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Scientific and Technical Information Branch

INTRODUCTION

That portion of the flight-simulation community involved in tactical fighter simulation has been concerned over the utility of both g-seat cueing devices and platform motion systems for several years. The literature is voluminous, with articles by proponents and opponents of each or both (ref. 1). Recent experiences at Langley Research Center (LaRC) in separate applications of a representative of each cueing system have been quite favorable (refs. 2 and 3).

In spite of the successful application and pilot acceptance at Langley, deficiencies in motion cueing exist with each system. The Langley-designed g-seat (ref. 4) has been most effective in presenting normal acceleration cues, particularly sustained cues. It is less effective in its presentation of rotational and translational onset cues and sustained side-force and surge cues. The conventional, six-degree-of-freedom, synergistic platform motion system, the Langley Visual/Motion Simulator (VMS), has no capability for sustained normal acceleration cueing and very limited capability for transient vertical cueing. In fact, the vertical axis is used primarily for turbulence and buffet cueing. The other degrees of freedom are effectively presented by the platform washout system, a system which was also developed at Langley Research Center. Intuitively, the meshing of the two systems to provide an augmented system for six-degree-of-freedom motion cueing was desirable.

In order to measure and analyze the effects of the motion plus g-seat cueing system, a simulation experiment was designed utilizing a pursuit tracking task and an F-16 simulation model with the standard fixed side-arm controller. This paper presents the comparative effects on simulated-pursuit-tracking performance of the following combinations of motion cueing: no motion (fixed-base operation), g-seat only, platform motion only, and platform motion augmented by g-seat. The performance results are presented as standard root-mean-square (rms) error measures, while the analysis tools utilized standard univariate statistical techniques.

SIMULATION FACILITY

The experiment was conducted using LaRC real-time simulation facilities. The mathematical model of the aircraft and the simulation hardware drives were implemented on the Langley Real-Time Simulation System. This system, consisting of a CYBER 175 computer and associated interface equipment, solved the programmed equations 32 times per second. The average time delay from input to output was approximately 47 msec (1.5 times the sample period). The simulation hardware and software utilized are described below.

g-Seat

The g-seat used in this study is one of the Langley-designed and fabricated seat cushions (ref. 2) installed in the Langley Visual/Motion Simulator. The four-cell seat (fig. 1), using a thin air cushion with highly responsive pressure control, was designed to reproduce the same events which occur in an aircraft seat under acceleration loading. The seat is initially biased such that the seat conforms to the pilot to support most of his weight. The initial air pressure allows the two main support areas, the ischial tuberosities, to touch a wood surface and thus begin to compress the flesh near these areas. In this manner, the bias establishes the "firmness" of the seat. As accelerations increase (positive g values), air is removed from the seat, giving the effect of compressing the cushion material and causing more of the pilot's weight to be supported by the area around the tuberosities. However, some air is left in the seat to enhance the cue of sinking into the seat while preventing the false cue of the seat falling away from the sides of the legs and buttocks. For negative g values, sufficient air is added to the seat to remove all contact with the wood and, thus, to uniformly support the body weight without allowing the seat to become firm because of too much air.

This manner of seat operation (i.e., reproducing the aircraft-seat actions) automatically reproduces other related pilot events, such as raising or lowering the body with the resulting change in the eyepoint and the joint (hips and knees) angles. It also results in proper loosening and tightening of the lap belt and shoulder harness. The seat-cushion steady-state time lags are about 35 msec, yielding a total average delay, including computational throughput, of slightly more than 80 msec.

Motion System

The Langley Visual/Motion Simulator (VMS) is a six-degree-of-freedom, synergistic platform motion system with acceleration, velocity, and positional limits. (See fig. 2.) These limits are presented in table I. Time lags of less than 15 msec are achieved by driving the base with lead compensation (ref. 5). Thus, the average total motion delay, including computational throughput, is less than 70 msec and is quite compatible with the rest of the system, including visual delays. The washout system used to present the motion-cue commands to the motion base is nonstandard. It was conceived and developed at Langley Research Center (ref. 6). The basis of the washout is the continuous adaptive change of parameters to (1) minimize a cost functional through continuous steepest descent method and (2) produce the motion cues in translational accelerations and rotational rates within the motion envelope of the synergistic base.

Visual Display

The Langley VMS is provided with an "out-the-window" virtual-image system of the beam-splitter, reflective-mirror type. The system, located nominally 4.17 ft from the pilot's eye, presents a nominal field of view 48° wide and 36° high and uses a 525-line TV raster system. The image system provides a 46° by 26° instantaneous field of view and supplies a color picture of unity magnification with a resolution on the order of 9 minutes of arc.

The scene depicted in the virtual-image display was obtained by video mixing a terrain-model-board picture with a target aircraft and a reticle display. The composite scene presented to the pilot is as shown on a monitor in figure 3 with about 70° left wing down and the target aircraft at 800 ft in the 2 o'clock position of the reticle outer circle. The state-of-the-art TV camera transport system used in conjunction with a sophisticated terrain model board is described in reference 7. The maximum scaled speed capability of the system is 444 knots, with vertical-speed capabilities of ±30 000 ft/min. The translational lags of the system are 15 msec or less. The target-aircraft display was generated by the small model, closed-circuit television system described in reference 3. Elevation and azimuth changes as well as target roll were accomplished electronically. Relative pitch and yaw were obtained by rotation of the two-gimbal support mount. The average total visual delay, including computational throughput delay, was less than 70 msec. The reticle is generated by a computer graphics system with a second-order filter added to match the reticle response to the servo response of the terrain board and target aircraft.

Cockpit Hardware

The general-purpose cockpit of the VMS was modified to represent a fighter by removing the wheel and column and installing a side-arm force-actuated controller on the pilot's right-hand side. The rudder pedals were also configured to be force-actuated. The throttle was installed in the conventional left position; however, the pilot seat was of the general transport type, rather than the special inclined seat of the F-16. No special armrest was provided to support the forearm, although the elbow rest of the transport seat mimicked this function because of the placement of the controller in the same general location as the controller in the actual airplane. Primary instrumentation consisted of an attitude indicator, a vertical-speed indicator, an altimeter, angle-of-attack and sideslip meters, an airspeed indicator, a Mach meter, a turn-and-bank indicator, and a compass card.

Aircraft Mathematical Model

The equations used to describe the motions of the F-16 were nonlinear, six-degree-of-freedom, rigid-body equations referenced to a body-fixed axis system. The aerodynamic data used in the equations of motion were derived from static and dynamic (forced oscillation) wind-tunnel force tests conducted with a 0.15-scale model at a Reynolds number of about 0.8×10^6 and a Mach number of about 0.1. The data included an angle-of-attack range from -10° to 90° and a sideslip range from -40° to 40°. Effects of Mach number, Reynolds number, or aeroelasticity were not included in the mathematical model. Special features of the F-16 model with motion-cue implications included (1) the use of a normal-acceleration command longitudinal control system which provides static stability, normal-acceleration limiting, and angle-of-attack limiting; (2) the use of a roll-rate command system in the roll axis; and (3) the use of an aileron rudder interconnect and a stability-axis yaw damper in the yaw axis. The mass and geometric characteristics of the simulation aircraft are presented in table II. Complete details of the model are documented in reference 8.

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSES

A $2^2 \times 8$ factorial design with a six-degree-of-freedom pursuit tracking task formed the environment within which the data were gathered. Univariate analyses of variance were performed on the root-mean-square (rms) data.

Experimental Design and Task

The factors of the $2^2 \times 8$ factorial design were motion (on or off), g-seat (on or off), and test subjects (eight pilots). Each cell within the design was replicated 10 times; that is, each pilot flew the tracking task 10 times at each combination of the motion and g-seat factors (40 data runs). The tracking task used was approximately 2 minutes in length. The target aircraft was driven by a computer-generated taped maneuver consisting of a 3g turn at a constant airspeed of 285 knots and constant altitude of 2500 ft. The pilot of the pursuit aircraft (simulated F-16) was required to track the target while maintaining a 1000-ft range. If the range became less than 800 ft, the run was repeated. Range information was provided by a standard range analog bar on the reticle scaled for 2000 ft. This caused the required 1000-ft range to appear at the 6 o'clock tab. During the task, the pursuit pilot's tracking reference (reticle) was driven in vertical aircraft body axis by a sum of 13 sinusoids. The sinusoids had a fixed set of amplitudes and frequencies but randomly chosen phases (between -180° and 180°). The phases were randomly chosen so that the test subjects would not learn the movements of the reticle. Table III presents the amplitudes and frequencies in the sum of sine waves. The amplitudes were scaled to limit the maximum deflection of the reticle to ±10°. In order to track the target, the pilot was required to keep the target in the center of the reticle. This provides the same type of tracking task that the pilot would normally encounter in gun tracking with a lead-angle-computing gunsight.

Test Subjects and Procedure

Eight active F-15 pilots, stationed at Langley Air Force Base, were used as test subjects. None of these pilots had previous experience in a research simulator such as the VMS, although some of the pilots had "flown" a moving-base training simulator before and all eight were familiar with the instrument-only F-15 training simulator. Each pilot "flew" the simulation at the four motion/g-seat level combinations. The order in which the pilots flew the combinations was randomly chosen to reduce any learning/fatigue effects. Ten replicates of each combination were performed by the pilots for training and 10 replicates for data. The pilots completed all training combinations before any data runs were started in order to minimize learning effects.

A data-collection period for each simulation combination took about 2 minutes per run, starting from a zero-error trim condition. The first 20 seconds were used to phase in the sum of sines disturbance. The next 15 seconds were used to allow the pilot to stabilize at the full amplitude of the sum of sines disturbance. The remaining 2 minutes were used for data collection. As a means of encouraging the pilots to do their best, they were given the "best" scores to date before their session. Then, their rms vertical and lateral tracking errors and mean range were given to them after each simulation run. This created a very high level of competition among the pilots to achieve lower error scores.

From previous experience, it was suggested that about 15 continuous runs of the tracking task were the maximum number that could be completed without a break before the pilot's performance began to deteriorate because of fatigue. Therefore, one pilot could perform two different cell combinations of 10 replicates, each (with proper rest between the cells) during one 3-hour simulation session. A first session was devoted entirely to familiarizing the pilot with the simulator and the experimental task. Then, two to three sessions were used to complete the entire set for training. Also, before data were taken for a cell combination, the pilot usually took between three to six practice runs.

Performance Measures and Statistical Analyses

The root mean squares of the vertical-height error, lateral displacement error, and control stick force for roll and pitch were computed as measures of performance.

Univariate analysis techniques were applied to the performance measures. The statistical techniques are described in most standard texts on the subject, such as references 9 and 10.

RESULTS

The primary question to be addressed is, Do motion and g-seat cues have an additive effect on the performance of this task?

The rms performance measures and the mnemonics used are shown in table IV. Tables V and VI show mean rms error, standard deviation, and standard error for the lateral and vertical tracking errors (EL and EV) and the roll and pitch control inputs (TAP and TSP) for the four combinations of g-seat and motion conditions. These results are plotted in figures 4 to 7. Tables VII and VIII show the results of an analysis of variance on these four measures.

Table V and figure 4 exhibit highly significant differences (very much less than at 5-percent level) between the fixed-base and g-seat/motion conditions for lateral tracking error. Mean rms error is reduced from 9.043 ft (fixed base) to 7.555 ft by g-seat cues and to 7.746 ft by motion-base cues, a reduction of 16.5 percent and 14.3 percent, respectively. However, the two cues combined provide a significantly lower lateral tracking error of 6.420 ft. The analysis of variance for the lateral tracking error (table VII) shows that there are highly significant effects of pilot, motion, g-seat, pilot by motion, and pilot by g-seat on the lateral tracking error; however, there is no effect of motion by g-seat. Similar results are shown for roll control input (TAP). The plots (fig. 5) for roll control input show a highly significant lowering of the control input (TAP) for motion conditions (F-value of 158.51 versus 6.74 for significance at 1-percent level) with a lesser but still significant (F-value of 9.85 versus 6.74 for significance at 1-percent level) lowering of roll control input for g-seat conditions. As shown in figures 4 and 5, this lowering of the roll stick force is associated with a lowering of the lateral tracking error for both conditions.

The results of the analysis of variance on the vertical tracking error (EV) and pitch control input (TSP) are presented in table VIII. The effects of pilot, g-seat, pilot by motion, and pilot by g-seat are all significant at the l-percent level for EV. No motion effects were expected in the vertical axis, and no significance with respect to vertical error is recorded for the effects of motion and motion by g-seat. The same trends hold for pitch control inputs. Visual presentations of the data for vertical error and pitch input are in figures 6, 7, and 12 to 15. Figures 8 to 15 show the individual pilot differences.

DISCUSSION

From these results, we can see that the g-seat and motion cues have their greatest effect on the pilot's lateral tracking error, even though the reticle is driven vertically only. Similar results are shown in references 11 and 12 for normal acceleration cues presented through g-seat and helmet devices. Our interpretation of this would be as follows: The pilot's first task, in this full six-degree-of-freedom task, is to correct for lateral error so that his X body axis is in the vertical plane of the target body axis system. (See fig. 16.) Once he is "in-plane," the pilot can then reduce the vertical tracking error. This strategy is evidenced by the fact that the lateral error (EL) is less than one-half of the vertical tracking error (EV).

As far as the lateral error is concerned, the data (fig. 4 and tables V and VII) show that the g-seat or motion platform causes a significant and approximately equal reduction of the lateral tracking error. Moreover, the data also show an additive effect (evidenced by fig. 4 and a nonsignificant motion by g-seat effect) in that the combined cues lower the lateral error over each cue used alone. Our interpretation of the additive effect is that the roll-motion cue lowers the pilot's rms roll control (fig. 5), thereby reducing translations which move the pilot's aircraft "out-of-plane." The g-seat provides primarily normal acceleration cues and reduces the lateral error by allowing the pilot to "feel" a normal acceleration which would take him out-of-plane before he would see the translation. The two cues (roll motion and normal acceleration) used together provide the pilot with onset cues from the motion platform and sustained cues from the g-seat, which he uses to lower his lateral error by an amount almost equal to the amount each cue lowers the fixed-base case.

For the vertical tracking error (EV) and pitch control (TSP), the motion platform shows no first-order effect (figs. 6 and 7 and tables VI and VIII). This is to be expected since the motion drive algorithms (refs. 2 and 5) provide very little vertical cue. However, a further look at the data (figs. 12 and 14) and knowledge that there are significant pilot interactions lead to the conclusion that a small vertical cue, possibly the pitch-rate cue, presented by the motion base does affect pilot performance, but not in a uniform manner across all pilots. Motion cues improve the vertical performance of pilots 3, 4, and 5 (fig. 12) but degrade the vertical performance of all the other pilots. Therefore, the effect of motion on some individual pilots is significant (pilots 2, 3, 4, and 6 by a t-test), but the pilot effect (the different response to motion by individual pilots) washes out any first-order motion effect.

The vertical cue with respect to the g-seat is much clearer. In figure 13, pilots 1, 2, and 5 show the g-seat cues leading to slightly larger vertical errors. None of these pilots show any statistically significant difference when tested with a t-test between g-seat on or off performance with respect to EV; however, the other pilots show significant reductions in vertical error with g-seat cues. Overall, the g-seat produces a significant reduction of the vertical error (F-value of 9.85 versus 6.74 for significance at 1-percent level) by providing normal acceleration cues which relate directly to the error (EV) when the pilot is "in-plane" with the target.

CONCLUDING REMARKS

In order to measure and analyze the effects of the motion plus g-seat cueing system, a manned-flight-simulation experiment was conducted utilizing a pursuit tracking task and an F-16 simulation model in the NASA Langley Visual/Motion Simulator.

This experiment provided the information necessary to answer the primary question, Do motion and g-seat cues have an additive effect on the performance of this task? With respect to the lateral tracking error and roll-control stick force, the answer is affirmative. When the motion platform (onset motion cues) and the g-seat (normal acceleration cues) are used separately, the pilot uses the information provided to prevent overcontrol in roll and is therefore able to reduce his lateral tracking error. When the two cues are used together, the information provided has an effect of lowering the roll-control stick force and the lateral tracking error generated by an amount almost equal to the sum of the amount that each cue case differs from the fixed-base case. For the vertical tracking error, the g-seat significantly lowers the error whether motion is used or not. The motion cue may have an effect on an individual pilot's vertical performance, but overall, motion does not appear to have a consistent effect on the vertical tracking error. Neither the g-seat nor the motion platform affects the amount of pitch-control stick force used.

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REFERENCES

1. Puig, Joseph A.; Harris, William T.; and Ricard, Gilbert L.: Motion in Flight Simulation: An Annotated Bibliography. Rep. No. NAVTRAEQUIPCEN IH-298, U.S. Navy, July 1978.

2. Ashworth, Billy R.; McKissick, Burnell T.; and Martin, Dennis J., Jr.: Objective and Subjective Evaluation of the Effects of a G-Seat on Pilot/Simulator Performance During a Tracking Task. Proceedings - 10th NTEC/Industry Conference, Tech. Rep. NAVTRAEQUIPCEN IH 294, U.S. Navy, Nov. 1977, pp. 61-80. (Available from DTIC as AD A047 905.)

3. Parrish, R. V.: Platform Motion for Fighter Simulations - Let's be Realistic. A Collection of Technical Papers - AIAA Flight Simulation Technologies Conference, Sept. 1978, pp. 21-31. (Available as AIAA Paper 78-1574.)

4. Ashworth, Billy R.: A Seat Cushion To Provide Realistic Acceleration Cues for Aircraft Simulators. NASA TM X-73954, 1976.

5. Parrish, Russell V.; Dieudonne, James E.; Martin, Dennis J., Jr.; and Copeland, James L.: Compensation Based on Linearized Analysis for a Six-Degree-of-Freedom Motion Simulator. NASA TN D-7349, 1973.

6. Parrish, Russell V.; Dieudonne, James E.; Bowles, Roland L.; and Martin, Dennis J., Jr.: Coordinated Adaptive Washout for Motion Simulators. J. Aircr., vol. 12, no. 1, Jan. 1975, pp. 44-50.

7. Rollins, John D.: Description and Performance of the Langley Visual Landing Display System. NASA TM-78742, 1978.

8. Gilbert, William P.; Nguyen, Luat T.; and Van Gunst, Roger W.: Simulator Study of the Effectiveness of an Automatic Control System Designed To Improve the High-Angle-of-Attack Characteristics of a Fighter Airplane. NASA TN D-8176, 1976.

9. Cochran, William G.; and Cox, Gertrude M.: Experimental Designs, Second ed. John Wiley & Sons, Inc., 1957.

10. Morrison, Donald F.: Multivariate Statistical Methods, Second ed. McGraw-Hill Book Co., c.1976.

11. Ashworth, Billy R.; McKissick, Burnell T.; and Parrish, Russell V.: The Effects of Simulation Fidelity on Air-to-Air Tracking. Fifteenth Annual Conference on Manual Control, Frank L. George, ed., AFFDL-TR-79-3134, U.S. Air Force, Nov. 1979, pp. 147-167. (Available from DTIC as AD A080 563.)

12. Ashworth, B. R.; and McKissick, B. T.: Effects of Helmet Loader Cues on Simulator Pilot Performance. J. Aircr., vol. 16, no. 11, Nov. 1979, pp. 787-791.

TABLE I.- LIMITS OF LANGLEY VISUAL/MOTION SIMULATOR

Axis	Displacement	Velocity	Acceleration
Pitch	+30°, -20°	±15 deg/sec	±50 deg/sec^2
Roll	±22°	±15 deg/sec	±50 deg/sec^2
Yaw	±32°	±15 deg/sec	±50 deg/sec^2
Vertical	+39, -30 in.	±24 in/sec	[a]±0.8g
Lateral	±48 in.	±24 in/sec	[a]±0.6g
Longitudinal	±48 in.	±24 in/sec	[a]±0.6g

[a]1g = 9.81 m/sec^2.

TABLE II.- MASS AND DIMENSIONAL CHARACTERISTICS OF F-16 SIMULATION MODEL

Weight, lb	16 519
Moments of inertia:	
I_X, slug-ft^2	9339
I_Y, slug-ft^2	39 199
I_Z, slug-ft^2	46 492
I_{XZ}, slug-ft^2	132
Wing:	
Span, ft	29.0
Area, ft^2	280
Mean aerodynamic chord, ft	10.94
Surface deflection limits:	
Horizontal tail:	
Symmetric, deg	±25
Differential (per surface), deg	±5
Ailerons (flaperons), deg	±20
Rudder, deg	±30

TABLE III.- PARAMETERS OF SUM OF SINES USED TO DRIVE THE RETICLE

Frequencies, rad/sec	Relative amplitudes
0.245	1.150
.540	.747
.933	.319
1.424	.121
2.013	.051
2.896	.022
4.074	.009
5.547	.004
8.001	.002
10.946	.001
16.248	.0003
22.040	.0001
32.094	.00006

TABLE IV. - ROOT-MEAN-SQUARE PERFORMANCE MEASURES

State	Units	Mnemonics
Pitch control input	Pounds	TSP
Roll control input	Pounds	TAP
Vertical tracking error	Feet	EV
Lateral tracking error	Feet	EL

TABLE V.- LATERAL PERFORMANCE MEASURES

Variable	Motion condition	g-seat condition	Sample points	Mean rms error	Standard deviation	Standard error
EL	Off	Off	80	9.043	2.883	0.324
	Off	On	80	7.555	2.117	.238
	On	Off	80	7.746	1.973	.222
	On	On	80	6.420	1.603	.180
EL	Off	(a)	160	8.299	2.630	
	On	(a)	160	7.083	1.911	
EL	(a)	Off	160	8.394	2.547	
	(a)	On	160	6.987	1.957	
TAP	Off	Off	80	2.119	0.263	0.029
	Off	On	80	2.064	.249	.028
	On	Off	80	1.862	.209	.023
	On	On	80	1.783	.209	.023
TAP	Off	(a)	160	2.092	0.257	
	On	(a)	160	1.822	.212	
TAP	(a)	Off	160	1.991	0.270	
	(a)	On	160	1.923	.269	

[a]Data combined across this condition.

TABLE VI.- VERTICAL PERFORMANCE MEASURES

Variable	Motion condition	g-seat condition	Sample points	Mean rms error	Standard deviation	Standard error
EV	Off	Off	80	18.498	3.860	0.434
	Off	On	80	17.621	2.981	.335
	On	Off	80	18.470	3.072	.346
	On	On	80	17.702	3.522	.396
EV	Off	(a)	160	18.060	3.466	
	On	(a)	160	18.086	3.316	
EV	(a)	Off	160	18.484	3.477	
	(a)	On	160	17.662	3.253	
TSP	Off	Off	80	4.010	0.215	0.024
	Off	On	80	3.988	.224	.025
	On	Off	80	4.004	.279	.031
	On	On	80	3.968	.252	.028
TSP	Off	(a)	160	3.999	0.219	
	On	(a)	160	3.986	.265	
TSP	(a)	Off	160	4.007	0.248	
	(a)	On	160	3.978	.238	

[a]Data combined across this condition.

TABLE VII.- RESULTS OF F-TESTS ON LATERAL PERFORMANCE MEASURES

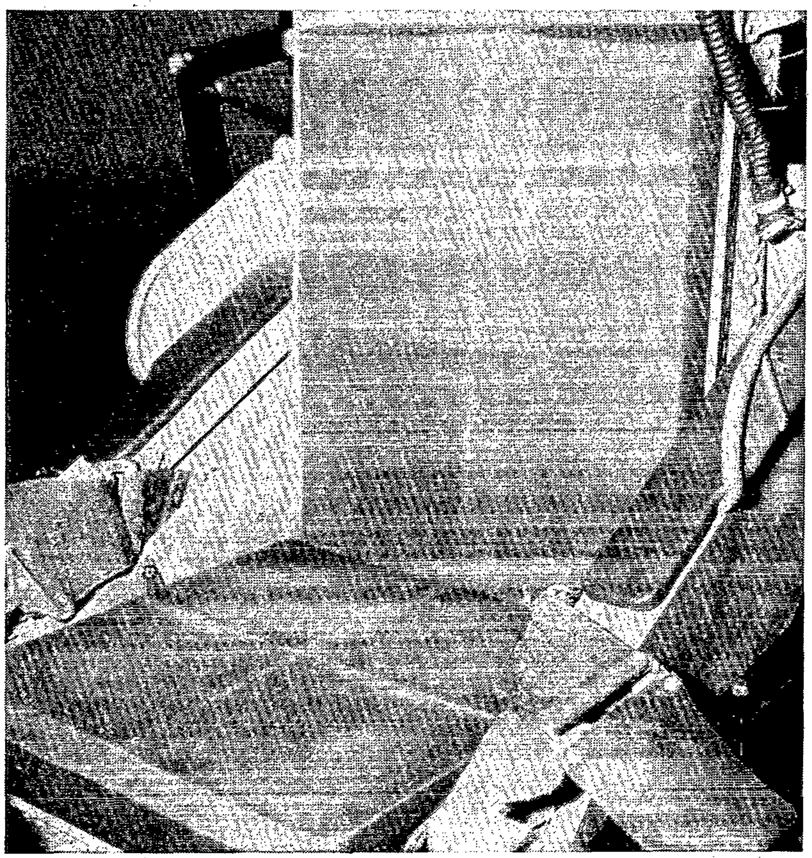
Source of variation (a)	F-value	F-value for significance at 5-percent level	F-value for significance at 1-percent level
Lateral tracking error			
P	23.70	2.04	2.72
M	41.26	3.88	6.74
P × M	5.01	2.04	2.72
GS	55.28	3.88	6.74
P × GS	4.79	2.04	2.72
M × GS	.18	3.88	6.74
P × M × GS	1.74	2.04	2.72
Replicates	.57	1.91	2.48
Roll control input			
P	11.93	2.04	2.72
M	158.51	3.88	6.74
P × M	3.56	2.04	2.72
GS	9.85	3.88	6.74
P × GS	3.21	2.04	2.72
M × GS	.319	3.88	6.74
P × M × GS	7.24	2.04	2.72
Replicates	1.10	1.91	2.48

[a]P - pilot; M - motion; GS - g-seat.

TABLE VIII.- RESULTS OF F-TESTS ON VERTICAL PERFORMANCE MEASURES

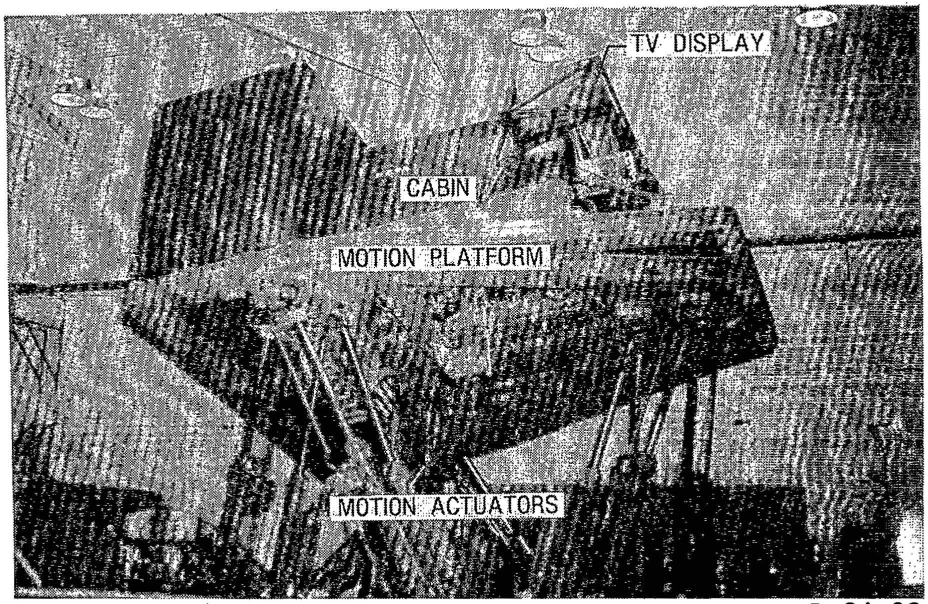
Source of variation (a)	F-value	F-value for significance at 5-percent level	F-value for significance at 1-percent level
Vertical tracking error			
P	39.55	2.04	2.72
M	.01	3.88	6.74
P × M	5.95	2.04	2.72
GS	9.85	3.88	6.74
P × GS	3.02	2.04	2.72
M × GS	.04	3.88	6.74
P × M × GS	3.45	2.04	2.72
Replicates	1.46	1.91	2.48
Pitch control input			
P	80.80	2.04	2.72
M	.74	3.88	6.74
P × M	9.06	2.04	2.72
GS	3.68	3.88	6.74
P × GS	4.00	2.04	2.72
M × GS	.25	3.88	6.74
P × M × GS	9.34	2.04	2.72
Replicates	2.95	1.91	2.48

[a]P - pilot; M - motion; GS - g-seat.



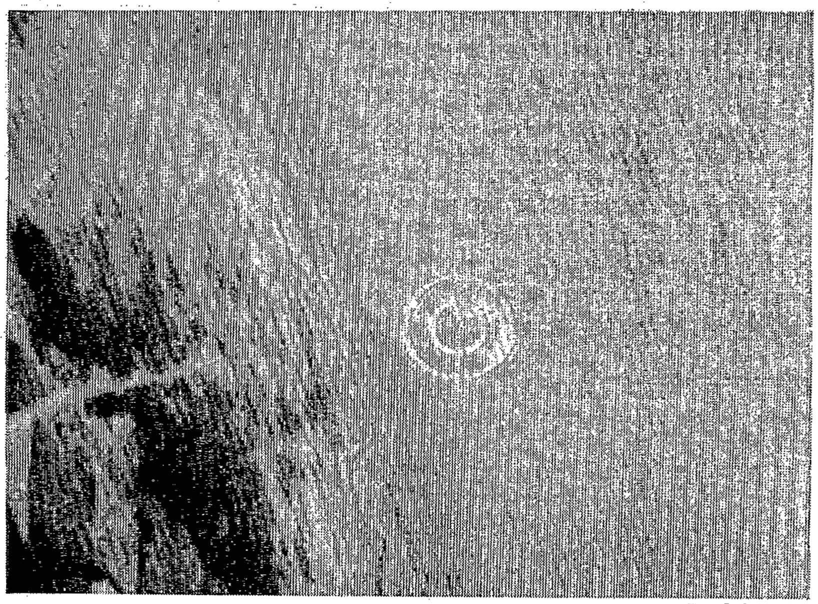
L-84-01

Figure 1.- g-seat system.



L-84-02

Figure 2.- Langley Visual/Motion Simulator.



L-84-03

Figure 3.- Pilot's visual scene.

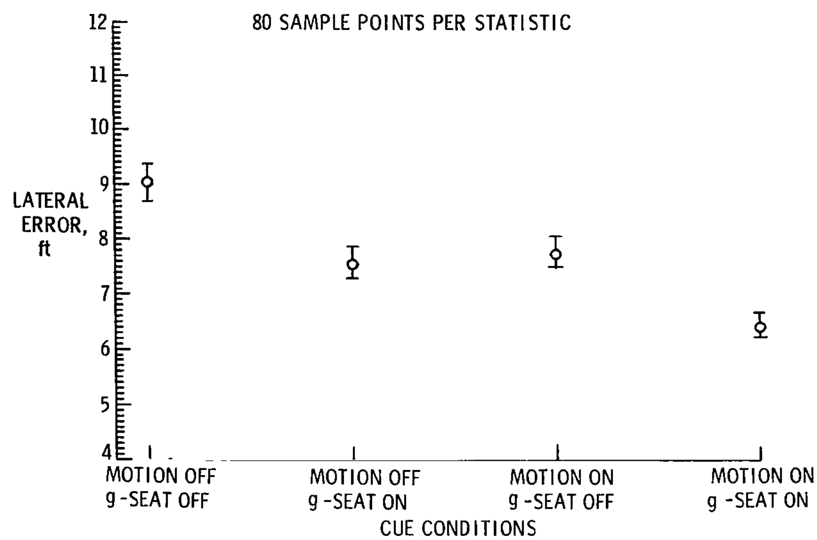


Figure 4.- Lateral tracking error.

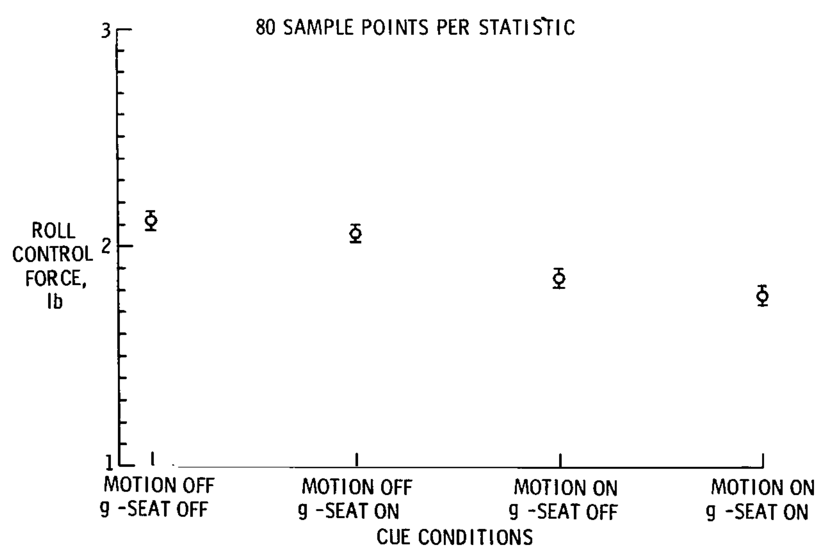


Figure 5.- Roll control input.

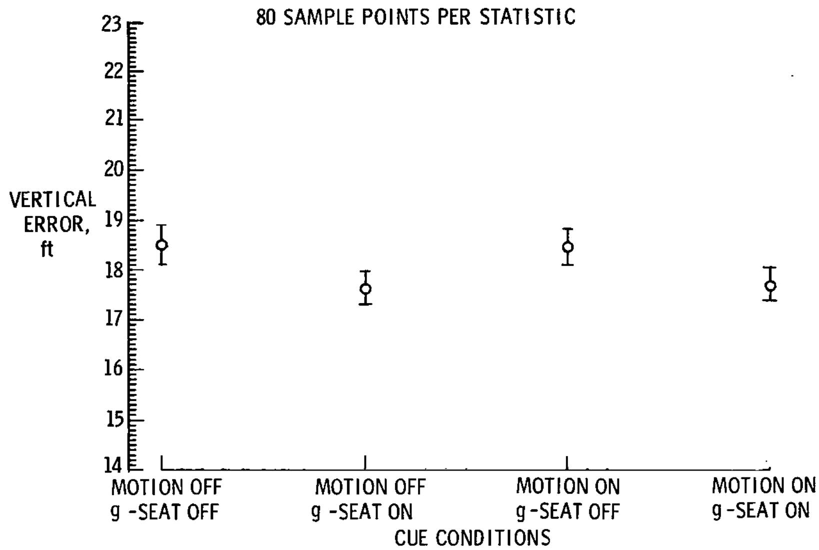


Figure 6.- Vertical tracking error.

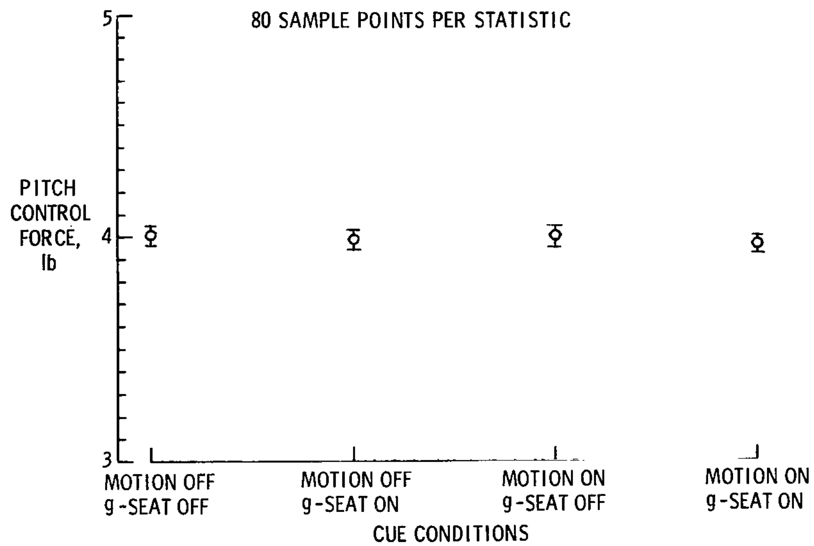


Figure 7.- Pitch control input.

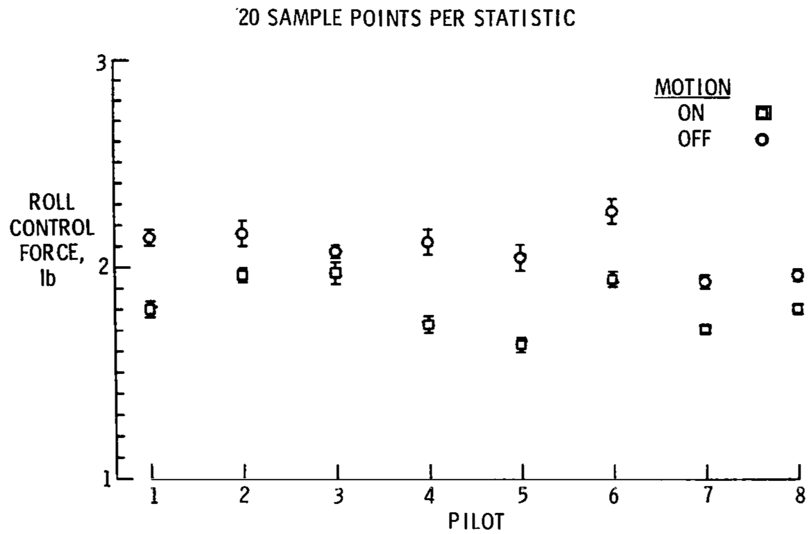


Figure 8.- Effect of motion on pilots' roll command. (Data taken across g-seat conditions.)

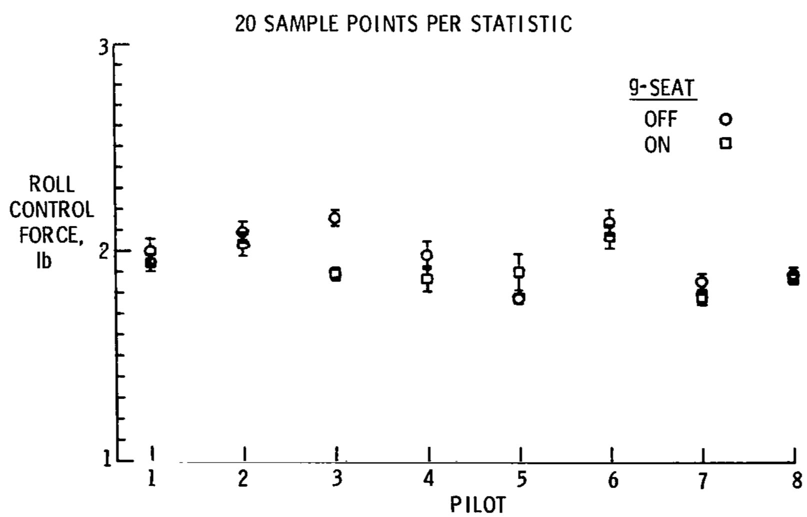


Figure 9.- Effect of g-seat on pilots' roll command. (Data taken across motion conditions.)

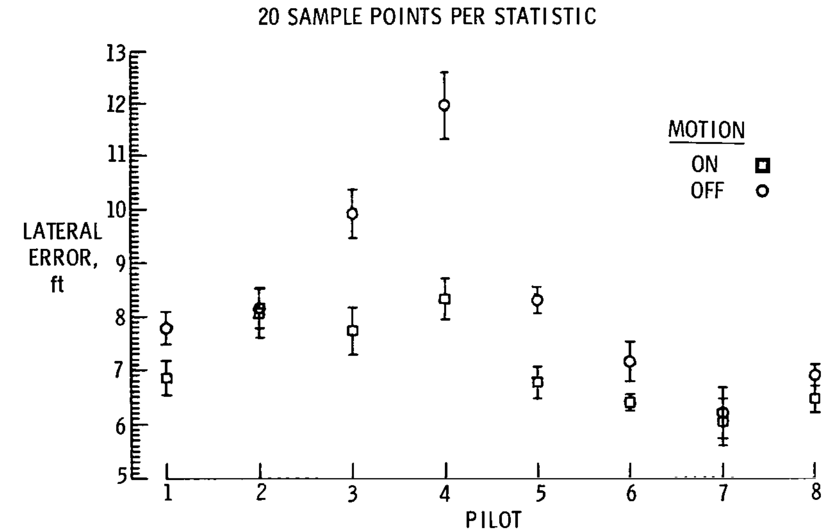


Figure 10.- Effect of motion on pilots' lateral error. (Data taken across g-seat conditions.)

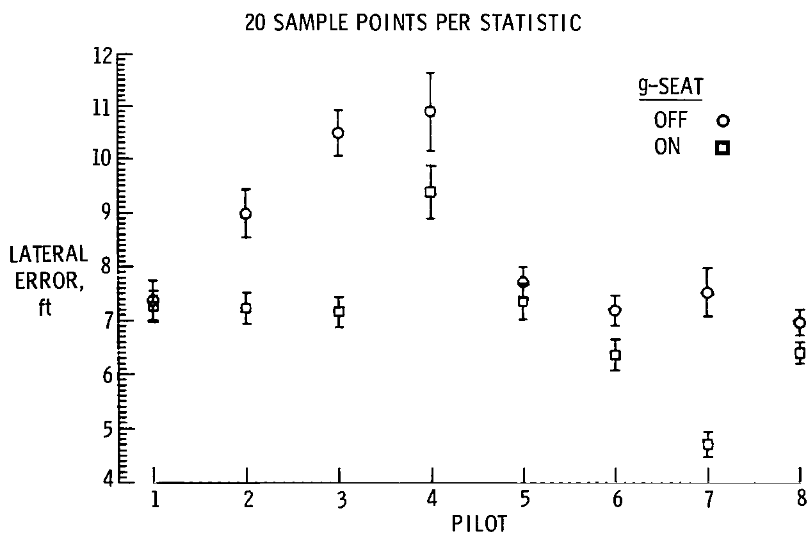


Figure 11.- Effect of g-seat on pilots' lateral error.

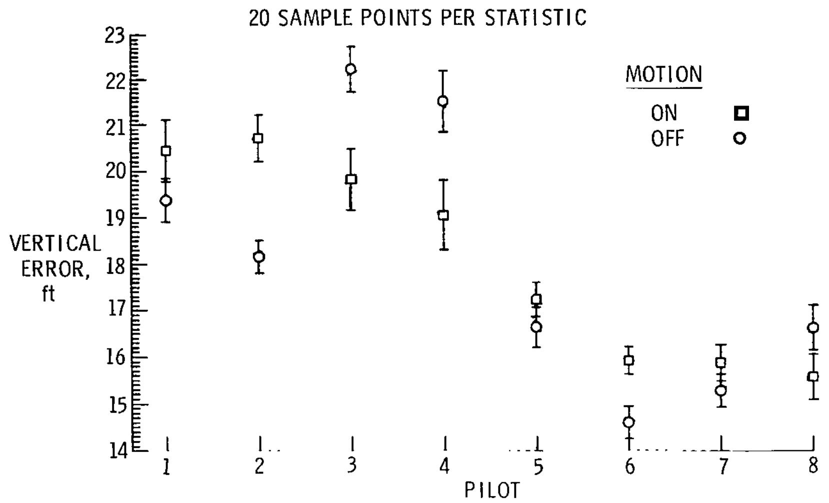


Figure 12.- Effect of motion on pilots' vertical error.

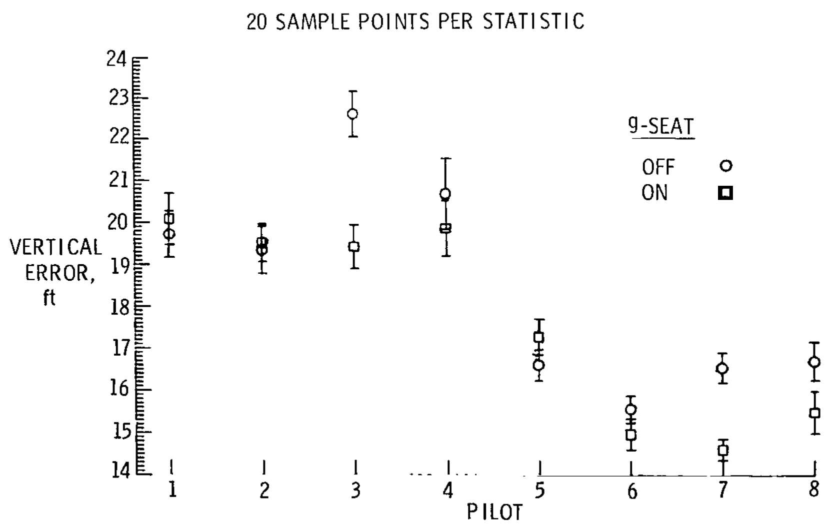


Figure 13.- Effect of g-seat on pilots' vertical error.

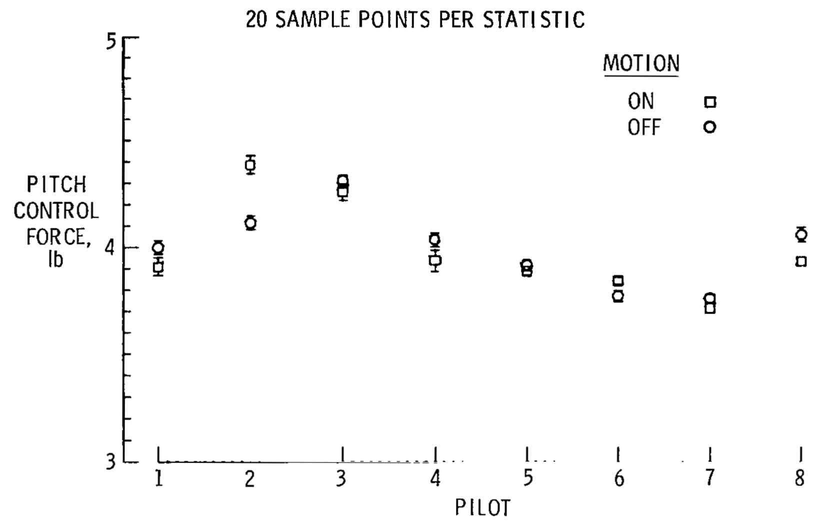


Figure 14.- Effect of motion on pilots' pitch command.

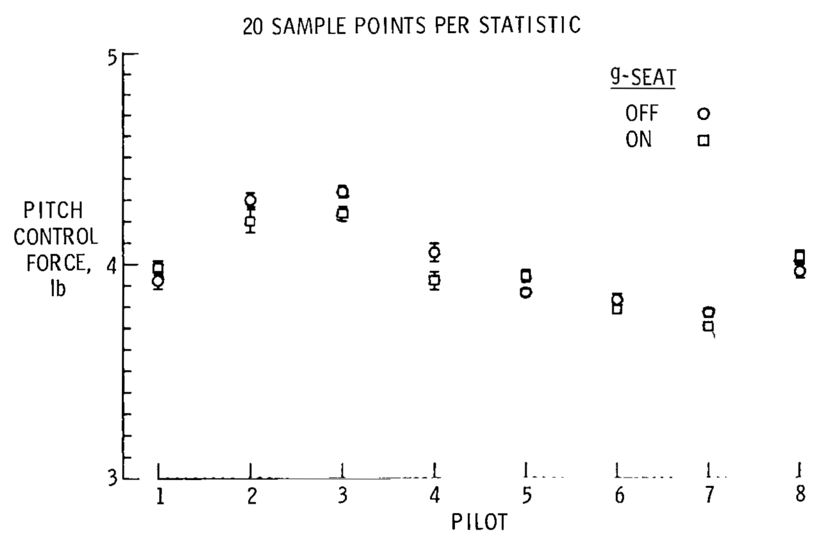


Figure 15.- Effect of g-seat on pilots' pitch command.

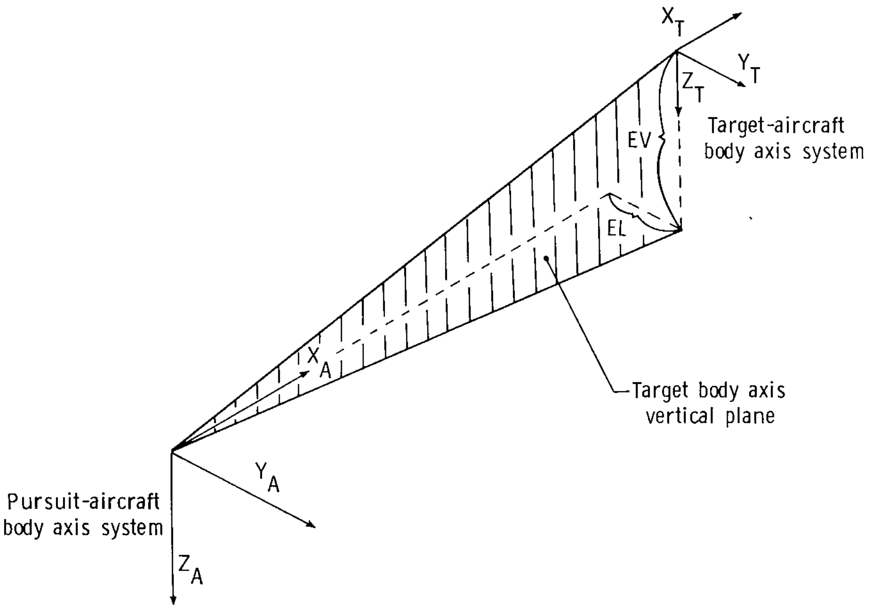


Figure 16.- Definition of vertical and lateral tracking error.

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15. Supplementary Notes

16. Abstract

In order to measure and analyze the effects of a motion plus g-seat cueing system, a manned-flight-simulation experiment was conducted utilizing a pursuit tracking task and an F-16 simulation model in the NASA Langley Visual/Motion Simulator. This experiment provided the information necessary to answer the primary question, Do motion and g-seat cues have an additive effect on the performance of this task? With respect to the lateral tracking error and roll-control stick force, the answer is affirmative. In this paper it is shown that presenting the two cues simultaneously caused significant reductions in lateral tracking error and that using the g-seat and motion base separately provided essentially equal reductions in the pilot's lateral tracking error.

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