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THE EFFECT OF VISUAL-MOTION TIME DELAYS ON PILOT PERFORMANCE IN A SIMULATED PURSUIT TRACKING TASK

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16. Abstract

An experimental study has been made to determine the effect on pilot performance of time delays in the visual and motion feedback loops of a simulated pursuit tracking task. Three major interrelated factors were identified: task difficulty either in the form of airplane handling qualities or target frequency, the amount and type of motion cues, and time delay itself. In general, the greater the task difficulty, the smaller the time delay that could exist without degrading pilot performance. Conversely, the greater the motion fidelity, the greater the time delay that could be tolerated. The effect of motion was, however, pilot dependent.

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SUMMARY

An experimental study has been made to determine the effect on pilot performance of time delays in the visual and motion feedback loops of a simulated pursuit tracking task. Three major interrelated factors have been identified: task difficulty either in the form of airplane handling qualities or target frequency, the amount and type of motion cues, and time delay itself. In general, the greater the task difficulty, the smaller the time delay that could exist without degrading pilot performance. The general effect of adding motion to the system was to increase the permissible time delay. The benefit of including motion cues was pilot dependent in addition to being a function of the amount and type of motion employed. The pilots can become nauseated if the delays inherent in the motion system and the visual system differ by more than about 187 msec. In some cases, time delays can be added to the visual system to better match the response of the motion system so that the pilot performance improves.

INTRODUCTION

The exact duplication in flight simulators of the visual and motion cues experienced during actual flight is often prohibitively expensive, if not impossible. Consequently, it is important to determine the departure from exact duplication that can be tolerated in simulated flight. This problem has many aspects: the color, detail, and texture of the model used in the visual-scene generation, the amount of motion available, the type of washout used to limit the motion base, and the fidelity of the simulator response.

A previous study (ref. 1) examined the effect of time delays in the visual feedback loop of a pursuit tracking task for 17 different sets of aircraft handling qualities using a fixed-base simulator. Reference 1 reported adverse effects of relatively small time delays on pilot performance for some aircraft configurations. The present study employed three airplanes selected from those studied in reference 1 and examines the effect of adding motion to the simulation. The control case, representing the "real" vehicle, consisted of flying the simulator in the normal operating mode, that is, with the time delays inherent in the system. Time delays were then added to the visual and motion cue presentations in increments of 31.25 msec, and their effects were evaluated.

This study examines several experimental factors: time delays, motion cues, airplane handling qualities, target-aircraft frequencies, and pilots. In addition, combinations of unequal time delays in the visual and motion generating systems are examined to determine whether a combination exists that provides better coordination of cues than an equal-delay combination. Most of the experimental factors are examined using only one subject to minimize the required number of simulator runs. An attempt is then made to generalize the results by using four subjects to fly a given simulated airplane with and without motions and with different time delays.

SYMBOLS

a	acceleration caused by aerodynamic forces, m/sec^2
F	statistical quantity associated with F distribution
F_Y	side force, N
g	gravitational acceleration, 1g = 9.8 m/sec^2
I	moment of inertia, kg-m^2
K	gains used in motion-base drive equations
L	lift force, N
L_o	$= \dfrac{\text{Trim lift}}{mV_{x,o}}$, per sec
L_p	$= \dfrac{1}{I_X}\dfrac{\partial M_X}{\partial p}$, per sec
L_r	$= \dfrac{1}{I_X}\dfrac{\partial M_X}{\partial r}$, per sec
L_α	$= \dfrac{1}{mV_{x,o}}\dfrac{\partial L}{\partial \alpha}$, per sec-rad
L_β	$= \dfrac{1}{I_X}\dfrac{\partial M_X}{\partial \beta}$, per sec^2
L_{δ_a}	$= \dfrac{1}{I_X}\dfrac{\partial M_X}{\partial \delta_a}$, per sec^2
ℓ_j, m_j, n_j	direction cosines (j = 1, 2, 3)

M_q $= \frac{1}{I_Y} \frac{\partial M_Y}{\partial q}$, per sec

M_X rolling moment, N-m

M_Y pitching moment, N-m

M_Z yawing moment, N-m

M_α $= \frac{1}{I_Y} \frac{\partial M_Y}{\partial \alpha}$, per sec^2

M_{δ_e} $= \frac{1}{I_Y} \frac{\partial M_Y}{\partial \delta_e}$, per sec^2

m aircraft mass, kg

N_p $= \frac{1}{I_Z} \frac{\partial M_Z}{\partial p}$, per sec

N_r $= \frac{1}{I_Z} \frac{\partial M_Z}{\partial r}$, per sec

N_β $= \frac{1}{I_Z} \frac{\partial M_Z}{\partial \beta}$, per sec^2

N_{δ_a} $= \frac{1}{I_Z} \frac{\partial M_Z}{\partial \delta_a}$, per sec^2

N_{δ_r} $= \frac{1}{I_Z} \frac{\partial M_Z}{\partial \delta_r}$, per sec^2

p angular rate around aircraft longitudinal axis, rad/sec

p_K roll motion drive signal before compensation, rad/sec

q angular rate around aircraft lateral axis, rad/sec

r angular rate around aircraft normal axis, rad/sec

t( ) statistical quantity of "t" test of student's "t" distribution, parentheses designate particular factor considered

u,v,w aircraft velocities along longitudinal, lateral, and normal axes, respectively, m/sec

V aircraft velocity, m/sec

$V_{x,o}$ initial aircraft total velocity, m/sec

Y_β $= \frac{1}{mV_{x,o}} \frac{\partial F_Y}{\partial \beta}$, per sec-rad

y_c,z_c lateral and vertical drive commands for motion base, m

y_K horizontal motion drive signal before compensation, m

z_K vertical motion drive signal before compensation, m

α change in angle of attack from trim, rad

β sideslip angle, rad

δ_a aileron deflection, rad or deg

δ_e elevator deflection, rad or deg

δ_r rudder deflection, rad or deg

ε_h horizontal tracking error, m

ε_v vertical tracking error, m

$\varepsilon_v + \varepsilon_h$ total tracking error, m

ζ damping ratio of longitudinal short-period mode

θ_c,ϕ_c pitch and roll drive commands for motion base, rad or deg

$\bar{\sigma}$ unbiased estimate of standard deviation

τ units of added time delay in visual and motion cues (each unit equals 0.03125 sec)

τ_m units of added time delay in motion cues (each unit equals 0.03125 sec)

τ_v units of added time delay in visual-scene display (each unit equals 0.03125 sec)

ψ,θ,ϕ Euler angles, deg or rad

ω_n natural frequency of tracker aircraft longitudinal short-period mode, rad/sec

ω_T target altitude oscillation frequency, rad/sec

Subscripts:

o indicates initial condition

X,Y,Z denote aircraft axes

x,y,z denote inertial axes

Abbreviations:

ANOV analysis of variance

d.o.f. degrees of freedom

L.O.S. magnitude of radial line-of-sight angle of target from tracker

L.S.R. least significant range in Duncan multiple range test

rms root mean square

A dot over a quantity indicates a derivative with respect to time. The root mean square (rms ( )) indicates rms value of variable in parentheses for a single run. A bar over a symbol indicates the arithmetic mean of rms ( ) values for all runs having identical test conditions.

DESCRIPTION OF APPARATUS

The tests were performed in the Langley visual-motion simulator (VMS) which is a hydraulically operated, six-legged synergistic motion base. (See fig. 1.) Six computed leg positions are used to drive the motion base. The computed actuator extensions are passed from the computer to the motion base through digital-to-analog converters (DAC) every 0.03125 sec. To eliminate the stairstepping in this output and provide smooth, continuous signals for driving the motion base, the DAC outputs are passed through notch filters on the hardware. Filter characteristics are given in reference 2 and the transformations used to compute the leg extensions in reference 3. References 2 and 4 give the performance limits of the VMS. For the present study, the VMS was used both as a fixed-base and as a moving-base simulator.

The pilot's compartment is somewhat representative of a two-man cockpit (fig. 2). Although the panel instruments were illuminated, they were not operational and were not used by the pilot subjects. Visual cues (target aircraft) were generated by a small model and closed-circuit television. The model was mounted in a two-gimbal support, and rotated in pitch and yaw in response to the relative equations of motion of the two aircraft so that the subject saw the proper aspect of the target. Target aircraft roll was accomplished electronically. Elevation and azimuth changes of the target aircraft in the display were obtained by repositioning the television raster electronically. The repositioning was accomplished by using scaled voltages to represent angles of deflection in elevation and azimuth. This technique eliminated unwanted delays in visual-scene presentation; such delays occur when electromechanical systems (involving mirrors, gears, and electric motors) are used to obtain elevation and azimuth position. The image was displayed by use of a television screen (fig. 3) with an infinity optics mirror. The horizon was also projected on the screen. A reticle (crossed lines) was projected on the center of the screen to represent sights on the aircraft flown by the subject.

The subject maneuvered his aircraft by using a two-axis fingertip pencil controller of the force-stick type; this device controlled rotations about the aircraft pitch and roll axes. Force characteristics of the controller are given in figure 4. The controller is shown in the photograph of figure 2. The equations of motion of the pursuing aircraft (see appendix) were solved on a digital computer.

The digital outputs were then converted to analog signals to drive the visual-scene and motion generation equipment. The Langley Research Center hardware for computer signal processing from analog to digital back to analog can be represented mathematically as a prefilter, computational delay, and zero-order hold. The prefilter attenuates the analog input-signal high-frequency components to suppress "aliasing" during the analog-to-digital conversion. The computational delay is the delay associated with the input, the processing, and the output of a signal through the computer. Finally, a zero hold adds one-half the computing interval caused by the sample-hold characteristics. This latter delay represents an average value for that portion of the equipment which includes (1) the DAC, (2) the scene generation equipment for elevation and azimuth line-of-sight angles to the target, and (3) the television display of the scene to the subject. For the prefilter setting of this study, the described hardware characteristics create an average time delay from input to output of 1.5 times the update interval. This delay has an average value of 47 msec which becomes part of the delay in the visual-scene presentation. Motion cue presentation also has this 47 msec time delay. In addition, the motion-base mechanical drive system has those time lags after compensation described in reference 2.

PILOT TASK

The primary task, as in reference 1, was to track a target aircraft that was performing a sinusoidal oscillation in the vertical plane with an amplitude of ±30.48 m and a frequency of 0.210 rad/sec. Precognitive control related to the sinusoidal nature of the target motion should be impossible at frequencies below 0.630 rad/sec (ref. 5). The pursuit aircraft automatically maintained a 182.88-m separation distance behind the target aircraft. The pursuit aircraft could maneuver in the remaining five degrees of freedom and was controlled through the use of a two-axis fingertip controller.

This study used the secondary task of reference 1 to increase total pilot workload so that the pilot would have no reserve capability on which to draw when the difficulty of the primary task was altered. The secondary task consisted of alternately tapping two metal strips inlaid in a wooden board (fig. 5) strapped to the subject's left leg. A metal stylus about the size of a pencil was used to tap the metal strips. Stylus contact with a metal strip closed an electrical circuit, and a signal was sent to a strip chart recorder where the subject's tapping time history was recorded. The metal strips were about 1.27 cm wide and were placed 10.16 cm apart. A raised wooden strip, 2.54 cm wide and 0.635 cm high, separated the two strips to prevent the subject from sliding the stylus. The subject performed the secondary task with his left hand while he controlled the aircraft with his right hand. He was instructed to tap the metal strips alternately as rapidly as possible while keeping the center of the reticle crosshairs as close to the target center as possible. The subject was told that accuracy as well as speed was important in tapping the metal strips because the counter operated only when the strips were tapped alternately.

TEST PROGRAM

Three main factors were varied during this study. They were the magnitude of the time delays, task difficulty either in the form of airplane handling qualities or target frequency, and the type of simulator motion cues.

Time delays in visual and motion cue presentation were varied in multiples of 31.25 msec because that was the update interval of the series digital computer used in the study. After initial experimentation with multiples of 0, 1, 2, 3, 4, 5, 8, 12, and 16 units of delay, most of the data were collected for 0, 4, 8, 12, and 16 units of delay. This smaller sample was used to reduce the number of required runs.

Three airplanes were selected from those studied in reference 1 to vary task difficulty. For convenience, these airplanes are designated "good," "basic," and "bad." The good airplane is defined by the aircraft parameters listed in table I. The basic airplane was formed by changing M_q and M_α to -7.00 and 6.00, respectively, while the bad airplane was formed by $M_q = 1.10$ and $M_\alpha = 4.45$. The short-period frequency of the good airplane was 3.00 rad/sec, and the damping was 0.70; the parameters $\omega_n = 2.83$ and $\zeta = 1.59$ were used for the basic airplane, and $\omega_n = 1.50$ and $\zeta = 0.30$ were used for the bad airplane. Task difficulty was also varied by changing the frequency at which the target aircraft moved in the vertical plane. Target frequencies of 0.210, 0.315, and 0.420 rad/sec were examined.

Four types of motion cues were used in this study. The most complete motion, henceforth called "full motion," provided motion cues in four degrees of freedom: roll, pitch, heave, and sway. There was no yaw motion because, as reference 1 indicated, the pilots never used the rudder pedals, and the yaw cues due to aileron deflection were below threshold for this task. There was no surge motion because the longitudinal distance between the two aircraft was held constant throughout the study. The pitch signal was small enough so that neither washout nor scaling was required. Conversely, the roll motion and the lateral motion were employed in a coordinated manner (see ref. 6), primarily in an attempt to remove the false cue caused by the gravity component during the performance of a coordinated turn in a simulator. The heave motion employed second-order linear filtering. The values chosen for the filter or washout parameters are presented in table II. These parameters result from several preliminary runs in which the basic airplane and large time delays were used. During the preliminary runs, the washout parameters were relaxed until the motion-base limits were consistently reached. The scaling parameter was then adjusted to the point that the motion base seldom reached the limits. Thus, a constant set of washout parameters could be used throughout the study.

The second motion condition, referred to as "no heave," was formed from full motion by removing the heave component. Heave is often omitted (see ref. 7) from simulation studies but may be important because of its significance in longitudinal handling qualities. A third commonly used motion condition which employs angular motion through the presentation of angular position was studied and is referred to as "angular." The fourth motion condition considered for comparison purposes is called "no motion."

Performance in the primary task and the secondary task was measured for an interval of 2 min for each time delay. A minimum of 10 runs were performed at each airplane motion-delay combination. So many runs resulted in such a large data base that, in general, only one subject was used in collecting the data. An attempt was made to increase the generality of the results by using several subjects to fly the basic airplane with full motion and no motion over a range of time delays. The subjects were generally research engineers with either pilot training or extensive experience in various flight simulators. One subject was a research test pilot. In addition, a supplementary investigation was conducted to determine whether some unequal combination of visual and motion time delay exists that provides better coordination of cues than an equal combination.

RESULTS AND DISCUSSION

The pilot performance measures used in this study include the rms values (over the 2-min flight) of the vertical and lateral displacements of the center of gravity of the target aircraft from that of the pursuit aircraft. The rms values of the aileron and elevator control inputs were also collected. The primary performance measure, however, is the total error which is just the sum of the vertical and lateral center-of-gravity displacements. Each performance measure was examined statistically. An analysis of variance (ANOV) was conducted to determine whether any of the experimental factors or interactions of these factors were significant. (See ref. 8.) If the ANOV indicated a significant effect for a given factor, a t-test or Duncan multiple range test was performed to determine which levels of the factor differed significantly from other levels.

The t-tests treated each factor separately to keep the treatment of a given factor the same when it was included in different subsets of factors during the study (for example, motion-delay and pilot-delay).

The number of counts obtained on the secondary task was also recorded for each 2-min flight. Each of the subjects used in the current study performed the secondary task in a different manner. The resulting tap rates were affected by the amount of time delay present in the simulation for some subjects but were unaffected for other subjects. Because of this inconsistency, it was impossible to arrive at a constant workload indicator as was done in reference 1. In all cases, however, the secondary task increased the pilot workload and degraded the performance of the primary task.

Airplane-Motion-Delay Effects

The representative basic airplane and the good airplane were flown with full motion and with no motion for a range of time delays. Time histories of typical flights performed by using the basic airplane with no motion and with full motion are presented for reference in figures 6 and 7, respectively, for 8 units of time delay. The time histories obtained with motion are generally smoother than those performed without motion, and the control inputs are somewhat smaller. More important, the line-of-sight angle to the target is "on-target" (inside the wing span of the target aircraft) for most of the flight when motion is employed (fig. 7), but the pilot is unable to keep the line of sight on target without motion (fig. 6). The pilot believed that this improvement results largely from his increased ability to distinguish target-aircraft motion from pursuit-aircraft motion when motion is included. The computed motion-base response for the time history of figure 7 is presented in figure 8. The erroneous responses of the motion base in a_X and a_Y are not noticeable to the pilot.

The statistical data for this three-factor experiment are presented in table III. The ANOV indicated that each of the three factors (time delay, motion condition, and airplane) was statistically significant at the 5-percent level of significance. Consequently, a t-test was performed on each factor. In the case of the time-delay factor, zero delay was an obvious control level, and the t-test was used to determine whether any of the other time delays was significantly different from the control. The rms performance measures (total error, vertical error, horizontal error, aileron deflection, and elevator deflection) are plotted in figure 9 as functions of visual-motion time delay for the basic airplane at the two motion conditions. Each point in the figures represents the mean of 10 data runs. The fairing of the data points is used to help visualize the statistical significance of the time delays. If the second data point, at one unit of delay, is not significantly different from the zero delay point at the 5-percent level, the line continues at the original value. For succeeding time delays, the line continues until the 5-percent significance level is reached, at which time the line is faired to the data point. The main purpose of the fairing is to show the breakpoint at which the performance begins to degrade. Consequently, the lines are not extended beyond the breakpoint even though the t-test was applied at all time delays. The relative effect of motion at a given time delay is denoted through the use of solid symbols. When the no-motion performance is significantly different at the 5-percent level from that with full motion, the symbol is solid.

The general effect of increasing time delay (fig. 9) is to cause a degradation in pilot performance. In the fixed-base mode the breakpoint in total error, which is the primary performance measure, occurs at 4 units of delay. When motion is added to the simulation, the breakpoint in total error is delayed until 8 units of delay. This motion-delay interaction is statistically significant (table III) at the 5-percent level of significance. The tracking task occurs primarily in the vertical plane, and the breakpoints of the vertical error with and without motion also occur at 8 and 4 units of delay, respectively. The breakpoints in the control inputs $\bar{\delta}_a$ and $\bar{\delta}_e$ occur at smaller time delays when motion is present than when motion is absent. This evidence indicates that the pilot uses motion cues to alter his controls in order to maintain a low total error. As indicated by the shaded symbols, the pilot uses a significantly smaller amount of control, both laterally and longitudinally, when there is motion than when there is no motion for all time delays. The resulting total error is also significantly smaller. However, when 16 units of delay have been reached, the task has become so difficult that motion has no significant effect on total error. From a subjective standpoint, the time delays are noticeable at about 4 units of delay and become increasingly objectionable as the delay is increased. The performance with full motion and no secondary task is also presented in figure 9 for zero time delay. The effect of the secondary task on pilot workload is reflected in the approximate halving of total error when the secondary task is removed.

The performance measures for the good airplane are presented in figure 10 where a larger interval between time-delay test points has been used to reduce the required number of runs. All the tracking performance measures are, in general, significantly smaller than for the basic airplane. (See figs. 9 and 10.) In addition, the effect of motion is generally less noticeable for the good airplane than for the basic airplane. This airplane-motion interaction is significant (table III) at the 5-percent level. The item of primary importance, however, is that the breakpoint in total error does not occur until 6 and 12 units of delay for the fixed-base and full-motion conditions, respectively. This is a 50-percent increase over that experienced with the basic airplane. This airplane-delay interaction is significant at the 5-percent level of significance (table III). However, the breakpoint in total error can become very small as task difficulty increases. For the bad airplane, no time-delay breakpoint could be obtained with full motion. The moving-base simulator could not be run with even 1 unit of delay because the motion-base limits were reached and the simulator was shut down. In addition, the effect of motion is statistically significant even at zero time delay for this bad airplane. (See table IV.)

Target Frequency Effects

Another way to increase task difficulty is to increase the target frequency. The statistical data for the effect of target frequency on the basic airplane simulated under full-motion conditions are presented in table V. The basic airplane only is used in the remainder of the study because of the prohibitive amount of data needed to study more than one airplane. The performance measures for the target frequency effects are plotted in figure 11 where the solid data points denote a difference at the 5-percent significance level between a given target frequency and the original 0.210 rad/sec target frequency. The data at the original target frequency were collected by using a relatively poor lateral trim procedure which has been subsequently improved. This first procedure results in horizontal errors with the easiest condition, 0.210 rad/sec, that are larger than those with higher target frequencies. Consequently, the effect of target frequency, which is primarily a variable in the vertical plane, is partially obscured in the total tracking error. Therefore, the vertical error should be used to examine the effect of increasing target frequency by 50 and 100 percent. The vertical tracking error shows a significant increase, even at zero time delay, as the target frequency is increased. The increased task difficulty is also reflected in the significant increase in elevator input. In addition, the time-delay breakpoint is reduced from 8 units of delay to 2 units of delay only by a 50-percent increase in target frequency even though the task difficulty is believed by the pilots to be very little different from the task difficulty with the original target frequency. This frequency-delay interaction is statistically significant (table V) at the 5-percent level. It was expected that the time-delay breakpoint would be reduced to approximately zero units of delay when the target frequency was increased to 0.420 rad/sec. The resulting breakpoint is not reduced primarily because the task is very difficult at the high target frequency, and the resulting variances are relatively large. It should also be noted that it is necessary to rescale the washout parameters in order to avoid the motion-base limits, and pilot performance is affected by the amount of motion available.

Motion-Type Effects

Performance is also affected by the type of motion used. Consequently, four motion conditions were examined by using the basic airplane and a target frequency of 0.210 rad/sec. In addition to the no-motion and full-motion conditions, two frequently used types of motion were included in the study, pure angular motion and the no-heave condition. The no-heave condition differs from the full-motion condition in that the vertical or heave component has been removed. The statistical data for the effects of motion condition are presented in table VI. The resulting performance measures are presented in figure 12 where solid data points denote a difference at the 5-percent significance level between a given motion condition and the full-motion condition. The total tracking error for the no-motion condition, the no-heave condition, and the pure angular condition, deteriorates at the same point, 4 units of delay. Only the full-motion condition data are different, the breakpoint being extended to 8 units of delay. These differences in breakpoint experienced with the different motion conditions do not appear as clear cut as some of the previously mentioned interaction effects because the motion-delay interaction shown in table VI is not significant at the 5-percent level. (However, the motion-delay interaction effects are significant at the 10-percent level for the total tracking error, the vertical tracking error, and the elevator inputs.) In addition, the no-motion, no-heave, and pure angular conditions result in a total error that is significantly greater than the total error with the full-motion conditions for time delays up to at least 8 units of delay. For the larger time delays, 12 or 16 units, the variance of the total error is so large that, in general, no significant difference exists between the four motion conditions. According to pilot opinion, any of the motion conditions was preferable to the no-motion condition. This preference for motion is reflected, at least up to 8 units of delay, by smaller control inputs with any of the motion conditions. The subjects preferred motion primarily because of the lead information it provided, but also because motion enabled the subjects to better separate the lateral task from the longitudinal task. However, the subjects had a definite preference for the full-motion condition. The pure angular condition was the least preferred motion condition because it felt very mechanical when compared with the more complete motion conditions.

Thus far, threr interrelated major effects have been identified. They are time delays, task difficulty (either in the form of airplane handling qualities or target frequency), and the amount and type of motion cues presented to the subject.

Relative Time Delays

Thus far, the time delays have been added equally both to the visual system and the motion system. However, there may be some unequal combination of visual time delay and motion time delay that provides better coordination of cues than an equal combination. The tracking task is primarily a visual task although motion cues strongly interact. Thus, it is believed that visual time delays will be dominant, and motion delays will be of a perturbational nature. Because of the expected difficulty in separating the effects of motion delays from visual delays, an automatic lateral trim circuit was employed before each run. This automatic trim circuit is much more consistent than the manual trim previously used for the handling qualities, target frequency, and motion condition investigations. The automatic trim circuit results in a pilot task that is generally somewhat easier than with manual trim and will be used in the remainder of the paper unless otherwise noted.

Motion-delay effects.- Tracking runs were made with various amounts of motion delay and with visual delay held constant at 8 units. These time-delay conditions were selected because the difference in total tracking error was the largest between full motion and no motion for the previous tests with visual and motion delays set equal to 8 units. (See fig. 9.) The statistical data for 8 units of visual delay and a range of various amounts of motion delay are presented in table VII where the Duncan multiple range test (ref. 8) is used to test for level effects because there is no obvious motion delay to choose as a control level. The performance measures for this relative delay comparison are presented in figure 13. Although the mean total error, vertical error, and horizontal error begin to degrade after 8 units of motion delay (fig. 13), the degradation becomes significant only after 16 units of motion delay at the 5-percent level. A simplified analysis using the hardware description given in reference 2 is presented in table VIII to explain why the degradation in performance is not significant until after more than 16 units of motion delay. The simplified analysis assumes a constant frequency for the normal acceleration so that timelags and time delays can be treated equivalently. The short period frequency of the airplane, 2.83 rad/sec, is a reasonable value for that frequency. (See fig. 8.) The resulting mismatch between the visual and motion systems exceeds 30° only after 12 units of delay for both the pitch and heave cues. Because high-fidelity simulator motion has been characterized by phase angles of less than 30° (ref. 9), it is not surprising that motion delays are not significant until after 12 units of delay.

It should be emphasized that the subject found that when the motion delay differed from the visual delay by more than about 4 units of delay, he tended to become nauseated even though his performance did not deteriorate. The subject believed that the tendency to become nauseated might be even greater if he spent all his time looking at the visual display rather than looking away as required by the secondary task. Consequently, a series of runs were performed without using the secondary task. The subject was able to accommodate the high values of motion delay without nausea although such conditions were still objectionable. What was most interesting when the secondary task was removed was that the subject no longer made discrete control inputs at small motion delays but switched to continuous inputs (fig. 14). However, the subject reverted to discrete inputs when under the influence of motion delays greater than about 12 units. Difficult tracking tasks have been characterized by discrete or pulsatile inputs while easier tasks are flown in a continuous manner (ref. 10). It appears, therefore, that the primary task alone is not very difficult at small time delays; it becomes difficult at large time delays, and the use of the secondary task results in a total task that is difficult even at small delays.

Visual-delay effects.- Although there was no significant effect of delays in the motion system, it is possible that there may be a visual-delay effect. The inertias associated with the motion system are very large in relation to the visual system and thus may result in delays that are inherently larger than those in the visual system. Consequently, a series of runs were performed with several levels of visual delay and with no motion delay. The statistical data to examine the effects of visual delays are presented in table IX. The Duncan multiple range test (ref. 8) is again used to test for level effects. The performance measures for this relative delay comparison are presented in figure 15. Based on the mean values of the total error and its components, there is no nonzero time delay for which the pilot performance is significantly better than at zero time delay, again at the 5-percent level of significance. However, the mean values of the total error and its components are somewhat smaller at 2 units of visual delay (table IX). In addition, the standard deviations at 2 units of visual delay are much smaller than at any other visual delay. Indeed, the test for homogeneity of variance (ref. 11) shows the variance at 2 units of visual delay to be significantly smaller at the 5-percent level than that at any other delay. Thus, there is a relative delay effect. Insight into the physical reason for this relative delay effect can be gained from a simplified analysis (table X) based on constant frequency inputs at 2.83 rad/sec as previously mentioned. The simplified analysis shows that the average (of the pitch and heave) mismatch between visual and motion cues is a minimum at about 2 units of visual delay.

It seemed possible that a significant difference in the mean total error might occur if the task difficulty were a little greater. Consequently, the target frequency was increased by 50 percent to 0.315 rad/sec, and several values of visual delay were examined in conjunction with zero units of motion delay. The resulting statistical data are presented in table XI, and the performance measures are plotted in figure 16. The data show that with the increase in task difficulty, both the mean total error and the variance are significantly smaller at 2 units of visual delay than at zero visual delay. A relative delay effect seems certain. However, it is not subjectively noticeable and probably would not be statistically detectable unless the subject was quite well trained. The effect may also be subject dependent. Although the subject's performance is statistically better with 2 units of visual delay than with zero visual delay, the difference is not subjectively detectable, at least under the influence of the secondary task. The effect is quite subtle and was not repeatable with a second subject. It should be pointed out that the visual and motion channels of the VMS are more closely matched (approximately 140 msec for the heave channel, for example) than for some simulators in which the transport lag associated with the motion system can approach 350 msec. On such poorly matched simulators, the improvement in pilot performance resulting from the addition of an artificial time delay to the visual channel may not be so subtle.

Pilot Effects

The effects of the experimental factors examined thus far have involved only one subject, who will be referred to as subject A. In order to increase the generality of the results, three subjects were added to examine possible pilot effects by using the basic airplane, a target frequency of 0.210 rad/sec, and both full motion and no motion. The analysis of variance (table XII) indicates that there is indeed a pilot effect based on a comparison made at 0, 4, and 8 units of delay. In addition, the pilot-motion, pilot-delay, and pilot-motion-delay interactions are significant.

That different pilots react differently to motion cues, are affected differently by time delays, and have different motion-delay interactions is to be expected. However, the significance of these interactions is clouded because subjects B, C, and D used the automatic lateral trim setup while subject A used the less accurate manual trim setup. In addition, it was necessary to rescale the heave channel for subjects C and D to avoid the motion-base limits. With these restrictions defined, the performances of the subjects are discussed individually.

The statistical results for subject A have been presented earlier in table III and figure 9. The statistical data for subject B are presented in table XIII, and the results are plotted in figure 17. The general levels of the total error and its components are somewhat larger for subject B than for subject A. However, the breakpoints in total error with and without motion are located at 8 and 4 units of delay, respectively, for each of the two subjects. Subject B did tend to use smaller control inputs under full-motion conditions than subject A did. However, it should be noted that the results for subject A were obtained before the automatic lateral trim setup was implemented. The effect of the automatic trim condition in relation to the poorer manual trim can be examined by comparing the no-motion results of subject B with the fixed-base study presented in reference 1 where subject B operated under the influence of the poor trim conditions. The statistical data for the comparison between the poor trim condition and the automatic trim condition are presented in table XIV.

The results are plotted in figure 18 where the solid symbols denote a significant trim difference at the 5-percent level of significance, but the comparison is made only at alternate points because the current study uses a coarser time-delay grid than was used in reference 1. The general effect of the automatic trim condition is to lower the level of the performance measures. This effect is particularly true in the case of the horizontal error and the aileron inputs which are directly related to lateral trim. The breakpoints in total error and vertical error are delayed by about 1 unit with the automatic trim condition. Thus the performance of subject A may be somewhat poorer and the breakpoints would occur somewhat earlier than they would if the automatic trim condition under which the other subjects were tested had been used. Discounting these differences due to trim conditions, the performances of subjects A and B are generally very similar. Subjects C and D, however, differed from subjects A and B in that they often encountered the limits of the moving-base simulator. The subjects reacted by altering their flying techniques to make more conservative control inputs and thus avoid encountering the limits of the motion base. Although they were able to avoid the motion-base limits, subjects C and D found the required modification of their flying techniques objectionable. Consequently, the heave channel of the motion washout was rescaled to permit only one-third of the usual response. Subjects C and D much preferred the rescaled washout to the original setup and increased the magnitude of their control inputs to what they believed was their normal level. The statistical data for subjects C and D are presented in tables XV and XVI, and the results are plotted in figures 19 and 20, respectively. In general, subjects C and D have smaller tracking errors, both with and without motion, than do subjects A and B. In addition, subjects C and D do not show the statistically significant effects of motion on tracking performance shown by subjects A and B. The use of motion also fails to shift the breakpoint in tracking performance to larger time delays for subject C. This absence of motion effect is partially a result of having reduced to one-third the magnitude of the heave cue given to subjects C and D from that given to subjects A and B. The small amount of heave that remains essentially reduces the full-motion condition to approximately the no-heave condition, and subject A generally showed no significant motion effects when the no-heave condition was compared with the no-motion condition. (See fig. 12.) However, it is also known that certain subjects are relatively insensitive to motion cues.

Subjects C and D were not totally insensitive to motion, however, and used significantly smaller control inputs (figs. 19 and 20) when motion cues were included as did subjects A and B. There are no consistent statistically significant pilot effects as far as the control inputs are concerned, with the exception of subject A who employed larger aileron inputs than did the other subjects. This is not believed to be a true pilot effect because subject A was the only subject to use the poor lateral trim setup.

Subjective evaluation.- The subjective evaluations of the motion conditions were very consistent. The subjects preferred any of the motion conditions to the fixed-base (or no-motion) condition. However, they did prefer the full-motion condition to the other motion conditions. The difference between the no-heave and the full-motion conditions was very subtle, but the absence of heave was a detracting factor. The subjects rated the pure-angular motion condition lowest because it felt quite mechanical.

Secondary task.- Reference 1 incorporated the tap rate of the secondary task in a linear expression with aileron and elevator inputs to form what was called a work-level indicator (WLI). This WLI was constant over the range of time delays examined; the magnitude of the control inputs increased proportionately with the decrease in tap rate. The results of the present paper were not put into the WLI format because the pilots performed the secondary task differently. The resulting tap rates of subjects A and C remained essentially constant over the entire range of time delays, whereas the tap rates of subjects B and D fell off as time delay was increased. The lack of controls on the secondary task makes it impossible to force the subjects to implement the task in a consistent manner. However, as indicated in figures 9, 17, 19, and 20, the secondary task did increase the total pilot workload and reduced the performance of the primary task.

CONCLUDING REMARKS

An experimental study has been made to determine the effect on pilot performance of time delays in the visual and motion feedback loops of a simulated pursuit tracking task. Three major interrelated factors have been identified: task difficulty, motion cues, and time delays. Results from this study can be summarized as follows:

1. The amount of time delay that can be tolerated decreases as task difficulty increases. In these tests, the task difficulty was altered by changing the frequency and damping of the short-period longitudinal mode of the pursuit aircraft. The task difficulty was also altered by changing the sinusoidal frequency of oscillation of the target aircraft.

2. When relatively complete motion cues are included in the simulator, considerably larger time delays can exist without degrading pilot performance. The amount of motion available and the number of degrees of freedom of motion are important factors.

3. Although only four subjects were used in the study, there is a significant pilot effect. In general, the subjects fall into two groups. For the first group, the tracking error is significantly improved when motion is included; for the second group, motion has considerably less effect on tracking error. All the subjects preferred motion to no-motion conditions and used significantly smaller control inputs when motion cues were included in the simulation.

4. The response characteristics of the visual and motion system employed in the current study are well matched. However, pilot performance could be improved by adding a delay of 2 units (62.5 msec) to the visual system. The resulting improvement in tracking performance did not occur for all subjects. When the total difference (added delay plus 2 units for visual-motion mismatch) between the visual delay and the motion delay exceeded about 6 units (187 msec), the subjects tended to become nauseated.

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APPENDIX

EQUATIONS OF MOTION

The linearized equations used in this study for the pursuing aircraft are written about the aircraft body axes and are:

$$a_X = 0 \tag{A1}$$

$$a_Y = Y_\beta \beta V_{x,o} \tag{A2}$$

$$a_Z = -(L_\alpha \alpha + L_o)V_{x,o} \tag{A3}$$

$$\dot{p} = L_p p + L_\beta \beta + L_r r + L_{\delta_a}\delta_a \tag{A4}$$

$$\dot{q} = M_\alpha \alpha + M_q q + M_{\delta_e}\delta_e \tag{A5}$$

$$\dot{r} = N_r r + N_\beta \beta + N_p p + N_{\delta_r}\delta_r \tag{A6}$$

In equations (A2) and (A3)

$$\alpha = \tan^{-1} \frac{w}{u}$$

$$\beta = \sin^{-1} \frac{v}{V}$$

$$V = (V_x^2 + V_y^2 + V_z^2)^{1/2}$$

and

$$u = \ell_1 V_x + \ell_2 V_y + \ell_3 V_z$$

$$v = m_1 V_x + m_2 V_y + m_3 V_z$$

$$w = n_1 V_x + n_2 V_y + n_3 V_z$$

Aircraft orientation and velocity relative to inertia are required to generate the proper position of the target relative to the pursuer (for display purposes). The orientation of the pursuer in space is specified by Euler angles. These angles are determined from body angular rates by

$$\dot{\phi} = p + q \sin\phi \tan\theta + r \cos\phi \tan\theta$$

$$\dot{\theta} = q \cos\phi - r \sin\phi$$

$$\dot{\psi} = (r \cos \phi + q \sin \theta)\frac{1}{\cos \theta}$$

Inertial accelerations are given by

$$\dot{V}_x = \ell_1 a_X + m_1 a_Y + n_1 a_Z$$

$$\dot{V}_y = \ell_2 a_X + m_2 a_Y + n_2 a_Z$$

$$\dot{V}_z = \ell_3 a_X + m_3 a_Y + n_3 a_Z + g$$

Direction cosines are defined as follows:

$$\ell_1 = \cos \psi \cos \theta$$

$$\ell_2 = \sin \psi \cos \theta$$

$$\ell_3 = -\sin \theta$$

$$m_1 = \cos \psi \sin \theta \sin \phi - \sin \psi \cos \phi$$

$$m_2 = \sin \psi \sin \theta \sin \phi + \cos \psi \cos \phi$$

$$m_3 = \cos \theta \sin \phi$$

$$n_1 = \cos \psi \sin \theta \cos \phi + \sin \psi \sin \phi$$

$$n_2 = \sin \psi \sin \theta \cos \phi - \cos \psi \sin \phi$$

$$n_3 = \cos \theta \cos \phi$$

Initial conditions were $V_{x,o} = 304.8$ m/sec; $V_{y,o} = V_{z,o} = 0$; $\psi_o = \theta_o = \phi_o = 0$; and $p_o = q_o = r_o = 0$.

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TABLE I.- PARAMETERS OF "GOOD" AIRCRAFT

Parameter	Value
L_{α}	2.0
L_{o}	.0322
M_{α}	-4.50
M_{q}	-2.20
M_{δ_e}	-10.0
L_{β}	-42.14
L_{p}	-2.74
L_{r}	2.058
N_{β}	5.544
N_{p}	.0148
N_{r}	-2.782
Y_{β}	-.1589
L_{δ_a}	-10.0
N_{δ_a}	0
N_{δ_r}	-10.0

TABLE II.- MOTION-BASE DRIVE EQUATIONS AND GAIN VALUES USED

[Alternate pure angular motion case can be obtained with all gains set to zero except $K_0 = 0.15$, $K_8 = 0.50$, and $K_{11} = 0.075$]

(a) Motion-base drive equation

$$\theta_c = \theta + K_0\dot{\theta}$$

$$\dot{p}_K = K_1 p - K_2 p_K - K_3 a_Y$$

$$\ddot{y}_K = K_4 a_Y + K_5 p_K - K_6 \dot{y}_K - K_7 y_K$$

$$\phi_c = K_8 \phi + K_9 p_K + K_{10} \dot{p}_K + K_{11} \dot{\phi}$$

$$y_c = y_K + K_{12} \dot{y}_K + K_{13} \ddot{y}_K$$

$$\ddot{z}_K = K_{14} \dot{V}_z - K_{15} \dot{z}_K - K_{16} z_K$$

$$z_c = z_K + K_{17} \dot{z}_K + K_{18} \ddot{z}_K$$

(b) Gain values

Gain	Motion cases		
	Full motion	No heave	Pure angular
K_0[a]	0.15	0.15	0.15
K_1	.50	.50	.50
K_2	.322	.322	.322
K_3	.01	.01	.01
K_4	1.00	1.00	0
K_5	32.2	32.2	0
K_6	1.134	1.134	0
K_7	.67	.67	0
K_8	0	0	0
K_9	1.0	1.0	1.0
K_{10}[a]	.15	.15	.15
K_{11}[a]	0	0	0
K_{12}[a]	.15	.15	0
K_{13}[a]	.007	.007	0
K_{14}	.15	0	0
K_{15}	2.02	0	0
K_{16}	2.01	0	0
K_{17}[a]	.1333	0	0
K_{18}[a]	.007	0	0

[a]Hardware compensation parameters.

TABLE III.- SUMMARY OF DATA FOR AIRPLANE-MOTION-DELAY INTERACTION WITH SUBJECT A

[t-tests performed treating each factor separately]

(a) Total error

	Total error in meters for units of time delay[a] of -								
	0	1	2	3	4	5	8	12	16
	Basic airplane - no motion								
	6.684	6.715	9.568	8.608	10.375	10.339	13.856	9.604	9.653
	6.264	7.541	8.181	8.903	8.196	9.418	10.866	9.485	11.485
	6.099	6.242	6.925	7.602	8.547	6.468	10.342	9.894	9.860
	7.370	6.078	7.602	8.708	7.678	8.193	8.595	11.189	8.629
	5.752	8.111	8.760	6.465	9.327	9.147	8.394	14.624	12.524
	8.111	8.089	7.276	9.083	7.757	8.092	7.903	8.809	11.384
	7.239	8.303	8.476	7.480	7.443	9.309	7.279	8.888	10.214
	7.583	7.343	5.685	7.279	8.861	12.674	9.946	15.222	11.585
	7.230	6.111	7.995	6.224	7.556	5.816	9.720	8.970	10.266
	7.498	6.422	5.611	5.364	6.468	6.885	9.050	9.360	11.777
$\bar{\epsilon}_v + \bar{\epsilon}_h$	6.983	7.095	7.608	7.572	8.224	8.634	9.595	10.605	10.738
$\bar{\sigma}$	.751	.886	1.276	1.266	1.104	2.020	1.869	2.380	1.195
t(time delay)	Control	.12	.91	.84	1.82	[b]2.77	[b]3.89	[b]5.40	[b]5.61
t(airplane)									
	Basic airplane - full motion								
	7.446	6.322	5.697	7.861	6.806	7.114	7.004	8.217	7.977
	7.175	6.245	6.861	7.254	6.379	7.065	6.764	7.148	10.394
	6.187	5.867	6.550	6.215	7.105	6.660	6.733	8.236	10.747
	7.330	5.428	5.806	6.654	7.081	5.965	5.297	7.714	8.498
	5.276	5.285	5.270	5.051	5.901	6.956	6.069	11.421	13.219
	5.666	6.117	5.499	6.507	5.566	6.130	6.130	10.144	6.837
	6.215	6.184	5.938	6.611	6.779	5.816	6.709	8.220	7.928
	7.337	6.242	4.703	6.035	7.132	7.565	6.608	8.501	9.991
	7.772	7.044	6.035	6.251	8.867	9.336	7.693	7.958	7.443
	5.718	6.517	7.007	5.791	7.093	5.715	8.915	7.724	9.824
$\bar{\epsilon}_v + \bar{\epsilon}_h$	6.612	6.128	5.937	6.423	6.871	6.832	6.792	8.529	9.286
$\bar{\sigma}$	.896	.507	.716	.772	.888	1.081	.978	1.282	1.920
t(time delay)	Control	1.01	1.40	.39	.54	.46	.32	[b]3.98	[b]5.56
t(motion)	.76	[b]3.00	[b]3.08	[b]2.45	[b]3.01	[b]2.94	[b]4.06	[b]2.58	1.53
t(airplane)									

	Total error in meters for units of time delay[a] of -					
	0	4	6	8	12	16
	Good airplane - no motion					
	6.785	8.452	6.024	7.044	7.163	7.541
	7.138	6.812	7.012	7.087	7.900	8.656
	6.087	8.062	6.427	7.657	8.676	8.531
	6.008	7.410	6.492	7.175	13.350	9.034
	4.901	5.505	6.487	6.258	7.269	6.962
	5.319	6.593	6.035	7.675	6.026	5.877
	5.270	5.392	7.220	8.562	8.443	7.306
	4.386	7.361	7.498	5.870	7.507	7.306
	5.453	6.294	8.014	11.939	6.453	6.523
	7.154	5.855	7.520	6.309	7.199	8.605
$\bar{\epsilon}_v + \bar{\epsilon}_h$	5.850	6.773	6.873	7.561	7.999	7.634
$\bar{\sigma}$	.951	1.047	.681	1.730	2.047	1.041
t(time delay)	Control	1.54	1.71	[b]2.86	[b]3.59	[b]2.98
t(airplane)	[b]3.10	[b]3.01		[b]2.53	[b]2.62	[b]6.21
	Good airplane - full motion					
	6.632	6.242	-----	6.020	7.849	7.745
	5.855	6.072	-----	6.139	6.291	8.291
	5.806	7.132	-----	6.907	7.239	5.742
	7.135	7.647	-----	6.550	6.032	8.842
	5.919	5.816	-----	5.703	5.672	7.588
	4.874	4.813	-----	6.069	6.904	9.095
	5.904	5.136	-----	5.907	6.011	5.358
	5.404	5.374	-----	5.733	5.316	6.615
	6.767	6.404	-----	5.230	6.224	6.075
	5.218	5.901	-----	5.364	6.212	7.916
$\bar{\epsilon}_v + \bar{\epsilon}_h$	5.952	6.054	-----	5.962	6.375	7.348
$\bar{\sigma}$	.712	.868	-----	.505	.754	1.297
t(time delay)	Control	.26	-----	.03	1.09	[b]3.59
t(motion)	.27	1.67	-----	[b]2.80	[b]2.26	.55
t(airplane)	1.83	2.08	-----	[b]2.38	[b]4.59	[b]2.65

Interaction	Airplane	Motion	Time delay	Airplane-motion	Airplane-delay	Motion-delay	Airplane-motion-delay	Replicates	Error
d.o.f.	1	1	4	1	4	4	4	9	171
ANOV[c] F	[b]80.05	[b]41.80	[b]20.38	[b]3.93	[b]3.00	[b]4.37	0.36	0.98	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE III.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -									Vertical error in meters for units of time delay[a] of -					
	0	1	2	3	4	5	8	12	16	0	4	6	8	12	16
	Basic airplane - no motion									Good airplane - no motion					
	4.936	5.029	6.156	5.766	7.218	7.021	10.321	6.589	6.261	3.632	4.401	3.529	4.206	4.448	4.878
	4.767	4.346	5.736	6.459	5.307	7.374	6.608	6.353	7.287	3.705	4.108	3.872	4.186	4.550	5.181
	4.050	4.069	5.162	5.205	5.571	4.632	7.686	6.823	6.927	4.092	4.271	3.823	4.507	5.572	5.536
	5.730	4.687	4.533	6.161	5.393	5.299	5.891	6.524	6.534	3.954	4.221	4.495	4.326	5.468	5.435
	3.970	5.372	6.256	4.957	6.265	7.130	5.894	6.972	8.838	3.561	3.341	4.483	4.473	4.466	4.712
	5.221	5.991	5.386	6.215	5.567	6.104	5.554	9.715	7.165	3.807	4.185	3.735	4.954	4.050	4.499
	4.805	4.765	5.313	5.236	5.198	5.940	5.418	5.871	7.317	3.620	3.889	4.669	3.762	5.232	4.955
	4.054	5.403	4.308	4.813	5.604	6.870	6.713	6.415	6.999	3.637	3.774	4.163	4.543	4.246	4.955
	4.359	4.380	4.964	4.629	5.089	4.371	6.297	9.927	6.091	4.063	4.212	4.484	5.951	4.468	4.275
	4.901	4.640	3.509	4.237	4.257	6.082	5.675	6.351	7.084	4.112	4.440	4.228	4.688	4.842	5.975
$\bar{\epsilon}_v$	4.679	4.868	5.132	5.368	5.547	6.082	6.006	7.154	7.050	3.818	4.084	4.146	4.560	4.734	5.040
$\bar{\sigma}$	.570	.585	.848	.748	.774	1.051	1.471	1.437	.758	.217	.332	.389	.584	.523	.508
t(time delay)	Control	.44	1.04	1.59	2.00	[b]3.24	[b]4.44	[b]5.71	[b]5.47	Control	1.31	[b]3.74	1.65	[b]4.62	[b]6.16
t(airplane)										[b]4.46	[b]5.49		[b]4.09	[b]5.00	[b]6.97
	Basic airplane - full motion									Good airplane - full motion					
	4.543	4.572	4.052	5.751	4.415	5.054	5.236	5.273	5.724	4.295	4.408	------	4.404	5.827	5.385
	4.659	4.380	5.074	5.519	4.514	4.758	4.812	5.046	6.499	3.546	3.871	------	4.313	4.268	6.236
	4.425	3.834	4.125	4.375	5.414	4.841	5.161	6.040	7.495	4.076	5.275	------	4.761	4.697	3.965
	4.794	3.762	4.198	4.085	4.882	4.645	3.589	5.463	5.886	4.720	5.528	------	4.708	3.887	5.894
	4.034	3.527	3.581	3.782	3.702	4.253	4.662	6.628	6.211	3.764	4.271	------	3.866	4.691	5.340
	3.911	4.288	3.666	4.082	3.731	4.433	3.845	6.544	5.028	3.526	3.557	------	3.787	5.193	6.080
	4.596	3.942	3.677	4.426	3.828	4.200	4.451	4.953	4.766	4.297	4.044	------	4.396	4.285	3.741
	4.520	3.932	3.429	4.685	4.784	5.450	4.427	5.219	5.664	4.142	3.881	------	4.185	3.771	4.812
	4.516	4.276	4.609	4.737	4.818	6.973	4.617	4.729	4.524	5.100	4.235	------	4.054	4.835	4.446
	4.172	4.582	5.462	4.386	4.834	4.762	5.878	5.519	6.742	3.878	3.831	------	3.923	4.527	5.394
$\bar{\epsilon}_v$	4.417	4.109	4.187	4.583	4.492	4.937	4.668	5.541	5.854	4.134	4.290	------	4.240	4.598	5.129
$\bar{\sigma}$	.285	.360	.674	.626	.574	.806	.667	.656	.926	.500	.639	------	.338	.609	.866
t(time delay)	Control	1.06	.79	.57	.26	1.80	.87	[b]3.89	[b]4.97	Control	.57	------	.38	1.68	[b]3.61
t(motion)	1.01	[b]3.49	[b]2.76	[b]2.54	[b]3.55	[b]2.74	[b]4.90	[b]3.76	[b]2.27	1.83	.90	------	1.50	.53	.28
t(airplane)										1.98	.74	------	1.81	[b]3.33	1.81

Interaction	Airplane	Motion	Time delay	Airplane-motion	Airplane-delay	Motion-delay	Airplane-motion-delay	Replicates	Error
d.o.f.	1	1	4	1	4	4	4	9	171
ANOV[c] F	[b]124.82	[b]31.79	[b]28.40	[b]35.28	[b]3.36	[b]4.02	0.94	1.52	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE III.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -								
	0	1	2	3	4	5	8	12	16
	Basic airplane - no motion								
	1.749	1.686	3.412	2.840	3.156	3.318	3.535	3.015	3.391
	1.497	3.193	2.446	2.445	2.891	2.044	4.257	3.132	4.199
	2.049	2.174	1.764	2.398	2.982	1.836	2.656	2.537	2.935
	1.639	1.390	3.070	2.549	2.284	2.894	2.704	3.370	2.096
	1.782	2.738	2.505	1.509	3.062	2.018	2.501	4.218	3.687
	2.890	2.097	1.888	2.869	2.189	1.990	2.348	4.909	4.218
	2.432	3.537	3.163	2.243	2.246	3.368	1.861	2.938	2.897
	3.531	1.938	1.378	2.162	3.256	5.804	3.232	2.473	4.586
	2.871	1.732	3.030	1.600	2.498	1.444	3.394	5.295	4.175
	2.596	1.782	2.104	1.129	2.209	2.746	3.376	2.620	4.695
$\bar{\epsilon}_h$	2.304	2.227	2.476	2.174	2.678	2.746	2.986	3.451	3.668
$\bar{\sigma}$	.668	.703	.684	.583	.432	1.256	.699	1.009	.844
t(time delay)	Control	.21	.48	.36	1.05	1.24	1.91	[b]3.21	[b]3.88
t(airplane)									
	Basic airplane - full motion								
	2.633	1.748	1.645	2.111	2.391	2.061	1.770	2.633	2.252
	2.788	1.867	1.787	1.735	1.865	2.307	1.952	2.102	3.894
	1.764	2.033	2.427	1.840	1.692	1.819	1.574	2.195	3.254
	2.536	1.665	1.608	2.568	2.197	1.321	1.729	2.251	2.612
	1.241	1.758	1.689	1.268	2.198	2.702	1.406	4.794	7.007
	1.754	1.829	1.832	2.426	1.836	1.697	2.284	3.599	1.809
	1.618	2.240	2.262	2.185	2.952	1.622	2.257	3.268	3.163
	2.816	2.311	1.273	1.351	2.349	2.115	2.183	3.281	4.327
	3.256	2.769	1.427	1.514	4.049	2.362	3.077	3.229	2.924
	1.546	1.935	1.546	1.406	2.258	.954	3.040	2.206	3.082
$\bar{\epsilon}_h$	2.195	2.016	1.750	1.841	2.379	1.896	2.127	2.956	3.432
$\bar{\sigma}$	.684	.338	.355	.464	.686	.522	.570	.853	1.452
t(time delay)	Control	.55	1.36	1.08	.56	.91	.21	[b]2.32	[b]3.78
t(motion)	.31	.86	[b]2.98	1.42	.89	1.98	1.92	1.02	.40
t(airplane)									

	Horizontal error in meters for units of time delay[a] of -					
	0	4	6	8	12	16
	Good airplane - no motion					
	3.154	4.053	2.385	2.839	2.716	2.661
	3.921	2.705	2.745	2.902	3.350	3.476
	1.995	3.790	2.546	3.148	3.104	2.996
	2.055	3.189	2.704	2.849	7.882	3.599
	1.341	2.164	2.680	1.785	2.804	2.251
	1.513	2.408	2.412	2.720	1.977	1.379
	1.649	1.504	2.768	4.801	3.211	2.351
	.749	3.585	3.436	1.327	3.260	2.351
	1.391	2.082	3.477	5.987	1.984	2.249
	3.043	1.416	2.886	1.622	2.357	2.269
$\bar{\epsilon}_h$	2.083	2.690	2.804	2.998	3.264	2.558
$\bar{\sigma}$	.988	.935	.378	1.434	1.699	.656
t(time delay)	Control	1.34	1.58	1.97	[b]2.52	1.15
t(airplane)	.77	.04		.02	.30	[b]3.26
	Good airplane - full motion					
	2.337	1.835	-----	1.617	2.023	2.360
	2.309	2.201	-----	1.825	2.023	2.055
	1.731	1.858	-----	2.145	2.541	1.776
	2.417	2.120	-----	1.842	2.144	2.949
	2.155	1.546	-----	1.836	.982	2.156
	1.349	1.255	-----	2.283	1.710	3.014
	1.608	1.092	-----	1.512	1.725	1.616
	1.263	1.493	-----	1.549	1.545	2.005
	1.666	2.170	-----	1.176	1.390	1.629
	1.340	2.069	-----	1.442	1.684	2.521
$\bar{\epsilon}_h$	1.818	1.764	-----	1.723	1.777	2.208
$\bar{\sigma}$	.449	.397	-----	.332	.433	.501
t(time delay)	Control	.28	-----	.50	.21	[b]2.10
t(motion)	.67	[b]2.89	-----	[b]2.74	[b]2.68	1.45
t(airplane)	2.05	[b]2.46	-----	1.94	[b]3.90	[b]2.51

Interaction	Airplane	Motion	Time delay	Airplane-motion	Airplane-delay	Motion-delay	Airplane-motion-delay	Replicates	Error
d.o.f.	1	1	4	1	4	4	4	9	171
ANOV[c] F	[b]20.12	[b]23.77	[b]6.26	[b]4.10	1.88	[b]2.49	0.35	0.68	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE III.- Continued

(d) Aileron deflection

	Basic airplane: Aileron deflection (× 10^2), radians, for units of time delay[a] of - 0	1	2	3	4	5	8	12	16
	Basic airplane - no motion								
	2.968	2.124	3.546	3.044	3.297	2.406	3.453	2.933	3.460
	2.363	2.394	1.991	2.035	2.583	2.458	3.070	2.878	4.803
	2.013	3.612	2.025	2.030	2.709	2.096	2.507	3.138	3.692
	2.070	1.685	2.426	2.091	1.661	2.269	2.931	3.942	2.762
	2.162	2.248	1.877	1.662	2.337	1.486	2.061	3.935	3.778
	1.662	1.726	2.186	2.054	1.800	1.995	2.579	4.280	4.241
	2.334	2.635	2.689	2.131	2.898	2.393	2.115	2.674	2.069
	3.644	1.867	2.241	2.046	3.267	3.366	2.685	2.341	2.895
	3.233	2.129	2.834	2.364	3.552	2.449	3.208	1.897	2.910
	2.734	1.855	3.023	2.396	2.424	2.324	2.743	2.450	3.302
$\bar{\delta}_a$	2.518	2.228	2.484	2.186	2.653	2.324	2.735	3.047	3.391
σ	.615	.572	.533	.363	.626	.471	.446	.780	.788
t(time delay)	Control	1.10	.13	1.25	.51	.73	.82	1.99	[b]3.29
t(airplane)									
	Basic airplane - full motion								
	1.328	1.369	1.531	1.684	1.732	1.541	1.758	2.404	2.468
	1.563	1.632	1.638	1.462	1.207	1.803	1.583	2.497	2.470
	1.441	1.746	1.814	1.899	1.461	1.539	1.842	3.099	2.799
	1.618	1.321	1.297	1.600	1.573	1.351	1.886	2.147	2.386
	1.108	1.926	1.337	1.560	1.723	1.999	1.424	2.253	3.022
	1.213	1.812	1.357	1.929	1.417	1.640	1.951	2.281	2.659
	1.977	2.077	1.611	1.769	1.844	1.849	2.253	2.634	2.472
	2.608	2.383	2.536	1.275	3.002	1.575	2.826	2.404	2.727
	2.708	2.350	1.162	1.386	2.955	1.449	2.516	1.793	1.477
	1.290	1.487	1.539	1.412	1.752	.982	3.070	1.184	1.415
$\bar{\delta}_a$	1.685	1.810	1.582	1.597	1.867	1.573	2.111	2.275	2.389
σ	.568	.377	.386	.221	.616	.285	.542	.508	.533
t(time delay)	Control	.60	.49	.42	.87	.54	2.04	[b]2.82	[b]3.37
t(motion)	[b]3.61	1.93	[b]4.33	[b]4.38	[b]3.62	[b]4.31	[b]2.81	[b]2.98	[b]2.77
t(airplane)									

	Good airplane: Aileron deflection (× 10^2), radians, for units of time delay[a] of - 0	4	6	8	12	16
	Good airplane - no motion					
	1.901	3.379	2.481	3.084	3.541	2.906
	3.036	2.371	3.547	2.419	2.556	2.811
	2.922	3.016	2.123	2.946	2.824	3.605
	2.055	2.561	2.539	2.340	5.512	4.328
	2.229	3.226	2.684	2.350	2.213	2.929
	1.815	3.626	2.904	2.643	1.480	1.814
	2.163	2.319	2.293	4.530	2.214	1.758
	1.905	3.548	2.859	1.566	3.118	1.758
	1.738	3.187	3.391	4.589	1.865	2.416
	2.900	1.824	3.429	2.049	2.925	1.633
$\bar{\delta}_a$	2.266	2.907	2.825	2.852	2.825	2.596
σ	.497	.609	.495	.997	1.124	.897
t(time delay)	Control	1.77	1.54	1.62	1.54	.91
t(airplane)	1.01	.92		.34	.51	[b]2.10
	Good airplane - full motion					
	1.555	1.764	-----	1.859	1.679	1.346
	1.787	1.840	-----	1.352	1.910	2.111
	1.653	1.357	-----	1.969	1.547	1.764
	1.515	1.626	-----	1.522	1.878	1.822
	1.115	1.478	-----	1.630	1.131	1.557
	1.488	1.754	-----	1.932	2.009	2.119
	1.750	1.169	-----	1.389	1.895	1.916
	1.174	1.441	-----	1.376	1.891	1.627
	1.720	1.504	-----	1.214	1.885	1.692
	1.255	1.424	-----	1.774	1.663	2.410
$\bar{\delta}_a$	1.501	1.536	-----	1.602	1.749	1.836
σ	.244	.209	-----	.270	.259	.313
t(time delay)	Control	.22	-----	.64	1.58	1.73
t(motion)	[b]4.37	[b]6.85	-----	[b]3.79	[b]2.99	[b]2.42
t(airplane)	.94	1.60	-----	[b]2.66	[b]2.92	[b]2.41

Interaction	Airplane	Motion	Time delay	Airplane-motion	Airplane-delay	Motion-delay	Airplane-motion-delay	Replicates	Error
d.o.f.	1	1	4	1	4	4	4	9	171
ANOV[c] F	[b]12.23	[b]104.18	[b]4.30	2.23	1.41	0.38	0.84	0.57	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE III.- Concluded

(e) Elevator deflection

	Elevator deflection (× 10^2), radians, for units of time delay[a] of -								
	0	1	2	3	4	5	8	12	16
	Basic airplane - no motion								
	0.843	1.060	1.074	1.253	1.288	1.341	1.297	0.766	0.771
	.996	1.090	1.159	1.132	.986	1.339	1.243	.853	.906
	.975	.854	.734	.925	.928	.946	1.186	.954	1.103
	.883	.736	.948	1.090	1.105	1.003	.900	.905	.935
	.749	.955	1.099	.958	1.091	1.116	1.080	1.056	1.048
	.908	1.146	.983	1.252	1.118	1.149	.967	1.262	1.051
	.980	.743	.926	.505	.675	.810	.736	.572	.865
	.771	.630	.728	.724	.945	.967	.938	.825	.976
	.852	.514	1.024	.782	1.140	.776	1.068	.995	.837
	1.066	.601	.484	.562	.723	1.050	.809	.701	.987
$\bar{\delta}_e$	0.902	0.833	0.916	0.924	1.000	1.050	1.022	0.889	0.948
σ	.102	.223	.208	.260	.191	.193	.185	.194	.105
t(time delay)	Control	.70	.14	.22	1.00	1.49	1.22	.14	.46
t(airplane)									
	Basic airplane - full motion								
	0.525	0.528	0.543	0.529	0.632	0.596	0.583	0.710	0.602
	.566	.623	.586	.612	.634	.611	.580	.632	.540
	.535	.681	.624	.639	.651	.665	.644	.599	.642
	.712	.574	.592	.670	.725	.706	.622	.626	.610
	.601	.634	.678	.659	.712	.788	.782	.722	.600
	.568	.643	.608	.064	.649	.722	.664	.592	.637
	.603	.552	.529	.657	.609	.560	.636	.585	.629
	.675	.630	.609	.574	.665	.594	.712	.606	.663
	.604	.542	.484	.521	.694	.665	.684	.596	.514
	.454	.438	.517	.522	.553	.545	.684	.566	.521
$\bar{\delta}_e$	0.584	0.585	0.577	0.599	0.653	0.646	0.659	0.623	0.596
σ	.074	.072	.058	.069	.051	.077	.061	.052	.053
t(time delay)	Control	.01	.25	.55	[b]2.39	[b]2.15	[b]2.63	1.37	.40
t(motion)	[b]6.86	[b]3.36	[b]4.95	[b]3.83	[b]6.41	[b]3.26	[b]5.54	[b]4.22	[b]4.60
t(airplane)									

	Elevator deflection (× 10^2), radians, for units of time delay[a] of -					
	0	4	6	8	12	16
	Good airplane - no motion					
	0.568	0.665	0.530	0.696	0.750	0.767
	.573	.584	.607	.529	.732	.807
	.546	.628	.553	.638	.763	.780
	.629	.564	.714	.724	1.006	.991
	.489	.729	.670	.564	.635	.782
	.543	.647	.517	.609	.612	.614
	.677	.603	.704	.916	.971	.636
	.597	.694	.725	.643	.742	.636
	.616	.658	.738	.754	.572	.645
	.605	.683	.558	.495	.640	1.038
$\bar{\delta}_e$	0.584	0.646	0.631	0.657	0.722	0.770
σ	.052	.051	.088	.123	.123	.149
t(time delay)	Control	1.32	1.01	1.56	[b]2.96	[b]3.98
t(airplane)	[b]8.74	[b]5.68		[b]5.22	[b]2.30	[b]3.10
	Good airplane - full motion					
	0.550	0.433	-----	0.387	0.526	0.487
	.475	.396	-----	.465	.514	.500
	.409	.486	-----	.439	.421	.509
	.416	.471	-----	.427	.497	.552
	.401	.421	-----	.552	.488	.536
	.378	.409	-----	.458	.525	.461
	.427	.403	-----	.454	.493	.502
	.402	.408	-----	.440	.551	.525
	.445	.465	-----	.430	.543	.522
	.455	.388	-----	.482	.531	.596
$\bar{\delta}_e$	0.436	0.428	-----	0.453	0.509	0.518
σ	.050	.035	-----	.043	.038	.037
t(time delay)	Control	.43	-----	.96	[b]4.01	[b]4.53
t(motion)	[b]6.51	[b]10.87	-----	[b]4.96	[b]5.33	[b]5.19
t(airplane)	[b]5.30	[b]12.20	-----	[b]8.58	[b]5.73	[b]3.87

Interaction	Airplane	Motion	Time delay	Airplane-motion	Airplane-delay	Motion-delay	Airplane-motion-delay	Replicates	Error
d.o.f.	1	1	4	1	4	4	4	9	171
ANOV[c] F	[b]222.31	[b]334.36	[b]3.34	[b]16.71	[b]5.75	1.00	0.45	0.90	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE IV.- SUMMARY OF DATA FOR "BAD" AIRPLANE WITH SUBJECT A

[t-tests performed treating each factor separately]

(a) Total error

	Total error in meters for units of time delay[a] of -			
	0	0	4	8
	Bad airplane - full motion	Bad airplane - no motion		
	6.491	9.168	8.305	12.882
	5.904	7.819	7.950	20.620
	5.573	9.587	13.210	18.225
	6.487	12.002	8.133	10.398
	7.250	8.086	6.674	11.311
	5.253	10.518	7.157	7.414
	4.926	6.247	8.697	9.496
	6.887	7.038	6.378	7.143
	6.494	8.130	8.764	8.463
	5.684	7.494	7.033	8.366
$\bar{\varepsilon}_v + \bar{\varepsilon}_h$	6.110	8.554	8.230	11.432
$\bar{\sigma}$	.755	1.727	1.936	4.598
t(time delay)		Control	.28	[b]2.11
t(motion)	Control	[b]4.94		

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.

TABLE IV.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -			
	0	0	4	8
	Bad airplane - full motion	Bad airplane - no motion		
	5.128	6.580	5.316	8.086
	4.906	6.214	5.441	12.199
	4.679	7.423	8.399	11.678
	5.151	6.560	6.408	7.592
	5.895	5.187	5.202	8.240
	4.130	7.823	5.423	5.163
	4.206	4.885	6.207	7.868
	5.146	5.111	5.221	5.599
	4.278	4.996	6.519	6.608
	4.871	5.722	5.748	6.505
$\bar{\varepsilon}_v$	4.839	6.050	5.988	7.954
$\bar{\sigma}$	.542	1.043	.980	2.342
t(time delay)		Control	.09	[b]2.69
t(motion)	Control	[b]3.81		

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE IV.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -			
	0	0	4	8
	Bad airplane - full motion	Bad airplane - no motion		
	1.364	2.588	2.987	4.796
	.998	1.604	2.509	8.421
	.894	2.164	4.811	6.547
	1.488	5.443	1.725	2.806
	1.355	2.899	1.472	3.072
	1.123	2.695	1.734	2.251
	.720	1.362	2.491	1.629
	1.741	1.926	1.157	1.544
	2.216	3.134	2.245	1.856
	.813	1.771	1.285	1.861
$\bar{\varepsilon}_h$	1.271	2.558	2.242	3.478
$\bar{\sigma}$	.463	1.169	1.080	2.360
t(time delay)		Control	.04	1.25
t(motion)	Control	[b]4.28		

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.

TABLE IV.- Continued

(d) Aileron deflection

	Aileron deflection (× 10²), radians, for units of time delay[a] of -			
	0	0	4	8
	Bad airplane - full motion	Bad airplane - no motion		
	0.449	1.390	1.205	1.296
	.528	1.227	1.270	1.963
	.484	1.539	1.842	1.801
	.530	1.532	1.669	1.686
	.583	1.803	1.425	1.738
	.451	1.195	1.088	1.461
	.648	1.644	1.649	1.072
	.660	1.388	1.063	.926
	.844	1.240	1.715	1.261
	.684	1.356	1.134	1.088
$\bar{\delta}_a$	0.586	1.431	1.406	1.429
σ	.124	.197	.292	.354
t(time delay)		Control	.20	.02
t(motion)	Control	[b]6.09		

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.

TABLE IV.- Concluded

(e) Elevator deflection

	Elevator deflection (× 10^2), radians, for units of time delay[a] of -			
	0	0	4	8
	Bad airplane - full motion	Bad airplane - no motion		
	0.148	0.514	0.572	0.665
	.185	.455	.555	.798
	.172	.471	.664	.766
	.153	.805	.515	.537
	.142	.490	.354	.556
	.164	.622	.334	.319
	.154	.444	.332	.418
	.172	.433	.313	.277
	.209	.379	.451	.427
	.236	.391	.336	.326
$\bar{\delta}_e$	0.174	0.500	0.443	0.509
σ	.029	.127	.126	.187
t(time delay)		Control	.86	.13
t(motion)	Control	[b]6.83		

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.

TABLE V.- SUMMARY OF DATA FOR TARGET FREQUENCY EFFECTS WITH SUBJECT A

[Basic airplane with full motion;
t-tests performed treating
each factor separately]

(a) Total error

	Total error in meters for units of time delay[a] of -														
	0	2	4	8	12	16	0	2	4	8	12	0	2	4	8
	ω_T = 0.210 rad/sec						ω_T = 0.315 rad/sec					ω_T = 0.420 rad/sec			
	7.446	5.697	6.806	7.004	8.217	7.977	5.797	6.713	7.832	8.644	10.008	8.748	8.389	9.316	9.868
	7.175	6.861	6.379	6.764	7.148	10.394	5.532	6.149	9.621	8.737	9.323	8.624	8.167	9.393	13.654
	6.187	6.550	7.105	6.733	8.236	10.747	6.269	6.331	6.094	7.591	8.169	9.183	12.895	11.862	11.773
	7.330	5.806	7.081	5.297	7.714	8.498	6.873	6.393	6.415	7.316	8.192	8.471	10.614	11.117	13.236
	5.276	5.270	5.901	6.069	11.421	13.219	6.643	7.617	7.335	6.226	7.831	9.019	8.848	11.253	10.890
	5.666	5.499	5.566	6.130	10.144	6.837	6.033	5.767	9.404	7.498	7.539	10.339	8.286	11.752	14.109
	6.215	5.938	6.779	6.709	8.220	7.928	5.565	5.995	7.336	8.320	7.235	9.764	9.706	12.791	14.468
	7.337	4.703	7.132	6.608	8.501	9.991	5.275	5.626	5.213	7.510	7.591	9.933	9.654	9.790	10.092
	7.772	6.035	8.867	7.693	7.958	7.443	7.587	6.214	7.303	7.330	8.921	7.031	10.312	11.658	12.137
	5.718	7.007	7.093	8.915	7.724	9.824	6.899	5.853	5.913	6.380	8.478	7.671	10.312	11.811	12.892
$\bar{\varepsilon}_v + \bar{\varepsilon}_h$	6.612	5.937	6.871	6.792	8.529	9.286	6.247	6.266	7.247	7.555	8.329	8.878	9.718	11.074	12.312
$\bar{\sigma}$	.896	.716	.888	.978	1.282	1.920	.741	.574	1.437	.845	.872	1.014	1.437	1.179	1.637
t(time delay)	Control	1.28	.49	.34	[b]3.03	[b]5.069	Control	.04	[b]2.38	[b]3.11	[b]4.951	Control	1.29	[b]3.67	[b]5.75
t(target frequency)							.91	.75	.71	1.41	.41	[b]5.69	[b]8.50	[b]7.90	[b]10.22

Interaction	Frequency	Time delay	Frequency-delay	Replicates	Error
d.o.f.	2	3	6	9	99
ANOV[c] F	[b]166.99	[b]17.51	[b]4.07	1.03	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE V.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -														
	0	2	4	8	12	16	0	2	4	8	12	0	2	4	8
	ω_T = 0.210 rad/sec						ω_T = 0.315 rad/sec					ω_T = 0.420 rad/sec			
	4.543	4.052	4.415	5.236	5.273	5.724	5.040	5.846	6.906	7.514	8.704	7.145	8.447	7.757	8.296
	4.659	5.074	4.514	4.812	5.046	6.499	4.766	5.430	8.378	7.472	7.947	7.191	7.259	8.092	11.909
	4.425	4.125	5.414	5.161	6.040	7.495	5.233	5.355	5.229	6.916	7.351	7.286	7.227	9.871	10.065
	4.794	4.198	4.882	3.589	5.463	5.886	5.565	5.533	5.426	6.115	6.999	7.380	10.786	9.170	10.666
	4.034	3.581	3.702	4.662	6.628	6.211	5.586	6.256	6.277	5.571	6.403	7.958	8.978	9.082	9.517
	3.911	3.666	3.731	3.845	6.544	5.028	5.275	4.925	7.236	6.562	6.517	8.433	7.763	9.931	11.731
	4.596	3.677	3.828	4.451	4.953	4.766	4.699	4.968	6.558	7.198	6.626	8.477	7.380	10.293	11.432
	4.520	3.429	4.784	4.427	5.219	5.664	5.937	5.019	4.588	6.443	6.302	8.064	8.330	8.376	8.550
	4.516	4.609	4.818	4.617	4.729	4.524	4.504	4.684	6.124	6.063	6.913	6.374	8.087	9.959	10.697
	4.172	5.462	4.834	5.878	5.519	6.742	5.689	4.944	5.196	5.093	7.435	6.820	8.447	9.561	10.534
$\bar{\varepsilon}_V$	4.417	4.187	4.492	4.668	5.541	5.854	5.229	5.296	6.192	6.495	7.120	7.513	8.270	9.209	10.341
$\bar{\sigma}$	.285	.674	.574	.667	.656	.926	.473	.486	1.135	.804	.760	.695	1.059	.875	1.245
t(time delay)	Control	.78	.26	.86	[b]3.86	[b]4.94	Control	.19	[b]2.79	[b]3.67	5.48	Control	1.67	[b]3.83	[b]6.39
t(target frequency)							[b]3.54	[b]3.19	[b]4.26	[b]4.35	[b]4.98	[b]13.49	[b]11.70	[b]11.83	[b]13.52

Interaction	Frequency	Time delay	Frequency-delay	Replicates	Error
d.o.f.	2	3	6	9	99
ANOV[c] F	[b]312.82	[b]20.72	[b]4.70	0.83	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE V.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -														
	0	2	4	8	12	16	0	2	4	8	12	0	2	4	8
	ω_T = 0.210 rad/sec						ω_T = 0.315 rad/sec					ω_T = 0.420 rad/sec			
	2.633	1.645	2.391	1.770	2.633	2.252	0.757	0.867	0.927	1.130	1.304	1.603	1.866	1.559	1.572
	2.788	1.787	1.865	1.952	2.102	3.894	.766	.719	1.243	1.265	1.376	1.434	1.130	1.301	1.746
	1.764	2.427	1.692	1.574	2.195	3.254	1.036	.975	.865	.675	.818	1.897	.940	1.686	1.708
	2.536	1.608	2.197	1.729	2.251	2.612	1.308	.860	.988	1.201	1.193	1.092	2.109	1.947	2.570
	1.241	1.689	2.198	1.406	4.794	7.007	1.058	1.361	1.058	.655	1.428	1.062	1.636	2.171	1.373
	1.754	1.832	1.836	2.284	3.599	1.809	.758	.841	2.168	.936	1.022	1.907	1.085	1.821	2.379
	1.618	2.262	2.952	2.257	3.268	3.163	.866	1.026	.778	1.121	.964	1.286	.906	2.498	3.036
	2.816	1.273	2.349	2.183	3.281	4.327	.770	.607	.625	1.067	.933	1.869	1.376	1.414	1.541
	3.256	1.427	4.049	3.077	3.229	2.924	1.651	1.530	1.179	1.266	2.008	.657	1.567	1.699	1.440
	1.546	1.546	2.258	3.040	2.206	3.082	1.209	.909	.717	1.287	1.043	.850	1.866	2.250	2.357
$\bar{\epsilon}_h$	2.195	1.750	2.379	2.127	2.956	3.432	1.018	0.970	1.055	1.060	1.209	1.366	1.448	1.835	1.972
$\bar{\sigma}$	.684	.355	.686	.570	.853	1.452	.299	.280	.437	.234	.346	.451	.425	.382	.569
t(time delay)	Control	1.19	.49	.18	2.03	[b]3.30	Control	.33	.25	.29	1.31	Control	.18	[b]2.30	[b]2.97
t(target frequency)							[b]5.23	[b]6.70	[b]5.71	[b]4.93	1.97	[b]3.68	[b]2.96	[b]2.35	.72

Interaction	Frequency	Time delay	Frequency-delay	Replicates	Error
d.o.f.	2	3	6	9	99
ANOV[c] F	[b]55.35	[b]4.43	1.62	1.27	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE V.- Continued

(d) Aileron deflection

	Aileron deflection ($\times 10^2$), radians, for units of time delay[a] of -														
	0	2	4	8	12	16	0	2	4	8	12	0	2	4	8
	ω_T = 0.210 rad/sec						ω_T = 0.315 rad/sec					ω_T = 0.420 rad/sec			
	1.328	1.531	1.732	1.758	2.404	2.468	1.394	1.667	1.247	1.511	1.495	0.998	1.261	1.541	1.573
	1.563	1.638	1.207	1.583	2.497	2.470	1.645	1.941	1.708	1.303	1.200	1.591	1.363	1.450	1.760
	1.441	1.814	1.461	1.842	3.099	2.799	1.238	1.253	1.335	1.615	1.593	1.519	1.277	1.096	1.777
	1.618	1.297	1.573	1.886	2.147	2.386	1.689	1.497	1.150	1.266	1.971	1.232	1.165	1.120	1.536
	1.108	1.337	1.723	1.424	2.253	3.022	1.749	2.038	1.367	1.347	2.111	1.038	1.372	1.297	2.041
	1.213	1.357	1.417	1.951	2.281	2.659	1.466	1.564	1.451	1.786	1.542	1.084	1.526	1.539	1.416
	1.977	1.611	1.844	2.253	2.634	2.472	1.348	1.784	1.465	1.522	1.666	1.304	1.185	1.495	1.303
	2.608	2.536	3.002	2.826	2.404	2.727	1.440	1.152	1.555	1.426	1.950	1.005	1.246	1.305	1.784
	2.708	1.162	2.955	2.516	1.793	1.477	1.288	1.464	1.116	1.062	1.666	1.332	1.065	1.146	1.450
	1.290	1.539	1.752	3.070	1.184	1.415	1.407	1.464	1.294	1.464	1.559	1.273	1.155	1.162	1.240
$\bar{\delta}_a$	1.685	1.582	1.867	2.111	2.275	2.389	1.466	1.582	1.369	1.430	1.675	1.238	1.261	1.315	1.588
$\bar{\sigma}$	.568	.386	.616	.542	.508	.533	.173	.282	.182	.201	.269	.209	.133	.179	.250
t(time delay)	Control	.44	.77	1.80	[b]2.49	[b]2.97	Control	1.15	.97	.36	2.07	Control	.27	.88	[b]3.97
t(target frequency)							1.35	.00	[b]2.89	[b]4.19	[b]3.30	[b]2.75	[b]2.51	[b]3.20	[b]3.22

Interaction	Frequency	Time delay	Frequency-delay	Replicates	Error
d.o.f.	2	3	6	9	99
ANOV[c] F	[b]19.11	[b]3.26	2.00	1.25	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE V.- Concluded

(e) Elevator deflection

	Elevator deflection ($\times 10^2$), radians, for units of time delay[a] of -														
	0	2	4	8	12	16	0	2	4	8	12	0	2	4	8
	ω_T = 0.210 rad/sec						ω_T = 0.315 rad/sec					ω_T = 0.420 rad/sec			
	0.525	0.543	0.632	0.583	0.710	0.602	0.591	0.596	0.745	0.758	0.803	1.008	0.997	1.097	1.173
	.566	.586	.634	.580	.632	.540	.674	.712	.656	.778	.847	.983	1.090	1.023	1.111
	.535	.624	.651	.644	.599	.642	.675	.773	.643	.860	.734	1.127	1.054	1.014	1.039
	.712	.592	.725	.622	.626	.610	.747	.670	.639	.751	.712	1.075	1.045	1.031	1.004
	.601	.678	.712	.782	.722	.600	.658	.748	.714	.673	.704	1.106	1.046	.982	1.001
	.568	.608	.649	.664	.592	.637	.679	.750	.686	.683	.740	1.009	.982	1.012	1.055
	.603	.529	.609	.640	.585	.629	.820	.716	.631	.780	.763	.861	.900	.978	1.044
	.675	.609	.665	.712	.606	.663	.785	.739	.638	.839	.724	.973	.968	.983	.951
	.604	.484	.694	.684	.596	.514	.682	.707	.769	.893	.869	.940	.876	.980	1.035
	.454	.517	.553	.684	.566	.521	.783	.775	.877	.754	.837	.911	1.012	1.047	.971
$\bar{\delta}_e$	0.584	0.577	0.653	0.659	0.623	0.596	0.709	0.719	0.700	0.777	0.773	0.999	0.997	1.015	1.038
σ	.074	.058	.051	.061	.052	.053	.071	.054	.079	.071	.061	.085	.068	.038	.065
t(time delay)	Control	.27	[b]2.39	[b]2.63	1.49	.43	Control	.30	.31	[b]2.24	[b]2.10	Control	.07	.52	1.32
t(target frequency)							[b]3.64	[b]5.26	1.82	[b]3.99	[b]5.92	[b]12.07	[b]15.62	[b]13.88	[b]12.85

Interaction	Frequency	Time delay	Frequency-delay	Replicates	Error
d.o.f.	2	3	6	9	99
ANOV[c] F	[b]385.45	[b]5.83	1.14	0.63	

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE VI.- SUMMARY OF DATA FOR MOTION CONDITION EFFECTS WITH SUBJECT A

[Basic airplane; t-tests performed treating each factor separately]

(a) Total error

	Total error in meters for units of time delay[a] of -																			
	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16
	Full motion					No heave					Angular					No motion				
	7.446	6.806	7.004	8.217	7.977	8.833	8.092	10.250	11.159	13.411	6.511	7.971	6.559	8.245	17.270	6.684	10.375	13.856	9.604	9.653
	7.175	6.379	6.764	7.148	10.394	9.110	8.105	10.488	7.547	12.491	7.699	5.703	8.001	7.815	7.120	6.264	8.196	10.866	9.485	11.485
	6.187	7.105	6.733	8.236	10.747	5.922	8.391	9.056	10.659	11.363	6.980	8.778	9.092	7.001	6.809	6.099	8.547	10.342	9.894	9.860
	7.330	7.081	5.297	7.714	8.498	9.254	9.461	11.512	12.067	10.619	6.181	7.401	7.654	7.977	7.980	7.370	7.678	8.595	11.189	8.629
	5.276	5.901	6.069	11.421	13.219	5.861	6.340	8.309	8.742	11.363	6.873	8.281	10.153	8.373	11.442	5.752	9.327	8.394	14.624	12.524
	5.666	5.566	6.130	10.144	6.837	6.646	7.635	6.315	9.138	11.054	6.437	8.428	9.827	8.260	8.534	8.111	7.757	7.903	8.809	11.384
	6.215	6.779	6.709	8.220	7.928	5.660	8.955	8.592	8.754	12.101	6.849	7.303	9.074	10.110	8.406	7.239	7.443	7.279	8.888	10.214
	7.337	7.132	6.608	8.501	9.991	5.925	9.330	7.873	11.025	9.635	7.401	7.026	9.882	13.253	9.619	7.583	8.861	9.946	15.222	11.585
	7.772	8.867	7.693	7.958	7.443	8.306	7.818	8.251	8.772	12.003	9.254	9.104	7.178	7.035	8.315	7.230	7.556	9.720	8.970	10.266
	5.718	7.093	8.915	7.724	9.824	9.275	8.236	10.494	11.552	9.534	8.233	9.525	12.034	8.848	10.238	7.498	6.468	9.050	9.360	11.777
$\bar{\epsilon}_v + \bar{\epsilon}_h$	6.612	6.871	6.792	8.529	9.286	7.479	8.236	9.114	9.941	11.857	7.240	7.952	8.946	8.692	9.573	6.983	8.224	9.595	10.605	10.738
$\bar{\sigma}$	.896	.888	.978	1.282	1.920	1.599	.907	1.559	1.523	1.911	.939	1.129	1.635	1.832	3.044	.751	1.104	1.869	2.380	1.195
t(time delay)	Control	.46	.39	[b]3.42	[b]4.77	Control	1.10	[b]2.38	[b]3.59	[b]6.38	Control	.85	[b]2.10	1.74	[b]2.79	Control	1.72	[b]3.68	[b]5.11	[b]5.31
t(motion)						1.77	[b]2.97	[b]3.36	1.76	[b]2.71	1.29	[b]2.28	[b]3.11	.20	.09	.76	[b]3.01	[b]4.06	[b]2.58	1.53

Interaction	Motion	Time delay	Motion-delay	Replicates
d.o.f.	3	4	12	9
ANOV[c] F	[b]11.7	[b]26.1	1.5	1.3

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE VI.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -																			
	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16
	Full motion					No heave					Angular					No motion				
	4.543	4.415	5.236	5.273	5.724	4.738	5.737	5.930	6.326	7.304	4.715	5.207	4.646	3.826	8.848	4.936	7.218	10.321	6.589	6.261
	4.659	4.514	4.812	5.046	6.499	6.250	4.743	5.307	4.817	6.553	4.930	4.348	5.692	5.641	5.131	4.767	5.307	6.608	6.353	7.287
	4.425	5.414	5.161	6.040	7.495	3.909	5.291	5.910	6.466	6.048	5.084	5.277	5.571	5.364	5.425	4.050	5.571	7.686	6.823	6.927
	4.794	4.882	3.589	5.463	5.886	5.903	5.556	5.000	6.151	6.995	4.532	4.535	5.129	5.552	4.998	5.730	5.393	5.891	6.524	6.534
	4.034	3.702	4.662	6.628	6.211	4.262	3.930	4.725	5.534	6.260	4.171	5.587	5.498	5.324	6.848	3.970	6.265	5.894	6.972	8.838
	3.911	3.731	3.845	6.544	5.028	4.627	5.336	4.754	6.662	11.509	4.897	6.590	5.340	5.558	5.924	5.221	5.567	5.554	9.715	7.165
	4.596	3.828	4.451	4.953	4.766	4.224	5.426	5.602	6.018	6.278	4.581	5.047	5.507	5.799	6.125	4.805	5.198	5.418	5.871	7.317
	4.520	4.784	4.427	5.219	5.664	4.247	5.957	5.818	6.047	6.797	5.296	4.794	5.827	7.506	6.703	4.054	5.604	6.713	6.415	6.999
	4.516	4.818	4.617	4.729	4.524	5.227	4.982	5.331	5.562	6.943	5.011	4.986	4.393	5.198	5.408	4.359	5.089	6.297	9.927	6.091
	4.172	4.834	5.878	5.519	6.742	6.401	5.218	6.118	6.746	5.846	4.952	6.260	6.079	6.280	7.411	4.901	4.257	5.675	6.351	7.084
$\bar{\varepsilon}_v$	4.417	4.492	4.668	5.541	5.854	4.979	5.218	5.450	6.033	7.053	4.817	5.263	5.368	5.605	6.282	4.679	5.547	6.606	7.154	7.050
$\bar{\sigma}$	.285	.574	.667	.656	.926	.913	.574	.505	.591	1.631	.323	.713	.519	.918	1.201	.570	.774	1.471	1.437	.758
t(time delay)	Control	.26	.85	[b]3.84	[b]4.91	Control	.57	1.12	[b]2.51	[b]4.93	Control	1.25	1.55	[b]2.21	[b]4.12	Control	1.81	[b]4.03	[b]5.17	[b]4.95
t(motion)						[b]2.16	[b]2.44	1.97	1.14	[b]2.28	1.54	[b]2.60	1.77	.15	.81	1.01	[b]3.55	[b]4.90	3.76	[b]2.27

Interaction	Motion	Time delay	Motion-delay	Replicates
d.o.f.	3	4	12	9
ANOV[c] F	[b]16.7	[b]28.7	1.8	1.5

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE VI.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -																			
	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16
	Full motion					No heave					Angular					No motion				
	2.633	2.391	1.770	2.633	2.252	4.094	2.356	4.319	4.834	6.108	1.796	2.765	1.914	3.199	8.422	1.749	3.156	3.535	3.015	3.391
	2.788	1.865	1.952	2.102	3.894	2.860	3.362	3.748	2.731	5.939	2.769	1.356	2.309	2.174	1.990	1.497	2.891	4.257	3.132	4.199
	1.764	1.692	1.574	2.195	3.254	2.014	3.101	5.603	4.193	5.314	1.895	3.502	3.520	1.636	1.383	2.049	2.982	2.656	2.537	2.935
	2.536	2.197	1.729	2.251	2.612	3.352	3.905	3.310	5.916	3.623	1.649	2.865	2.525	2.425	2.983	1.639	2.284	2.704	3.370	2.096
	1.241	2.198	1.406	4.794	7.007	1.600	2.409	1.590	3.209	5.102	2.702	2.694	4.654	3.047	4.595	1.782	3.062	2.501	4.218	3.687
	1.754	1.836	2.284	3.599	1.809	2.021	2.299	3.729	2.477	4.544	1.541	1.839	4.486	2.702	2.546	2.890	2.189	2.348	4.909	4.218
	1.618	2.952	2.257	3.268	3.163	1.436	3.527	2.272	2.736	5.821	2.268	2.257	3.566	4.315	2.281	3.042	2.246	1.861	2.938	2.897
	2.816	2.349	2.183	3.281	4.327	1.677	3.374	2.432	4.978	2.836	2.105	2.232	4.055	5.748	2.918	3.531	3.256	3.232	2.473	4.586
	3.256	4.049	3.077	3.229	2.924	3.080	2.836	5.164	3.211	5.059	4.244	4.120	2.784	1.836	2.907	2.871	2.498	3.394	5.295	4.175
	1.546	2.258	3.040	2.206	3.082	2.872	3.019	4.370	4.807	3.689	3.281	3.264	5.955	2.570	2.829	2.596	2.209	3.376	2.620	4.695
$\bar{\epsilon}_h$	2.195	2.379	2.127	2.956	3.432	2.501	3.019	3.654	3.909	4.604	2.425	2.690	3.577	2.965	3.286	2.304	2.678	2.986	3.451	3.688
$\bar{\sigma}$	.684	.686	.570	.853	1.452	.879	.543	1.284	1.188	1.106	.845	.815	1.246	1.239	1.987	.679	.432	.699	1.009	.844
t(time delay)	Control	.45	.17	1.88	[b]3.06	Control	.67	[b]2.36	[b]2.88	[b]4.71	Control	.46	1.99	.93	1.48	Control	1.11	2.02	[b]3.40	[b]4.10
t(motion)						.88	1.36	[b]3.23	1.97	[b]2.17	.66	.91	[b]3.23	.02	.23	.31	.89	1.92	1.02	.40

Interaction	Motion	Time delay	Motion-delay	Replicates
d.o.f.	3	4	12	9
ANOV[c] F	[b]7.0	[b]11.4	1.3	1.5

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE VI.- Continued

(d) Aileron deflection

	Aileron deflection (× 10^2), radians, for units of time delay[a] of -																			
	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16
	Full motion					No heave					Angular					No motion				
	1.328	1.732	1.758	2.404	2.468	2.186	1.408	2.859	2.794	3.388	1.141	1.408	1.698	2.429	4.698	2.968	3.297	3.453	2.933	3.460
	1.563	1.207	1.583	2.497	2.470	2.797	1.884	2.475	2.120	2.946	1.576	1.118	1.167	2.377	1.778	2.363	2.583	3.070	2.878	4.803
	1.441	1.461	1.842	3.099	2.799	1.347	2.092	2.649	2.709	2.759	1.232	1.300	1.290	1.796	1.833	2.013	2.709	2.507	3.138	3.692
	1.618	1.573	1.886	2.197	2.386	1.864	2.063	2.300	3.168	2.441	.913	.998	1.412	1.024	1.406	2.070	1.661	2.931	3.942	2.762
	1.108	1.723	1.424	2.253	3.022	1.765	2.138	2.074	2.679	2.753	1.405	1.617	2.503	1.767	3.106	2.162	2.337	2.061	3.935	3.778
	1.213	1.417	1.951	2.281	2.659	2.202	2.044	2.183	2.340	2.313	.851	1.311	2.301	2.008	1.355	1.662	1.800	2.579	4.280	4.241
	1.977	1.844	2.253	2.634	2.472	2.038	1.804	2.280	2.276	2.831	1.150	1.093	1.407	2.239	1.195	2.334	2.898	2.115	2.674	2.067
	2.608	3.002	2.826	2.404	2.727	1.878	1.532	1.030	1.849	1.032	1.209	1.546	2.301	2.452	1.686	3.644	3.267	2.685	2.341	2.895
	2.708	2.955	2.516	1.793	1.477	1.007	1.821	2.356	1.923	1.713	1.559	2.130	1.656	1.569	1.953	3.233	3.552	3.208	1.897	2.910
	1.290	1.752	3.070	1.184	1.415	1.094	1.865	2.156	1.679	1.188	1.524	1.636	2.047	1.294	2.104	2.734	2.424	2.743	2.450	3.302
$\bar{\delta}_a$	1.685	1.867	2.111	2.275	2.389	1.818	1.865	2.236	2.354	2.336	1.256	1.416	1.751	1.896	2.111	2.518	2.653	2.735	3.047	3.391
$\bar{\sigma}$	.568	.616	.542	.508	.533	.548	.241	.486	.497	.781	.258	.335	.477	.496	1.053	.615	.626	.448	.780	.788
t(time delay)	Control	.73	1.72	[b]2.38	[b]2.84	Control	.20	1.75	[b]2.24	[b]2.17	Control	.60	1.85	[b]2.39	[b]3.20	Control	.45	.73	1.78	[b]2.94
t(motion)						.57	.01	.56	.30	.00	1.86	[b]2.10	1.62	1.46	.77	[b]3.61	[b]3.62	[b]2.81	[b]2.98	[b]2.77

Interaction	Motion	Time delay	Motion-delay	Replicates
d.o.f.	3	4	12	9
ANOV[c] F	[b]34.8	[b]10.1	0.3	1.1

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE VI.- Concluded

(e) Elevator deflection

	Elevator deflection (× 10^2), radians, for units of time delay[a] of -																			
	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16	0	4	8	12	16
	Full motion					No heave					Angular					No motion				
	0.525	0.634	0.583	0.710	0.602	0.687	0.583	0.615	0.858	0.860	0.850	0.733	0.877	1.232	1.730	0.843	1.288	1.297	0.766	0.771
	.566	.632	.580	.632	.540	.875	.575	.842	.993	1.134	.714	.470	.639	1.061	.947	.996	.986	1.243	.853	.906
	.535	.651	.644	.599	.642	.664	.766	.669	.819	.850	.617	.536	.805	.761	.934	.975	.928	1.186	.954	1.103
	.712	.725	.622	.626	.610	.569	.694	.833	1.030	.968	.571	.802	.795	.703	.919	.883	1.105	.900	.905	.935
	.601	.712	.782	.722	.600	.592	.752	.893	.960	1.075	.657	.716	1.225	.948	1.227	.749	1.091	1.080	1.056	1.048
	.568	.649	.664	.592	.637	.571	.592	.748	1.018	1.162	.667	.692	.750	.957	1.254	.908	1.118	.967	1.262	1.051
	.603	.609	.638	.585	.629	.704	.730	.887	.929	.900	.606	.499	.525	.875	.780	.980	.675	.736	.572	.865
	.675	.665	.712	.606	.663	.628	.690	.794	.808	.913	.629	.579	.730	1.053	.690	.771	.945	.938	.825	.976
	.604	.694	.684	.596	.514	.835	.593	.702	.735	.924	.778	.769	.641	.740	1.000	.852	1.140	1.068	.995	.837
	.454	.553	.684	.566	.521	.654	.664	.865	.990	.771	.604	.730	.954	.807	1.001	1.066	.723	.809	.701	.987
$\bar{\delta}_e$	0.584	0.653	0.659	0.623	0.596	0.678	0.664	0.785	0.914	0.956	0.669	0.652	0.794	0.914	1.048	0.902	1.000	1.022	0.889	0.948
$\bar{\sigma}$	.074	.051	.062	.052	.053	.105	.074	.097	.102	.129	.088	.120	.196	.169	.295	.102	.191	.185	.194	.105
t(time delay)	Control	[b]2.59	[b]2.85	1.49	.43	Control	1.10	1.36	[b]3.96	[b]4.81	Control	.20	1.49	[b]2.91	[b]4.52	Control	1.35	1.66	.19	.64
t(motion)						[b]2.88	.21	1.92	[b]4.61	[b]4.70	1.83	.00	2.06	[b]4.61	[b]5.91	[b]6.86	[b]6.41	[b]5.54	[b]4.22	[b]4.60

Interaction	Motion	Time delay	Motion-delay	Replicates
d.o.f.	3	4	12	9
ANOV[c] F	[b]51.5	[b]11.5	[b]5.8	[b]2.6

[a]Each unit of time delay equals 0.03125 sec.
[b]Significant difference at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE VII.- EFFECT OF MOTION DELAYS FOR 8 UNITS VISUAL DELAY WITH SUBJECT A

(a) Total error

	Total error in meters for units of added time delay[a] in motion cues τ_m of -					
	0	4	8	12	16	20
	Basic airplane - full motion					
	5.570	6.415	8.046	6.865	6.912	7.490
	6.876	6.979	5.650	5.535	6.203	9.334
	7.332	7.284	6.724	7.223	9.927	8.099
	6.585	6.221	5.331	6.524	7.059	7.014
	6.556	5.927	6.124	6.696	6.650	5.916
	6.202	6.798	6.474	6.843	6.591	9.395
	6.352	7.779	6.241	7.449	8.940	6.173
	6.339	7.429	6.819	7.588	6.743	7.974
	6.932	5.574	6.647	6.723	6.942	7.262
	6.236	6.300	6.944	7.211	6.360	7.427
$\bar{\varepsilon}_v + \bar{\varepsilon}_h$	6.498	6.616	6.500	6.865	7.233	7.608
$\bar{\sigma}$	.483	.708	.750	.584	1.211	1.154
L.S.R. = 0.768, 0.811, 0.838, 0.853, and 0.869						
For analysis of variance [b]F = 2.90						

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE VII.- Continued

(b) Vertical error

	Vertical error in meters for units of added time delay[a] in motion cues τ_m of -					
	0	4	8	12	16	20
	Basic airplane - full motion					
	4.083	4.548	5.986	5.100	5.641	5.196
	5.246	5.266	4.442	4.040	5.011	5.364
	5.293	5.135	4.651	5.311	6.428	5.092
	4.946	4.736	4.221	4.722	4.483	5.512
	5.100	3.782	4.734	4.719	5.031	4.135
	4.228	5.375	4.770	4.730	4.709	5.546
	4.764	6.238	4.790	5.922	5.636	4.260
	4.531	5.014	5.261	5.249	4.374	5.519
	5.178	3.935	4.284	4.924	5.218	5.446
	4.581	4.678	4.830	5.307	4.958	5.133
$\bar{\varepsilon}_v$	4.795	4.871	4.797	5.002	5.149	5.120
$\bar{\sigma}$	.429	.714	.514	.502	.617	.514
L.S.R. = 0.532, 0.560, 0.578, 0.589, and 0.601						
For analysis of variance F = 0.81						

[a]Each unit of time delay equals 0.03125 sec.

TABLE VII.- Continued

(c) Horizontal error

	Horizontal error in meters for units of added time delay[a] in motion cues τ_m of -					
	0	4	8	12	16	20
	Basic airplane - full motion					
	1.487	1.865	2.060	2.165	1.271	2.295
	1.631	1.713	1.208	1.487	1.193	3.969
	2.039	2.149	2.073	1.913	3.500	3.007
	1.639	1.485	1.110	1.803	2.575	1.502
	1.456	2.145	1.389	1.978	1.618	1.781
	1.974	1.423	1.704	2.113	1.882	3.849
	1.588	1.541	1.451	2.262	3.304	1.913
	1.807	2.414	1.559	2.338	2.369	2.455
	1.755	1.640	2.363	1.799	1.724	1.816
	1.656	1.603	2.114	1.903	1.403	2.294
$\bar{\varepsilon}_h$	1.703	1.798	1.703	1.976	2.084	2.488
σ	.192	.334	.428	.253	.825	.859
L.S.R. = 0.548, 0.577, 0.596, 0.608, and 0.619						
For analysis of variance [b]F = 3.05						

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE VII.- Continued

(d) Aileron deflection

	Aileron deflection (× 10^2), radians, for units of added time delay[a] in motion cues τ_m of -					
	0	4	8	12	16	20
	Motion A (τ_v = 8 units)					
	1.753	1.447	1.415	1.604	1.491	1.391
	1.275	1.979	2.123	1.316	1.132	2.141
	1.447	1.254	1.843	1.477	2.279	1.718
	1.013	1.514	1.117	1.312	2.123	1.518
	1.209	2.231	1.530	1.779	.962	1.555
	1.286	1.039	1.502	1.589	1.686	1.786
	1.002	.924	1.261	1.444	2.011	1.566
	1.439	2.006	1.171	1.392	1.941	1.784
	1.401	2.143	2.063	2.113	1.924	1.334
	1.540	1.388	1.973	1.761	1.260	1.543
$\bar{\delta}_a$	1.336	1.593	1.000	1.579	1.681	1.639
σ	.231	.468	.375	.250	.450	.232
	L.S.R. = 0.340, 0.358, 0.370, 0.377, and 0.384					
	For analysis of variance F = 1.17					

[a]Each unit of time delay equals 0.03125 sec.

TABLE VII.- Concluded

(e) Elevator deflection

	Elevator deflection ($\times 10^2$), radians, for units of added time delay[a] in motion cues τ_m of -					
	0	4	8	12	16	20
	Motion A (τ_v = 8 units)					
	0.575	0.682	0.665	0.610	0.646	0.580
	.623	.620	.734	.615	.613	.499
	.625	.506	.606	.621	.637	.488
	.564	.637	.559	.626	.658	.517
	.536	.601	.498	.601	.644	.438
	.569	.593	.552	.638	.670	.429
	.601	.618	.555	.779	.726	.454
	.688	.688	.611	.619	.666	.454
	.502	.537	.622	.600	.583	.474
	.467	.456	.547	.524	.526	.498
$\bar{\delta}_e$	0.575	0.594	0.595	0.623	0.637	0.483
$\bar{\sigma}$	.064	.074	.068	.063	.054	.044
L.S.R. = 0.058, 0.061, 0.063, 0.065, and 0.066						
For analysis of variance [b]F = 10.91						

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE VIII.- SIMPLIFIED ANALYSIS OF MOTION-DELAY EFFECTS USING

ω_n = 2.83 RADIANS PER SECOND WITH SUBJECT A

[Top value is in milliseconds; bottom value is in degrees]

τ_v, units of time delay	τ_m, units of time delay	Pitch or roll cue			Sway or heave cue		
		Visual	Motion	Mismatch (a)	Visual	Motion	Mismatch (a)
8	0	-297 -48.1	-97 -15.7	+200 +32.4	-297 -48.1	-140 -22.6	+157 +22.5
8	4	-297 -48.1	-222 -35.9	+75 +12.2	-297 -48.1	-265 -42.8	+33 +5.3
8	8	-297 -48.1	-347 -56.2	-50 -8.1	-297 -48.1	-390 -63.1	-93 -15
8	12	-297 -48.1	-472 -76.4	-175 -28.3	-297 -48.1	-515 -83.3	-217 -35.2
8	16	-297 -48.1	-597 -96.7	-300 -48.6	-297 -48.1	-640 -103.6	-343 -55.5
8	20	-297 -48.1	-722 -116.9	-425 -68.8	-297 -48.1	-765 -123.8	-468 -75.7

[a]Motion leads visual denoted by +; visual leads motion denoted by -.

TABLE IX.- EFFECT OF VISUAL DELAYS FOR ZERO MOTION DELAY WITH SUBJECT A

(a) Total error

	Total error in meters for units of added time delay[a] in visual-scene display τ_v of -				
	0	2	4	8	16
	Basic airplane - full motion				
	4.913	3.798	3.947	4.237	10.467
	4.846	3.807	4.112	4.764	9.114
	5.051	4.051	4.282	4.417	8.379
	4.246	4.036	4.371	5.185	7.641
	4.167	4.304	4.042	5.084	7.184
	4.267	3.981	5.450	4.956	10.232
	3.633	4.255	4.145	4.346	8.370
	3.609	3.932	4.599	4.874	7.391
	3.697	3.938	3.801	3.914	6.590
	3.676	3.917	3.767	4.124	7.516
$\bar{\varepsilon}_v + \bar{\varepsilon}_h$	4.211	4.002	4.253	4.604	8.288
$\bar{\sigma}$	.564	.168	.491	.435	1.296
L.S.R. = 0.631, 0.664, 0.686, and 0.701					
For analysis of variance [b]F = 81.2					

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE IX.- Continued

(b) Vertical error

	Vertical error in meters for units of added time delay[a] in visual-scene display τ_v of -				
	0	2	4	8	16
	Basic airplane - full motion				
	3.722	3.225	3.206	3.408	7.852
	3.014	3.161	3.243	3.676	6.376
	3.621	3.255	3.402	3.453	6.709
	3.749	3.100	3.283	3.661	5.480
	3.325	3.063	3.200	3.908	5.139
	3.271	3.222	3.694	3.734	7.093
	3.210	3.353	3.258	3.499	5.538
	3.112	3.219	3.819	3.545	5.681
	2.962	3.197	3.200	3.130	5.279
	3.000	3.149	3.106	3.213	5.852
$\bar{\varepsilon}_v$	3.299	3.194	3.341	3.522	6.100
σ	.301	.082	.233	.237	.884
	L.S.R. = 0.402, 0.424, 0.439, and 0.446				
	For analysis of variance [b]F = 86.3				

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE IX.- Continued

(c) Horizontal error

	Horizontal error in meters for units of added time delay[a] in visual-scene display τ_v of -				
	0	2	4	8	16
	Basic airplane - full motion				
	1.191	0.573	0.742	0.831	2.645
	.661	.649	.869	1.089	2.735
	1.226	.795	.882	1.102	1.670
	1.302	.935	1.087	1.524	2.162
	.921	1.241	.841	1.178	2.047
	.894	.760	1.754	1.223	3.139
	1.059	.903	.885	.849	2.831
	.521	.715	.780	1.329	1.710
	.647	.742	.600	.785	1.308
	.696	.768	.661	.882	1.664
$\bar{\varepsilon}_h$	0.912	0.808	0.910	1.082	2.191
$\bar{\sigma}$	.275	.186	.326	.241	.614
	L.S.R. = 0.326, 0.341, 0.354, and 0.360				
	For analysis of variance [b]F = 31.9				

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE IX.- Continued

(d) Aileron deflection

	Aileron deflection (× 10^2), radians, for units of added time delay[a] in visual-scene display τ_v of -				
	0	2	4	8	16
	Basic airplane - full motion				
	1.989	1.375	1.154	1.658	1.585
	1.657	1.243	1.886	1.670	1.795
	1.725	1.734	1.332	1.613	1.929
	1.219	1.420	1.543	1.785	1.315
	1.592	2.037	1.938	1.337	1.737
	1.285	1.472	2.202	1.770	2.018
	1.868	1.968	1.690	1.583	1.546
	1.141	1.714	2.191	1.978	1.745
	1.424	1.776	1.576	1.861	1.184
	1.451	1.257	1.227	1.970	2.111
$\bar{\delta}_a$	1.535	1.600	1.674	1.723	1.697
σ	.281	.285	.377	.194	.296
	L.S.R. = 0.263, 0.276, 0.285, and 0.291				
	For analysis of variance F = 0.6				

[a]Each unit of time delay equals 0.03125 sec.

TABLE IX.- Concluded

(e) Elevator deflection

	Elevator deflection ($\times 10^2$), radians, for units of added time delay[a] in visual-scene display τ_V of -				
	0	2	4	8	16
	Basic airplane - full motion				
	0.448	0.485	0.424	0.471	0.719
	.478	.487	.536	.588	.614
	.514	.599	.544	.557	.592
	.510	.506	.511	.489	.587
	.509	.540	.510	.593	.527
	.533	.533	.577	.516	.743
	.425	.533	.535	.533	.603
	.485	.591	.627	.568	.631
	.521	.526	.544	.590	.688
	.343	.438	.458	.518	.583
$\bar{\delta}_e$	0.476	0.524	0.526	0.542	0.629
$\bar{\sigma}$	.058	.048	.057	.044	.068
	L.S.R. = 0.050, 0.053, 0.055, and 0.056				
	For analysis of variance [b]F = 13.8				

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE X.- SIMPLIFIED ANALYSIS OF VISUAL-DELAY EFFECTS USING

ω_n = 2.83 RADIANS PER SECOND WITH SUBJECT A

[Top value is in milliseconds; bottom value is in degrees]

τ_v, units of time delay	τ_m, units of time delay	Pitch or roll cue			Sway or heave cue			Average mismatch (a)
		Visual	Motion	Mismatch (a)	Visual	Motion	Mismatch (a)	
0	0	-47 -7.6	-97 -15.7	-50 -8.1	-47 -7.6	-140 -22.6	-93 -15.0	-72 -11.6
2	0	-109 -17.7	-97 -15.7	+12 +2.0	-109 -17.7	-140 -22.6	-31 -4.9	-9.5 -1.4
4	0	-172 -27.9	-97 -15.7	+75 +12.2	-172 -27.9	-140 -22.6	+32 +5.3	+54 +8.8
8	0	-297 -48.1	-97 -15.7	+200 +32.4	-297 -48.1	-140 -22.6	+157 +25.5	+178.5 +29.0

[a]Motion leads visual denoted by +; visual leads motion denoted by -.

TABLE XI.- EFFECT OF VISUAL DELAY FOR ZERO MOTION DELAY WITH FULL MOTION AND BASIC AIRPLANE

BUT WITH ω_T OF 0.315 RADIAN PER SECOND WITH SUBJECT A

[t-tests performed treating each factor separately]

	Units of added time delay[a] in visual-scene display τ_v of -														
	Total error in meters			Vertical error in meters			Horizontal error in meters			Aileron deflection (× 10^2) in radians			Elevator deflection (× 10^2) in radians		
	0	2	4	0	2	4	0	2	4	0	2	4	0	2	4
	6.022	5.665	6.069	5.297	5.046	5.413	0.724	0.619	0.656	1.298	1.453	1.756	0.754	0.835	0.707
	7.220	6.330	6.243	5.748	5.723	5.433	1.473	.607	.810	1.465	1.550	1.541	.761	.734	.822
	5.984	5.978	7.079	4.854	5.109	5.812	1.130	.869	1.267	1.822	1.166	1.348	.805	.759	.851
	8.118	5.891	7.350	6.707	4.828	5.276	1.412	1.063	2.073	1.382	1.546	1.764	.883	.725	.672
	5.469	5.579	6.501	4.485	4.708	5.245	.985	.872	1.256	1.571	1.820	1.826	.657	.669	.694
	7.038	5.877	6.705	5.722	4.682	5.172	1.316	1.195	1.534	1.772	1.521	1.633	.716	.727	.732
	6.859	5.030	5.743	5.689	4.388	4.672	1.170	.641	1.071	1.211	1.829	1.980	.786	.648	.738
	8.920	5.988	6.086	7.215	5.035	5.146	1.705	.953	.940	1.157	1.442	1.657	.718	.829	.766
	5.318	5.687	6.353	4.548	4.801	5.175	.771	.887	1.178	1.323	1.509	1.707	.689	.730	.778
	5.571	6.349	7.382	4.716	5.225	6.344	.855	1.124	1.038	1.410	1.626	1.264	.702	.759	.837
Mean	6.652	5.838	6.551	5.498	4.955	5.369	1.154	0.883	1.182	1.441	1.546	1.648	0.747	0.741	0.760
$\bar{\sigma}$	1.202	.383	.565	.916	.365	.446	.325	.210	.400	.222	.191	.216	.066	.059	.062
L.S.R. =	.732 and .770			.573 and .602			.294 and .310			.193 and .202			.057 and .060		
ANOV[c] F =	[b]3.40			2.07			2.65			2.44			.38		

[a]Each unit of added time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.
[c]ANOV denotes analysis of variance.

TABLE XII.- ANALYSIS OF VARIANCE FOR FOUR PILOTS

(a) Total error in meters

Interaction	Time delay	Motion	Pilot	Delay motion	Delay pilot	Motion pilot	Delay-motion pilot	Replicates	Error
d.o.f.	2	1	3	2	6	3	6	9	207
F	[a]35.3	[a]18.8	[a]98.8	[a]4.5	[a]3.3	[a]12.6	[a]5.4	1.12	

(b) Vertical error in meters

Interaction	Time delay	Motion	Pilot	Delay motion	Delay pilot	Motion pilot	Delay-motion pilot	Replicates	Error
d.o.f.	2	1	3	2	6	3	6	9	207
F	[a]42.2	[a]37.4	[a]135.9	[a]12.1	[a]4.9	[a]11.7	2.0	1.25	

(c) Horizontal error in meters

Interaction	Time delay	Motion	Pilot	Delay motion	Delay pilot	Motion pilot	Delay-motion pilot	Replicates	Error
d.o.f.	2	1	3	2	6	3	6	9	207
F	[a]8.8	[a]13.4	[a]41.6	[a]5.2	1.22	1.6	1.7	1.32	

(d) Aileron deflection ($\times 10^2$) in radians

Interaction	Time delay	Motion	Pilot	Delay motion	Delay pilot	Motion pilot	Delay-motion pilot	Replicates	Error
d.o.f.	2	1	3	2	6	3	6	9	207
F	[a]12.1	[a]277.8	[a]26.6	1.6	0.4	[a]36.2	1.1	1.77	

(e) Elevator deflection ($\times 10^2$) in meters

Interaction	Time delay	Motion	Pilot	Delay motion	Delay pilot	Motion pilot	Delay-motion pilot	Replicates	Error
d.o.f.	2	1	3	2	6	3	6	9	207
F	[a]15.4	[a]168.5	[a]19.2	2.2	0.3	[a]63.4	1.5	[a]3.49	

[a]Statistical significance at 5 percent level.

TABLE XIII.- STATISTICAL DATA FOR PILOT B

[t-tests performed treating each factor separately]

(a) Total error

	Total error in meters for units of time delay[a] of -											
	0	2	4	6	8	12	0	2	4	6	8	12
	No motion						Full motion					
	7.736	8.699	10.708	13.917	13.493	---	7.288	7.144	7.459	8.793	7.121	7.853
	12.144	7.105	9.746	12.950	13.661	---	6.888	8.696	8.176	7.000	8.573	11.293
	5.917	7.373	8.750	8.992	10.153	---	7.089	8.797	7.497	9.299	6.894	12.444
	7.476	7.936	8.881	10.239	10.229	---	5.410	5.924	8.533	8.357	7.847	7.336
	7.264	8.267	9.299	8.710	16.905	---	7.469	7.102	7.208	10.601	8.255	8.279
	5.453	7.793	11.010	9.526	11.782	---	6.901	7.784	6.893	8.600	9.205	6.432
	8.571	8.429	7.212	8.386	15.302	---	9.393	6.684	6.541	6.959	7.820	7.777
	7.647	6.024	8.468	12.300	10.421	---	6.893	5.570	6.258	5.902	8.789	8.251
	4.721	4.793	5.131	5.542	6.781	---	7.957	6.254	7.156	6.329	8.888	9.794
	5.039	4.638	6.398	7.051	9.219	---	6.168	6.816	6.744	5.941	7.095	9.066
$\bar{\varepsilon}_v + \bar{\varepsilon}_h$	7.197	7.105	8.560	9.761	11.795	---	7.146	7.077	7.247	7.778	8.049	8.853
$\bar{\sigma}$	2.170	1.471	1.855	2.644	3.047	---	1.054	1.084	.706	1.584	.824	1.850
t(time delay)	Control	.09	1.32	[b]2.49	[b]4.46	---	Control	.21	.18	1.13	1.62	[b]3.05
t(motion)							.07	.05	[b]2.10	2.03	[b]3.75	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIII.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -											
	0	2	4	6	8	12	0	2	4	6	8	12
	No motion						Full motion					
	4.234	5.328	5.880	6.447	6.453	---	3.652	3.977	4.771	4.914	4.716	5.371
	6.033	4.403	6.011	7.616	8.927	---	4.508	3.732	5.229	4.604	5.372	6.780
	3.865	4.458	5.861	5.760	6.633	---	4.075	4.275	4.570	4.726	4.606	8.948
	4.819	5.033	5.444	6.690	7.073	---	3.890	4.149	4.740	4.948	4.339	5.562
	5.435	5.807	5.914	7.173	9.179	---	4.084	4.055	4.368	7.294	5.042	5.529
	3.662	5.126	6.489	5.683	7.864	---	4.187	4.137	3.751	5.975	6.483	4.527
	5.738	5.852	5.561	7.992	10.015	---	7.039	4.302	4.451	4.195	5.460	6.217
	5.861	4.613	5.879	4.438	7.313	---	3.734	4.024	4.714	4.395	6.524	5.254
	3.621	3.811	3.730	5.267	4.806	---	6.343	4.440	5.161	4.746	6.810	5.242
	3.567	3.571	4.772	6.080	6.009	---	4.386	4.450	4.384	4.532	5.352	5.906
$\bar{\varepsilon}_V$	4.684	4.800	5.554	6.308	7.427	---	4.589	4.154	4.614	5.033	5.471	5.934
$\bar{\sigma}$	1.011	.772	.780	1.092	1.592	---	1.150	.222	.424	.928	.865	1.221
t(time delay)	Control	.24	1.78	[b]3.33	[b]5.62	---	Control	1.11	.10	1.13	[b]2.25	[b]3.43
t(motion)							.20	[b]2.55	[b]3.69	[b]2.81	[b]2.28	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIII.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -											
	0	2	4	6	8	12	0	2	4	6	8	12
	No motion						Full motion					
	3.502	4.103	4.709	7.471	6.876	---	3.637	3.167	2.687	3.880	2.405	2.483
	6.111	2.701	3.734	5.334	4.734	---	2.380	4.965	3.597	2.396	3.200	4.513
	2.052	2.915	2.890	3.232	3.520	---	3.015	4.522	2.927	4.574	2.288	3.496
	2.657	2.903	3.437	3.619	3.156	---	1.520	1.775	3.794	3.409	4.005	1.774
	1.829	2.460	3.384	2.630	7.726	---	3.385	3.047	2.840	3.307	3.669	2.750
	1.791	2.667	4.521	2.352	3.918	---	2.720	3.647	3.141	2.624	2.722	1.905
	2.833	2.576	1.650	2.703	5.286	---	2.354	2.382	2.090	2.765	2.360	1.559
	1.786	1.411	2.589	4.308	3.107	---	3.159	1.545	1.544	1.507	2.265	3.422
	1.100	.982	1.401	1.104	1.975	---	1.615	1.814	1.996	1.583	2.078	4.553
	1.472	1.066	1.626	1.784	3.210	---	1.782	2.366	2.360	1.409	1.743	3.608
$\bar{\varepsilon}_h$	2.513	2.379	2.994	3.454	4.351	---	2.557	2.923	2.698	2.745	2.674	2.919
$\bar{\sigma}$	1.447	.965	1.181	1.863	1.813	---	.752	1.173	.714	1.064	.726	1.055
t(time delay)	Control	.20	.72	1.41	[b]2.75	---	Control	.90	.35	.46	.05	.89
t(motion)							.08	1.13	.68	1.04	[b]2.95	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIII.- Continued

(d) Aileron deflection

	Aileron deflection (× 10^2), radians, for units of time delay[a] of -											
	0	2	4	6	8	12	0	2	4	6	8	12
	No motion						Full motion					
	4.806	4.899	5.136	6.668	4.964	---	2.300	2.276	1.318	1.504	1.164	1.092
	4.570	2.215	4.199	4.215	4.051	---	1.571	1.439	1.053	1.318	1.000	.984
	2.470	2.131	3.305	2.826	3.172	---	1.093	1.054	1.200	1.558	1.283	1.169
	2.631	2.872	3.062	3.303	3.753	---	1.221	1.315	1.369	1.118	1.353	1.180
	3.587	4.388	3.501	3.323	5.222	---	1.312	1.305	1.192	1.283	1.149	1.152
	2.241	2.890	4.154	3.566	3.455	---	.969	1.109	1.332	1.223	.974	1.388
	4.090	3.168	2.669	3.229	4.577	---	1.013	.832	.860	1.142	.961	1.267
	2.675	2.224	2.790	4.204	3.925	---	1.209	1.088	1.030	1.063	1.167	1.527
	2.456	1.782	2.608	2.777	3.048	---	1.014	.978	.988	1.210	1.076	1.365
	2.176	3.386	2.915	3.733	3.887	---	.988	1.436	1.172	1.309	1.289	1.351
$\bar{\delta}_a$	3.170	2.995	3.434	3.784	4.006	---	1.269	1.283	1.151	1.273	1.142	1.247
$\bar{\sigma}$	1.003	1.011	.824	1.126	.725	---	.407	.402	.166	.160	.139	.162
t(time delay)	Control	.41	.62	1.45	1.97	---	Control	.27	.83	.18	.91	.31
t(motion)							[b]5.59	[b]4.98	[b]8.58	[b]6.98	[b]12.28	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIII.- Concluded

(e) Elevator deflection

	Elevator deflection (× 10^2), radians, for units of time delay[a] of -											
	0	2	4	6	8	12	0	2	4	6	8	12
	No motion						Full motion					
	0.902	1.104	1.312	1.452	1.269	---	0.601	0.827	0.415	0.398	0.341	0.321
	1.355	.889	1.213	1.340	1.222	---	.453	.422	.325	.389	.323	.256
	.750	.769	1.211	.930	1.096	---	.290	.333	.351	.322	.375	.325
	.831	.830	.968	1.101	1.245	---	.292	.299	.300	.314	.333	.294
	1.175	1.212	1.092	1.159	1.390	---	.345	.294	.338	.284	.293	.296
	.711	.919	1.247	1.301	1.252	---	.295	.343	.249	.331	.261	.329
	.737	.734	.648	.705	.964	---	.259	.224	.246	.315	.279	.306
	.652	.634	.692	.915	.866	---	.334	.327	.267	.350	.268	.361
	.547	.468	.511	.673	.636	---	.274	.294	.327	.313	.293	.353
	.457	.742	.576	.819	.778	---	.273	.310	.316	.286	.307	.293
$\bar{\delta}_e$	0.812	0.830	0.947	1.039	1.072	---	0.342	0.367	0.316	0.330	0.307	0.313
$\bar{\sigma}$	.274	.217	.311	.273	.248	---	.107	.169	.052	.039	.036	.031
t(time delay)	Control	.15	1.14	1.91	[b]2.19	---	Control	.65	.26	.29	.88	.72
t(motion)							[b]5.05	[b]5.32	[b]6.34	[b]8.14	[b]9.63	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIV.- STATISTICAL DATA FOR PILOT B WITH

POOR TRIM CONDITION FROM REFERENCE 1[a]

[t-tests performed treating each factor separately]

(a) Total error

	Total error in meters for units of time delay[b] of -							
	0	1	2	3	4	5	6	8
	7.900	5.819	8.473	7.029	6.989	8.071	13.917	13.493
	7.870	6.696	8.446	8.391	12.274	10.711	15.737	10.217
	6.965	9.653	9.793	10.991	10.708	14.310	17.514	19.187
	7.736	10.717	10.153	12.472	9.699	11.902	11.573	15.347
	6.952	10.738	8.699	6.322	14.548	12.710	20.327	15.563
	7.855	8.132	9.513	10.104	14.917	19.361	14.696	18.483
	8.388	6.376	7.760	11.034	9.354	22.772	9.107	10.951
$\bar{\epsilon}_v + \bar{\epsilon}_h$	7.666	8.306	8.976	9.476	11.214	14.262	14.697	14.749
$\bar{\sigma}$	.527	2.085	.856	2.280	2.880	5.121	3.703	3.444
t(time delay)	Control	.40	.82	1.14	[c]2.23	[c]4.15	[c]4.42	[c]4.45
t(trim)	.67		[c]3.63		[c]2.80		[c]3.88	[c]2.25

[a]To be compared with no-motion data using automatic trim presented in table XIII.
[b]Each unit of time delay equals 0.03125 sec.
[c]Statistical significance at 5 percent level.

TABLE XIV.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -							
	0	1	2	3	4	5	6	8
	4.182	3.947	4.572	4.508	4.234	4.840	6.447	6.617
	4.599	4.151	4.404	4.383	7.212	5.959	9.083	6.273
	3.972	4.840	5.084	6.395	5.880	7.257	6.757	8.159
	4.234	4.666	5.986	6.620	4.910	6.480	5.861	7.294
	4.279	5.471	5.328	3.874	6.794	6.352	9.696	7.446
	4.447	4.029	4.807	4.554	6.383	7.163	7.231	8.300
	4.167	3.956	4.642	5.706	5.800	11.963	5.538	6.096
$\bar{\varepsilon}_V$	4.267	4.438	4.974	5.148	5.889	7.145	7.230	7.169
$\bar{\sigma}$	.204	.579	.546	1.067	1.042	2.274	1.585	.878
t(time delay)	Control	.88	1.11	1.38	[b]2.54	[b]4.52	[b]4.66	[b]4.55
t(trim)	1.29		.62		.92		1.72	.47

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIV.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -							
	0	1	2	3	4	5	6	8
	3.719	1.871	3.901	2.521	2.755	3.231	7.471	6.876
	3.271	2.545	4.042	4.008	5.063	4.752	6.654	3.944
	2.993	4.813	4.709	4.596	4.828	7.053	10.756	11.028
	3.502	6.050	4.167	5.852	4.788	5.422	5.712	8.053
	2.673	5.267	3.371	2.448	7.754	6.358	10.631	8.117
	3.408	4.103	4.706	5.550	8.534	12.198	7.464	10.183
	4.221	2.420	3.118	5.328	3.554	10.808	3.569	4.855
$\bar{\varepsilon}_h$	3.399	3.868	4.002	4.328	5.621	7.117	7.465	7.580
$\bar{\sigma}$	.500	1.606	.608	1.402	2.140	3.255	2.576	2.591
t(time delay)	Control	.41	.52	.80	1.92	[b]3.22	[b]3.52	[b]3.62
t(trim)	1.86		[b]4.74		[b]3.15		[b]4.52	[b]3.66

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIV.- Continued

(d) Aileron deflection

	Aileron deflection (× 10^2), radians, for units of time delay[a] of -							
	0	1	2	3	4	5	6	8
	9.772	3.256	5.163	3.797	3.789	4.860	6.668	4.964
	4.441	4.155	4.034	4.254	5.408	6.603	6.352	5.889
	3.779	5.950	4.300	4.974	5.136	5.897	5.860	6.968
	4.806	4.914	5.206	6.036	5.527	5.870	6.597	5.974
	4.441	5.210	4.899	4.780	6.319	6.572	7.292	6.322
	4.682	5.710	5.620	7.019	6.531	6.882	7.068	11.125
	6.132	4.742	5.763	6.423	6.531	7.532	9.636	5.753
$\bar{\delta}_a$	5.436	4.848	4.998	5.326	5.606	6.317	7.068	6.714
$\bar{\sigma}_a$	2.040	.924	.641	1.189	.982	.860	1.225	2.034
t(time delay)	Control	.65	.62	.16	.24	1.24	[b]2.30	1.81
t(trim)	[b]3.69		[b]5.82		[b]5.97		[b]6.90	[b]4.72

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XIV.- Concluded

(e) Elevator deflection

	Elevator deflection ($\times 10^2$), radians, for units of time delay[a] of -							
	0	1	2	3	4	5	6	8
	2.092	0.691	1.066	0.750	0.861	1.178	1.452	1.269
	1.051	.775	.943	.902	1.177	1.299	1.484	1.312
	.844	1.061	.980	1.331	1.312	1.307	1.513	1.291
	.902	1.174	.956	1.392	1.084	1.339	1.533	1.438
	1.039	1.295	1.104	1.209	1.402	1.356	1.556	1.571
	1.118	1.162	1.213	1.382	1.413	1.450	1.581	2.040
	1.184	1.142	1.372	1.434	1.466	1.540	1.953	1.204
$\bar{\delta}_e$	1.176	1.043	1.091	1.200	1.245	1.353	1.582	1.446
σ	.421	.224	.157	.269	.218	.116	.169	.289
t(time delay)	Control	1.12	.76	.05	.39	1.19	[b]2.91	1.89
t(trim)	[b]2.72		[b]3.26		[b]2.64		[b]5.60	[b]3.65

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XV.- PILOT-MOTION-DELAY INTERACTION (PILOT C)

(a) Total error

	Total error in meters for units of time delay[a] of -							
	0	4	8	12	0	4	8	12
	No motion				Full motion			
	5.694	4.585	5.147	11.600	3.754	3.936	3.849	5.322
	4.725	5.182	6.677	5.540	3.967	4.876	5.288	5.332
	4.464	5.858	5.482	5.675	4.109	4.702	5.247	5.045
	6.518	4.637	5.007	5.542	4.412	4.922	5.645	5.104
	5.729	4.969	6.205	11.144	4.198	4.288	5.365	4.936
	3.798	4.707	5.336	7.049	5.355	5.059	4.408	5.070
	3.761	3.729	5.036	6.290	4.490	4.994	4.547	4.413
	3.662	4.665	5.036	6.598	4.618	5.350	4.528	4.767
	5.072	4.411	4.790	5.679	4.453	4.310	4.325	5.294
	4.824	4.327	5.089	5.375	3.690	4.229	4.158	4.820
$\bar{\varepsilon}_v + \bar{\varepsilon}_h$	4.824	4.707	5.380	7.049	4.305	4.666	4.736	5.011
$\bar{\sigma}$	.953	.561	.600	2.342	.485	.451	.602	.289
t(time delay)	Control	.20	.94	[b]3.74	Control	1.72	2.05	[b]3.36
t(motion)					2.06	.18	[b]2.40	[b]2.73

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XV.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -							
	0	4	8	12	0	4	8	12
	No motion				Full motion			
	3.880	3.266	3.796	4.850	2.959	2.996	2.929	3.769
	3.418	3.415	4.841	3.847	2.930	3.549	3.281	3.439
	3.395	3.406	3.739	4.087	2.957	3.435	3.595	3.363
	3.360	3.492	3.629	3.539	3.005	3.164	3.505	3.628
	3.633	3.464	4.051	5.722	3.094	3.155	3.595	3.401
	3.035	3.259	3.708	4.141	3.407	3.324	3.237	3.401
	2.807	2.925	3.302	3.693	3.202	3.230	2.882	3.064
	2.816	3.221	3.397	3.826	3.217	3.198	3.249	3.354
	2.749	3.058	3.363	4.099	2.872	3.004	2.974	3.333
	3.233	3.082	3.241	3.605	2.842	2.944	3.102	3.303
$\bar{\varepsilon}_v$	3.233	3.259	3.707	4.141	3.049	3.200	3.235	3.406
$\bar{\sigma}$	.378	.191	.473	.670	.179	.195	.267	.189
t(time delay)	Control	.13	[b]2.30	[b]4.40	Control	1.61	1.98	[b]3.79
t(motion)					1.39	.68	[b]2.75	[b]3.34

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XV.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -							
	0	4	8	12	0	4	8	12
	No motion				Full motion			
	1.810	1.319	1.351	3.703	0.796	0.941	0.920	1.552
	1.307	1.767	1.836	1.694	1.037	1.327	2.007	1.892
	1.069	2.452	1.743	1.588	1.152	1.266	1.652	1.683
	3.158	1.145	1.379	2.003	1.407	1.757	2.139	1.476
	2.096	1.504	2.154	5.422	1.103	1.134	1.770	1.535
	1.592	1.448	1.629	2.570	1.948	1.735	1.171	1.669
	.764	.804	1.734	2.596	1.287	1.764	1.298	1.350
	.954	1.444	1.639	2.772	1.401	2.152	1.646	1.413
	.846	1.354	1.427	1.580	1.581	1.306	1.352	1.961
	2.323	1.244	1.847	1.770	.848	1.286	1.056	1.517
$\bar{\varepsilon}_h$	1.592	1.448	1.674	2.570	1.256	1.467	1.501	1.605
$\bar{\sigma}$	.767	.459	.247	1.208	.348	.368	.406	.198
t(time delay)	Control	.41	.23	[b]2.76	Control	1.39	1.61	[b]2.30
t(motion)					1.46	.08	1.15	[b]2.49

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XV.- Continued

(d) Aileron deflection

	Aileron deflection (× 10^2), radians, for units of time delay[a] of -							
	0	4	8	12	0	4	8	12
	No motion				Full motion			
	1.725	1.739	2.368	5.166	1.455	1.399	1.799	2.736
	1.186	1.856	3.157	2.809	1.178	1.195	1.402	2.232
	1.380	1.267	1.500	3.253	1.056	1.172	1.386	1.281
	1.215	1.044	1.550	3.092	.943	1.405	1.826	1.919
	1.290	1.878	2.156	2.686	.965	1.633	1.988	2.939
	1.471	2.123	2.511	3.282	1.540	1.511	1.621	1.985
	2.369	2.814	3.222	3.972	1.131	1.619	1.027	1.781
	1.320	1.426	2.020	2.649	1.036	.999	1.452	1.251
	1.218	1.645	1.912	2.592	.999	1.245	1.343	1.506
	1.539	1.325	1.666	3.321	1.130	1.001	1.515	1.481
$\bar{\delta}_a$	1.471	1.712	2.206	3.282	1.143	1.318	1.536	1.911
$\bar{\sigma}$	.358	.507	.615	.783	.202	.232	.281	.582
t(time delay)	Control	.75	[b]2.82	[b]6.96	Control	1.09	[b]2.45	[b]4.80
t(motion)					[b]2.52	2.05	[b]3.13	[b]4.45

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XV.- Concluded

(e) Elevator deflection

	Elevator deflection (× 10^2), radians, for units of time delay[a] of -							
	0	4	8	12	0	4	8	12
	No motion				Full motion			
	0.637	0.668	0.923	1.200	0.553	0.795	1.009	1.298
	.382	.691	.725	.780	.636	.744	.728	1.153
	.458	.427	.388	.911	.542	.625	.563	.815
	.570	.330	.442	1.033	.411	.762	.785	.893
	.656	.603	.897	1.097	.516	.811	.793	1.060
	.599	.589	.879	1.187	.723	.771	.735	.803
	.993	.893	.843	.957	.598	.485	.544	.798
	.703	.594	.651	1.076	.420	.463	.576	.721
	.514	.607	.729	.786	.475	.553	.519	.701
	.476	.485	.527	.813	.480	.571	.638	.749
$\bar{\delta}_e$	0.599	0.588	0.700	0.984	0.535	0.658	0.689	0.899
σ	.170	.163	.194	.159	.097	.134	.152	.202
t(time delay)	Control	.11	1.07	[b]3.81	Control	1.82	[b]2.27	[b]5.38
t(motion)					.74	.80	.15	.80

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XVI.- PILOT-MOTION-DELAY EFFECTS (PILOT D)

(a) Total error

	Total error in meters for units of time delay[a] of -							
	0	3	4	8	0	4	8	12
	No motion				Full motion			
	4.426	6.482	5.752	5.636	5.364	5.825	5.531	6.840
	4.901	6.002	5.169	6.273	5.218	4.356	7.030	6.977
	4.612	5.613	5.246	5.672	5.459	4.383	5.314	6.069
	4.505	5.137	5.139	7.907	5.563	5.837	7.202	9.056
	4.782	5.270	7.876	5.950	5.883	5.294	6.512	9.760
	5.188	4.449	4.621	5.794	5.800	5.230	6.716	7.410
	4.953	5.096	5.380	6.008	4.651	5.023	7.058	10.769
	5.688	4.361	4.867	6.602	5.736	6.639	5.612	7.273
	4.100	5.146	5.672	6.718	5.209	5.761	5.801	6.995
	4.307	6.212	6.215	7.989	4.715	4.548	5.018	8.562
$\bar{\varepsilon}_v + \bar{\varepsilon}_h$	4.745	5.377	5.593	6.500	5.360	5.289	6.180	7.971
$\bar{\sigma}$	.465	.704	.922	.867	.424	.742	.811	1.498
t(time delay)	Control	1.85	[b]2.49	[b]5.16	Control	.17	1.92	[b]6.13
t(motion)					[b]3.08	.81	.85	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XVI.- Continued

(b) Vertical error

	Vertical error in meters for units of time delay[a] of -							
	0	3	4	8	0	4	8	12
	No motion				Full motion			
	3.293	3.535	3.808	3.956	3.602	3.503	3.681	4.132
	3.175	3.600	3.741	4.099	3.441	3.261	4.916	4.580
	3.042	3.276	3.396	4.076	3.536	3.042	3.668	4.500
	2.628	3.236	3.278	4.673	3.550	3.696	4.333	5.172
	3.215	3.480	4.868	4.068	3.570	3.694	4.154	5.671
	3.337	3.091	3.307	3.906	3.872	3.813	4.364	4.773
	2.925	3.373	3.346	3.624	3.509	3.589	3.994	4.976
	2.985	3.048	3.091	3.754	3.825	3.778	3.930	5.073
	2.660	3.455	3.776	4.108	3.292	3.570	3.682	4.106
	3.095	4.181	3.942	3.681	3.592	3.375	3.624	4.807
$\bar{\varepsilon}_v$	3.036	3.427	3.655	3.994	3.579	3.532	4.035	4.779
$\bar{\sigma}$	.243	.322	.510	.298	.169	.244	.415	.479
t(time delay)	Control	[b]2.45	[b]3.87	[b]5.99	Control	.30	[b]2.91	[b]7.66
t(motion)					[b]5.81	.69	.25	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XVI.- Continued

(c) Horizontal error

	Horizontal error in meters for units of time delay[a] of -							
	0	3	4	8	0	4	8	12
	No motion				Full motion			
	1.133	2.947	1.944	1.680	2.067	2.322	1.850	2.708
	1.725	2.402	1.427	2.625	1.779	1.095	2.114	2.398
	1.571	2.336	1.849	1.597	1.925	1.340	1.647	1.569
	1.878	1.901	1.861	3.233	2.014	2.142	2.869	3.883
	1.568	1.790	3.008	1.883	2.314	1.599	2.359	4.090
	1.851	1.358	1.315	1.888	1.928	1.419	2.352	2.637
	2.028	1.723	2.033	2.384	1.143	1.435	3.063	5.793
	2.703	1.314	2.082	2.848	1.911	2.861	1.681	2.199
	1.438	1.691	1.896	2.610	1.917	2.190	2.119	2.889
	1.211	2.031	2.271	4.306	1.124	1.171	1.394	3.754
$\bar{\varepsilon}_h$	1.711	1.949	1.969	2.505	1.812	1.757	2.145	3.192
$\bar{\sigma}$	.451	.501	.465	.830	.384	.584	.535	1.213
t(time delay)	Control	.92	.99	[b]3.05	Control	.16	.99	[b]4.12
t(motion)					.54	.90	1.15	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XVI.- Continued

(d) Aileron deflection

	Aileron deflection ($\times 10^2$), radians, for units of time delay[a] of -							
	0	3	4	8	0	4	8	12
	No motion				Full motion			
	1.757	2.192	2.328	2.005	1.250	1.434	1.548	1.903
	2.116	2.069	1.983	2.249	1.147	1.364	1.693	1.934
	2.524	2.062	2.693	2.439	1.213	1.533	1.615	1.849
	2.841	2.895	3.165	3.073	1.191	1.352	1.829	2.001
	1.551	2.142	3.696	2.564	1.376	1.509	1.645	1.939
	1.281	2.174	1.809	3.243	1.558	1.619	1.729	2.058
	2.585	1.968	2.246	2.846	1.273	1.592	1.641	2.052
	2.146	2.443	2.445	3.389	1.377	1.818	1.775	1.845
	3.029	2.175	3.579	3.320	1.104	1.517	1.301	1.507
	2.432	1.989	1.885	4.004	.955	1.246	1.396	1.806
$\bar{\delta}_a$	2.226	2.211	2.583	2.913	1.244	1.498	1.617	1.889
$\bar{\sigma}$	.555	.275	.685	.609	.167	.161	.164	.161
t(time delay)	Control	.06	1.44	[b]2.77	Control	[b]3.48	[b]5.10	[b]8.82
t(motion)					[b]5.27	[b]4.87	[b]6.50	

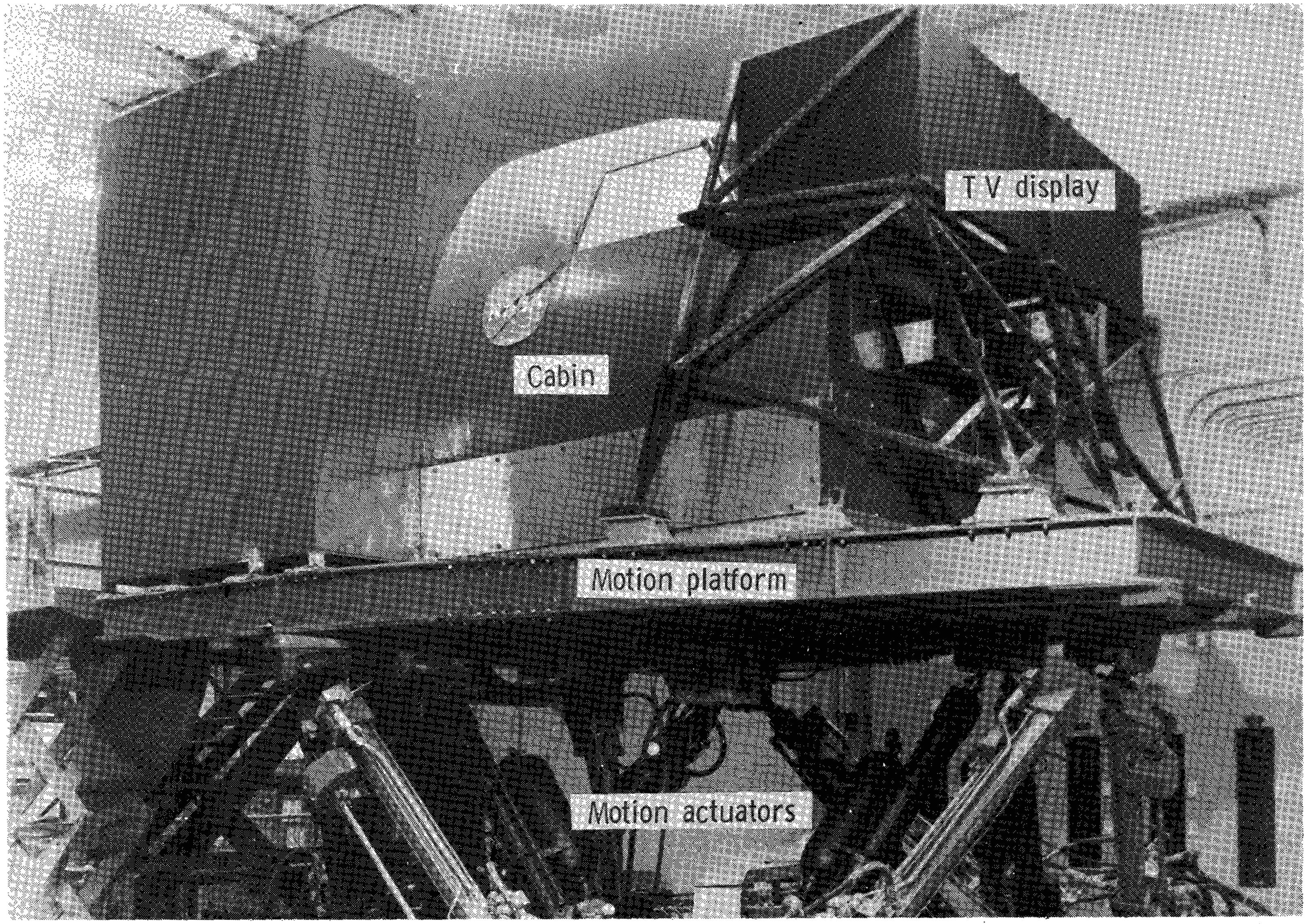
[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.

TABLE XVI.- Concluded

(e). Elevator deflection

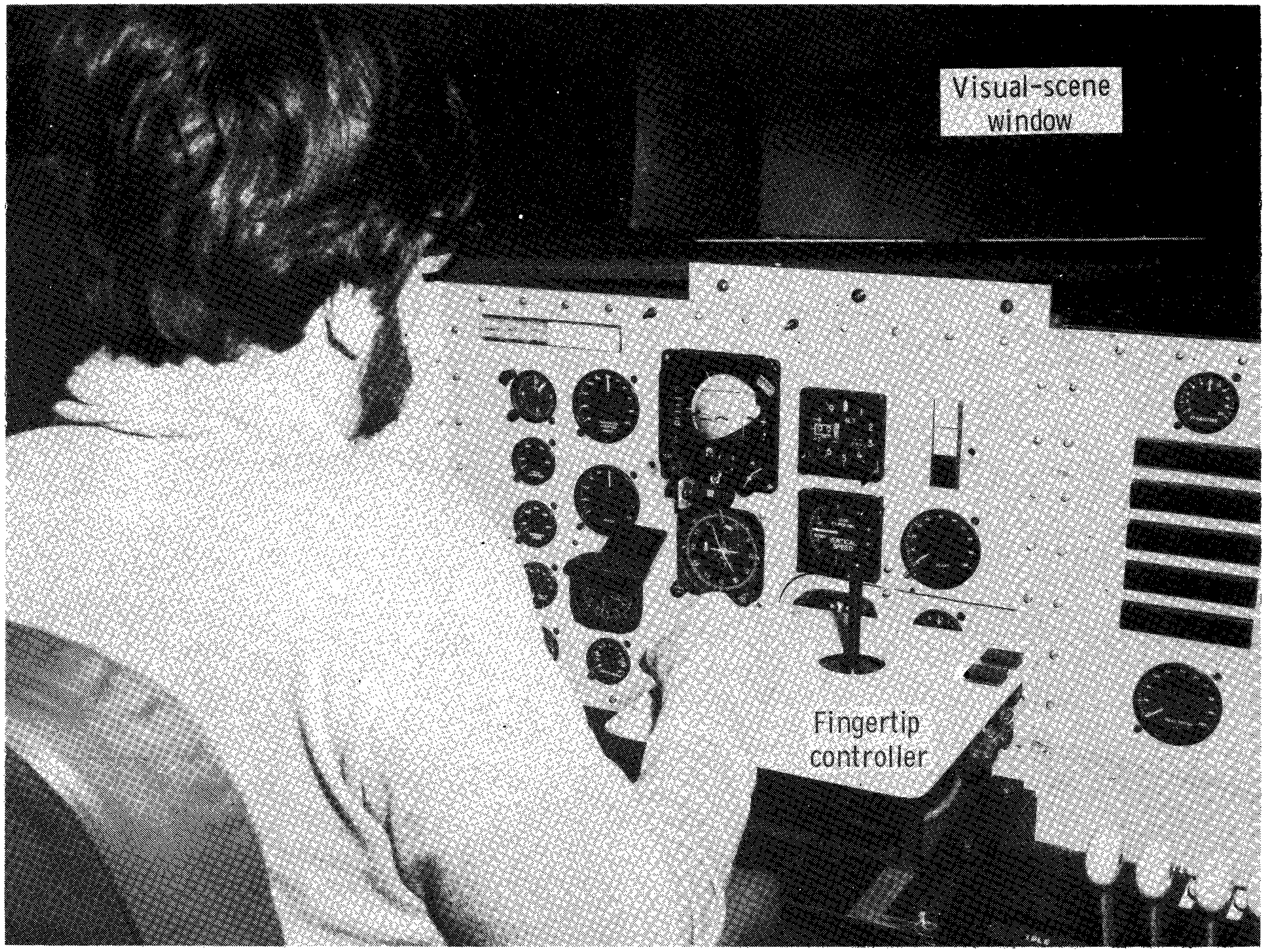
	Elevator deflection ($\times 10^2$), radians, for units of time delay[a] of -							
	0	3	4	8	0	4	8	12
	No motion				Full motion			
	0.444	0.634	0.622	0.516	0.692	0.841	0.752	0.866
	.538	.491	.578	.698	.595	.682	.861	.885
	.526	.501	.623	.687	.644	.571	.660	.803
	.566	.609	.693	.808	.608	.584	.731	.711
	.448	.495	.958	.814	.550	.658	.737	.862
	.484	.508	.543	.648	.629	.643	.697	.678
	.678	.508	.527	.836	.654	.600	.818	.621
	.557	.539	.575	.876	.647	.719	.735	.659
	.798	.708	.841	.851	.589	.770	.784	.777
	.639	.802	.843	1.060	.472	.597	.593	.804
$\bar{\delta}_e$	0.568	0.579	0.680	0.779	0.608	0.667	0.737	0.767
$\bar{\sigma}$	.110	.107	.149	.149	.062	.088	.077	.094
t(time delay)	Control	.20	1.93	[b]3.63	Control	1.61	[b]3.54	[b]4.36
t(motion)					1.01	.25	.80	

[a]Each unit of time delay equals 0.03125 sec.
[b]Statistical significance at 5 percent level.



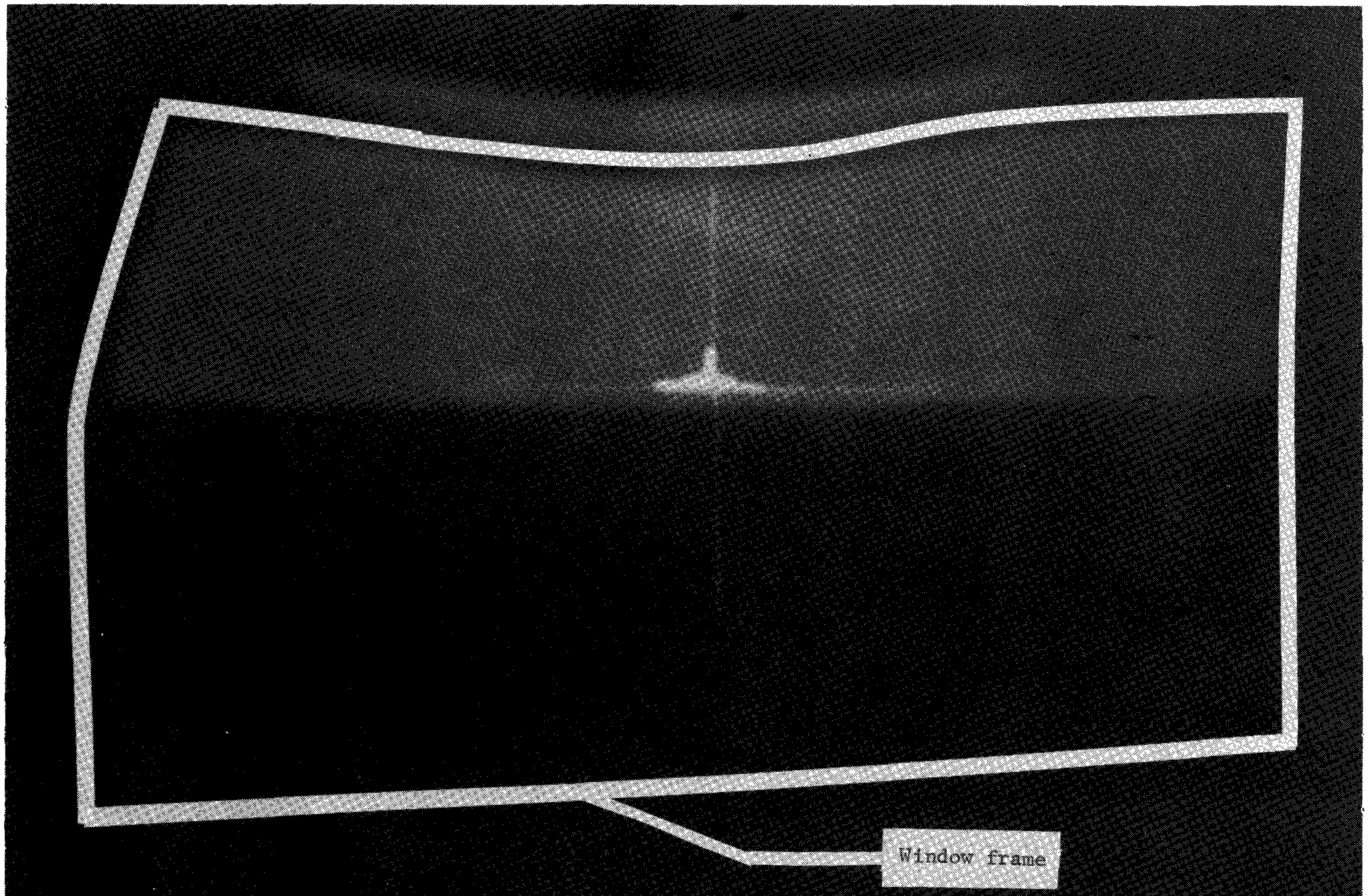
L-73-7163.1

Figure 1.- Langley visual-motion simulator.



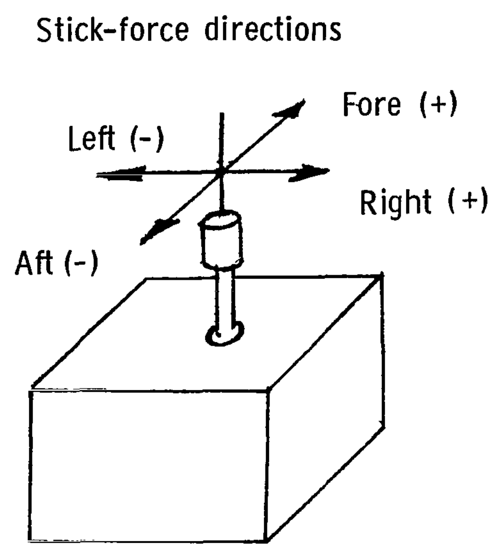
L-75-1306.1

Figure 2.- Cockpit interior showing two-axis fingertip controller (instruments and throttles not activated for tests).



L-75-3154.1

Figure 3.- Photograph of visual scene observed by subject when tracker aircraft was nearly alined with target.



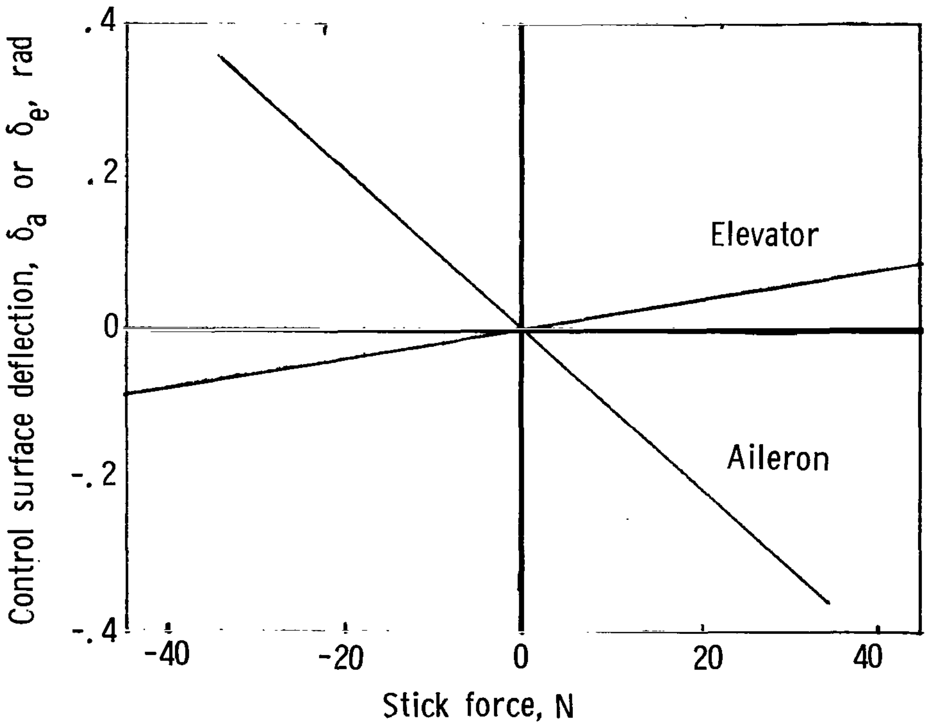


Figure 4.- Two-axis stick force characteristics.

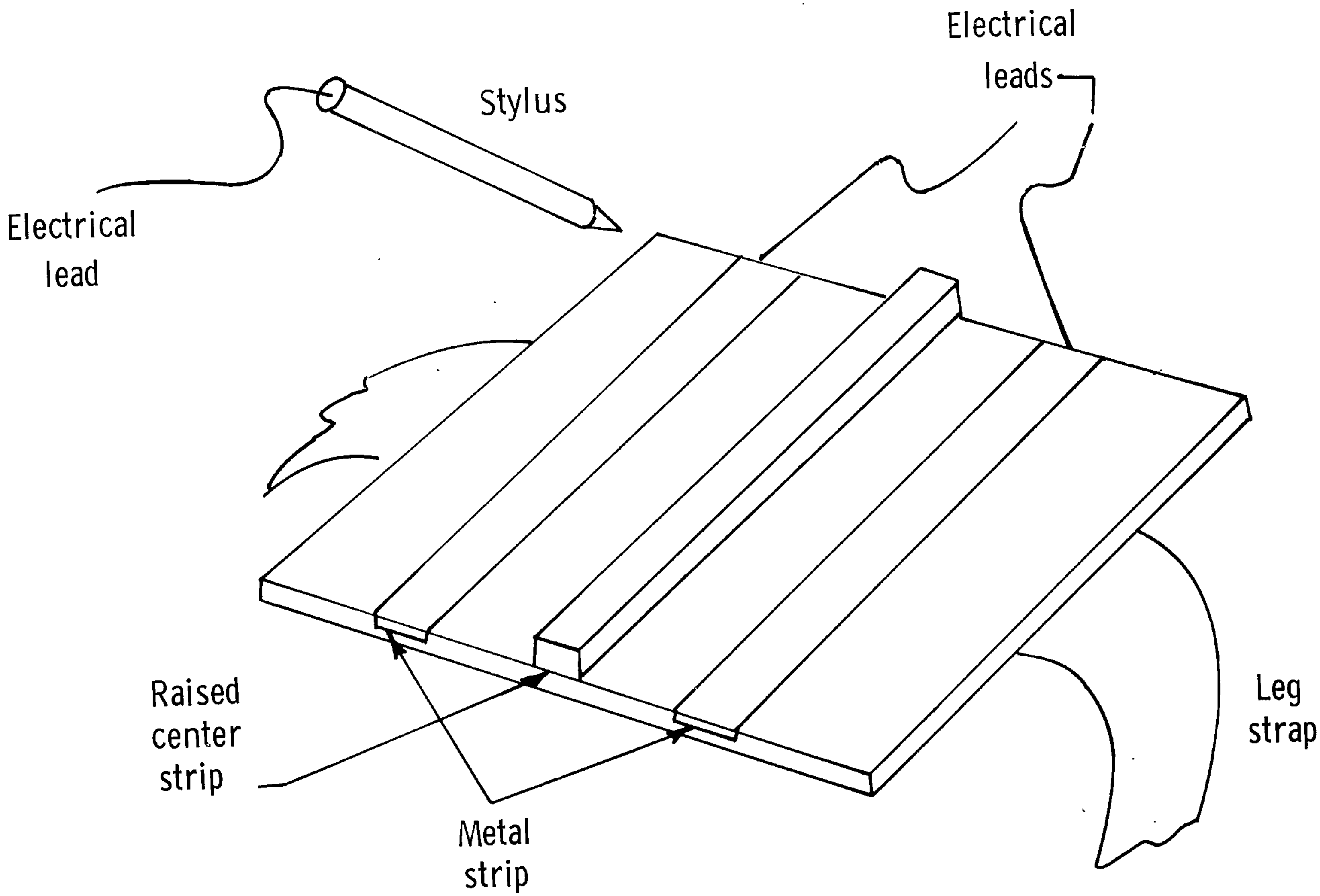


Figure 5.- Sketch of secondary task board and stylus.

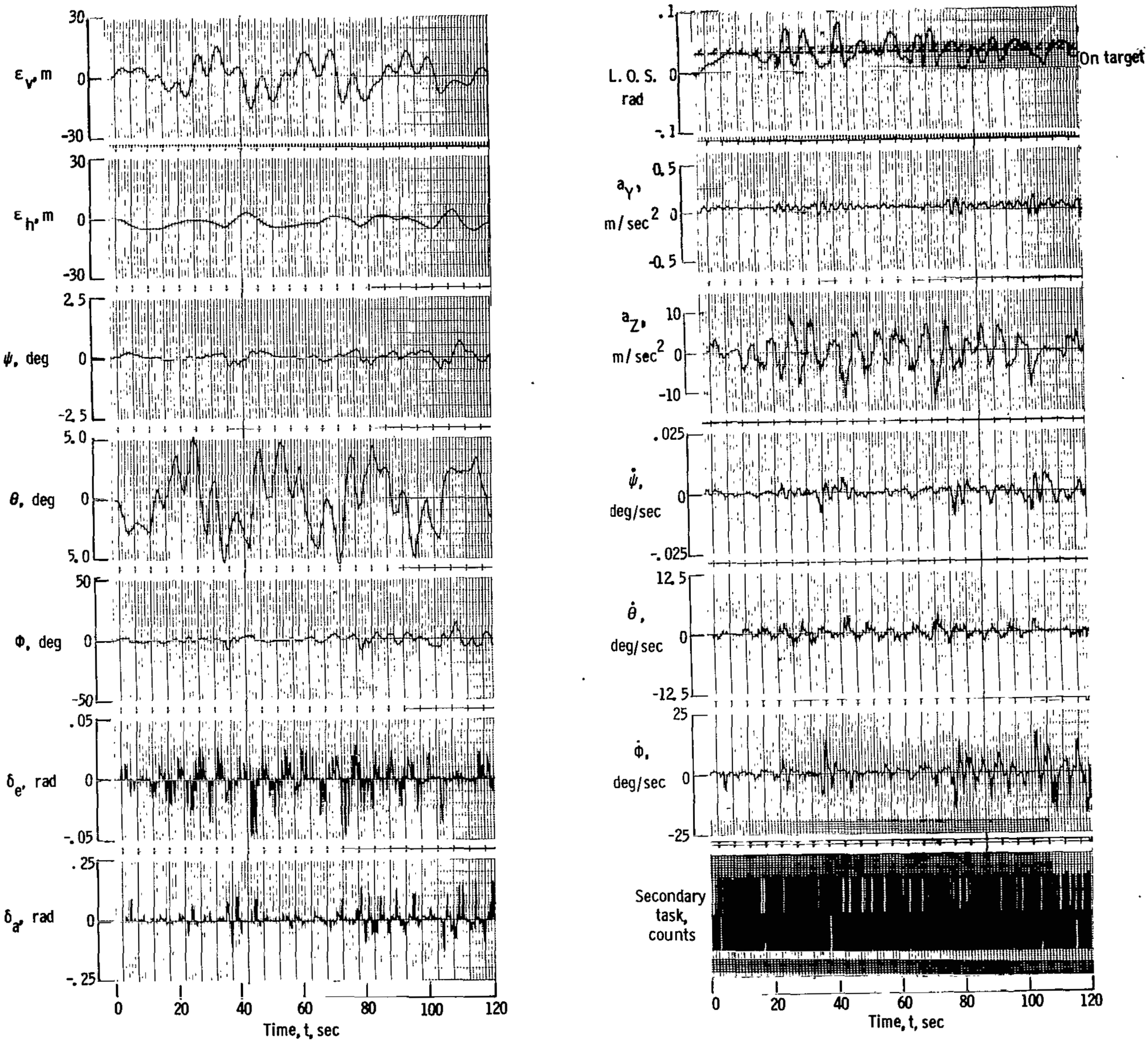


Figure 6.- Typical time history using basic airplane with no motion and 8 units of time delay. Subject A.

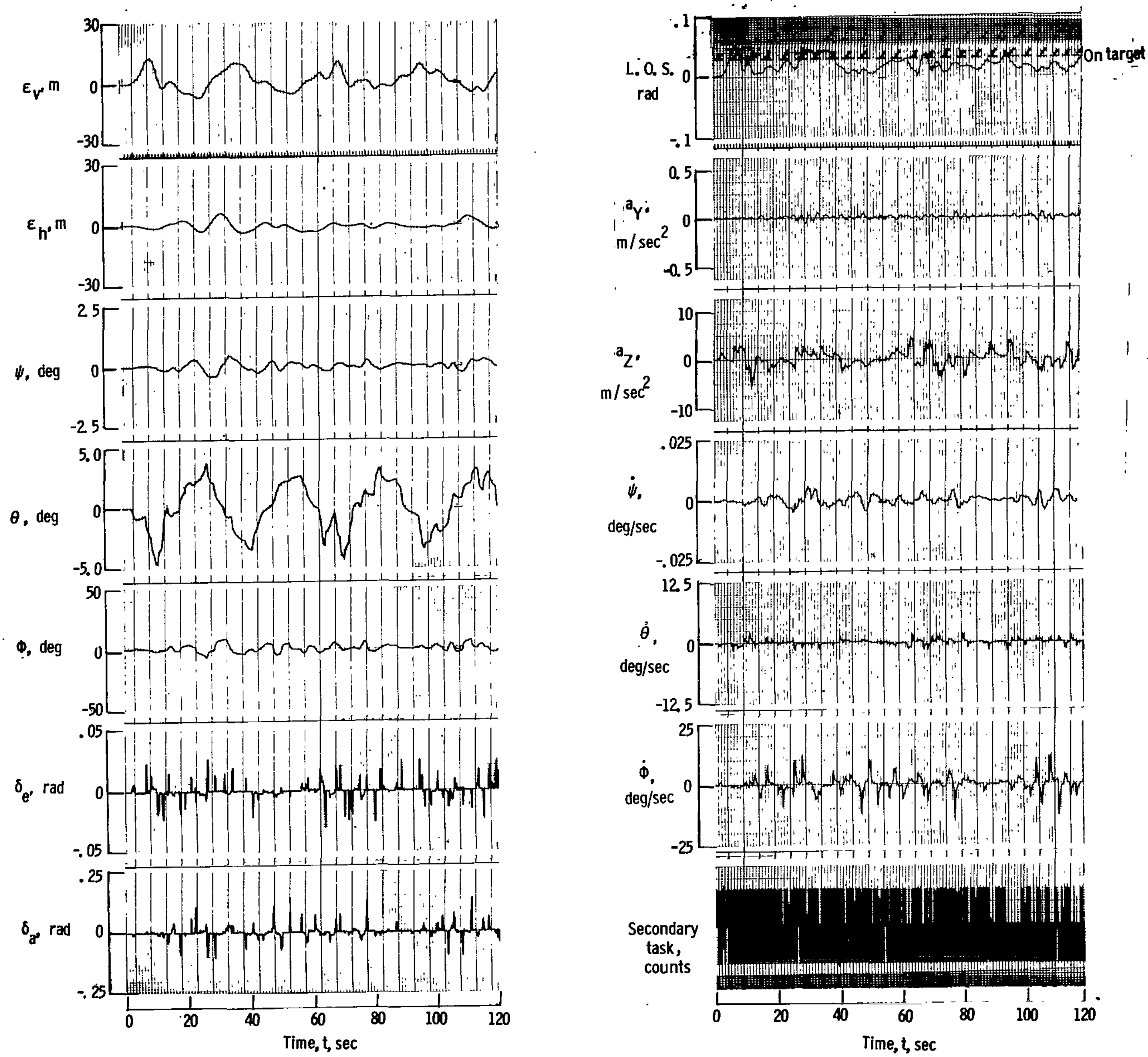


Figure 7.- Typical time history using basic airplane with full motion and 8 units of time delay. Subject A.

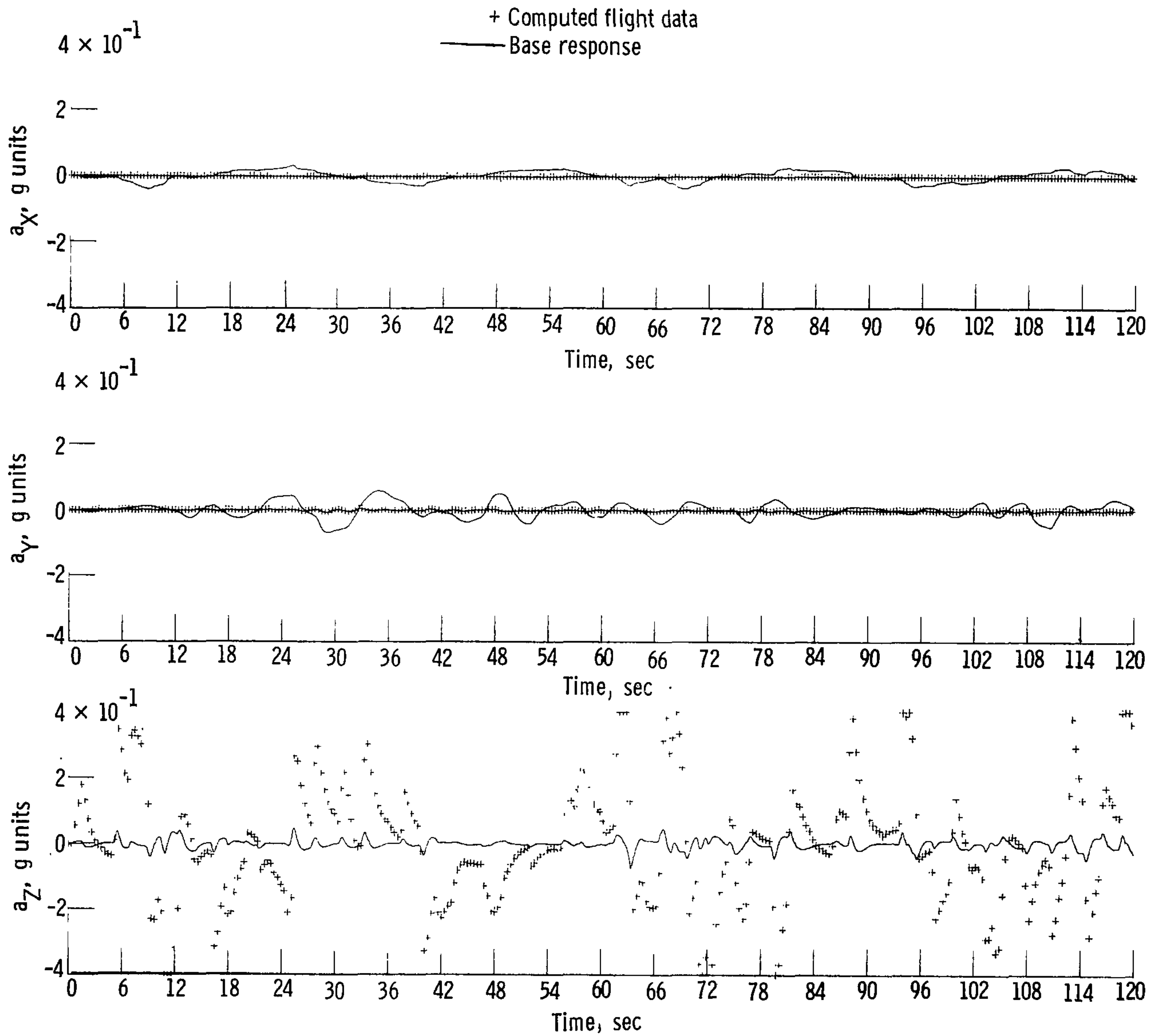


Figure 8.- Computed motion-base response for typical time history for basic airplane with full motion and 8 units of time delay. Subject A.

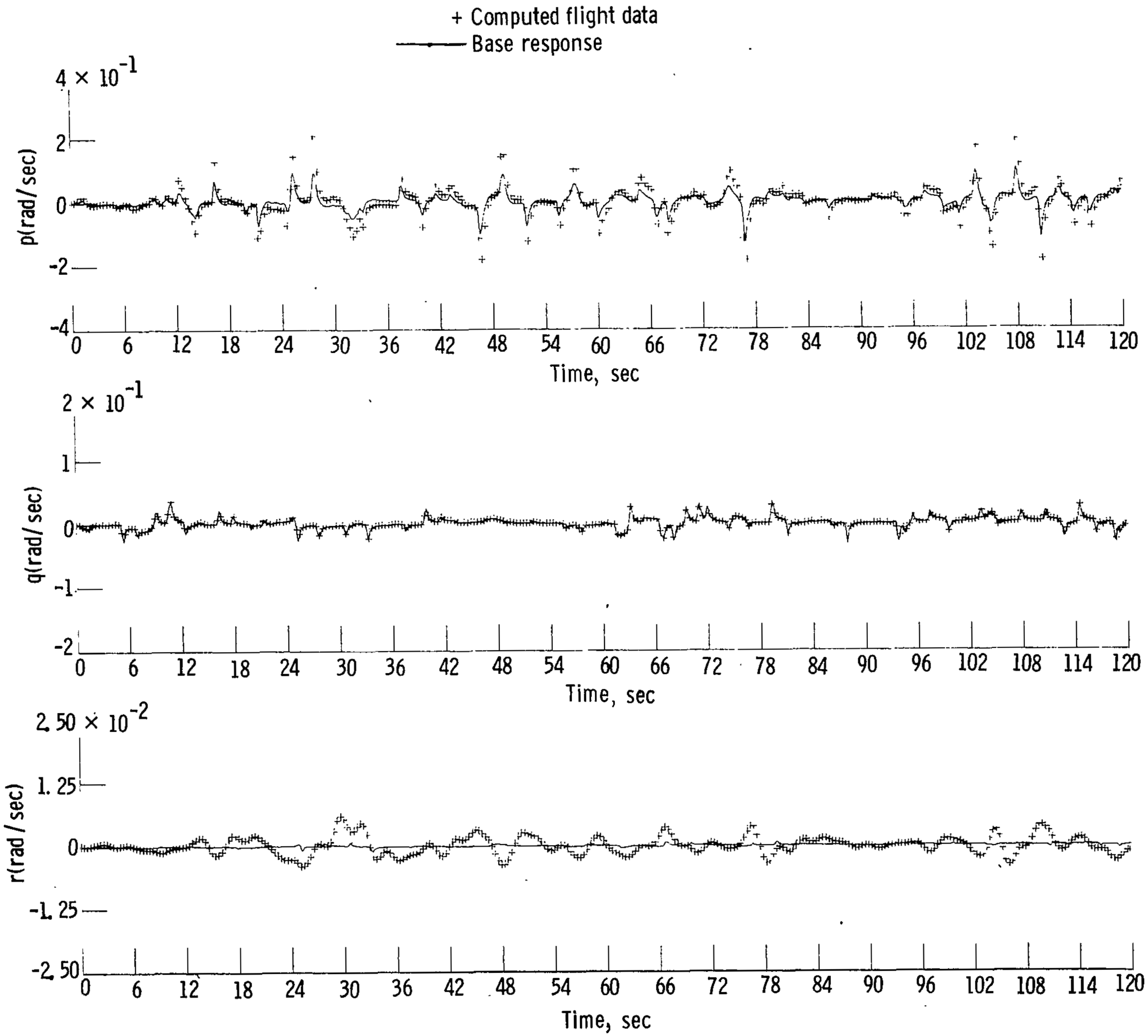


Figure 8.- Concluded.

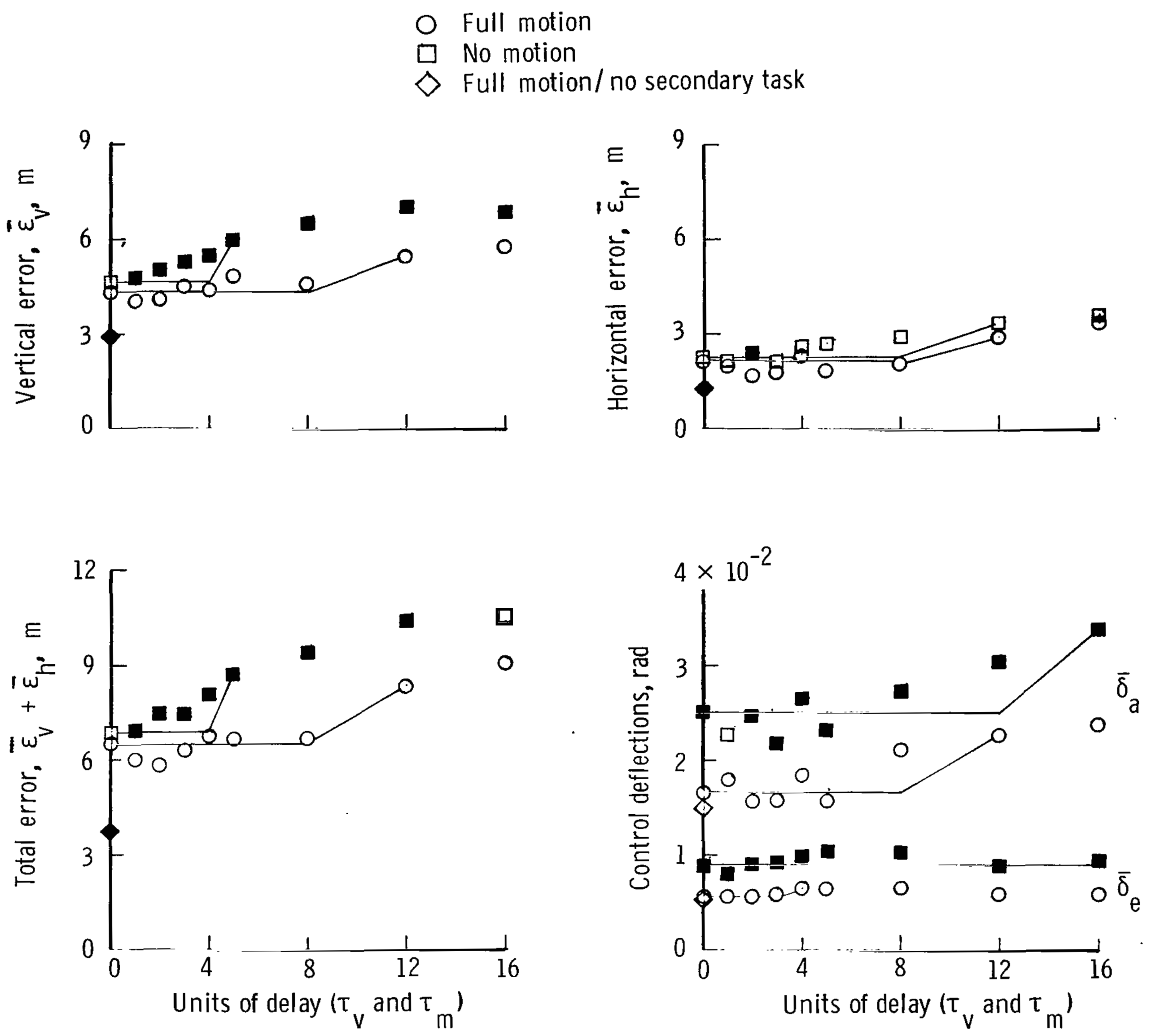


Figure 9.- Performance measures for basic airplane with and without motion. Subject A. (Lines and solid symbols are used to denote statistical significance of time delays and motion cues, respectively. One unit of time delay equals 0.03125 sec.)

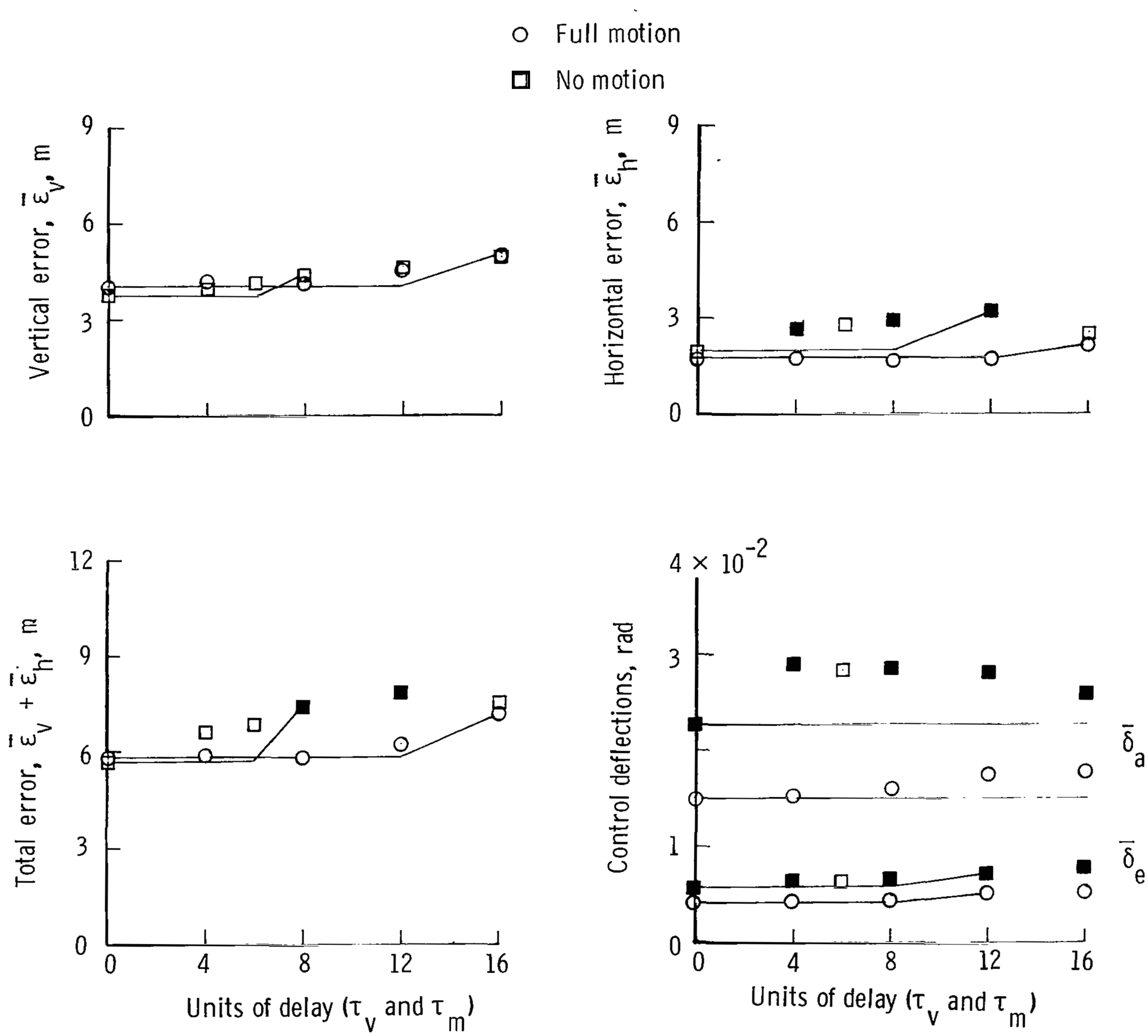


Figure 10.- Performance measures for good airplane with and without motion. Subject A. (Lines and solid symbols are used to denote statistical significance of time delays and motion cues, respectively. One unit of time delay equals 0.03125 sec.)

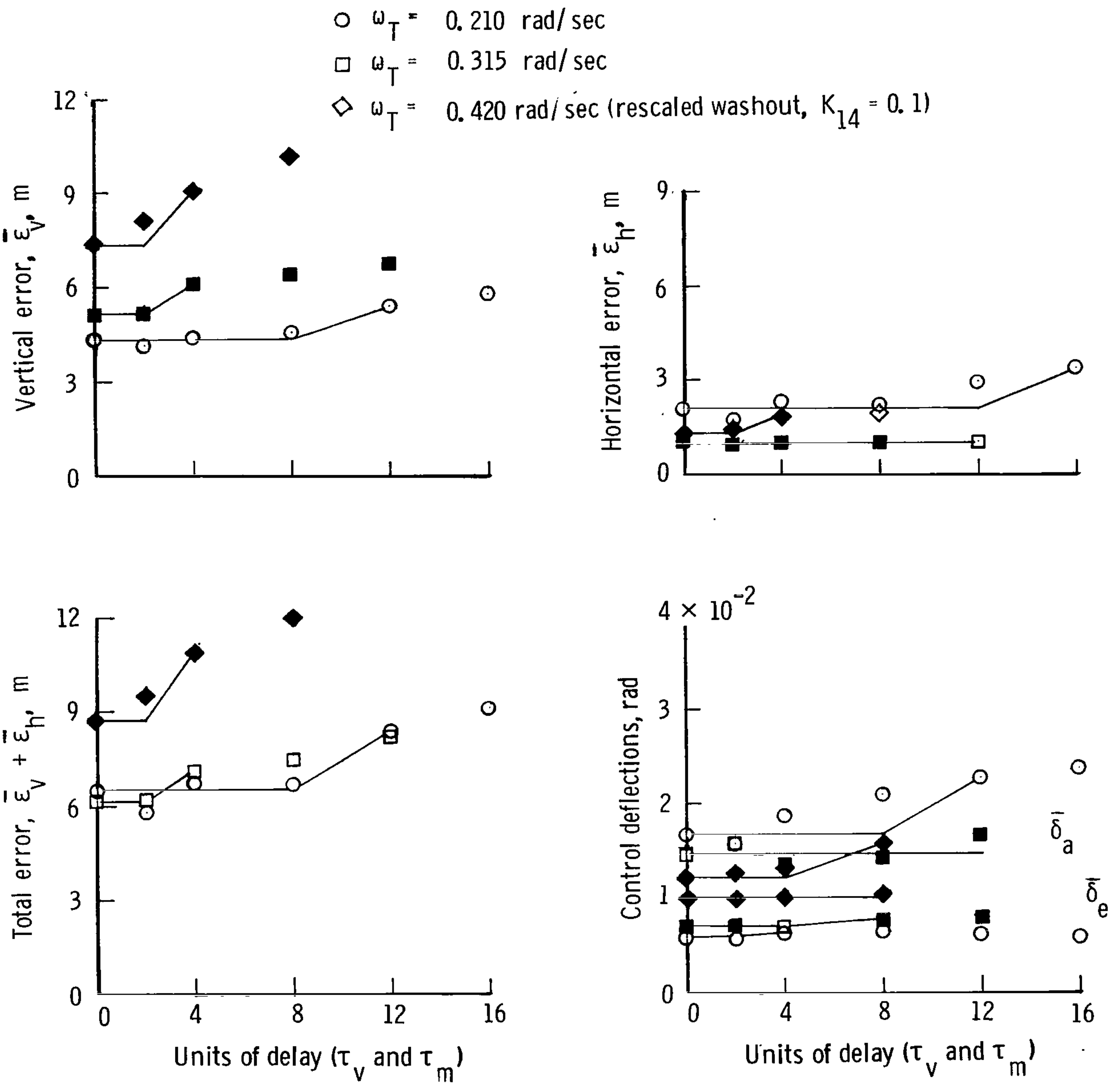


Figure 11.- Target frequency effects for basic airplane with full motion. Subject A. (Lines and solid symbols are used to denote statistical significance of time delays and target frequency, respectively. One unit of time delay equals 0.03125 sec.)

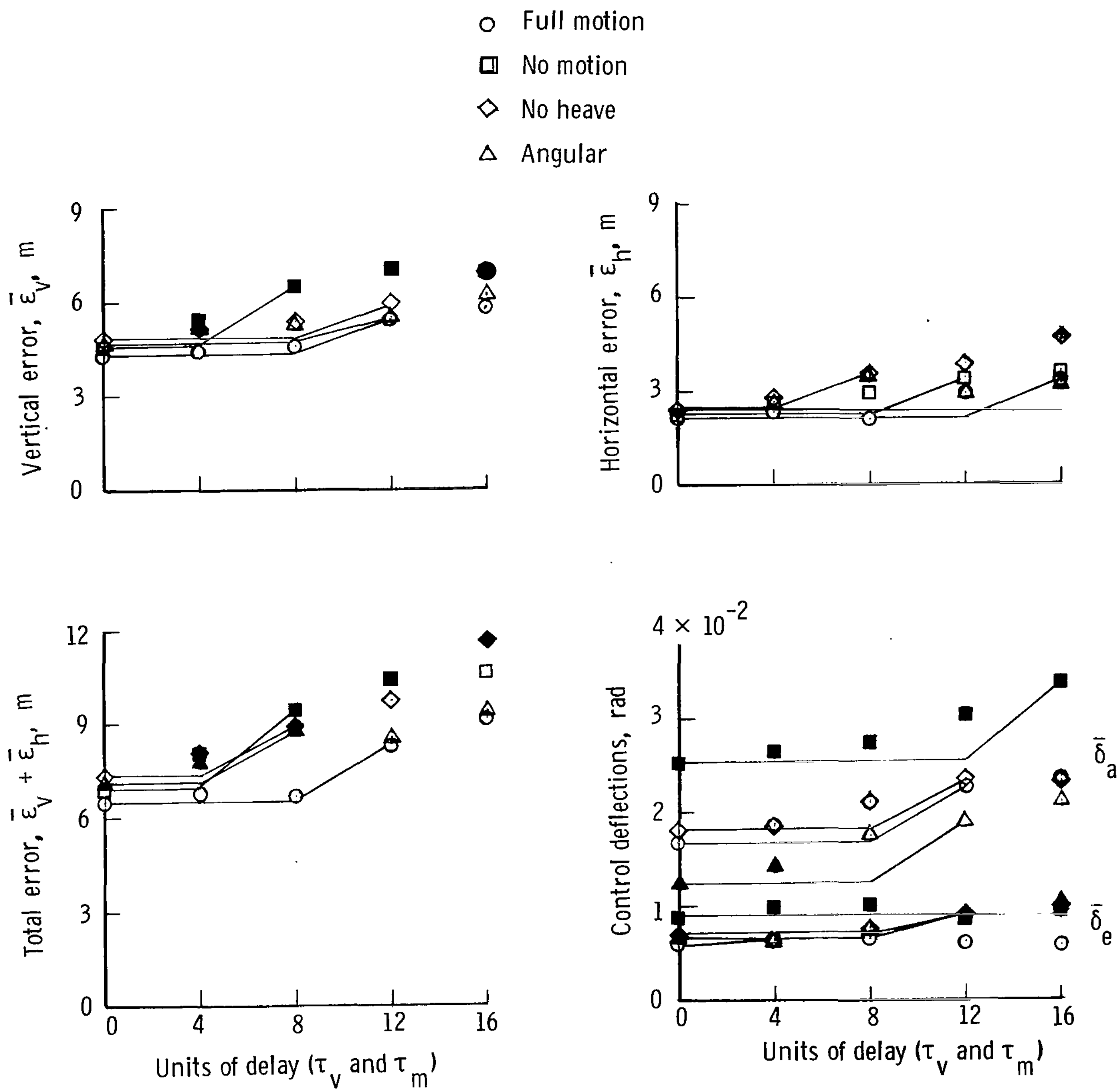


Figure 12.- Motion-condition effects for basic airplane. Subject A. (Lines and solid symbols are used to denote statistical significance of time delays and motion cues, respectively. One unit of time delay equals 0.03125 sec.)

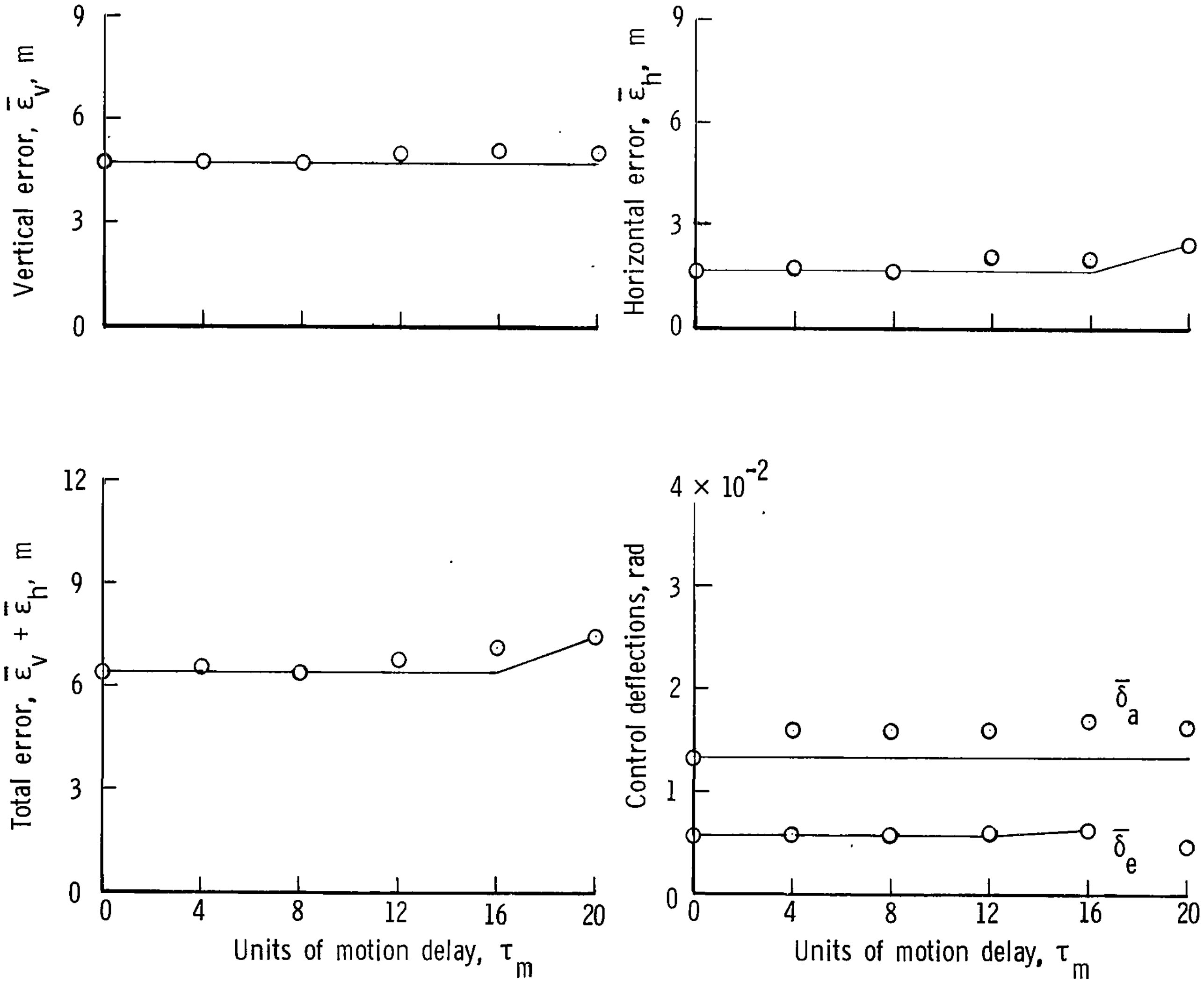


Figure 13.- Effect of time delays in motion system (with τ_v = 8 units). Subject A.

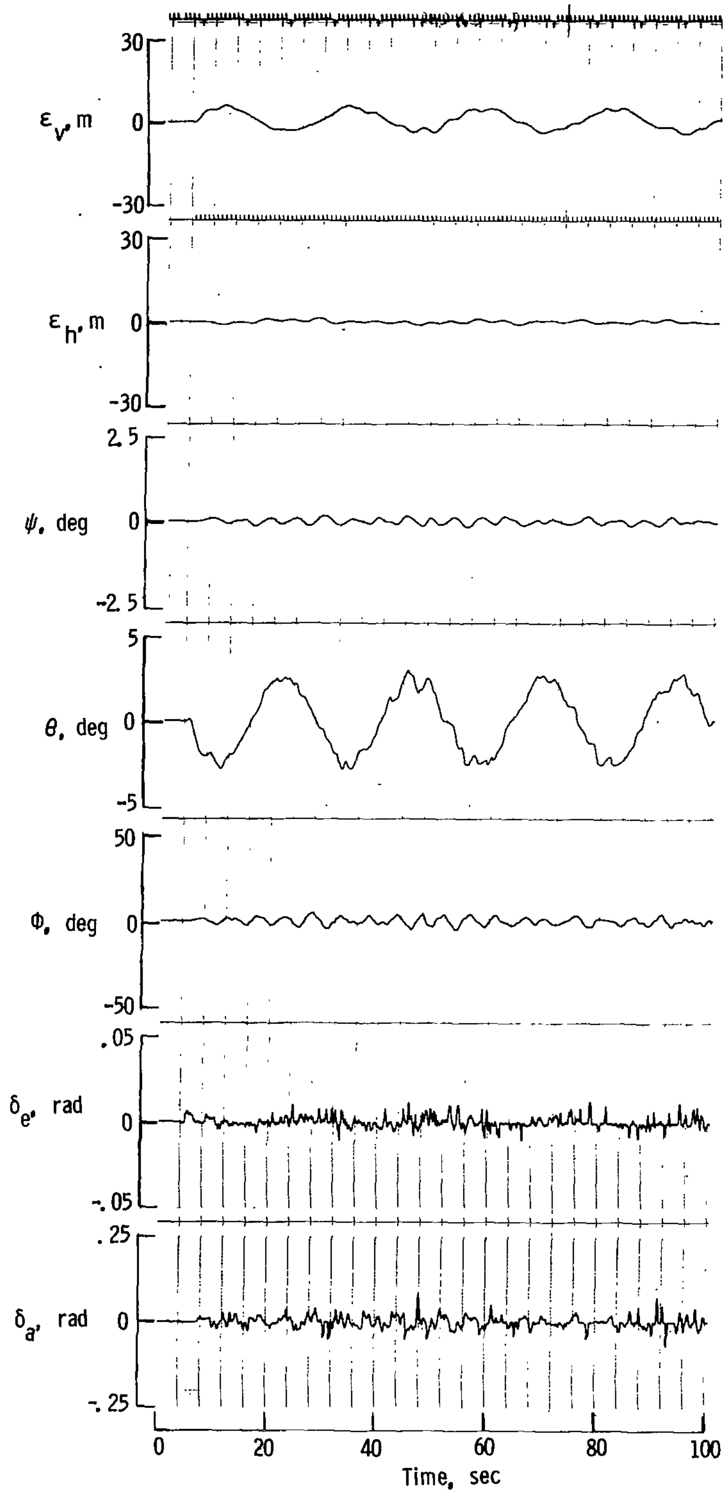


Figure 14.- Typical time history of flight with full motion but no time delays and no secondary task. Subject A.

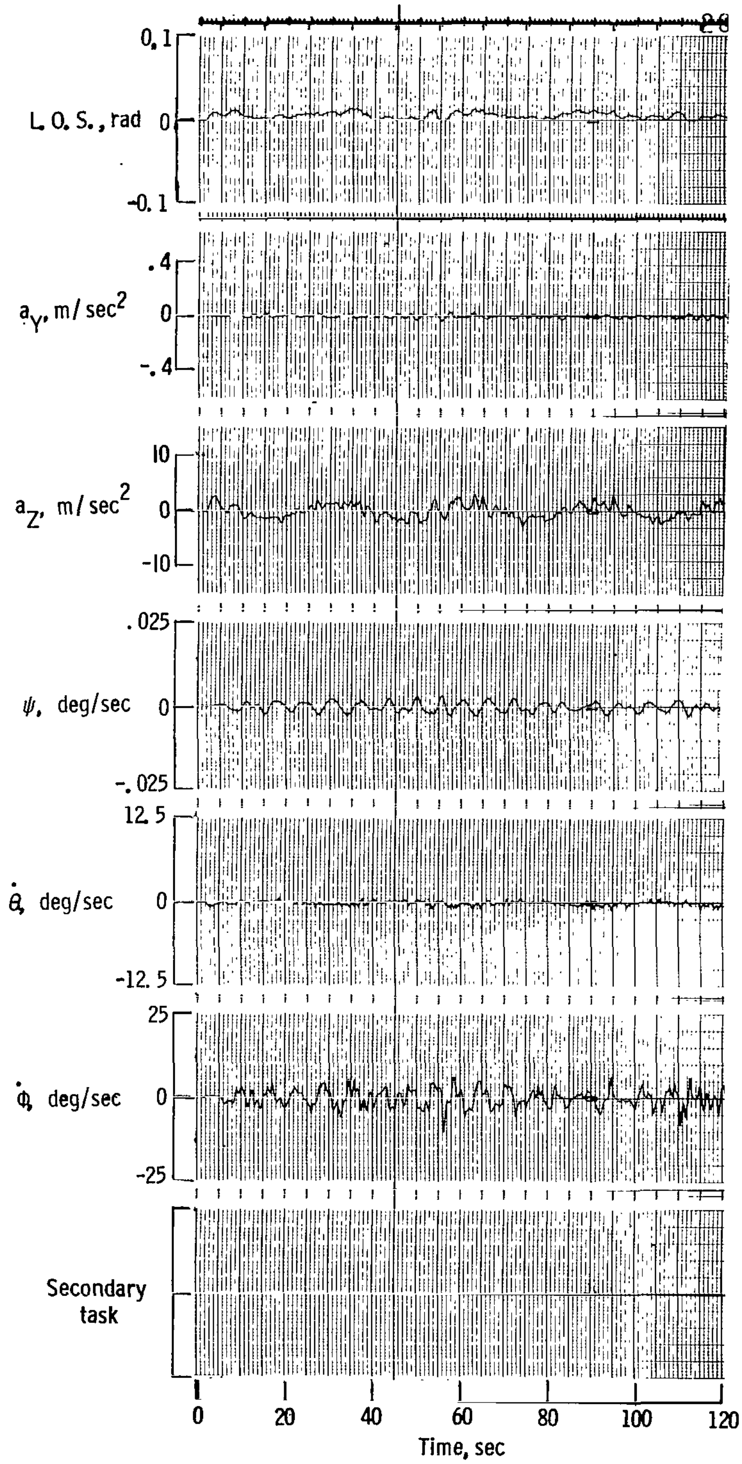


Figure 14.- Concluded.

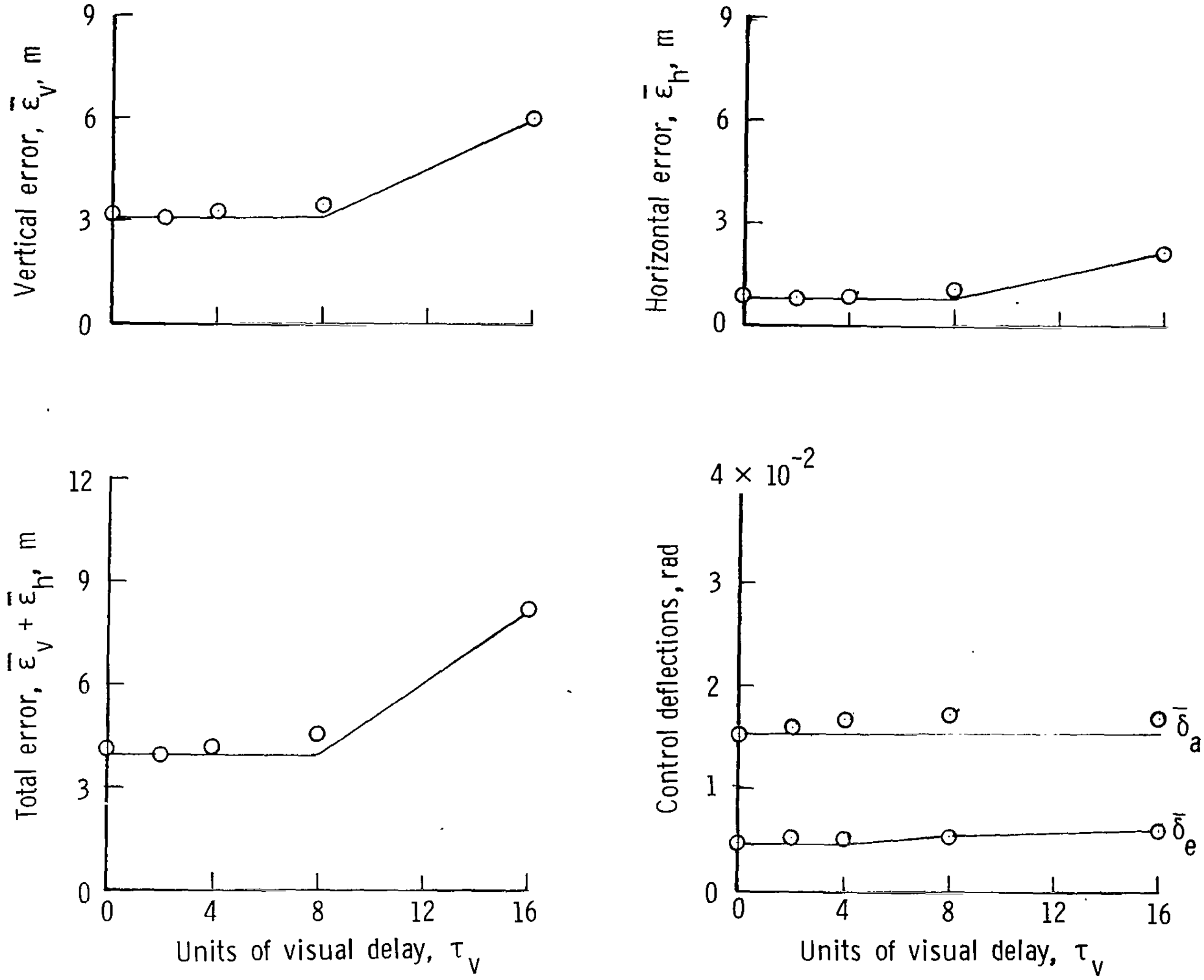


Figure 15.- Effect of time delays in visual system (with $\tau_m = 0$ units). Subject A.

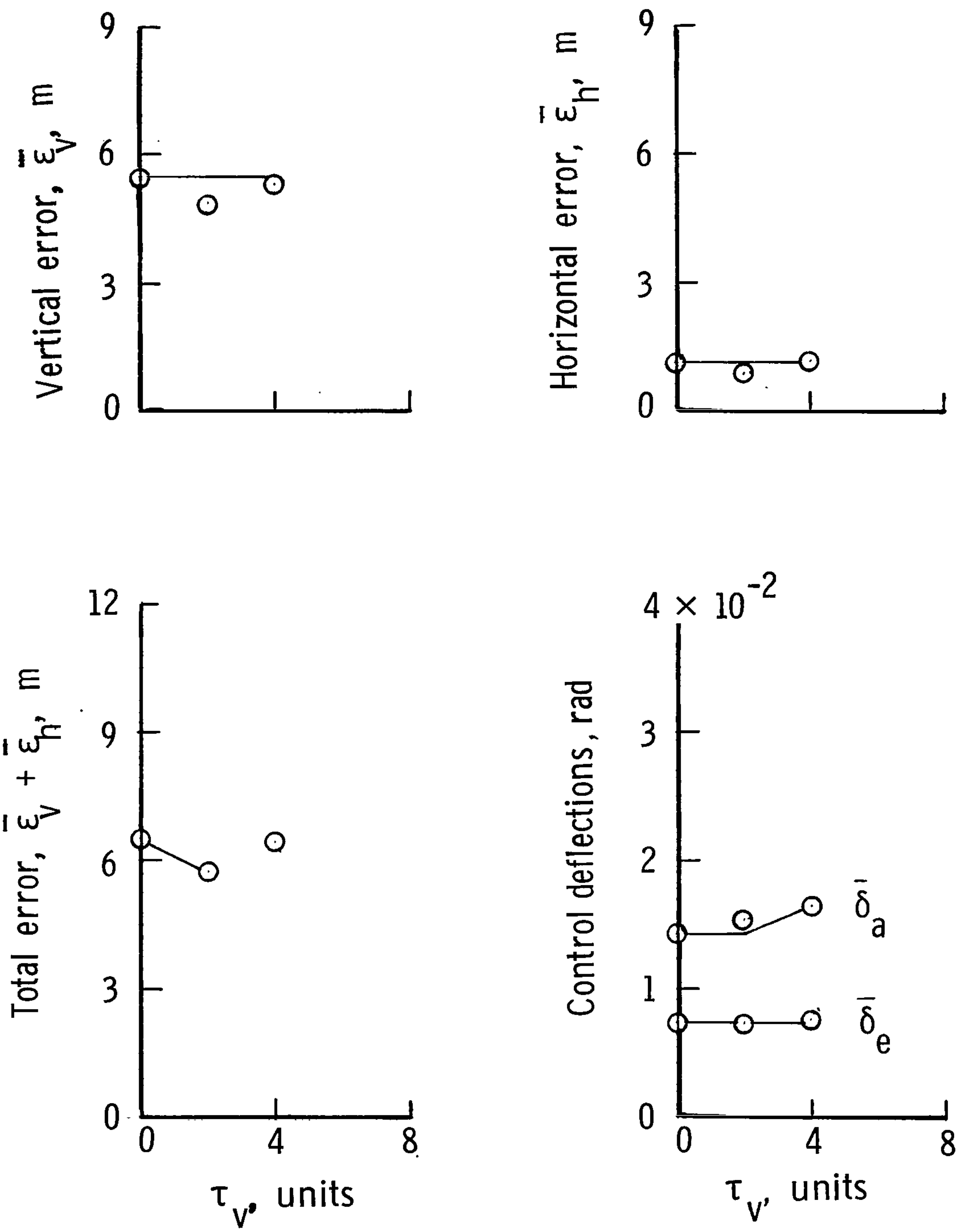


Figure 16.- Effect of visual time delays when ω_T is 0.315 rad/sec (with $\tau_m = 0$). Subject A.

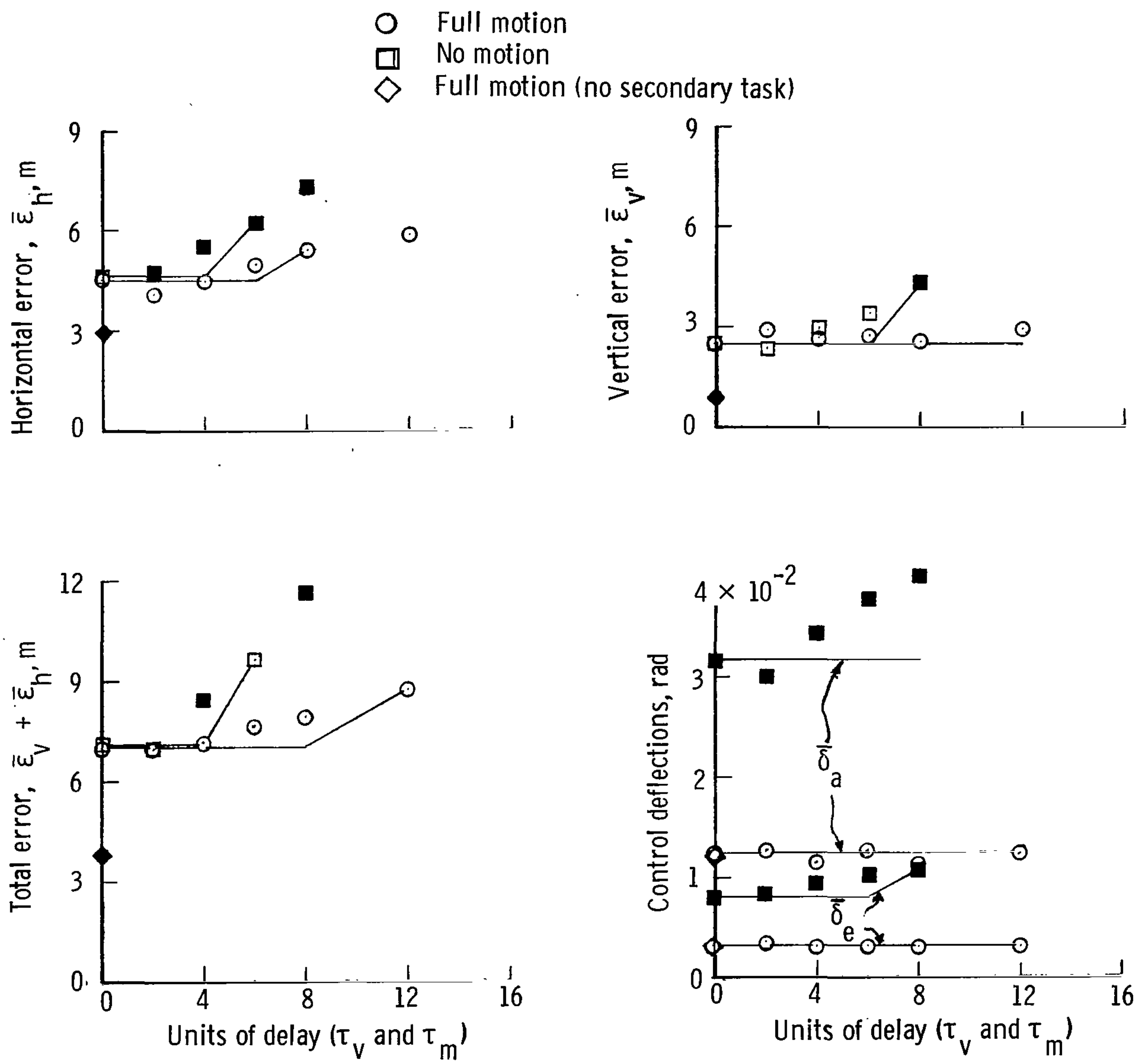


Figure 17.- Motion and time-delay effects for pilot B with basic airplane. (Lines and solid symbols are used to denote statistical significance of time delays and motion cues, respectively. One unit of time delay equals 0.03125 sec.)

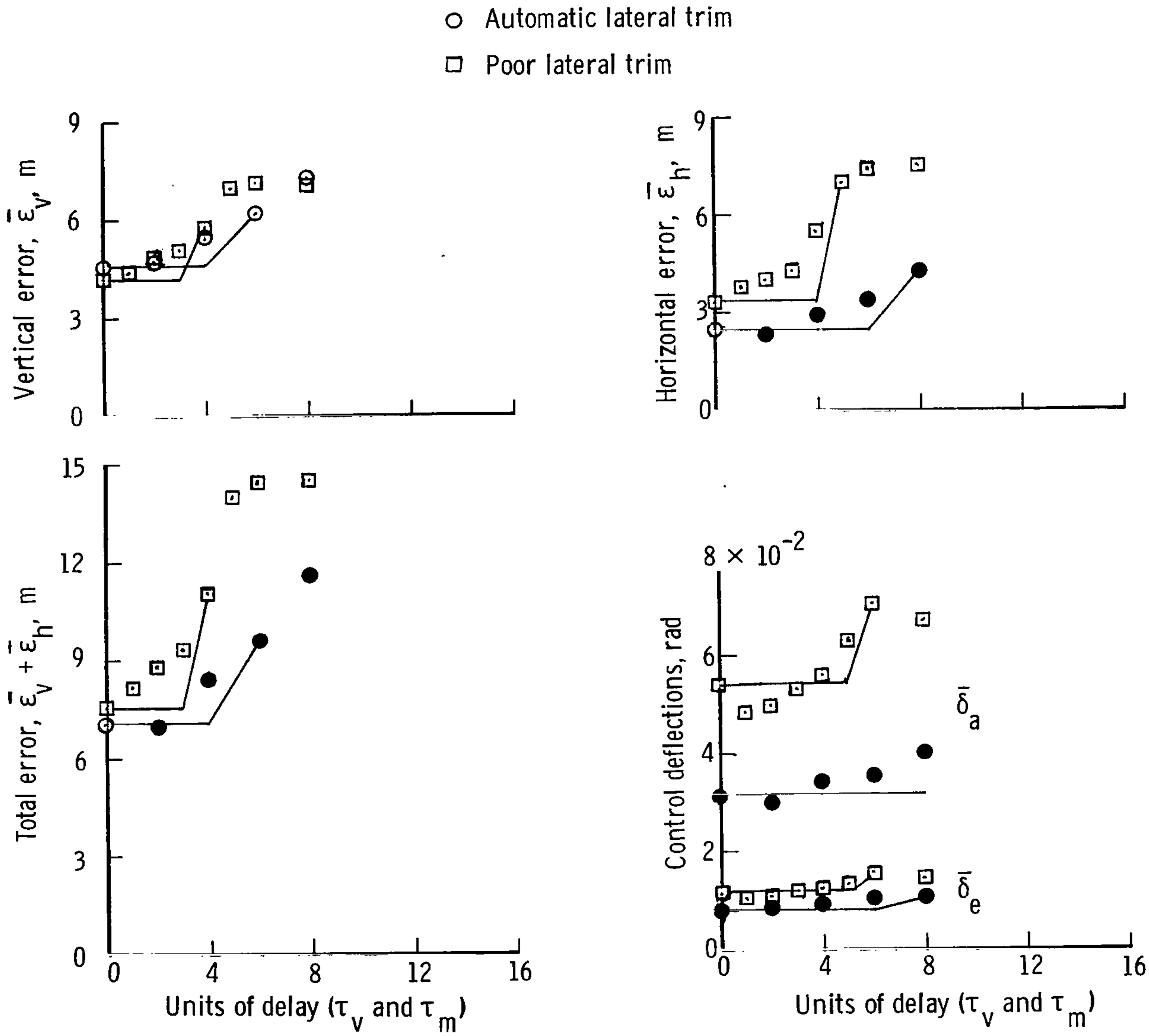


Figure 18.- Trim effects for pilot B. (Solid symbols denote difference at 5 percent level of significance between two trim conditions.)

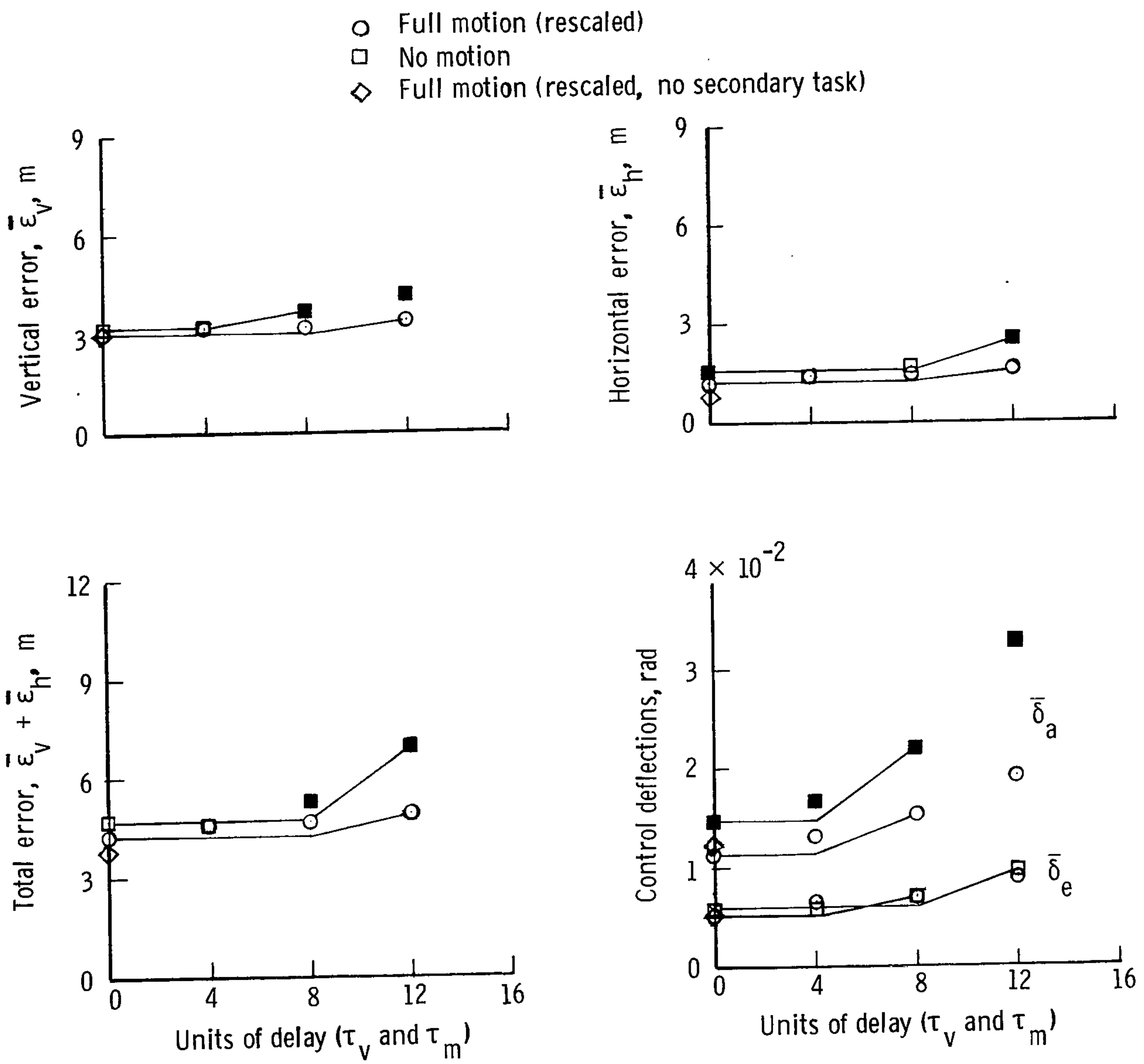


Figure 19.- Motion and time-delay effects for pilot C with basic airplane and reduced heave cue. (Lines and solid symbols are used to denote statistical significance of time delays and motion cues, respectively. One unit of time delay equals 0.03125 sec.)

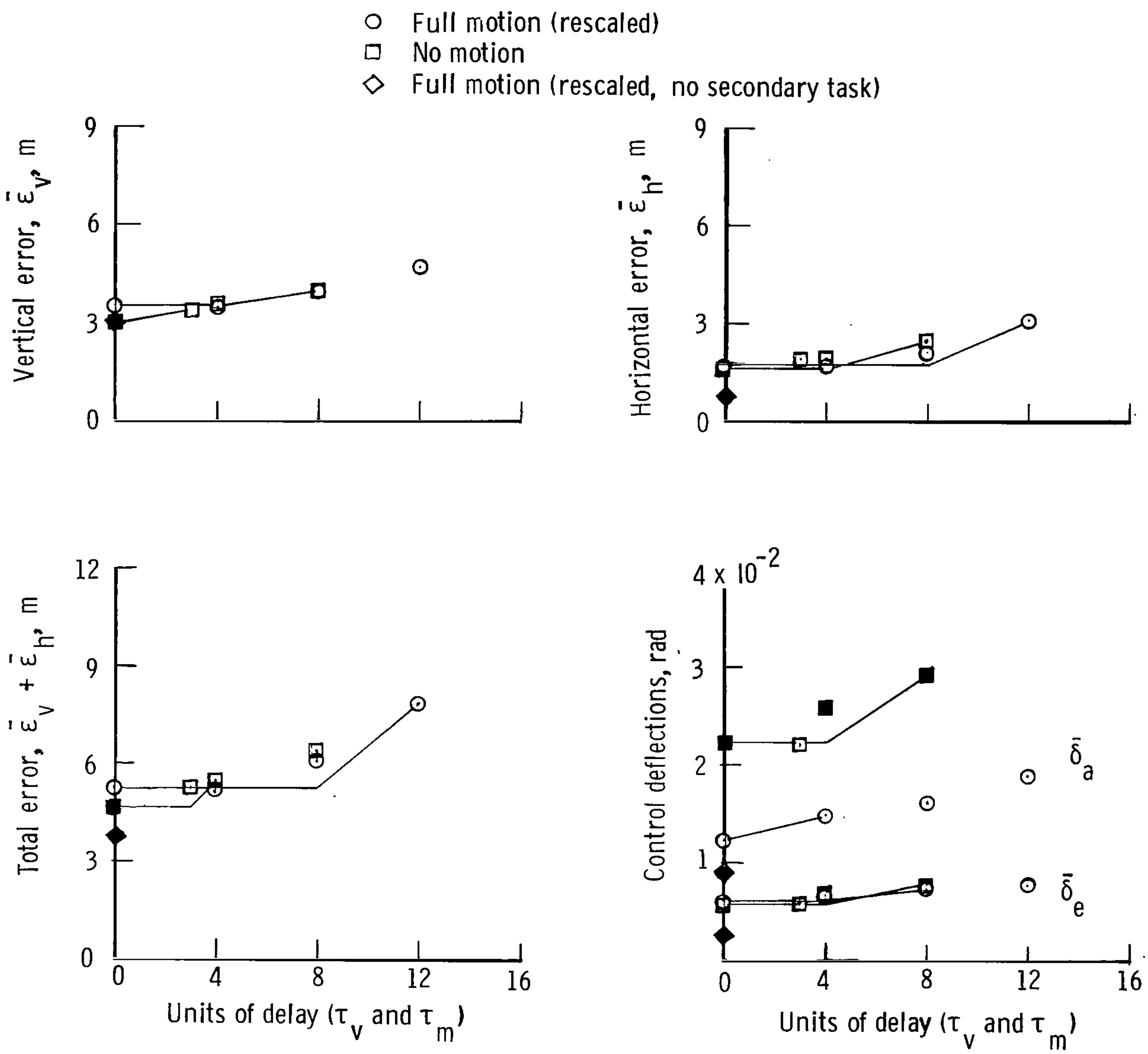


Figure 20.- Motion and time-delay effects for pilot D with basic airplane and reduced heave cue. (Lines and solid symbols are used to denote statistical significance of time delays and motion cues, respectively. One unit of time delay equals 0.03125 sec.)

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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