surveillance
116	Out-of-cockpit surveillance
124	Radar in-cockpit surveillance tasks (2 min)
125	Navigation: new heading and ETA required
127	Out-of-cockpit surveillance
130	ECM jamming operation
131	Out-of-cockpit surveillance
133	Out-of-cockpit surveillance
136	TV in-cockpit surveillance tasks (2 min)
138	Navigational information charting
141	Navigation: new heading, ETA, current ground speed and wind velocity required
144	Out-of-cockpit surveillance
145	ECM jamming operation
147	Out-of-cockpit surveillance
148	Navigation: new heading and ETA required
150	Out-of-cockpit surveillance
152	Out-of-cockpit surveillance
153	ECM jamming operation
155	Out-of-cockpit surveillance
157	ECM jamming operation
158	IR and radar in-cockpit surveillance tasks (4 min)

159	ECM jamming operation
160	ECM jamming operation
161	ECM jamming operation
162	Out-of-cockpit surveillance
164	Out-of-cockpit surveillance
165	Navigation: new heading and ETA required
168	Out-of-cockpit surveillance
170	Out-of-cockpit surveillance
171	Out-of-cockpit surveillance
173	Out-of-cockpit surveillance
174	Out-of-cockpit surveillance
175	ECM jamming operation
177	ECM jamming operation
180	End of mission

APPENDIX IX
PILOT'S BRIEFING FORM

1. **Type of airplane the G-Seat simulates:**

   a) Set optimally for .9 Mach

   b) Can be flown at .4 Mach

   c) The aircraft is well damped in attitude (pitch, roll, yaw) and should not give the pilot any undue concern about controlling attitude.

   d) Control Forces

      1) 4.5 lbs/G at 0.9 Mach

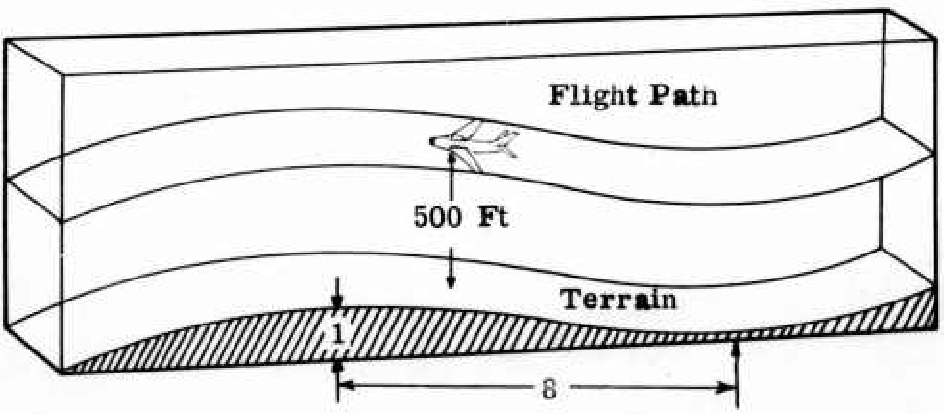
      2) 21 lbs/G at 0.4 Mach

      3) Will feel like power controls with sort of a spring feel in pitch

   e) Simulates an aircraft in the F-86 or F-84 category

2. **Terrain Following:**

   a) 1:8 undulation type terrain



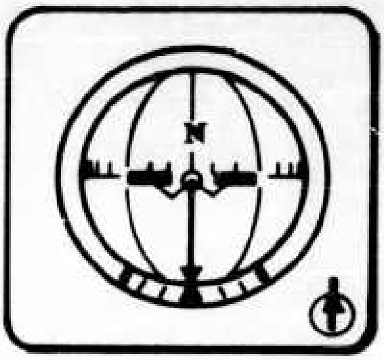
X - Section of terrain-following mission

b) Speed 1004/sec at 0.9 Mach

c) 446/sec at 0.4 Mach

3. <u>Instrumentation:</u>

a) All Attitude Indicator (AAI)



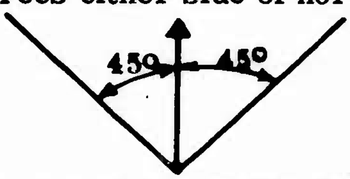
1) Heading (slaved to fluxgate unit in wing)

2) Pitch

3) Roll

4) Yaw

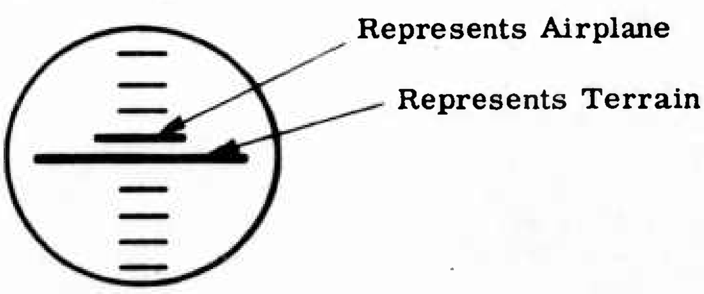
b) Due to a 90 degree limitation in the computer we are able to fly only 45 degrees either side of north.



Therefore, our mission will be within these confines.

c) <u>Terrain Following:</u>

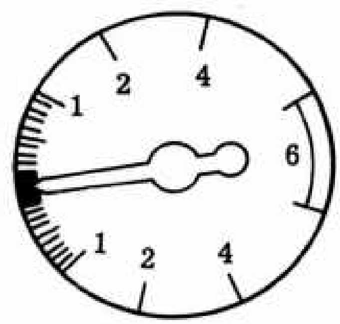
1) Gives an indication to fly a predetermined distance above the ground. This instrument will indicate altitude only when the bars are superimposed; then it will indicate 500 feet above the ground.

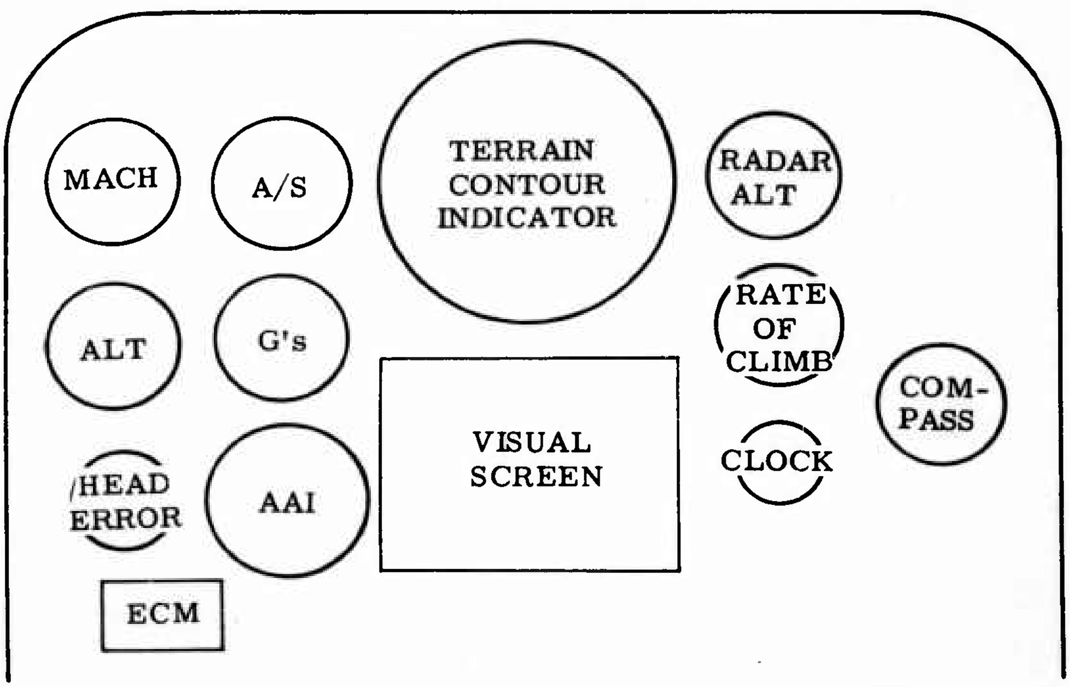


Fly the airplane to the terrain; the terrain line will be the moving line on the scope. The instrument will be used like an attitude indicator.

d) <u>Rate-of-Climb Indicator:</u>

To be used in conjunction with the terrain-following line:





NOTES: The radar altimeter will be used to read altitude.

There is a "kill button" on the upper left portion of the pilot's stick grip. This button will be used by the pilot in the event of an emergency. It is requested that if he is able, he should ask the controller to bring him down, since this is much easier on the hydraulic system of the seat.

The pilot will not need to worry about the ECM frequency unless the green light is on.

4. <u>Mission and Tasks:</u>

a) This mission simulates a low-altitude high-speed surveillance flight. The flight will proceed down a north-south valley over a river, where the enemy is located to the east and our own troops to the west of the river. On this flight the pilot will give his visual sightings to one of the three control stations located in friendly territory. He will receive no acknowledgement of his transmissions.

Because the pilot has only a terrain contour line and no forward-looking terrain avoidance radar, he will fly a preplotted mission with predetermined checkpoints to enable him to navigate safely down the valley. A departure from the flight plan will end in collision with the ridges.

b) Tasks:

1) The pilot will maintain control of the aircraft under varying conditions of turbulence and speed.

a) .9 Mach

b) .4 Mach

c) gusts from 2 to 10 ft/sec (max of about 3 G's)

2) He will adhere to a predetermined flight plan which will involve assessment of both visual and instrument indications and engage in pilot-controller or pilot-observer communications.

3) The pilot will use the terrain-contour line indicator to maintain a 500-foot distance between his aircraft and the ground.

4) He will be required to carry out surveillance tasks, such as reporting railway tracks, trees, armament, etc. These displays will be flashed on a screen (slides) which the pilot will be able to see while in flight.

5) Because of entry into enemy territory, the pilot will be required to monitor an electronic countermeasure (ECM) indicator in the cockpit. Detection of enemy radar by the ECM equipment will result in a green light on the indicator, accompanied by a frequency reading. The pilot will report the frequency and then zero the needle with the knob.

6) The pilot will be required to identify certain check points from film strips that will be presented to him through the visual screen in the cockpit. The film strips will be divided into TV, infrared, and radar type film strips. He will be shown the checkpoints prior to identification.

7) In conclusion, the importance of staying within the predetermined flight path will be noted. Flying too high could result in missile kill; too low will result in collision with the ground; too far to either side, of course, will result in a collision with the mountains.

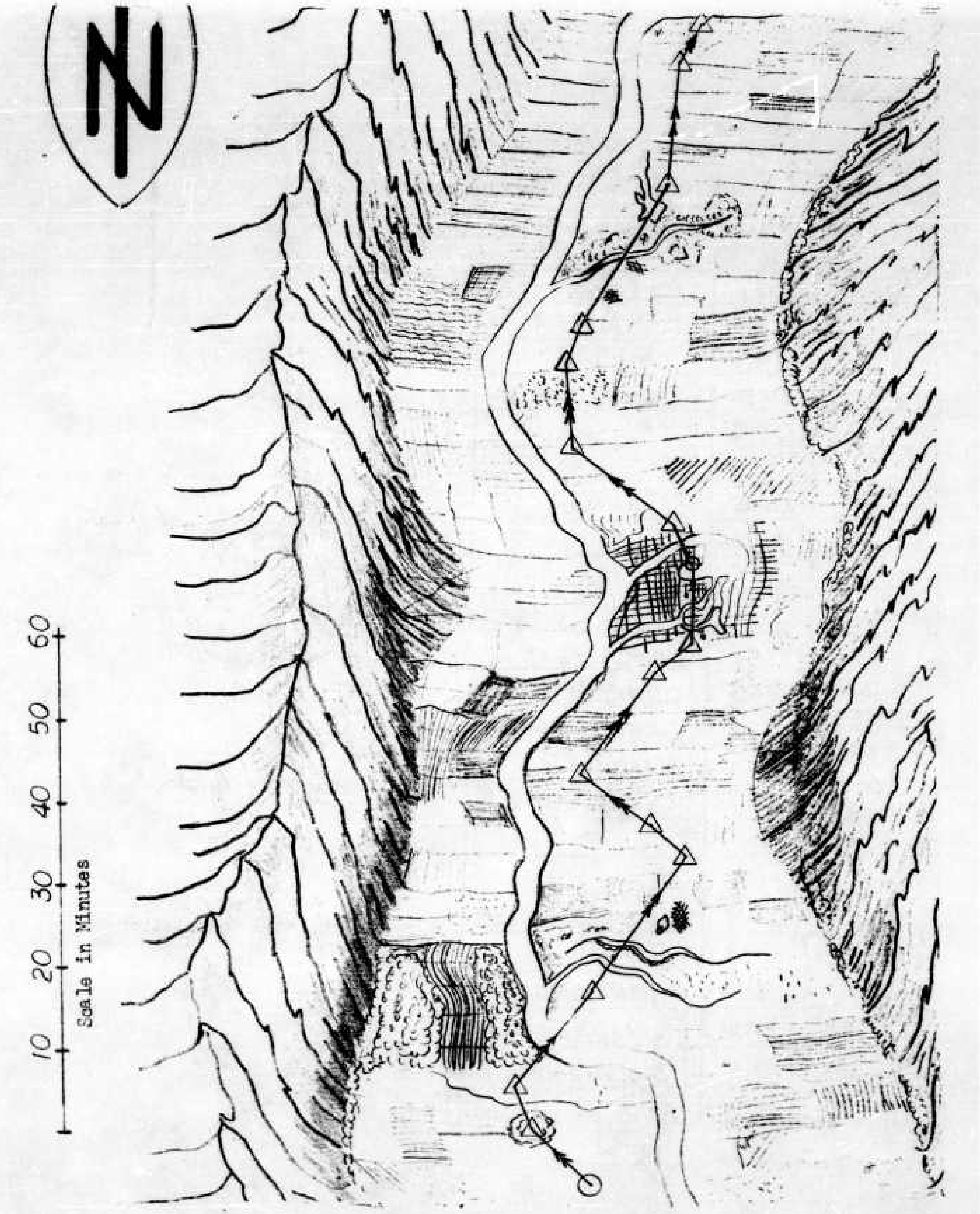


Figure 17
Mission Profile

APPENDIX X

SAMPLES OF OPERATOR HANDWRITING

UNDER HIGH TURBULENCE

START	347	DELAND
+12	330	St Aug. 4 W
	320	[illegible]
+21	015	JACKSONVILLE
+29	030	[illegible]
+43	005	SAVANNAH
1+00	012	Bamberg
1+11	025	Col
1+19	352	LANCASTER
1+23	045	CHARLOTTE
1+30	031	GREENSBORO
1+32	012	DANVILLE
1+34	047	LYNCHBURG
1+55	030	
2+10	039	WASHINGTON DC
2+19	348	BALTIMORE
2+31	353	HARRISBURG
2+44	026	WILLIAMSPORT
2+5?	015	BINGHAMPTON
		END OF MISSION

Recording of Elapsed Time

ETA GS

~~[illegible]~~ 250

~~[illegible]~~ F42

WIND

258/25K 170NK

~~[illegible]~~ 286NK/100

WIND

~~[illegible]~~ 008/~~40K~~

020

Navigational Computations

APPENDIX XI

TEST PILOT OPINION

SUBJECTIVE DESCRIPTION OF GUST-

LEVELS SIMULATED IN STUDY

A brief familiarization flight lasting 22 minutes was made on the G-seat at varying rms levels of gust velocity. This flight was made by an NAA test pilot (W. J. Potocki) prior to the commencement of the experiment. Observations were made regarding tracking performance and associated effects under conditions of low-level, high-speed flight (0.9 Mach). This information is based on the gust response of aircraft characteristics specified in this study. The response of the seat for other configurations would, of course, be quite different.

The time spent at each level of gusts was as follows:

Gust: ft/sec RMS	2	4	6	8	10	12	14
Time - minutes	0.2	2	1	15	1.5	1	2

PILOT COMMENTS

Gusts at 2 ft/sec RMS (0.9 Mach)

The gusts are sharp and the motion appears more like low-frequency vibration. This motion is fairly uniform for up and down gusts, and the difference between the peaks is not readily discernible. Tracking task is not affected.

Gusts at 4 ft/sec RMS (0.9 Mach)

This is a similar case to the one above, except that it is somewhat more severe. There is no noticeable effect on the tracking task. The reading of small dials is now, however, affected and more concentration is needed. The body can still be in a relaxed state without any great need for bracing and tensioning of muscles.

Gusts at 6 ft/sec RMS (0.9 Mach)

At this level there appears for the first time a need for tensioning of the body muscles in order to brace it against the movement of the seat, to ensure that both moved as one unit. This means that the body is now actively participating in the motion, rather than being acted upon as before. This is the reason for the eventual setting-in of fatigue, resulting from G-jolts. The tracking is still quite easy, but the level of concentration now has gone up. This is the first time that the jarred pictures of the display appear. Smaller numbers on the dials are now becoming unreadable with an ordinary scan.

Gusts at 8 ft/sec RMS (0.9 Mach)

This is about the limit for effective tracking, which requires much concentration. The muscles are tense and make occasionally erratic stick input. The picture is now always jarred, but still well distinguishable. At higher G-loadings the task can barely be performed. It is now impossible to read small decals on the AAI and only large numbers can be absorbed. The width of the instrument pointers is insufficient to provide readily apparent indications. The overall level of perceptive power falls noticeably as the cues from peripheral vision are unrelated and reduced to the point that the instrument flight is no longer a matter of smooth visual and muscular correlation. Now, perception of attitude change is slow and halting, while the control movements are deliberate.

Gusts at 10 ft/sec RMS (0.9 Mach)

This is the beginning of an unworkable level. The instrument presentation is now always heavily jarred and reading of instruments is made with difficulty if accuracy is intended. The sense of stability in the display is no longer obvious, resulting in immediate deterioration in the tracking performance once the attention is diverted to other tasks. The neck muscles are now under noticeable tension in order to prevent excessive movement of the head. The body is also rather tensed and any relaxation gives rise to some slight body movement with respect to seat within the restraint of the harness.

Gusts at 12 ft/sec RMS (0.9 Mach)

The movement of eyes during seat motion gives rise to heavy jarring of cockpit display. Instruments in the cockpit can now only be read with marked attention and deliberation. The head movements result from the motion, although this can still be controlled. The performance level is low and flight on instruments is inaccurate.

Gusts at 14 ft/sec RMS (0.9 Mach)

Only about 3-5 minutes at this level could be contemplated for practical purposes on the simulator. The task is now rather beyond the capability of the pilot and the discomfort level is rapidly increasing. The deliberate tensioning of the neck muscles can still keep the head from moving excessively. The body is tensed all over and tires quickly. The body restraint is still acceptable, provided an effort is made to achieve rigidity of the limbs.

NOTE: The writer is in agreement with the opinion expressed by other sources that gust velocities in excess of 10 ft/sec RMS as simulated on the G-seat are seldom encountered in flight.

In view of severity of G-onset reversals and simultaneous high frequency of the motion, it would seem proper to approach the high gust region areas cautiously, particularly regarding duration of exposure. This appears to be a case for interest and active participation of aviation medicine experts.

Conclusions

Brief experience of G-seat jolts at varying gust velocities indicates that at velocities in excess of 6 ft/sec the main source of difficulty comes from jarred vision and tenseness of the muscles. The former impairs instrument flight and will also affect visual flight. The latter contributes in a large measure to fatigue experience in this flight regime.

At gust velocities in excess of 8 ft/sec there is a gradual onset of discomfort which becomes tolerable for only short periods of time at gust levels of 14 ft/sec.

The instrument design for low-level, high-speed cockpit should provide for larger face and more prominent decals and pointers. A heads-up display of vital information may be a requirement.

For gust velocities in the region of 6-10 ft/sec in designs for high-speed, low-level mission, it may be necessary to provide head and limb restraint for the crew.

In excess of 10 ft/sec gust intensity level, gust alleviation may be necessary.

APPENDIX XII
OBSERVER'S POST-FLIGHT COMMENTS

Detailed comments to certain key questions were solicited from all observers after certain selected simulator runs. Their comments are listed below.

Special Endurance Runs

These runs consisted of 180 minutes at 10 ft/sec, 0.9 Mach (heavy turbulence, maximum speed).

Question: Were you able to use your computer and plotter?

Observer A

1. There is very little trouble using the computer for general information. Detailed work is very difficult due to the high vibration level. The wind-free side is very hard to use due to the size and color of the figures.

2. Use of the plotter is almost impossible due to the size of numbers and distance from the eye to chart location. Mental calculations with relative distances worked faster and gave workable solutions.

3. Normal dividers are too dangerous.

Observer B

Yes, the computer could be used and the divider also. However, much less accuracy was obtained than at lower turbulence levels. Dividers used at this level should not be sharp-pointed. The navigator often pricks himself when they are. Also, the divider can and will bound around the cockpit at this level.

Observer C

Yes. Not during peak gusts or vibrations, though.

Observer D

Yes, but computer had to be held firmly and read at least three times for any degree of accuracy.

Question: How did the gusts affect your work?

Observer A

Many responses had to be stored up until the gust level subsided and then written down. Computer work was done with approximmate degrees, miles, etc, to enable quick responses. Detailed work was almost impossible and would have been too time-consuming at the calculated air speeds of the aircraft.

Observer B

Initially, at these levels, I have found myself highly frustrated due to blurred vision and the incapacity to use my hands when working problems. I became adapted to these levels after several runs by doing less writing and more mental solving of problems. Frustration was related directly to being able to get the tasks accomplished. The observation tasks were not affected by the gusts.

Observer C

Couldn't work; could read gauges okay.

Observer D

No noticeable effects.

Question: Did you feel you could go longer?

Observer A

I felt the same after (three hours) as I did after 15 minutes in the seat. The human body is able to withstand any level with practice. Other than becoming overly fatigued with six or more hours, I felt that the limit is not with the man, but with the level of training and association that the man has gone through. I feel I could go again and maybe six hours.

Observer B

Yes, this level became quite comfortable and I was more alert than at lower gust levels. It did take physical and mental conditioning to arrive at this stage. I don't believe one could accomplish the job with the same ease on his first mission.

Observer C

Yes.

Observer D

Yes, at least another hour.

Question: How did you feel physically after the ride? Any particular aches?

Observer A

I had no physical effects that would affect my continuing a mission. I would say the first 30 minutes were harder than the last two and one-half hours due to the body adjusting to the outer stimulant.

Observer B

After one hour and five minutes of the flight, I picked up a stomach cramp which lasted only 10 minutes. Other than this there were no physical discrepancies noted. After one hour and 50 minutes I felt quite elated, with no physical strain or fatigue.

Observer C

Okay

Observer D

None.

Question: Were you able to read the instruments?

Observer A

Instruments were very hard to read, and most responses were made by associating marks with known readings. The vertical alignment of the instruments magnifies the problem.

Observer B

Yes. The best time to read the instruments was during momentary periods between persistent gusts. There were times when the instruments could not be read at that instant, but within seconds there would be a pause long enough to permit accurate reading.

Observer C

During excessive vibration, the gauges were readable with some difficulty; fuel gauge was poor at all times.

Observer D

Yes.

Question: Were you able to read your computer?

Observer A

Black on white numbers could be read, but all areas in between were interpolated.

Observer B

The computer could be read on the computer side. The information on the wind side could be read also, but due to vibrations was unable to mark the wind accurately. (This causes the discrepancies in interpretation of wind speed, direction, and draft; not the fact that one is unable to read it.)

Observer C

Not during maximum vibrations.

Observer D

Yes

Question: Any general comments or suggestions ? (Take into account that these may be extremely useful for future Army surveillance aircraft design.)

Observer A

I feel that with practice anyone can accomplish a three-hour mission at this level or higher. By hanging forward in the harness, I found that the vertical effect was not transferred through my body. By relaxing and keeping my arms close to my body, I could work easily and not become fatigued.

The vibration level is transferred to the visual sense and tends to cause a mild frustration due to the inability to read and figure. This frustration is lessened greatly by training and association and can, I feel, be overcome by practice.

I feel the instrument panel could be tilted 45 degrees to reduce the vertical component of motion. This would help in making readings.

Work areas and computers should be closer to the user's eyes. This will enable the man to keep his arms in close to his body and have close visual reference to his charts.

Observer B

First, one should physically slump forward in the harness to give a recoil effect to the upper torso so that it can "give" with the pitch of the plane. To sit upright causes the vibrations and gust wallops to be transmitted from the base of the spine throughout the body.

All equipment should be clipped in place and tied down. It is not adequate to simply tie it down as the equipment would still be free to roam the cockpit.

Instruments should be read between peak gusts for accuracy. If read at any other time, they become merely "close guesses".

One should solve navigation problems by committing data to memory and working without the use of pen or pencil. This is most important. Observers operating under these conditions should get many practical navigation problems to solve without a pencil. I can see no other solution for this, even over a long period.

Fuel consumption should be plotted on the chart by following the chart in front of the body, with elbows next to the side. This prevents the two independent motions of the aircraft (and chart or clip board) and the body.

After the observer has become conditioned to the turbulence levels and frustrations are at a minimum, the turbulence level has little effect on aerial observations. Subsequently, speed alone remains the barrier in observation.

To more effectively observe at high speeds, the observers will have to be (1) highly alert to identify objects at a glance, (2) trained in the identification of all military weapons and equipment, (3) record times and ground speeds of observation on paper or have a recording made of time and identification.

Observer C

Softer seat is mandatory.

Observer D

None

Special Run

This special run consisted of 180 minutes at 10 ft/sec (0.9 Mach). Although like the preceding special runs, it was repeated on one subject. His comments on this report run appear below.

Question: Were you able to use your computer and plotter (and dividers)?

Observer B

The divider was not used because it is dangerous at this level and accurate readings cannot be taken with it. The computer was used effectively. However, on the windface side of the computer, less accuracy was received than at lower turbulence levels.

Question: How did the gusts affect your work?

Observer B

The gusts made writing extremely difficult but readable if the navigator is patient enough to "time" his writing between impossible gusts. More mental work becomes a necessity as physical writing is so difficult.

Question: Did you feel you could go longer?

Observer B

Yes, definitely. This was only my second prolonged ride at this level, yet I could tell surprising difference in the second over the first. One becomes adapted to this level as easily as the lower levels, though not quite so quickly. I do feel that a navigator who had had no previous flights at these turbulence and speed levels would get sick or nauseated readily. Also, there are noticeable strains on the muscles of the abdomen. These muscles are strengthened with previous flights. The novice will likely become nauseated and have stomach cramps if he doesn't advance to this level in increasingly difficult steps.

Question: How did you feel physically after the ride? Any particular aches?

Observer B

There were no aches and although I had no stomach cramps during the flight, I could feel the pressure there during the flight. After the flight the abdomen was sensitive. I feel that in a couple more similar flights it would not be noticeable at all. It was less fatiguing than the lower levels (this is speaking only of the simulator.) In actuality, I believe it would be worse (at this level) than lower levels, due to anxiety encountered in actual flight.

Question: Were you able to read the instruments?

Observer B

Yes, at all times. There was a slight chance of minute inaccuracy at the higher turbulence levels, but there were lulls in turbulence where the instruments could be read with absolute accuracy.

Question: Were you able to read your computer?

Observer B

Yes, but it was not very accurate due to the inaccurate pencil plots. It was still definitely useful. On the side opposite the windface there was no trouble in reading ground speed and ETA's.

Question: Any comments?

Observer B

Any ECM indicator in actuality should be an audio- or touch-indicator. Visual readings are not the final answer. Vision is often distorted. A touch-indicator could be a buzzer or heat-indicator attached to the leg.

I would like to reiterate that this level requires adjusting to. One inexperienced at it could expect nausea and maybe stomach cramps if not in good physical condition or if he had not worked himself up to this level. Also, one should eat lightly before a mission of this type.

Safety belts and shoulder harnesses should be kept as tight as possible and a helmet should be worn at all times. A fracture of the skull is probable without a helmet.

One's attitude must be geared to this level of turbulence and speed. It takes more of an effort to accomplish tasks and unless forcing oneself, one may develop a "could-care-less" attitude due to the difficulty of the tasks.

Again, I found this level less fatiguing in the simulator than the lower levels. I do not believe this is true in actuality due to anxiety at low level at these high speeds.

Regular Run

These runs consisted of 80 minutes at 8 ft/sec (0.4 Mach), 20 minutes at 10 ft/sec (0.9 Mach), and 80 minutes at 2 ft/sec (0.4 Mach). Only one observer was debriefed after these runs.

Question: Were you able to use your computer and plotter (and dividers)?

Observer B

Yes, I was able to use all of them. However, in the gusts at the 8 and 10 ft/sec gust level I discontinued the use of the divider and made distance measurements with my pencil.

Question: How did the gusts affect your work?

Observer B

Very little. Only with the divider. There were no computations to be made during the dash where I believe I would have had considerable difficulty.

Question: Did you feel you could go longer?

Observer B

Yes, definitely.

Question: How did you feel physically after the rides? Any particular aches?

Observer B

No after-effects at all. I felt well-rested and no fatigue.

Question: Were you able to read the instruments?

Observer B

Yes. The only difficulty was during the dash (0.9 Mach) where less reading accuracy was obtained. During the dash the error on the fuel consumption could have been $\pm .2$.

Question: Were you able to read your computers?

Observer B

Yes. There was no difficulty at any time in reading the computer. Even making pencil plots was little trouble. However, no plots were made during the dash (0.9 Mach).

Question: Any general comments or suggestions?

Observer B

At the start of these exercises I was very skeptical of the work I could accomplish, but after two weeks I could do all of the work required at any of the turbulence and speed levels given. I believe one could adapt oneself to even higher levels. The main ingredient missing is the anxiety that can't be encountered in a simulator. I think that the idea of using hypnosis on the participant to simulate battlefield conditions could produce much better test results than the tests are presently getting.

Regular Run

These runs consisted of 80 minutes at 2 ft/sec (0.4 Mach), 20 minutes at 8 ft/sec (0.9 Mach), and 80 minutes at 4 ft/sec (0.4 Mach). Only three observers were debriefed after these runs.

Question: Were you able to use your computer and plotter (and dividers)?

Observer B

Yes

Observer C

Yes, but with difficulty at the higher gust level.

Observer D

Yes, at all levels except the dash. Although there was no requirement during the dash period, I found the computer exceedingly difficult to read.

Question: How did the gusts affect your work?

Observer B

High gust level makes map and computer hard to read.

Observer C

Slightly.

Observer D

I could complete all tasks assigned with no problem areas during low gust levels (2 and 4 ft/sec). During the dash at 0.9 Mach, fuel and ECM were hard to read accurately. The ECM dial (crank) is not suitable for use during the dash as the hand slips and continuous cranking is required.

Question: Did you feel you could go longer?

Observer B

Yes

Observer C

Yes

Observer D

Yes, probably three hours longer.

Question: How did you feel physically after the rides? Any particular aches?

Observer B

Fine - no aches.

Observer C

None

Observer D

None

Question: Were you able to read the instruments ?

Observer B

Yes. Even during extreme turbulence, difficulty was slight.

Observer C

Yes

Observer D

Fuel and ECM difficult during dash (8 ft/sec-0.9 Mach).
Fuel reading would vary, depending upon pilot's position.

Question: Were you able to read your computers ?

Observer B

Yes

Observer C

Yes

Observer D

Yes. Computer was not required at 0.9 Mach but was effective at that level.

Question: Any general comments or suggestions?

Observer B

None

Observer C

ECM needle always moves before light comes on; this gives advance warning.

Observer D

Pushbutton instead of crank for ECM.

APPENDIX XIII

GROSS MISSION/TASK ANALYSIS

U.S. ARMY SURVEILLANCE MISSION

1. Mission Segments

There are five clearly defined segments in a typical surveillance mission: premission planning and preflight; takeoff and climb-out; cruise to surveillance area; dash over hostile territory; return cruise to base; and letdown approach and landing. This gross task analysis is restricted to the cruise and dash segments of the mission since these are the mission segments within which operator performance will be investigated in this study.

2. Mission Conditions

A mission is affected by conditions under which the weapon system must operate. These conditions include weather, checkpoint availability, terrain features, enemy defensive activity, and system malfunction. Variations in these conditions will result in changes in the task demands. Therefore, operator performance will vary under actual flight conditions from one mission to another. This analysis covers only those tasks which must be performed under all mission conditions.

3. Assumptions about the NSA Systems Pertinent to this Investigation

The assumption is made that the NSA will have the following basic equipment:

(a) automatic stabilization equipment
(b) self-contained navigation system
(c) terrain-following equipment
(d) automatic direction-finding equipment
(e) infrared, radar, and television (electro-optical) reconnaissance sensors
(f) electronic countermeasure equipment (ECM)

Therefore, operator tasks connected with operation of this equipment have been included in the mission task analysis.

4. Feasibility of One-Man Crew

Since one of the objectives of this contract is to study the feasibility of a one-man crew, the gross mission/task analysis has been combined to reflect tasks which must be performed by an airborne crew.

5. Pilot-Observer Gross Task Analysis (Cruise-to-Target, Dash-Over-Target, and Return Cruise Mission Segments)

5.1 Cruise-to-Target

Crew Member		Task
Pilot	Task 1.	Operate flight controls, taking into account terrain, weather conditions, and possible hostile activity.
Pilot	Task 2.	Maintain correct altitude-hold and cruise speed (approximately .4 Mach).
Pilot	Task 3.	Maintain heading to navigational check-point.
Pilot	Task 4.	Monitor all flight instruments and make flight adjustments as indicated.
Pilot	Task 5.	Utilize terrain avoidance display as necessary.
Pilot/Obser-ver	Task 6.	Change heading to new checkpoints as prescribed to maintain correct flight path.
Observer	Task 7.	Adjust ECM system: IR warn to "ON"; Jam control on "DASH-STBY" (standby) chaff control on "STBY". Adjust radar gain.
Pilot	Task 8.	Monitor engine system.
Observer	Task 9.	Maintain continuous visual search for checkpoints.

Observer	Task 10.	Utilize IR-Radar-TV to locate checkpoints and/or confirm out-of-cockpit visual location of checkpoints.
Pilot/Observer	Task 11.	Make investigation corrections as indicated by location of checkpoints. Alter course to next checkpoint (continuous task).
Pilot	Task 12.	Monitor air-conditioning system and make adjustments if necessary.
Pilot	Task 13.	Adjust flight controls as necessary.
Observer	Task 14.	Monitor ECM display and prepare to enact jamming procedures.
Pilot	Task 15.	Continuously monitor flight instruments as needed.
Pilot-Observer	Task 16.	Monitor fuel consumption rates.

5.2 Dash

Pilot	Task 1.	Increase speed to .9 Mach
Pilot	Task 2.	Operate flight controls under new speed, taking into account terrain, weather conditions, and possible hostile activity (fly at 500 feet altitude).
Pilot	Task 3.	Monitor all flight instruments.
Observer	Task 4.	Maintain correct heading and visual search out-of-cockpit for reconnaissance/surveillance information. Visually search for correct checkpoints as necessary.
Observer	Task 5.	Continuously monitor ECM display and perform jamming procedures as necessary.

Observer	Task 6.	Verbally record all surveillance information of military significance observed.
Observer	Task 7.	Record (verbally or otherwise) clock and compass readings of military targets and ECM contracts for reconnaissance/surveillance intelligence.
Pilot	Task 8.	Continuously monitor engine system.
Observer	Task 9.	Utilize IR-Radar-TV sensor displays as needed for reconnaissance/surveillance intelligence.
Pilot/Observer	Task 10.	Make navigation corrections as indicated by location of checkpoints.
Pilot	Task 11.	Monitor air-conditioning system and make adjustments if necessary.
Pilot/Observer	Task 12.	Prepare to abort if necessary.
Pilot/Observer	Task 13.	Monitor fuel consumption rates.

5.3 Return Cruise

Pilot	Task 1.	Reduce speed to economical cruising rate (.4 Mach).
Pilot	Task 2.	Maintain correct heading to follow prescribed flight path to return base. Operate flight controls taking into account terrain, weather conditions, and possible hostile activity.
Pilot	Task 3.	Monitor all flight instruments and make adjustments as necessary.
Pilot	Task 4.	Utilize terrain avoidance displays as necessary.

Observer	Task 5.	Continuously monitor ECM equipment until well into friendly territory.
Pilot	Task 6.	Monitor engine system and make adjustments if malfunctions occur.
Observer	Task 7.	Visually search for checkpoint acquisition in flight path.
Observer	Task 8.	Utilize IR-Radar-TV sensor displays to locate checkpoints and/or confirm out-of-cockpit visual location of checkpoint.
Pilot/Observer	Task 9.	Make navigation corrections as indicated by location of checkpoint.
Pilot	Task 10.	Monitor air-conditioning system and make adjustments as necessary.
Observer	Task 11.	Maintain continuous visual search out-of cockpit for next checkpoint.

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Unclassified Report

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