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# Oculometric Indices of Simulator and Aircraft Motion

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by

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ABSTRACT

OCULOMETRIC INDICES OF SIMULATOR AND AIRCRAFT MOTION

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In a series of three experiments on the effects on eye-scan behavior of both simulator and aircraft motion, the sensitivity of an oculometric measure to motion effects was demonstrated. "Fixation Time", defined as the time the eyes spend at a particular place before moving on (saccade) to another fixation point, was found to be sensitive to motion effects in each of three experiments conducted. A fixation was defined as a series of oculometer-measured lookpoints having X and Y coordinates that did not exceed a selected boundary limit (typically a radius) from the centroid of prior X and Y coordinates. In the first experiment, differences in eye-scan behavior were studied between simulator motion and no-motion conditions during a series of simulated Instrument Landing System (ILS) approaches, half with the motion base on and half with the base off. The mean fixation time for the no-motion condition was found to be significantly longer than for the motion condition for the five pilots tested. This was true particularly for the Flight Director, the instrument supplying attitude and deviation from glideslope information. Tests of the data

analysis algorithm showed that differences between motion and no-motion were not an artifact of the algorithm employed. Analyses were also conducted on control activity measures and ILS approach error. The second experiment investigated eye-scan parameters based on data collected in flight, with the oculometer onboard the NASA Transport Systems Research Vehicle (TSRV), and in the fixed base TSRV simulator. The results of the second experiment, which employed three highly experienced pilots as test subjects, were similar to the results of the first experiment and showed fixation time and rate measures to be sensitive to motion (flight) and no-motion. Motion effects were most evident when the test subject was viewing a display supplying attitude and flight path information. The third experiment addressed the question of the nature of the information provided by motion. Utilizing a part-task (monitoring one instrument), with motion in only one dimension (pitch), seven pilots and three non-pilots were tested on the following motion conditions: (a) no-motion, (b) correct motion, and (c) reverse motion. The mean fixation times for the no-motion condition were significantly longer than for either motion condition, while the two motion conditions did not differ significantly. The results of this experiment were like those of the preceding experiments except demonstrated with the part-task and single-axis motion. The results of the present series of experiments support the hypothesis that motion serves an alerting function, providing a "cue" or "clue" to the pilot that "something happened". The results do not support the hypothesis that direction of motion is conveyed through this type of motion information. This was also supported by self-report data from the subjects, where eight out of ten reported that they could not tell whether motion was correct or reversed on a given trial in the study. Mathematical curve fitting, particularly the use of a transformed Normal density function, and the analysis of the shape of the fixation time distributions was found to have advantages in describing and testing such distributions, and is recommended as a technique to use in future studies in this area.

ACKNOWLEDGEMENTS

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Special thanks are expressed to the members of my dissertation committee, Drs. Glynn D. Coates, Randall L. Harris, Sr., Raymond H. Kirby, and Ben B. Morgan, Jr., and to Mr. Amos A. Spady, Jr., for their guidance and direction throughout the project. My dissertation director, Dr. Coates, deserves special mention for his assistance in this and many other projects over the past few years.

A project of this type necessarily involves the assistance of many people, including those who served as subjects and those who provided technical support. Thanks are extended to Jeff Brown and Dan Burdette for their technical support in the operation of the NASA Langley Research Center oculometer system.

A final word of thanks is extended to my wife, Ellen, for continued patience and support during this project.

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## Introduction

One goal of high fidelity aircraft simulation is to present to the flight crew a situation with task requirements and sensory stimuli approximating those found in flight. In order to simulate the motion of the real aircraft, sophisticated motion devices are often employed in flight simulators. Despite the careful development of motion devices and motion washout techniques with regard to the sensitivity of the human operator, knowledge is lacking concerning the effects of perceptual fidelity on pilot performance (Huff & Nagel, 1975).

The evaluation of simulator motion with regard to piloting tasks has yielded equivocal results. For example, Ringland and Stapleford (1971) found that performance in a tracking task was facilitated with the introduction of angular motion cues, but that adding rotational and translational motion resulted in decreased opinion ratings of the simulator. Bray (1973) suggested that simulator motion cues become important when simulating aircraft with marginal longitudinal (pitch) handling qualities. It has also been demonstrated (Clark, Stewart, and Phillips, 1980) that pilots can detect maneuver or disturbance motion in the presence of fairly high levels of vibratory motion, such as may be found in helicopters or in helicopter simulators.

Some reviews of simulator motion (e.g., Gibino, 1968) report consistent added realism of the simulation when motion is present. Statements are found such as "experienced pilot's performance deteriorates immediately when cockpit motion cues are withdrawn, and does not improve with practice in static simulation" (Ruocco, Vitale, & Benfari, 1965), or "results and pilot opinion indicated preference for dynamic cockpit." "Control corrections in wrong direction were often made in static cockpit" (Brown, Johnson, & Mungall, 1960).

Other reviews of simulator motion fidelity (Huff & Nagel, 1975) suggest that "the main conclusion one might draw from these studies is that some motion may be helpful in certain piloting situations". In addition, low fidelity motion simulation may lead to vertigo, nausea, or other undesireable outcomes (Clark & Stewart, 1973).

Huff and Nagel (1975) note that there is very little knowledge concerning the interaction of motion and vision cues, and their related effects on pilot information processing. They suggested that the proper "analytic tools" required to evaluate motion drive systems are not presently available.

Not addressed in the literature is the assessment of the human operator in the motion system through oculometric measures, and specifically through assessment of eye-scan behavior. Before proceeding with the development of the present experimental investigations, a brief look at the interconnection of the vestibular and ocular systems is in order.

Physiological aspects of eye-movement control

As should be apparent from the design of the vestibular apparatus, the adequate stimulus is not a constant rate of motion but change of rate of motion (Geldard, 1972). The reader is referred to Geldard (1972) or Carpenter (1977) for details of the mechanics of the vestibular system, and to Cohen (1981) for recent research on the vestibular system.

The importance of vestibular factors in eye movement is apparent when considering how a fixed lookpoint is maintained while the head is in motion. The process has been labeled the Vestibular Ocular Reflex (VOR) and in general acts to rotate the eyes opposite in direction to head movements to maintain a given lookpoint. The phenomenon of counterrolling eye movement was first reported by Hunter (1786). The process was initially thought to be a simple reflex arc with possibly as few as three neurons serially connected. Lorente de No (1933) was credited with this model of VOR operation (Baker, Evinger, & McCrea, 1981), a model that has withstood the test of time.

Despite the apparent simplicity with which the VOR produces compensatory eye movement following head rotation, knowledge is lacking as to how the VOR and related neural pathways control other oculomotor subsystems such as controlling functions for saccadic and pursuit eye movement and fixation position (Baker, et. al., 1981). Cohen (1981) suggests that vestibular nuclei serve as a processing station for motion information from various sensory systems and may control the generation of slow and rapid eye movements.

While a cortical receiving area for the vestibular sense has not been identified, unlike the regions identified for vision or audition, projections from the nonauditory labyrinth to the cortex have been found (Andersson & Gernandt, 1954). Finding relatively few cortical projections, Andersson and Gernandt (1954) suggested that "the paucity of cortical projections suggests that these behavioural consequences are largely at the unconscious reflex level." At the vestibular nuclei of the brainstem are found many connections to areas important to both postural control and eye movement (Geldard, 1972), lending support to the idea that the vestibular nuclei serve as a processing center for motion information from various sensory systems. This is of particular importance in the aeronautical environment where motion may be experienced through force applied to the neck or limbs in addition to the vestibular apparatus.

Measurement of eye movement

In each of the three experiments reported here, eye movement was measured utilizing the corneal reflection technique. This technique allows unobtrusive measurement of eye lookpoint while permitting subject head movement over approximately one cubic foot of space. Details of the technology of the instrument may be found in Merchant and Morrisette (1974). Specifications of the system used in the present studies, a NASA Langley Research Center modified Honeywell Mark III, may be found in Spady (1978). A review of various techniques of eye movement recording, and typical applications, may be found in Young and Sheena (1975).

Analysis of eye movement data may be conducted in various ways, making it imperative that terms are carefully defined. For the present study "dwell" or "dwell time" is defined as the total time spent looking at an instrument prior to the eyes moving on to another instrument. "Fixation" or "fixation time" is defined as the time the eyes spend at a particular place before moving on (saccade) to another fixation point. Thus, multiple fixations may occur within the boundaries of a single instrument. In one sense, looking at fixation times may be thought of as analogous to examining the "sampling rate" of the human visual system.

Because there is always some error in measuring eye lookpoint, a fixation was defined mathematically as a series of lookpoints having X and Y coordinates that did not exceed a selected boundary limit (a radius) from the preceding centroid of X and Y coordinates. In addition, a single lookpoint, and movement to a new position beyond the selected radius, could not constitute a fixation. A minimum of three lookpoints (93.75 msec for data sampled 32 times per second; 100 msec for 30 samples per second) within the selected radius was required to constitute a fixation. The algorithm for computing fixations based on time and lookpoint geometry considerations was developed by Harris (Note 1).

Lookpoint data were collected at 30, 32, and 40 samples per second in the experiments to follow. Variations in sampling rate depended on the sampling rate of the data acquisition computer utilized. On a given data collection cycle, or count, three outcomes were possible: (1) no track - the oculometer was unable to determine the lookpoint, (2) transition - a single or series of coordinates not part of or forming a new fixation were considered transition counts, and (3) fixation - lookpoint coordinates within the fixation radius of the centroid of prior lookpoints. Thus, a typical sequence may be described as the following: a fixation at point A, followed by several transition counts, then a fixation at point B, and so on. Movement from fixation point to fixation point could occur either within the boundaries of a single instrument or from one instrument to another.

## Outline of the present research

Because of the importance that the motion and eye-scan interaction may play in providing high fidelity flight simulation, the present study was designed to investigate the differences between actual or simulated motion and simulation with no-motion. A series of three experiments were conducted, with the second and third experiments building upon the foundation established by the preceding study. Each of these experiments simulated a portion of instrument flight, as "out the window" visual scenes were not presented. The three experiments are briefly described below.

Experiment 1. In order to present to the flight crew a simulation with task requirements and sensory stimuli like those found in flight, techniques for assessing the differences between the two situations are necessary. The initial experiment involved the application of a new data analysis algorithm to a set of oculometer data. The experiment permitted exploration of the differences between simulator motion and no-motion through a series of simulated Instrument Landing System (ILS) approaches, half with the motion base on and half with the base off. The data analyzed were collected on the Piedmont Airlines Boeing 737 motion-base simulator, and were part of a larger NASA Langley Research Center study (Spady, 1978). Prior analyses of the effects of motion versus no-motion had not been conducted with these data (Spady, Note 2). Oculometric measures sensitive to motion were found. Tests of the data analysis algorithm, an important part of Experiment 1, showed that differences between motion and no-motion were not an artifact of the algorithm employed.

Experiment 2. The second experiment extended the data analysis techniques employed in the previous experiment. Since it can be argued that simulated motion may not have the same sensory impact on the subject as actual motion does, a second set of data from a NASA Langley Research Center study, was explored. The set of data examined in Experiment 2 was unique in that half of the data were collected in flight, with the oculometer onboard the NASA Transport Systems Research Vehicle (TSRV), and half collected in the fixed-base TSRV simulator. As in the preceding study, prior analyses between motion (flight) and no-motion (simulator) had not been conducted on the data (Spady, Note 2). The results of Experiment 2 showed similar oculometric indices to be sensitive to motion and no-motion, particularly when the subject was viewing instrumentation supplying attitude and flight path information. These results suggested the need for a third experiment employing only that type of display.

Experiment 3. The preceding experiments left several questions unresolved. The initial question was whether fixation time distributions obtained from subjects tested on a controlled single instrument task would resemble the distributions obtained in the full simulation experiments. The second question concerned the nature of the information provided by motion. Does motion information provide a "cue" or "clue" to direction of motion or just signal the onset of motion, regardless of direction. The third experiment was designed and conducted to address these questions as no existing set of data incorporated the desired experimental conditions. An additional outcome of Experiment 3 was the application of two-parameter mathematical curve-fitting to fixation time distributions.

## Experiment 1:
## Motion versus no-motion in a flight simulator

Experiment 1 permitted exploring the differences between simulator motion and no-motion through a series of Instrument Landing System (ILS) approaches, half conducted with the motion base on and half with the motion base off. The data analyzed were collected on the Piedmont Airlines Boeing 737 motion-base simulator, and were part of a larger NASA Langley Research Center study (see Spady, 1978).

The ILS approach is analogous to a high-order tracking task with aircraft deviation from the desired flight path representing tracking error. While maintaining the proper attitude, airspeed, and altitude, the task involves maintaining the aircraft or simulated aircraft on the desired flight path by utilizing indicators near the center of the Flight Director. The primary flight instruments for the instrument panel employed in the study are shown in Figure 1. The flight path deviation indicators on the Flight Director show: (1) Glideslope deviation, shown in Figure 1 as the horizontal line or "bar" labeled "A" which indicates whether the aircraft is above or below the desired glideslope, and (2) Localizer deviation, shown by the vertical line or bar labeled "B" in Figure 1, and indicates whether the aircraft

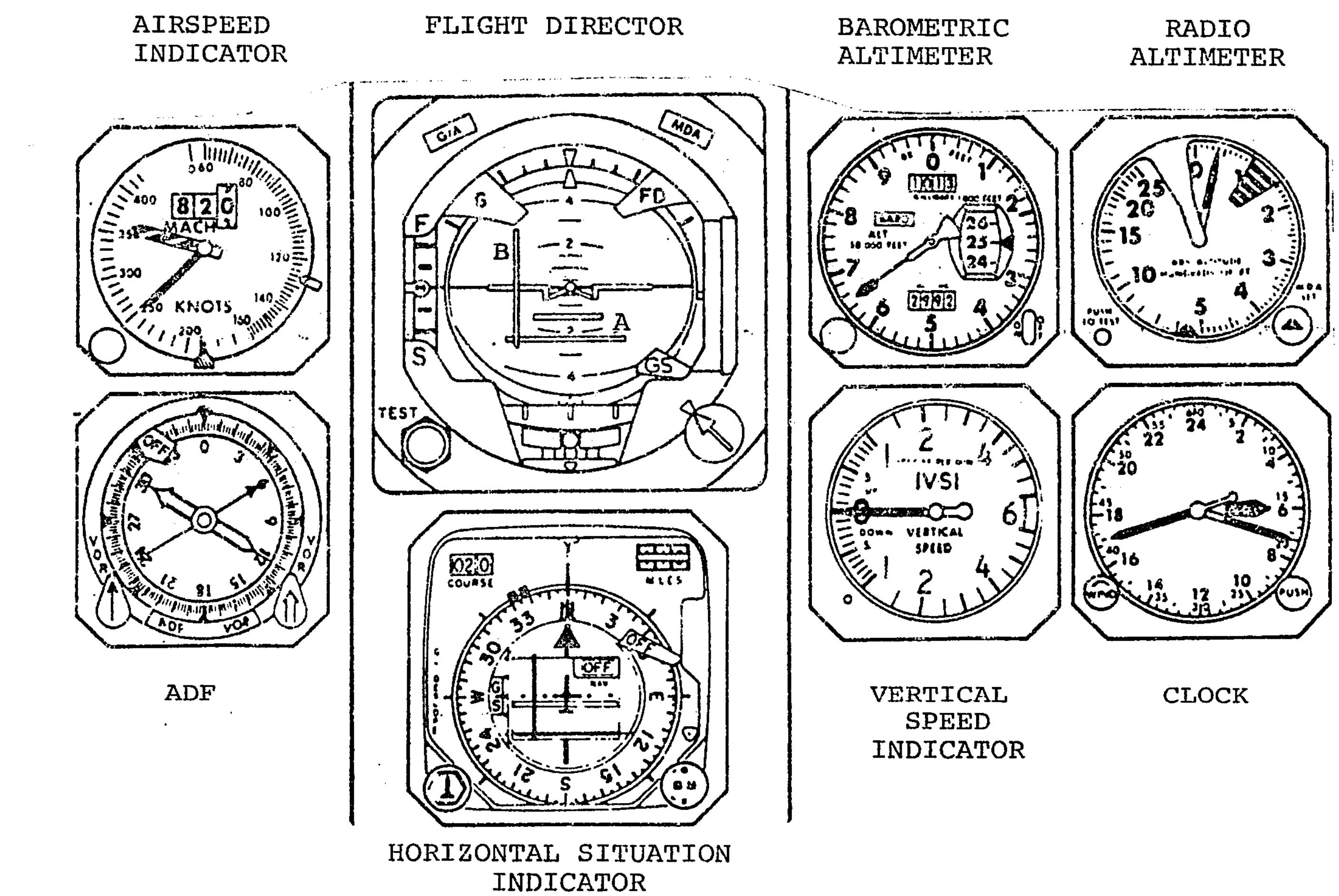


Figure 1. Primary Flight Instruments: Boeing 737 Simulator

is to the right or left of the desired approach position. Indicators in the Flight Director are arranged in a "fly-to" or "inside out" configuration, which means that the aircraft position indicated in Figure 1 is above and to the right of the desired flight path. To correct this deviation, the pilot would "fly-to" the position indicated by the horizontal and vertical bars, by going down and to the left. In the absence of any deviation, the bars would be positioned as a "+" at the center of the display.

In addition to eye-position on the instrument panel, activity of the controls used to maintain the aircraft position was also measured. Measurement of control activity permitted comparing control activity differences between the experimental conditions with the differences in oculometric indices between conditions.

Purpose of the experiment

Experiment 1 was designed with four emphases:

1. The initial emphasis of the present study was to evaluate the effect of simulator motion on eye-scan behavior. The data set included oculometer monitored simulated ILS approaches both with and without the simulator motion base in operation.

2. In order to assess eye-scan behavior adequately, a method of determining fixation points was employed that permitted assessment of fixations both within and between the boundaries of panel instruments. Furthermore, the algorithm

employed permitted classification of a given lookpoint as either part of a fixation or a transition between fixations (saccade) based on time and lookpoint geometry considerations.

3. Method checks of the eye-movement measurement technique were employed to insure that motion effects were not the by-product of the measurement system or algorithm employed.

4. Finally, motion effects on pilot control activity were assessed. Of specific interest were control activity of the stick, wheel, and throttle.

Methodology and Design

Subjects. The set of data employed in the present analyses were from five Piedmont Airlines Boeing 737 pilots. Each pilot made identical simulated ILS approaches, half with the simulator motion base on, and half with the motion base off.

Design and Stimuli. The profile of the ILS approach is shown in Figure 2. Constants in the simulated aircraft included: (1) aircraft weight of 21000 N (94000 lb); (2) the visual scene was set for category II conditions (30 m ceiling, 365 m Runway Visibility Range); (3) wind conditions were zero, and (4) no emergency conditions were imposed during these experimental runs. A detailed description of both the airline simulation and equipment and the oculometer system for real-time assessment of eye position may be found in Spady (1978).

In keeping with prior oculometer research on simulated ILS approaches, the flight profile was divided into four flight segments (Figure 2). For the present study, data from eight approaches for each of five pilots were examined. This meant that there were four approaches, or replications, with the motion base on, and four replications with the motion base off. As illustrated in Figure 3a, this provided a matrix of data for each pilot that held all variables constant, except with respect to the desired variable (motion / no-motion).

In order to obtain the desired number of motion and no-motion runs for a sample of five pilots, runs for pilots number 4 and 5 were in a "No Turbulence" condition (Figure 3b). Prior research (Spady, 1978) had demonstrated only a slight increase in scan rate for turbulence conditions and little, if any, change in instrument-to-instrument transition probabilities. Therefore, utilization of data pooled across the turbulence dimension would not be expected to add undue variability thus masking the effect of the factors of interest.

The experimental design permits an Analysis of Variance (ANOVA) test of the following effects: (1) motion / no-motion, (2) flight segment, (3) replication, (4) motion by segment interaction, (5) motion by replication interaction, (6) segment by replication interaction, and (7) motion by

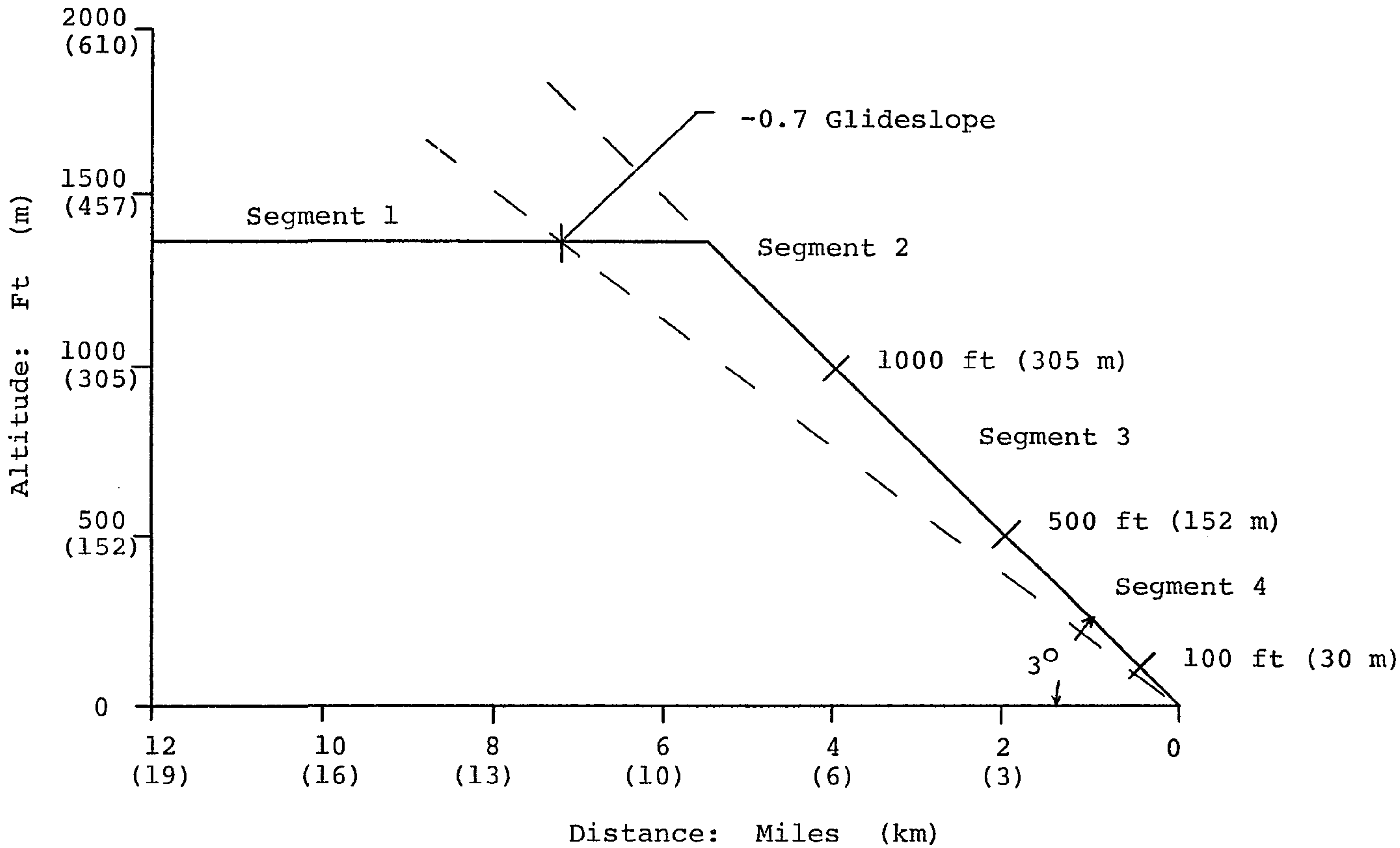


Figure 2. Simulated Flight Profile

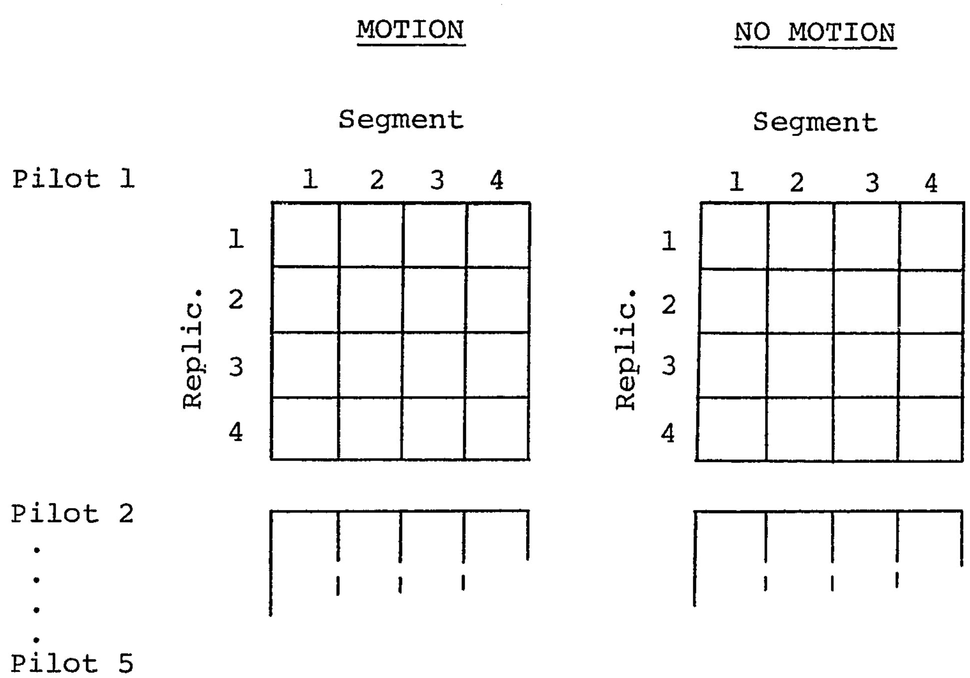


Figure 3a. Experimental Design

| | MOTION | NO MOTION |
|---|---|---|
| Pilot 1 | * Max Turbulence | Max Turbulence |
| Pilot 2 | Max Turbulence | Max Turbulence |
| Pilot 3 | Max Turbulence | Max Turbulence |
| Pilot 4 | No Turbulence | No Turbulence |
| Pilot 5 | No Turbulence | No Turbulence |

* The pilots report the simulator "Max Turbulence" corresponds to what they normally call <u>Moderate Turbulence</u>.

Figure 3b. Turbulence Levels

segment by replication interaction. There is no simultaneous test of subject or subject-interaction effects (Winer, 1971, pp. 496-498).

Calculation of fixations was according to the algorithm mentioned previously. For the analyses in Experiment 1, the radius, which approximately corresponds to absolute distances at the plane of the instrument panel, was 1.27 cm (a fixation area of 5.07 cm sq). Use of this radius was based on research by Harris (Note 1). Several other radii were tested, but 1.27 cm was selected as the optimum value. Subsequent analyses were conducted with a radius of 1.91 cm (a fixation area of 11.46 cm sq), as a measurement method check to insure that any motion effect was not a by-product of an overly restrictive algorithm. These analyses are reported in a later section.

## Global analyses of motion effects

The following analyses were labeled "global" as the dependent measures were obtained across individual instruments. Subsequent analyses by instrument are presented later.

Fixation time (all tracked instruments). Using the method of calculating fixation points described previously, fixation times were calculated for all eye fixation points within the boundaries of the tracked flight instruments. The mean fixation times for each pilot and flight segment are presented in Table 1. A significant difference ($F(1,4)$ =

9.09, $p<.05$; Appendix A-1) was obtained for the motion effect.

As shown in Table 1, the mean fixation time for the motion condition was 315 msec, while for no-motion it was significantly longer at 393 msec. It should be pointed out that the direction of the effect as indicated by the mean fixation time holds for each of the five pilots and for each of the four flight segments.

Fixation Rate (all tracked instruments). As would be expected in light of an increase in fixation time for the no-motion condition with respect to the motion condition, the fixation rate was significantly ($F(1,4) = 13.071$, $p<.05$; Appendix A-2) higher under the motion condition, with no-motion characterized by fewer fixations per second. As with the prior analysis the direction of the differences between means indicates that this holds for each pilot and each flight segment. The means and standard deviations for fixation rate are presented in Table 2.

Saccade Length (all tracked instruments). Saccade length was computed by averaging both within-instrument and between-instrument saccades within the eight tracked instruments. The ANOVA revealed no significant difference due to motion. A significant segment effect was noted ($F(3,12) = 13.542$, $p<.01$; Appendix A-3). Means for saccade length are presented in Table 3. Examination of the differences between means for the four flight segments indicates that this segment effect is probably due to the increased saccade length during segment 1 (straight and level flight) when the task was different. This may reflect that the command bars in the Flight Director were not of importance at that time, leading to longer average saccade length as the pilot made few of the short saccades found on the Flight Director during segments 2, 3, and 4.

Analysis of ILS approach error

In order to examine the effect of simulated motion on the maintenance of accurate aircraft position during approach, Root Mean Square (RMS) error was calculated for the simulator computed Glideslope Error and Localizer Error.

Glideslope Error. The glideslope error, calculated as RMS error, was measured over each flight segment for each replication. No significant motion effect was found. A significant segment effect ($F(3,12) = 257.005$, $p<.01$; Appendix A-4) can be attributed to segment 1, as shown by the mean values in Table 4. In segment 1 the flight path was straight and level prior to glideslope intercept, leading to the normal state of high glideslope error.

Localizer Error. Examination of RMS error on the localizer revealed no significant effects due to any main or interactive conditions (ANOVA in Appendix A-5). Unlike glideslope error, localizer error remained within typical limits during flight segment 1. Means and standard deviations for localizer error are presented in Table 5.

Analysis of control activity

The method of measurement of control activity selected was based on an algorithm developed by Harris (Note 1). Control activity was represented as the product of the following three factors: (1) the sum of the absolute value of control position change, (2) the standard deviation of the control position, and (3) scaling factors to insure additivity of control activity "work" measures for different controls. Essentially, the measure closely approximates a measure of control activity "work", providing a description of control activity per unit time.

Elevator control activity. Using the method of measurement of control activity described above, an ANOVA revealed a significant motion effect ($F(1,4) = 7.774$, $p<.05$; Appendix A-6), with greater control activity noted for the no-motion condition. Examination of the means, shown in Table 6, across the motion dimension shows that the direction of this difference holds for each pilot and for each flight segment. In addition, a significant flight segment effect ($F(3,12) = 25.587$, $p<.01$) was noted. The mean values for the flight segments indicate a generally increasing amount of control activity in proximity to the runway threshold (note the differences between segment 1 and segment 4).

Wheel control activity. No significant motion effect was noted for wheel control activity. There was a significant segment effect ($F(3,12) = 5.011$, $p<.05$; Appendix

A-7), and like that of elevator control activity, the means indicate a generally increasing level of wheel control activity in proximity to the runway. Means and standard deviations for wheel control activity are presented in Table 7. A significant replication effect ($F(3,12) = 4.000$, $p<.05$) was also found. The means over the four replications indicate a slight decrease in wheel control activity over replications, with the greatest amount of control activity found for replication 1. Practice, learning, or fatigue effects are plausible explanations of this finding. It should be noted, however, that a replication effect was not found for elevator or throttle control activity measures.

Throttle control activity. Throttle control activity revealed no significant effects due to any main or interactive conditions (ANOVA in Appendix A-8). Mean values for throttle activity are shown in Table 8.

Analyses by instrument

The analyses to follow examine several eye-scan parameters for each flight instrument having more than 1 percent of the total panel fixation time. Summaries of the total percentage of fixation time on each instrument and the probabilities of transitions between instruments appear in Fiqure 4. The skew of the fixation time distributions for each of these instruments may be found in Appendix B.

For the following analyses, segment 1 was omitted as that segment was prior to glideslope intercept and the

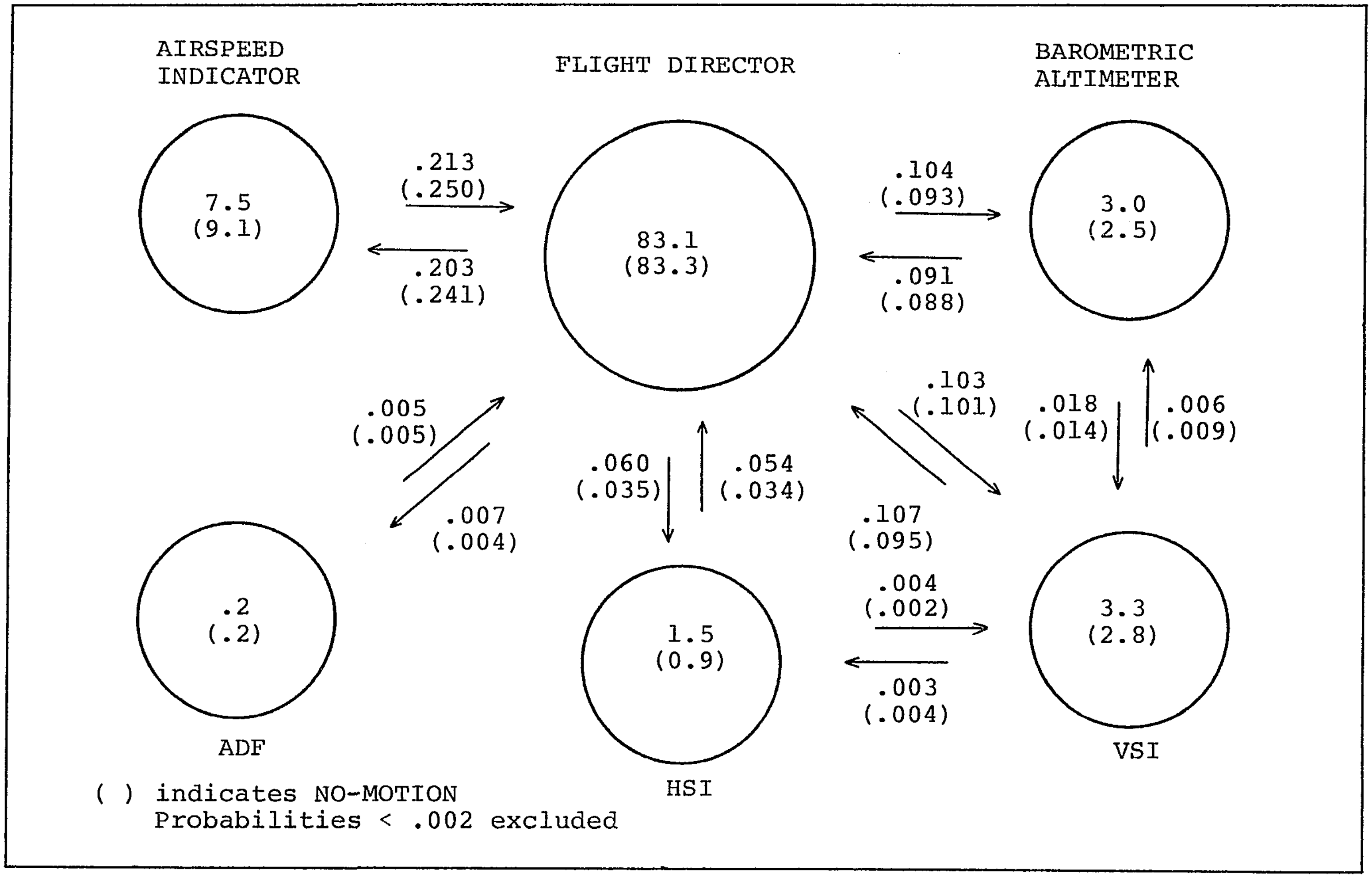


Figure 4. Primary Flight Instruments: Percentage of fixations and fixation transition probabilities for simulator motion and no-motion conditions

piloting task was different during that portion of the approach.

Flight Director. The Flight Director occupied 83.1 percent of the total fixation time in the motion condition and 83.3 percent of the total fixation time for the no-motion condition. Means and standard deviations for Flight Director fixation time are presented in Table 9. A significant ($F(1,4) = 7.354$, $p < .053$; Appendix A-9) difference was noted due to the motion effect with a mean fixation time of 345 msec for the motion condition and 445 msec for no-motion. Despite the large difference in mean fixation time, the total time spent viewing the instrument varied little between the motion and no-motion conditions. Averaged across pilots and replications, the total fixation time for a run (segments 2, 3, and 4 constituting a run) was 70.45 seconds for the motion condition and 70.38 seconds for the no-motion condition. Therefore, the longer fixation times noted for the no-motion condition are not the result of an overall increase in viewing time, but represent fewer, and longer fixations, relative to those found with the motion base on. Likewise, the motion condition can be characterized as having a greater number of fixations, though of shorter mean duration than found in the no-motion condition.

As shown in Table 9, the direction of the mean differences between motion and no-motion hold for each pilot and for each flight segment.

A cumulative plot of total time spent on the Flight Director versus fixation time appears in Figure 5. The cumulative plot illustrates that while total fixation time on the instrument remained practically the same for the motion and no-motion conditions, the division of this time into fixations of different length varied across the motion conditions. The vertical lines drawn from the motion and no-motion curves correspond to median fixation time. Figure 5 is based on the mean fixation times for all five pilots, and for four replications for each pilot.

Airspeed Indicator. The Airspeed Indicator occupied 7.5 percent of the total fixation time in the motion condition and 9.1 percent for the no-motion condition. An ANOVA revealed no significant difference in mean fixation time on this instrument by motion, segment, or other effects (Appendix A-10). Mean fixation times for the airspeed indicator are presented in Table 10.

Vertical Speed Indicator (VSI). The VSI occupied 3.3 percent of the total fixation time in the motion condition and 2.8 percent for the no-motion condition. The ANOVA showed no significant motion effect. A significant segment effect ($F(2,8) = 8.549$, $p<.05$; Appendix A-11) reflects a difference in mean fixation time between segments 2 and 3, with segment 2 having a shorter mean fixation time, as shown in Table 11.

Barometric Altimeter. The Barometric Altimeter occupied 3.0 percent of the fixation time for the motion condition and

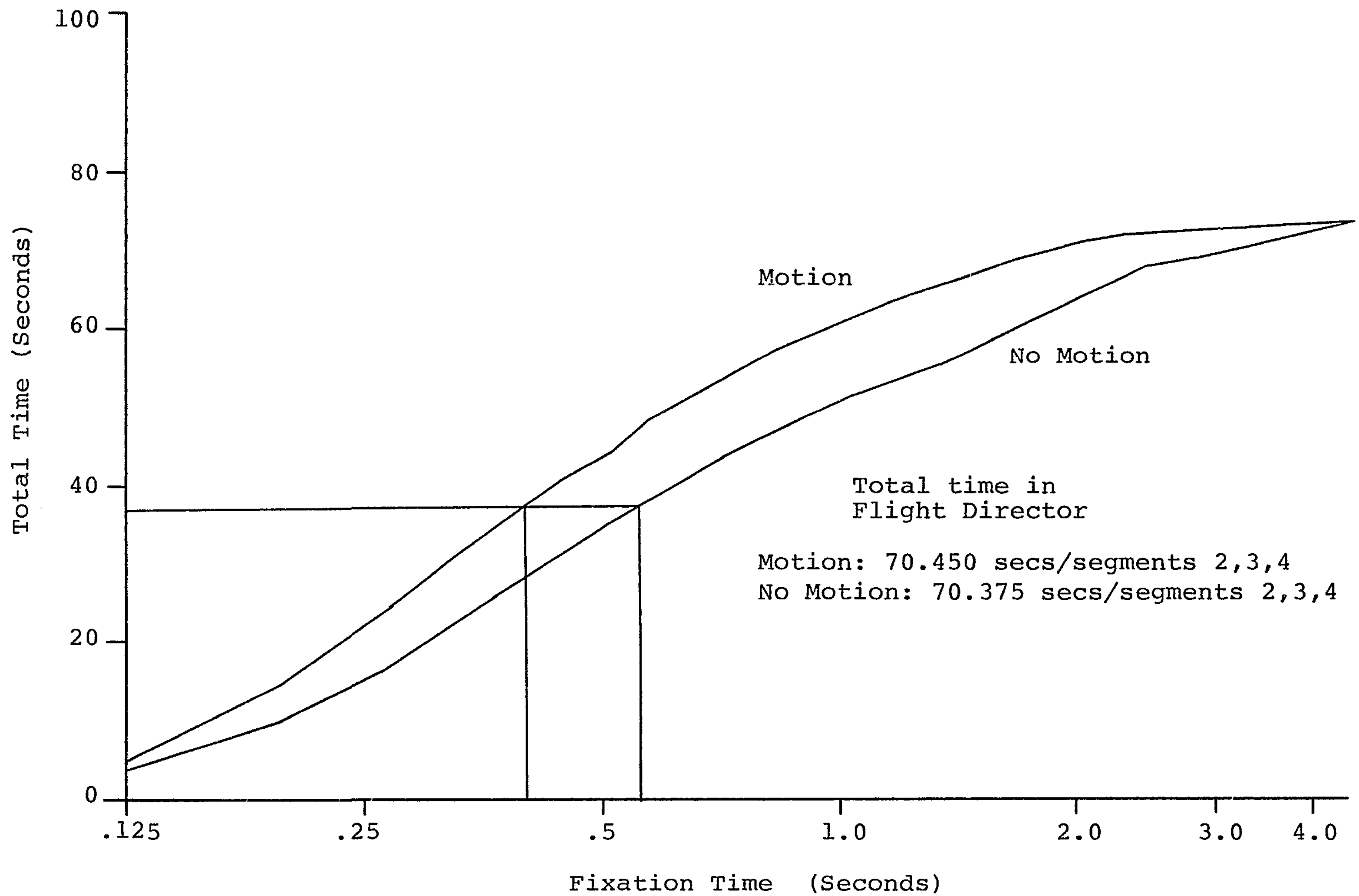


Figure 5. Cumulative plot of Total Time on Flight Director versus Fixation Time

2.5 percent of the fixation time for the no-motion condition. The ANOVA indicated no significant differences in fixation time due to any main or interaction effects (Appendix A-12). Means and standard deviations are presented in Table 12.

While the number of fixations on this instrument are small relative to the Flight Director, the skew of the fixation time distribution for the Barometric Altimeter (Appendix B) is negative for both motion and no-motion conditions (-0.347 and -0.109, respectively). This finding suggests a distribution with a larger number of longer fixations than shorter ones, unlike those found for most of the other instruments. This may be a function of the type of altimeter employed.

Horizontal Situation Indicator (HSI). Fixations on the HSI occupied 1.5 percent of the total fixation time for the motion condition and 0.9 percent of the fixation time for the no-motion condition. The ANOVA revealed no significant differences in fixation time due to any main or interaction effects (Appendix A-13). Table 13 presents the means for fixation time on the HSI.

When reading the table of means for the HSI (Table 13), bear in mind that the number of fixations per segment was quite small, resulting in some cases in large but non-significant differences between means.

Fixation-point-measurement method checks

In order to rule out the possibility that motion effects on eye-scan behavior were due to artifacts of the measurement process, several method checks were performed. These method checks are presented below.

Percentage of oculometer track time. The first method check consisted of an examination of the percentage of oculometer track time. If present, differences in track time due to motion would suggest problems in: (1) maintenance of stability of the head position of the subject, (2) problems in the oculometer tracking system hardware induced by motion, or (3) a combination of the previous two.

Consistent with the treatment of data in the preceding analyses, percentage of oculometer track time was calculated for each segment of each replication for each pilot. The means and standard deviations are presented in Table 14. An ANOVA revealed no significant difference in percentage of oculometer track time due to motion (Appendix A-14). A significant motion by-replication interaction was noted, but examination of these means indicated no systematic bias favoring motion or no-motion (see Table 14).

Ratio of transition times. A second method check involved examination of the time spent in transition between fixations. As noted previously, a fixation was defined as a series of lookpoints having X and Y coordinates that did not exceed a selected boundary limit (a radius) from the preceding centroid of X and Y coordinates. Transitions consisted of those cases in which a single or series of coordinates were found that were not part of the preceding fixation or forming a new fixation. Thus, there is an interaction between fixation boundary radius and percentage of transition time. Selection of an overly large boundary radius would minimize transition counts, as many transitions would be counted as part of a fixation. Selection of too small a boundary radius would result in an increase in transition counts as even small variations in lookpoint would exceed the radius (as would be the case if tracking system error exceeded the fixation radius).

To insure that any motion effect was not a by-product of an overly restrictive algorithm, transition times for each element of the segment-by-replication matrix were calculated with two radii. The first of these was a radius of 1.27 cm (a fixation area of 5.07 cm sq), the radius employed in the analyses in the preceding sections. The second radius was 1.91 cm (a fixation area of 11.46 cm sq), an approximate doubling of fixation area.

For the 1.27 cm radius, the percentage of time spent in transition was 16.7 percent for the motion condition and 13.9 percent for the no-motion condition. The greater time spent in transition in the motion condition was expected in light of the increased number of fixations found in that condition. The difference in percentage of transition time is significant for the motion effect ($F(1,4) = 30.380$, $p<.05$).

Using the larger radius (1.91 cm), percentage of transition time was approximately halved, falling to 8.3 percent for the motion condition and 6.7 percent for the no-motion condition. Again, the difference found would be expected and represents a significant motion effect ($F(1,4) = 20.789$, $p<.05$).

Of greatest interest in establishing confidence in the fixation measurement technique is that the ratio of transition times for the two radii was the same for the motion and no- motion conditions. As illustrated in Table 15, the ratio of percentage of transition time for the motion conditions differ little. An ANOVA performed on these data revealed no significant differences due to any main or interactive effects (Appendix A-15). In addition, the correlation between percentage of transition time for the two radii was $r = .938$ ($p<.001$, $N = 120$).

Equality of the transition percentage ratios for the two radii indicates that motion effects observed with the 1.27 cm radius are not the result of an overly restrictive algorithm.

Fixation rate based on an enlarged radius. A third method check involved computation of fixation rate using the enlarged (1.91 cm) radius. The means and standard deviations for fixation rate calculated using this radius are presented in Table 16. These values may be compared with those presented in Table 2, where the 1.27 cm radius was employed. As expected the ANOVA revealed a significant motion effect ($F(1,4) = 14.280$, $p<.05$; Appendix A-16), with significantly faster fixation rates for the motion condition with respect to the no-motion condition.

The preceding method checks make it apparent that any eye-scan motion effects observed are not likely an artifact of the measurement system or algorithm employed here.

## Summary: Experiment 1

These analyses suggest several differences that occurred during simulated ILS approaches with and without simulator motion:

1. The mean fixation time for the no-motion condition was significantly longer than for the motion condition. Likewise, the related measure of fixation rate showed a significantly higher fixation rate for the motion condition with respect to the no-motion condition. A check of fixations across the primary flight instruments revealed that the increased fixation time for the no-motion condition was found only for the Flight Director, where approximately 83 percent of the total fixation time was spent. Despite the difference in mean fixation time, the total time spent viewing the instrument did not vary between motion and no-motion conditions. Therefore, the longer fixation times noted for the no-motion condition are not the result of increased viewing time, but represent fewer, and longer fixations, relative to those found with the motion base on. The motion condition was characterized by a greater number of

fixations, though of shorter mean duration than found in the no-motion condition.

2. Method checks of the fixation-point-measurement technique were performed and indicate that the differences found in eye-scan behavior were not artifacts of the measurement system or algorithm employed.

3. Measures of control activity revealed a significant motion effect for the elevator control (stick) with greater control activity found for the no-motion condition. No significant differences were noted for wheel and throttle control activity across the motion conditions.

4. Despite the differences noted above, measures of ILS approach error (Glideslope RMS error; Localizer RMS error) showed no difference between motion conditions. Likewise, a subsequent test of the voltage levels driving the Pitch and Roll Command Bars showed no motion effect as reflected in Command Bar RMS error.

Table 1

Fixation Rate (All Tracked Instruments):
Table of Means and Standard Deviations
(Milliseconds)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 315 | (92.3) | 393 | (144.6) |
| Pilot 1 | 266 | (36.7) | 346 | (71.8) |
| 2 | 364 | (58.8) | 455 | (94.6) |
| 3 | 249 | (30.0) | 271 | (33.8) |
| 4 | 277 | (39.2) | 307 | (64.5) |
| 5 | 419 | (121.7) | 585 | (146.3) |
| Segment 1 | 300 | (56.7) | 375 | (96.4) |
| 2 | 324 | (101.3) | 404 | (180.8) |
| 3 | 308 | (74.5) | 386 | (142.0) |
| 4 | 329 | (126.0) | 407 | (155.2) |

Table 2

Fixation Rate (All Tracked Instruments):
Table of Means and Standard Deviations
(Fixations/Second)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 2.678 | (.463) | 2.323 | (.573) |
| Pilot 1 | 2.997 | (.285) | 2.485 | (.405) |
| 2 | 2.306 | (.313) | 1.927 | (.317) |
| 3 | 2.997 | (.249) | 2.885 | (.288) |
| 4 | 2.839 | (.239) | 2.686 | (.314) |
| 5 | 2.249 | (.488) | 1.635 | (.323) |
| Segment 1 | 2.611 | (.296) | 2.224 | (.441) |
| 2 | 2.655 | (.536) | 2.358 | (.666) |
| 3 | 2.709 | (.404) | 2.385 | (.578) |
| 4 | 2.735 | (.585) | 2.327 | (.613) |

Table 3

Saccade Length (All Tracked Instruments):
Table of Means and Standard Deviations
(Inches: X 2.54 = CM)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 1.920 | (.474) | 1.935 | (.472) |
| Pilot 1 | 1.847 | (.223) | 2.041 | (.395) |
| 2 | 1.973 | (.488) | 2.000 | (.450) |
| 3 | 2.182 | (.247) | 2.104 | (.223) |
| 4 | 2.086 | (.584) | 1.972 | (.512) |
| 5 | 1.512 | (.450) | 1.559 | (.550) |
| Segment 1 | 2.331 | (.459) | 2.466 | (.291) |
| 2 | 1.805 | (.373) | 1.776 | (.394) |
| 3 | 1.832 | (.303) | 1.816 | (.303) |
| 4 | 1.713 | (.496) | 1.683 | (.434) |

Table 4

Glideslope Error
Table of Means and Standard Deviations
(RMS Error: Degrees)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | .92 | (.80) | .97 | (.78) |
| Pilot 1 | 1.14 | (.79) | 1.05 | (.72) |
| 2 | .88 | (.82) | 1.03 | (.78) |
| 3 | .92 | (.79) | 1.08 | (.78) |
| 4 | .81 | (.84) | .83 | (.83) |
| 5 | .84 | (.84) | .86 | (.84) |
| Segment 1 | 2.21 | (.03) | 2.19 | (.05) |
| 2 | .35 | (.10) | .34 | (.10) |
| 3 | .34 | (.21) | .37 | (.17) |
| 4 | .78 | (.41) | .98 | (.34) |

Table 5

Localizer Error:
Table of Means and Standard Deviations
(RMS Error: Degrees)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | .111 | (.066) | .116 | (.071) |
| Pilot 1 | .076 | (.054) | .121 | (.097) |
| 2 | .076 | (.048) | .065 | (.018) |
| 3 | .133 | (.050) | .126 | (.056) |
| 4 | .137 | (.048) | .151 | (.052) |
| 5 | .133 | (.092) | .118 | (.081) |
| Segment 1 | .119 | (.065) | .134 | (.090) |
| 2 | .085 | (.058) | .099 | (.074) |
| 3 | .119 | (.081) | .110 | (.059) |
| 4 | .121 | (.056) | .121 | (.054) |

Table 6

Elevator Control Inputs
Table of Means and Standard Deviations

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 1954 | (1544) | 2389 | (1625) |
| Pilot 1 | 2327 | (1053) | 2803 | (1547) |
| 2 | 1506 | (1704) | 2515 | (967) |
| 3 | 3565 | (1710) | 3796 | (2125) |
| 4 | 1415 | (827) | 1772 | (1011) |
| 5 | 954 | (652) | 1060 | (666) |
| Segment 1 | 826 | (760) | 1087 | (703) |
| 2 | 1992 | (951) | 2544 | (1411) |
| 3 | 1966 | (1366) | 2274 | (1561) |
| 4 | 3031 | (2000) | 3651 | (1601) |

Table 7

Wheel Control Inputs
Table of Means and Standard Deviations

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 34746 | (22982) | 28994 | (23138) |
| Pilot 1 | 37890 | (19614) | 31099 | (21606) |
| 2 | 28755 | (23794) | 25621 | (14899) |
| 3 | 33592 | (16213) | 14463 | (10461) |
| 4 | 34883 | (23143) | 43880 | (27855) |
| 5 | 38609 | (31083) | 29907 | (27681) |
| Segment 1 | 21048 | (9227) | 18192 | (9904) |
| 2 | 27370 | (19339) | 25037 | (26390) |
| 3 | 38240 | (21965) | 32219 | (18197) |
| 4 | 52325 | (25720) | 40528 | (28463) |

Table 8

Throttle Control Inputs
Table of Means and Standard Deviations

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 7398 | (8586) | 7779 | (9605) |
| Pilot 1 | 7668 | (7334) | 7027 | (9269) |
| 2 | 8456 | (6438) | 8260 | (6270) |
| 3 | 15831 | (12256) | 17350 | (13661) |
| 4 | 2924 | (3035) | 3074 | (3211) |
| 5 | 2112 | (2306) | 3182 | (4361) |
| Segment 1 | 5222 | (5048) | 4506 | (4098) |
| 2 | 7710 | (6456) | 11669 | (13206) |
| 3 | 8398 | (8332) | 9220 | (7756) |
| 4 | 8264 | (12767) | 5719 | (9919) |

Table 9

Fixation Time (Flight Director):
Table of Means and Standard Deviations
(Milliseconds)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 345 | (116.5) | 445 | (184.2) |
| Pilot 1 | 264 | (31.2) | 339 | (33.2) |
| 2 | 424 | (77.8) | 571 | (124.7) |
| 3 | 262 | (34.1) | 285 | (46.6) |
| 4 | 299 | (45.1) | 335 | (68.2) |
| 5 | 475 | (142.9) | 694 | (142.2) |
| Segment 2 | 350 | (119.0) | 446 | (202.7) |
| 3 | 330 | (92.3) | 441 | (186.0) |
| 4 | 354 | (138.3) | 447 | (172.2) |

Table 10

Fixation Time (Airspeed):
Table of Means and Standard Deviations
(Milliseconds)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 236 | (81.3) | 257 | (90.6) |
| Pilot 1 | 226 | (83.5) | 282 | (71.7) |
| 2 | 271 | (99.2) | 300 | (120.8) |
| 3 | 251 | (35.3) | 256 | (33.8) |
| 4 | 210 | (36.9) | 242 | (70.4) |
| 5 | 220 | (115.3) | 205 | (110.9) |
| Segment 2 | 260 | (64.3) | 260 | (79.0) |
| 3 | 246 | (71.8) | 262 | (61.6) |
| 4 | 202 | (96.6) | 248 | (123.8) |

Table 11

Fixation Time (VSI):
Table of Means and Standard Deviations
(Milliseconds)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 171 | (115.9) | 139 | (122.7) |
| Pilot 1 | 209 | (32.3) | 218 | (35.4) |
| 2 | 138 | (146.9) | 93 | (125.7) |
| 3 | 203 | (32.0) | 213 | (30.0) |
| 4 | 95 | (129.9) | 61 | (117.8) |
| 5 | 209 | (141.1) | 109 | (161.8) |
| Segment 2 | 128 | (122.7) | 94 | (99.3) |
| 3 | 222 | (73.3) | 172 | (128.4) |
| 4 | 162 | (128.5) | 150 | (130.4) |

Table 12

Fixation Time (Barometric Altimeter):
Table of Means and Standard Deviations
(Milliseconds)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 182 | (100.7) | 158 | (109.2) |
| Pilot 1 | 220 | (95.8) | 217 | (79.5) |
| 2 | 136 | (95.4) | 118 | (99.5) |
| 3 | 190 | (33.7) | 198 | (27.3) |
| 4 | 210 | (123.2) | 145 | (110.1) |
| 5 | 157 | (119.9) | 109 | (157.9) |
| Segment 2 | 170 | (93.2) | 138 | (97.2) |
| 3 | 213 | (104.3) | 173 | (123.4) |
| 4 | 164 | (102.0) | 161 | (108.2) |

Table 13

Fixation Time (HSI):
Table of Means and Standard Deviations
(Milliseconds)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 117 | (123.6) | 73 | (92.7) |
| Pilot 1 | 78 | (92.5) | 45 | (68.5) |
| 2 | 189 | (174.7) | 44 | (81.4) |
| 3 | 135 | (116.0) | 86 | (99.4) |
| 4 | 181 | (48.3) | 188 | (50.4) |
| 5 | 0 | (0.0) | 0 | (0.0) |
| Segment 2 | 112 | (116.9) | 65 | (93.4) |
| 3 | 119 | (105.9) | 74 | (100.3) |
| 4 | 119 | (150.0) | 78 | (88.3) |

Table 14

Percentage of Oculometer Track Time:
Table of Means and Standard Deviations

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 91.0 | (8.2) | 92.3 | (6.8) |
| Pilot 1 | 83.1 | (8.1) | 91.0 | (4.3) |
| 2 | 93.1 | (4.3) | 91.2 | (9.0) |
| 3 | 89.8 | (10.9) | 94.5 | (4.6) |
| 4 | 91.4 | (4.5) | 90.0 | (4.4) |
| 5 | 97.8 | (2.0) | 94.8 | (9.2) |
| Segment 1 | 93.0 | (4.9) | 93.3 | (4.8) |
| 2 | 91.8 | (7.7) | 94.1 | (4.5) |
| 3 | 89.6 | (8.0) | 91.4 | (8.2) |
| 4 | 89.7 | (11.0) | 90.4 | (8.7) |

Table 15

Ratio of Transition Times
For Two Selected Radii
Table of Means and Standard Deviations

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 2.079 | (.358) | 2.073 | (.443) |
| Pilot 1 | 1.997 | (.251) | 2.166 | (.329) |
| 2 | 2.136 | (.489) | 2.261 | (.486) |
| 3 | 2.067 | (.183) | 2.208 | (.217) |
| 4 | 2.099 | (.418) | 1.990 | (.277) |
| 5 | 2.098 | (.408) | 1.739 | (.622) |
| Segment 2 | 2.004 | (.331) | 2.130 | (.465) |
| 3 | 2.096 | (.304) | 2.201 | (.401) |
| 4 | 2.139 | (.432) | 1.888 | (.418) |

Table 16

Fixation Rate (All Tracked Instruments)
Based on Enlarged Algorithm Radius (1.91 cm):
Table of Means and Standard Deviations
(Fixations/Second)

| | MOTION | | NO MOTION | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 2.020 | (.547) | 1.760 | (.625) |
| Pilot 1 | 2.317 | (.282) | 2.070 | (.148) |
| 2 | 1.722 | (.284) | 1.479 | (.372) |
| 3 | 2.515 | (.409) | 2.463 | (.296) |
| 4 | 2.162 | (.317) | 1.890 | (.400) |
| 5 | 1.384 | (.504) | .899 | (.359) |
| Segment 2 | 2.034 | (.603) | 1.858 | (.647) |
| 3 | 2.102 | (.488) | 1.835 | (.597) |
| 4 | 1.924 | (.558) | 1.588 | (.624) |

## Experiment 2:

## Aircraft versus fixed-base simulation

The second experiment permitted exploration of differences between motion and no-motion through oculometer data obtained in flight and in fixed-base simulation. The study also extended the use of the data analysis techniques employed in the initial experiment. The "ideal" study would include data from subjects tested in (a) flight, (b) motion base simulation, and (c) fixed base simulation. However, the simulator used for the present study did not incorporate a motion base, precluding such analyses.

### Purpose of the experiment

The primary emphasis of Experiment 2 was to evaluate the effect of motion in flight and simulation settings, utilizing a unique data set in which the NASA Langley Research Center oculometer was mounted in the Transport Systems Research Vehicle (TSRV) for eye movement recording in-flight, and in the TSRV fixed-base simulator. The data set included oculometer monitored Microwave Landing System (MLS) curved descending approaches both in-flight and in the simulator.

Methodology and Design

Subjects. The set of data evaluated for the present study were collected from three highly experienced NASA pilots. Each pilot made 20 MLS approaches in the aircraft and 20 simulated MLS approaches in the TSRV fixed-base simulator.

Design and Stimuli. The NASA TSRV is a modified Boeing 737, incorporating a second functional cockpit with advanced and functional displays. The overall design of the study divided the 20 flight or simulation runs into factorial combinations of the following experimental conditions: (a) five levels of traffic (other aircraft in the vicinity) were displayed on the Cockpit Display of Traffic Information (CDTI) which is one of the functions of the Electronic Horizontal Situation Indicator (EHSI). Traffic was only present in segment 2 of the 4 segment MLS approach. (b) two levels of control mode: Velocity Control Wheel Steering (VCWS) approximating the manual condition in Experiment 1, and Automatic, which included auto-throttle. The automatic control mode only occurred during segments 1 and 2 of the curved approach. Segments 3 and 4 did not employ the above variables (no traffic and VCWS only), and enabled a study of these segments with 20 replications for each pilot in flight and 20 replications for each pilot on the simulator. In addition, segments 3 and 4 were comparable in time length to the final three segments of the simulated ILS approaches examined in Experiment 1. Segments were differentiated on the basis of altitude (segment 1 through 3500 ft; segment 2, 1000 ft; segment 3, 500 ft; segment 4, 70 ft).

Instrumentation of the advanced cockpit included the Electronic Attitude Display Indicator (EADI), a CRT display of attitude information, and below it a second CRT display, the Electronic Horizontal Situation Indicator (EHSI) which was the map and traffic display. The EADI was located in the position of the Flight Director in the conventional 737 cockpit. The EADI display measured 17.1 cm wide by 13.3 cm high, somewhat larger than the conventional Flight Director. The EHSI was located below the EADI and measured 13.3 cm wide by 17.1 cm high. The majority of instrument fixations were on these two displays. Conventional electromechanical displays were located adjacent to the CRT displays.

The data sampling rate was different for flight and simulation due to different data acquisition computers used in each setting. For flight the data sampling rate was 40 samples per second, and for the simulator, 32 samples per second. The flight data were adjusted to 32 samples per second prior to statistical analysis and fixation time plotting. As noted previously, a fixation was defined mathematically as a series of lookpoints having X and Y coordinates that did not exceed a selected boundary limit, or radius, from the preceding centroid of X and Y coordinates. The radius used in Experiment 2 was 1.27 cm, the same radius that was employed in Experiment 1. Control activity data were not available for Experiment 2.

Global measures of motion effects

As in the preceding study, the following analyses were conducted across all tracked instruments and are therefore referred to as "global". Analyses by primary instruments are presented later.

Fixation time (all tracked instruments). Using the method of calculating fixation points that was described previously, fixation time was calculated for any eye fixation point within the boundaries of the nine tracked instruments across all four flight segments. A significant difference was noted between flight and simulation ($F(1,2) = 35.160$, $p<.05$; Appendix C-1); shorter mean fixation times occurred in flight.

As shown in Table 17, the mean fixation time for flight was 319 msec, and for the simulator 450 msec. The direction of the difference between flight and simulation is maintained for each of the three pilots and for each of the approach segments. Large variations in fixation time are noted between pilots.

Fixation rate (all tracked instruments). The related measure of fixation rate also indicated a significant difference between flight and simulation ($F(1,2)= 19.514$, $p<.05$; Appendix C-2), with a greater number of fixations per second occurring in flight. The finding of a greater number of fixations per second for the flight setting is present for each of the three pilots and for each of the approach segments. Means and standard deviations for fixation rate are presented in Table 18.

## Analyses by instrument

Electronic Attitude Display Indicator (EADI). As shown in Table 19, mean fixation time on the EADI (Segments 3 and 4), while not significantly different between flight and simulation ($F(1,2) = 14.03$, $p > .05$; Appendix C-3), does reflect the trend of shorter fixation times in flight. The cumulative plot of total time on the EADI versus how that time was accumulated are presented for each of the three pilots in the experiment in Figures 6, 7, and 8. The cumulative plots illustrate the difference between flight and simulator in terms of cumulative fixation frequency.

Large individual differences are noted in the cumulative fixation frequency plots. For example, examination of the cumulative fixation frequency distributions shows that median fixation time (shown by the vertical lines) varied considerably between subjects. Noting this variability between subjects, the non-significant F-ratio for EADI mean fixation time is understandable, despite differences between flight and simulation shown clearly on the fixation frequency plots.

Figures 6, 7, and 8, from the present experiment can be contrasted with Figure 5 from Experiment 1. In each case, the no-motion distribution is characterized by an increased number of longer fixations.

Examination of percentage of track time on the EADI showed no significant difference between flight and simulation ($F(1,2) = .444$, $p > .05$; Appendix C-4) an expected finding if the oculometer was recording properly. As shown in Table 20, the percentage of track time increased in proximity to the runway threshold. This was also reflected in a significant segment effect for EADI track time ($F(3,6) = 39.742$, $p < .01$).

Electronic Horizontal Situation Indicator (EHSI). As would be expected, an increase in EADI track time must represent a decrease in looks elsewhere. Table 21 presents the percentage of track time for the EHSI or Multi-Function Display (MFD). There was not a significant difference between flight and simulation for this instrument ($F(1,2) = 1.993$, $p > .05$; Appendix C-5). The decrease in track percentage by segment for the EHSI was significant ($F(3,6) = 32.153$, $p < .05$), as would be expected, as the flight path information of the EADI becomes of greater importance near the runway threshold.

Analyses of the fixations on the electromechanical displays, located adjacent to the CRT displays, were not conducted due to infrequent fixations on those instruments. It should be noted that much of the information supplied by the electromechanical displays was duplicated in the CRT displays, therefore, infrequent fixations on those instruments would be expected.

Summary: Experiment 2

Experiment 2 permitted an evaluation of motion effects in flight and simulation settings through oculometer monitored MLS curved descending approaches both in-flight and in fixed base simulation. Analyses of the flight and simulation data sets suggest the following:

1. Across all monitored instruments, the mean fixation time for flight was significantly shorter than for the fixed base simulation. This finding is similar and in the same direction as that found in Experiment 1, where the mean fixation time for simulation with motion was significantly shorter than for the corresponding no-motion condition. Analyses in Experiment 2 were primarily focused on the Electronic Attitude Display Indicator (EADI), a CRT display of attitude information. Due to a larger set of experimental conditions involving the Electronic Horizontal Situation Indicator (EHSI) during flight segments 1 and 2, the EADI was examined only for flight segments 3 and 4. Plots of cumulative fixation frequency for each of the three test subjects (Figures 6, 7, and 8) revealed differences between flight and simulation fixation distributions that were similar for each of the test subjects and also similar to the distribution obtained in Experiment 1 (Figure 5).

2. Large individual differences are noted in the cumulative fixation frequency plots. Examination of the cumulative fixation frequency distributions (Figures 6, 7, and 8) shows that median fixation time varied considerably

between test subjects. The variability found lends support to the use of techniques to describe such distributions other than through mean values, especially when small sample sizes must be employed. The benefits of using one such strategy, mathematical curve fitting, applied to such distributions will be explored in a later section.

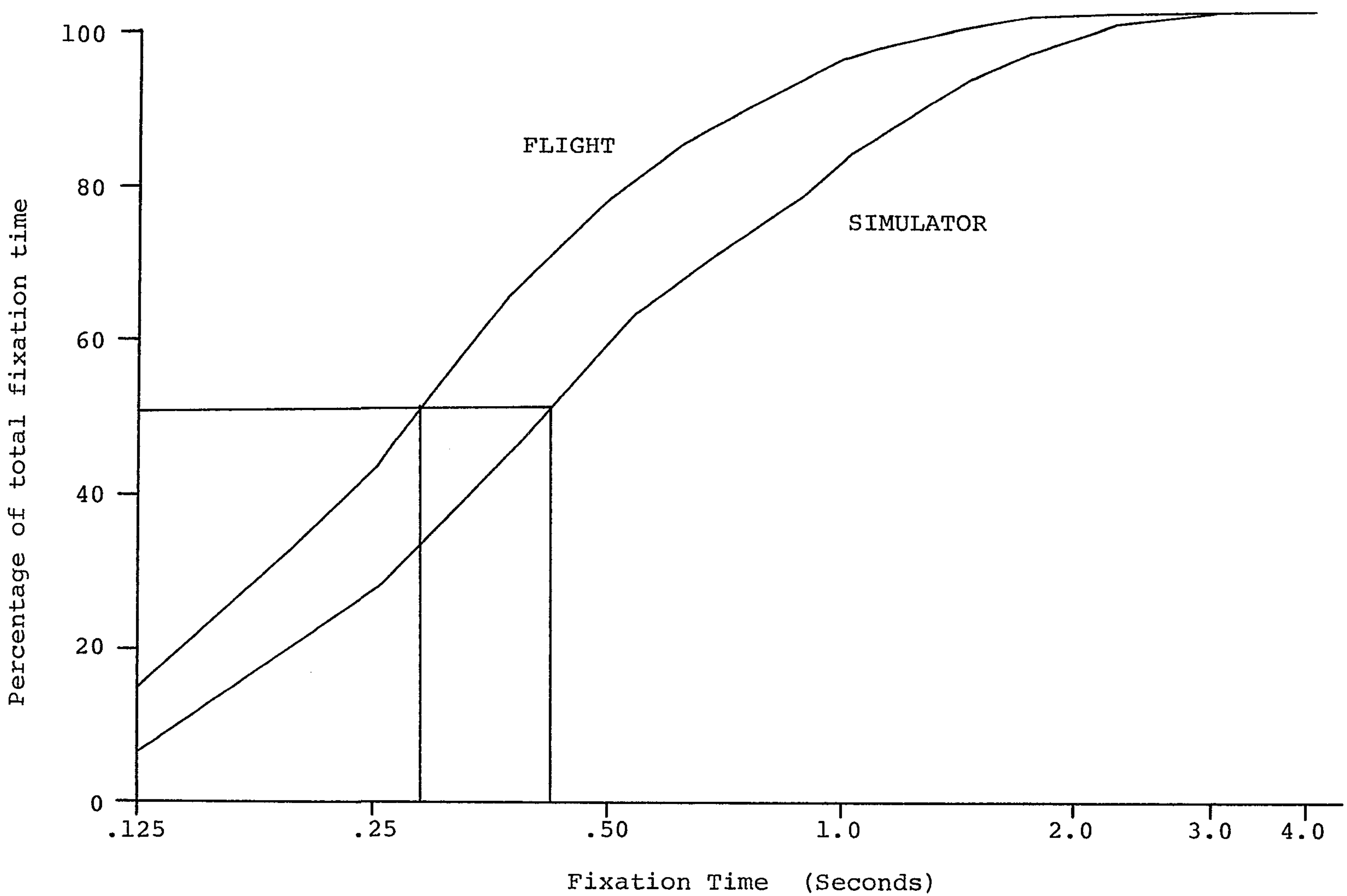


Figure 6. Cumulative plot of fixation time: EADI Segments 3 and 4, Pilot 1

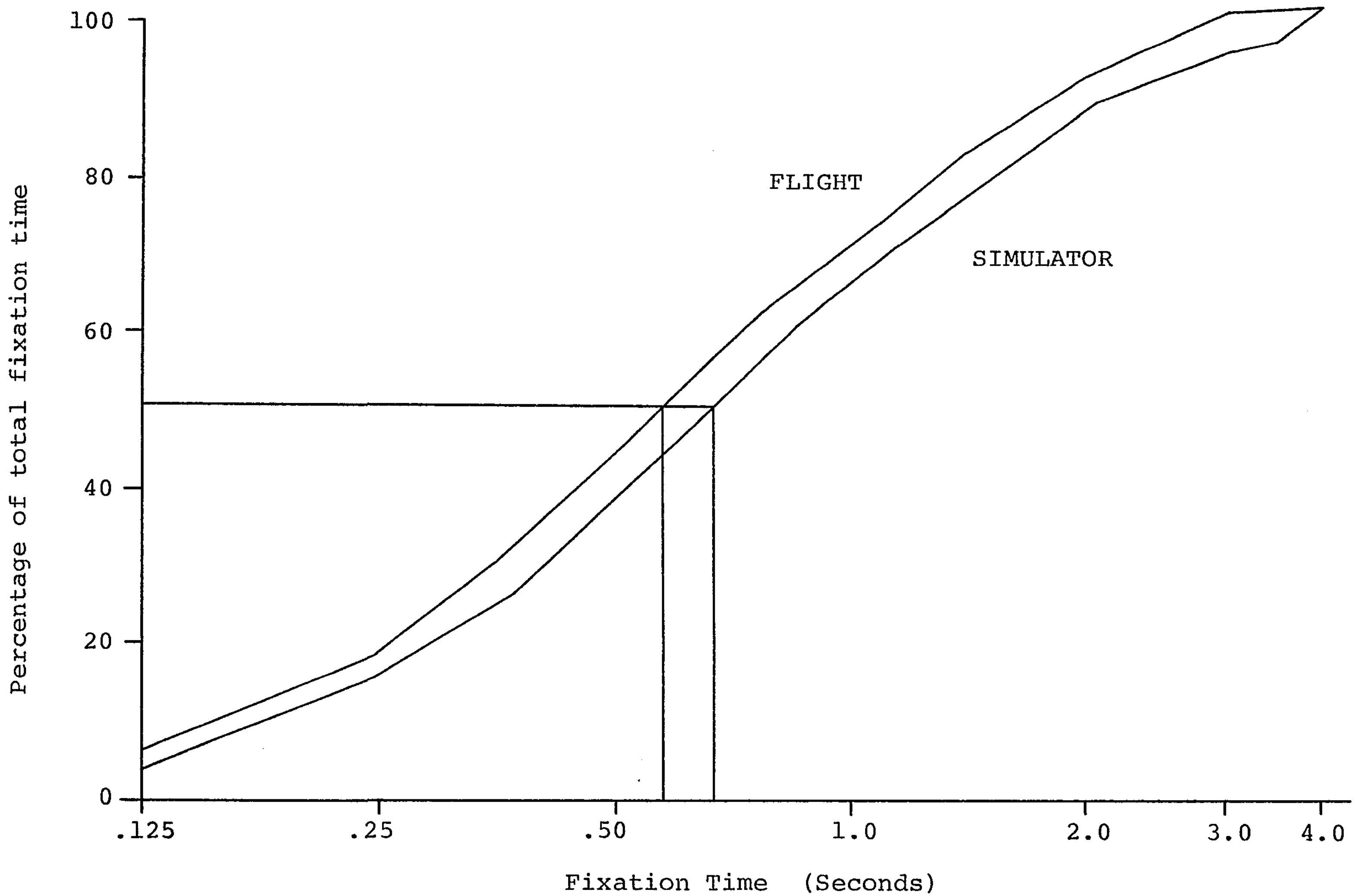


Figure 7. Cumulative plot of fixation time: EADI Segments 3 and 4, Pilot 2

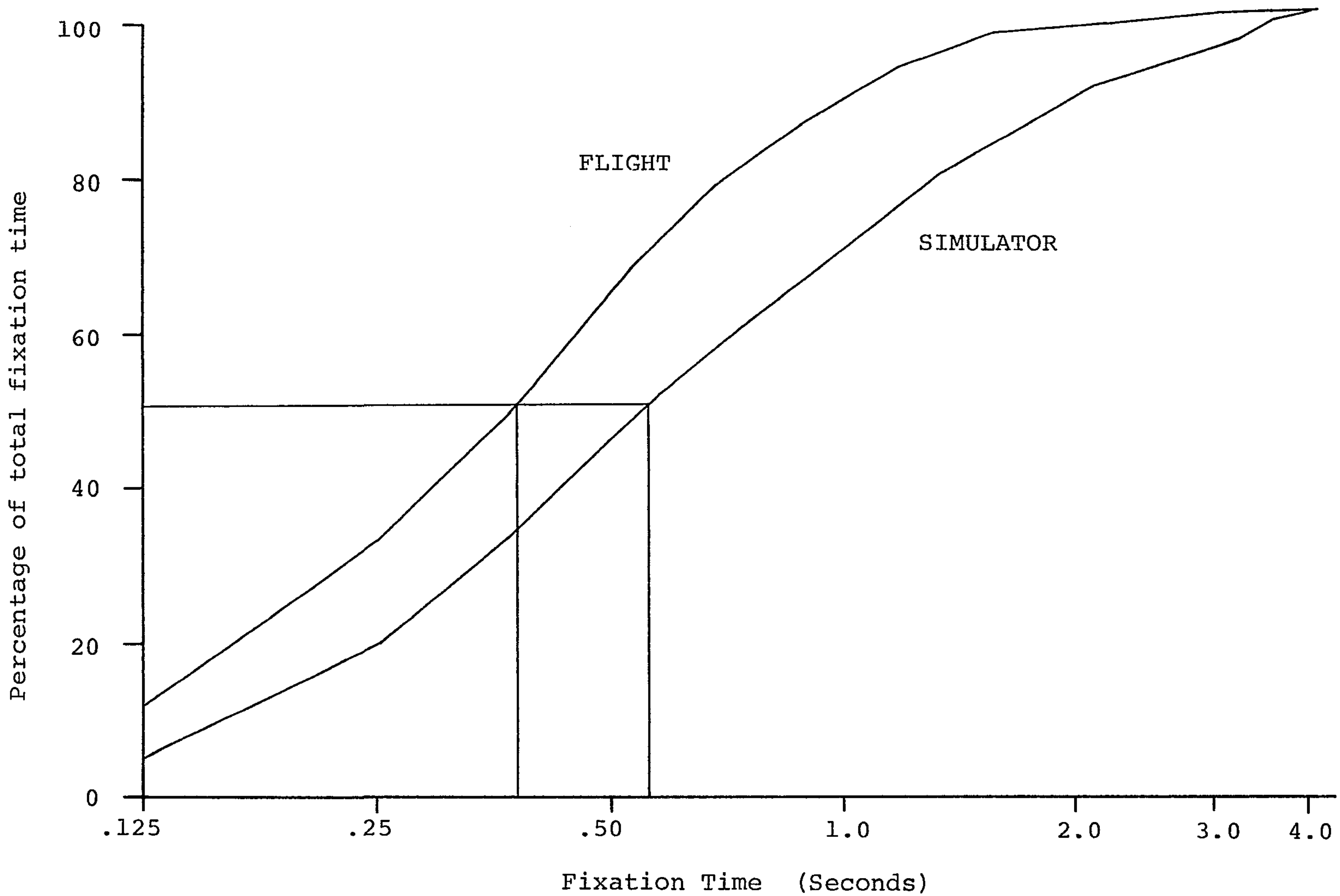


Figure 8. Cumulative plot of fixation time: EADI Segments 3 and 4, Pilot 3

Table 17

Fixation Time (All Tracked Instruments):
Table of Means and Standard Deviations
(Milliseconds)

| | FLIGHT | | SIMULATOR | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 319 | (109.0) | 450 | (120.3) |
| Pilot 1 | 238 | ( 36.4) | 347 | ( 40.9) |
| 2 | 436 | (103.3) | 544 | (127.3) |
| 3 | 284 | ( 45.8) | 458 | ( 78.0) |
| Segment 1 | 333 | (122.6) | 412 | ( 94.1) |
| 2 | 303 | ( 91.2) | 467 | (129.6) |
| 3 | 307 | ( 82.6) | 457 | (147.4) |
| 4 | 334 | (130.9) | 463 | ( 96.4) |

Table 18

Fixation Rate (All Tracked Instruments):
Table of Means and Standard Deviations
(Fixations/Second)

| | FLIGHT | | SIMULATOR | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 3.015 | (.694) | 2.151 | (.456) |
| Pilot 1 | 3.536 | (.429) | 2.606 | (.257) |
| 2 | 2.276 | (.466) | 1.780 | (.340) |
| 3 | 3.233 | (.425) | 2.069 | (.305) |
| Segment 1 | 2.871 | (.702) | 2.279 | (.404) |
| 2 | 3.112 | (.611) | 2.101 | (.485) |
| 3 | 3.125 | (.637) | 2.156 | (.530) |
| 4 | 2.953 | (.795) | 2.070 | (.373) |

Table 19

Fixation Time ( EADI - Segments 3 and 4)
Table of Means and Standard Deviations
(Milliseconds)

| | FLIGHT | | SIMULATOR | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 309 | (113.0) | 395 | (119.8) |
| Pilot 1 | 235 | ( 35.7) | 334 | ( 60.4) |
| 2 | 406 | (133.8) | 448 | (140.9) |
| 3 | 285 | ( 61.6) | 402 | (116.4) |
| Segment 3 | 275 | ( 67.9) | 324 | ( 57.3) |
| 4 | 342 | (137.2) | 465 | (124.8) |

Table 20

Percentage of Track Time on EADI
Table of Means and Standard Deviations

| | FLIGHT | | SIMULATOR | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 55.9 | (25.6) | 51.3 | (25.0) |
| Pilot 1 | 52.7 | (26.8) | 60.2 | (20.9) |
| 2 | 55.5 | (27.7) | 38.9 | (24.6) |
| 3 | 59.6 | (21.8) | 54.7 | (24.5) |
| Segment 1 | 36.7 | (19.9) | 47.6 | (13.6) |
| 2 | 38.4 | (13.7) | 28.1 | (13.3) |
| 3 | 62.4 | (14.8) | 46.1 | (18.4) |
| 4 | 85.9 | (14.3) | 83.3 | (14.2) |

Table 21

Percentage of Track Time on EHSI
Table of Means and Standard Deviations

| | FLIGHT | | SIMULATOR | |
|---|---|---|---|---|
| | Mean | St. Dev. | Mean | St. Dev. |
| All Pilots | 24.3 | (18.7) | 30.5 | (22.9) |
| Pilot 1 | 26.7 | (20.2) | 24.5 | (17.9) |
| 2 | 28.5 | (19.6) | 36.8 | (26.4) |
| 3 | 17.5 | (14.0) | 30.4 | (22.1) |
| Segment 1 | 34.1 | (14.0) | 27.6 | (11.0) |
| 2 | 39.4 | (12.4) | 55.7 | (12.1) |
| 3 | 22.9 | (12.8) | 37.2 | (17.2) |
| 4 | 0.6 | ( 2.1) | 1.7 | ( 3.0) |

## Experiment 3:
## Single-axis part-task motion effects

Both of the preceding experiments showed differences in fixation time and rate between motion and no-motion conditions. In each case, the differences appeared largest on the instrument supplying attitude and flight-path information. These were the Flight Director in Experiment 1 and the EADI in Experiment 2. The present experiment was designed to explore motion effects through a controlled single instrument task with motion in a single dimension (pitch). In addition, the question of whether directional information can be ascertained from motion could be assessed by incorporating three motion conditions. These were (a) no-motion, (b) correct motion, and (c) reverse motion.

### Purpose of the experiment

Experiment 3 was designed to answer three questions:

1. Would fixation time distributions obtained from subjects tested on a controlled single instrument task with motion in a single axis (pitch) resemble those found in the preceding full simulation and simulation-flight experiments?

2. Would direction of motion make any difference to the subject in terms of fixation time, control activity, or

latency of control activity? Three types of motion were presented. These were (a) no-motion, (b) correct motion, and (c) reverse motion. Utilizing correct and reverse motion conditions permits exploring the question of whether motion information provides a "cue" or "clue" as to direction of motion or just that "something happened", leading to visual search (new fixations) to find out what change had taken place. This question remained unanswered by Experiments 1 and 2 as motion was always of the correct or expected direction in those studies.

3. Would application of two-parameter mathematical curve fitting be advantageous in terms of (a) describing fixation time distributions, and (b) significance testing between fixation time distributions, especially when small sample sizes are utilized?

Methodology and Design

Subjects. Ten subjects were employed in the study. Of the 10 subjects, 7 were licensed pilots (6 General Aviation and 1 Test Pilot), and 3 were non-pilots with no flight training. Each of the pilots was required to have a minimum of 100 hours of flight time. The minimum flight time requirement was imposed so that the test subjects would have already developed a set of expectancies concerning the typical motion reaction to their movements of the control column.

Stimuli. The test site was the Visual Motion Simulator (VMS) a six degree-of-freedom motion base simulator located at the NASA Langley Research Center. The visual stimuli presented to the subjects was on a "heads-up" type display which contained vertical and horizontal lines analogous to the command bars found on the electromechanical Flight Director (described in Experiment 1). Upon presentation of a test trial a second horizontal line, or cursor, moved up or down relative to the fixed horizontal line, representing displacement of the "horizon" with simulated aircraft movement. The task for the subject was to move the control column in the appropriate manner to correct the cursor or "horizon" deflection. On trials when motion was present, simultaneous with movement of the cursor or horizon, simulator motion began. The task was similar to monitoring the Glideslope Deviation Command Bar (such as on the Electromechanical Flight Director) during an ILS approach with periodic (15 to 25 seconds apart) gust disturbances. Simulator response characteristics and control forces approximated those found in Boeing 737 type aircraft. The electromechanical displays on the simulator instrument panel were not in operation during the experiment.

Design and Procedure. Upon reporting to the test site, each subject was verbally briefed on the task, and was shown the visual scene. (In accordance with simulator safety requirements and to insure understanding of the task, a series of no-motion practice trials were conducted for the three non-pilot subjects.) After entering the VMS cockpit, fastening the safety harness, and receiving safety instructions from the VMS staff, oculometer calibration began. Upon completion of oculometer calibration, a set of 45 trials was begun. Data were recorded for a total of 45 trials per subject, these consisting of a randomized presentation of the three motion conditions (no-motion; correct motion; reverse motion) such that there were a total of 15 replications of each condition. Each trial averaged 20 seconds in length. Test sessions averaged 45 minutes in length for each subject. The data sampling rate for Experiment 3 was 30 samples per second for eye position, and also 30 samples per second for control column position.

Although each trial averaged 20 seconds in length (range: 15 to 25 seconds), subjects generally completed the task and motion was concluded (slow washout) by the 8-second point. Therefore, analyses of eye fixation point and control column position were conducted over the 8-second interval. The remaining time (intertrial interval) after the 8-second point was utilized to reset the position of the motion base and control column in preparation for the next trial. To the subject this interval was analogous to calm air between periodic gust disturbances.

Analyses were conducted on four dependent measures: (a) fixation time, (b) new fixation latency, (c) initial control movement latency, and (d) three measures of control activity.

In addition, analyses were conducted on the fixation time distributions.

## Analyses of motion effects

Fixation time. Fixation time was calculated using the method described previously, with one exception. Due to considerations of execution speed of the lookpoint data collection computer program, the boundary limit for defining a fixation was changed from a "circle" to a "square" of comparable area. Thus, a fixation was defined mathematically as a series of lookpoints having X and Y coordinates that did not exceed the selected boundary limit (fall outside of the square), based on the preceding centroid of X and Y coordinates.

Analysis of variance of mean fixation time for the 7 pilots showed a significant difference between experimental conditions ($F(2,12) = 12.294$, $p<.01$; Appendix D-1), with the no-motion condition having significantly longer fixation times than both correct or reverse motion. The two motion conditions did not differ significantly. Separate analysis of the 3 non-pilots indicated similar results, with significantly longer fixations for the no-motion condition, with respect to both correct and reverse motion ($F(2,4) = 7.791$, $p<.05$; Appendix D-2). Table 22 presents the mean fixation times for all subjects, the pilot and non-pilot groups, and for each subject.

Fixation time histograms will be presented later, in the section on mathematical curve fitting.

New fixation latency. New fixation latency was calculated as the elapsed time from the beginning of the trial (onset of cursor or "horizon" movement) to the first change in fixation position to a position constituting a new fixation. This measure was of interest in assessing whether motion would act to decrease fixation latency, as the subject hypothetically may change fixation position to find the source of the vestibular stimulation. Analysis of variance indicated no significant difference due to the motion conditions ($F(2,12) = 2.332$, $p > .05$; Appendix D-3). Mean values for new fixation latency are presented in Table 23.

Initial control movement latency. Initial control movement latency was defined as response time from trial onset to initial movement of the control column. Analysis of variance performed on this data set revealed no significant difference due to the motion conditions ($F(2,12) = 2.036$, $p > .05$; Appendix D-4). Mean values for initial control movement latency are presented in Table 24.

Control activity. Control activity was measured in three different ways. The first measure was based on the data acquisition algorithm. Much like determination of a fixation, control activity "plateaus" or the time at a particular control position were calculated when control position did not change more than a selected distance or boundary from the average of the plateau position for succeeding 1/30 of a second intervals. The first measure of control activity was simply a count of the number of plateaus, analogous to counting fixation points. Analysis of variance on this measure of control activity showed no significant difference due to the motion conditions ($F(2,12) = 1.273$, $p > .05$; Appendix D-5).

The second measure of control activity measured the average time length of the plateaus on a particular trial. This measure is analogous to fixation time. No significant differences were noted in the time measure with respect to the motion conditions ($F(2,12) = 1.871$, $p > .05$; Appendix D-6).

The third measure of control activity was a rate measure calculated as control activity per second. As with the preceding measures, no significant differences were noted ($F(2,12) = 1.866$, $p > .05$; Appendix D-7).

## Mathematical curve fitting

The application of mathematical curve fitting to fixation time distributions provides a convenient metric for both (a) describing such distributions, and (b) significance testing of distributions when sample sizes are small. Also of interest is the general shape of such distributions. Harris (Note 1) suggests, with the support of several data sets, that there are several dwell time distributions and that these distributions are dependent on the informational needs of the pilot. For example, when the pilot is making a control movement the distribution may be characterized by much longer fixations than would be found while not controlling. If the oculometric data are divided into distributions of controlling versus non-controlling (monitoring) these distributions can be distinguished.

Other factors, less easily identified than controlling versus non-controlling, may also exercise an influence on these distributions. Naturally, a best-fit curve could be found for each of these distributions, or a combination of them, if they were not separated by some other factor. The design of the present experiment attempted to reduce the problem of multiple distributions by focusing analyses only on that portion of the trial during which controlling occurred.

Transformation and choice of describing function. In selecting a describing function the goal was to choose one that would be conceptually meaningful, while accurately describing the data set. Two functions, each with two parameters, were selected for testing. These included: (a) the Gamma density function, and (b) the Normal distribution density function.

The skewed nature of fixation distributions made selecting a transformation a necessity. Hayes (1970), in discussing the selection of transformations states: "It is impossible to give any rules concerning this operation, though of course it is a vitally important step..." After testing several candidate transformations, a single transformation was selected that provided the proper scaling for both the Gamma and Normal functions. The transformation was

$$x_T = (10) \log(\text{base } 10)\ (x)$$

where x is the fixation length in 1/15 second increments. The following equation is for the Gamma density function

$$f(x_T;\alpha,\beta) = \frac{1}{\alpha!\ \beta^{\alpha+1}}\ x_T^{\alpha}\ e^{-x_T\ /\ \beta}$$

where $x_T$ is the transformed fixation time, and $\alpha$ and $\beta$ are the two parameters of the function. The equation for the Normal density function was

$$f(x_T;\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}}\ e^{-(x_T-\mu)^2/\ 2\sigma^2}$$

where $x_T$ is the transformed fixation time, and $\mu$ and $\sigma^2$ are the familiar parameters of mean and variance, respectively.

Testing the curve fit. Curves generated by the above equations were tested against the distributions obtained from both the 7 pilots and the 3 non-pilots using an iterative computer program that selected a least squares solution for each of the experimental conditions (correct motion, no-motion, reverse motion).

The Kolmogorov-Smirnov Statistic (Hoel, 1971) was employed to test the statistical significance of the fit of the mathematical functions with the obtained data, and to test differences between experimental conditions. The Kolmogorov-Smirnov test indicated that both the Gamma and Normal functions could fit the data with the fitted distributions not significantly differing from the obtained data. Because of the ease of interpretation of the normal function parameters, contrasted with those of the Gamma function, the analyses presented here were conducted using only the normal function. Values for the normal function parameters (mean and variance) are presented in Table 25 for the group of 7 pilots and in Table 26 for the 3 non-pilots.

The cumulative fixation time plots, based on the experimental data, for each of the three experimental conditions are presented in Figure 9. Figure 10 presents the cumulative fixation time plots based on the normal function best-fit curves. A comparison of Figures 9 and 10 demonstrates the closeness of the best-fit distributions to the distributions of the actual data.

The fixation time distributions are similar to those found in Experiments 1 and 2. The similarities in fixation time distributions can be appreciated by contrasting Figures 9 and 10 from the present experiment with Figure 5 from Experiment 1, and Figures 6, 7, and 8 from Experiment 2.

Tables 25 and 26 present the results of the Kolmogorov-Smirnov tests for the group of 7 pilots and the group of 3 non-pilots, respectively. For both groups of subjects, the tests between experimental conditions show that the distribution of the no-motion condition differs significantly from the distributions of the two motion conditions (correct and reverse motion), while the distributions of the two motion conditions do not differ significantly.

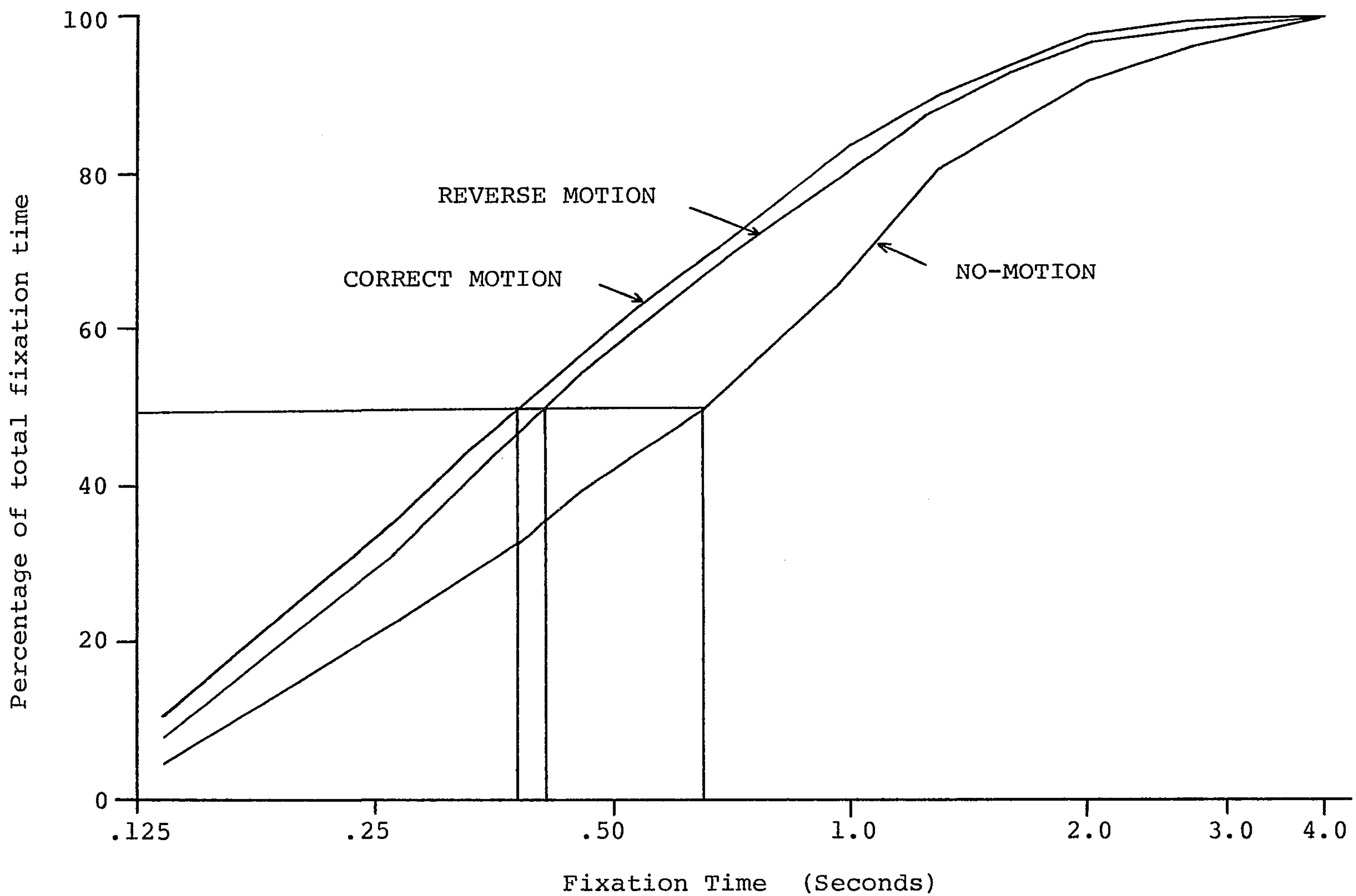


Figure 9. Cumulative plot of fixation time: Experimental Data (7 Pilots)

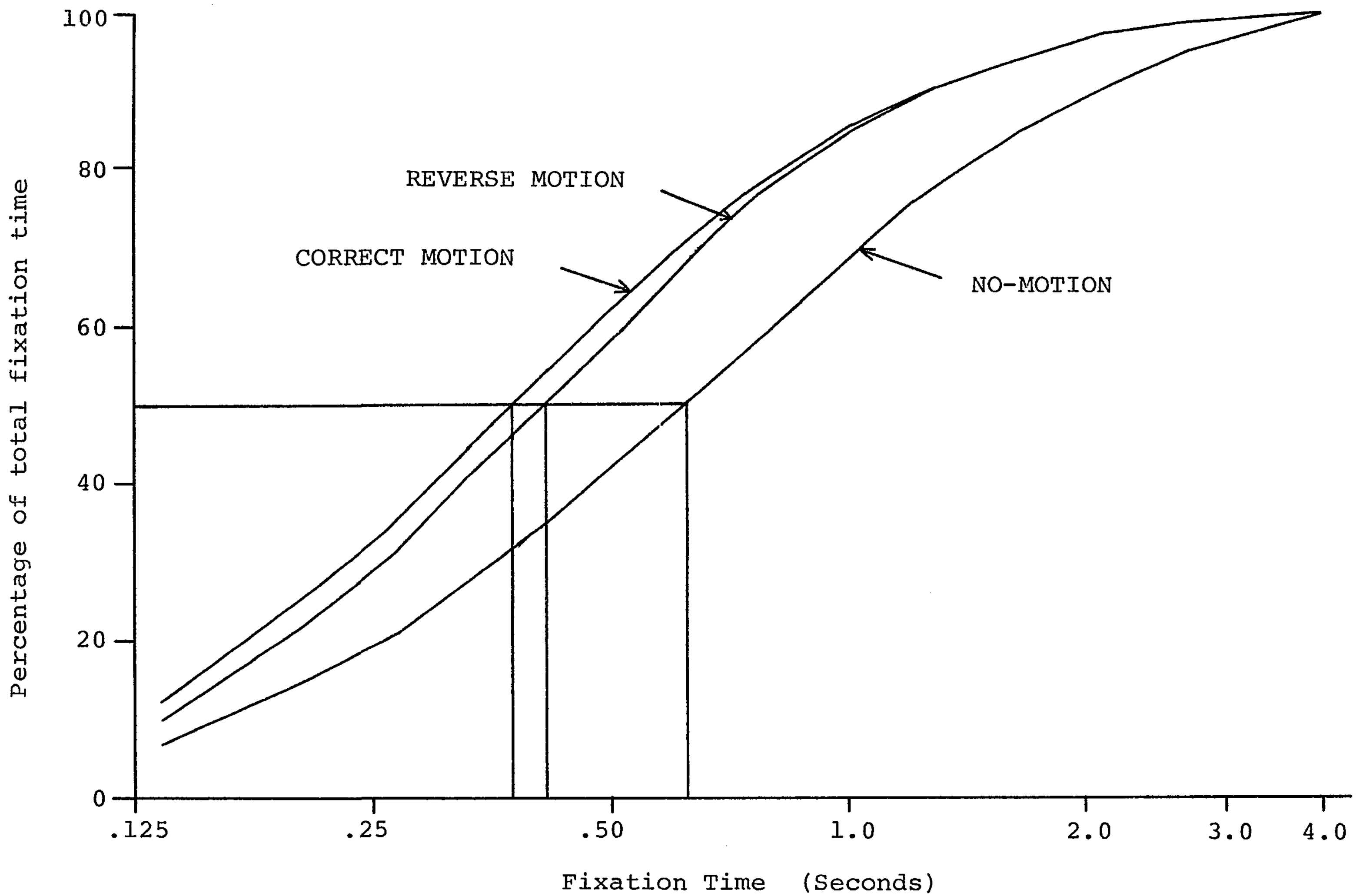


Figure 10. Cumulative plot of fixation time: Best-Fit Curves (7 Pilots)

Pilot versus Non-pilot groups. If the least squares parameters used in fitting the 7 pilots are applied to the distribution of the 3 non-pilots, a statistically acceptable fit is still obtained (correct motion D(n) = .064, no-motion D(n) = .114, reverse motion D(n) = .132; none exceed D(n) critical value of .179). This finding, coupled with the similarities of the present part-task results to those of the full simulation scenarios of Experiments 1 and 2, supports the independence of fixation time or rate measures from training and flight experience. The independence of the motion / eye-scan interaction from conscious control is an expected finding in light of the relatively few cortical projections stemming from the vestibular area (Andersson & Gernandt, 1954). Differences between the motion and no-motion conditions are much greater than the differences between the pilot and non-pilot groups.

This does not imply that overall visual search strategy would be the same from the pilot and non-pilot groups if the task was different (such as in a full simulation task). The present experiment utilized a part-task with only one instrument to scan, which meant that subjects were restricted in their visual search and also were restricted in their control response. Other studies, employing a larger number of active instruments, have demonstrated that novice subjects may even adopt an incorrect primary instrument (Tole, Stephens, Harris, & Ephrath, 1982).

Summary: Experiment 3

Experiment 3 explored motion effects through a single instrument task in which three types of motion could be present. These were (a) no-motion, (b) correct motion, and (c) reverse motion. Analyses of the data from the experiment suggest the following:

_1_. Mean fixation times for the no-motion condition were significantly longer than for both of the motion conditions, while the two motion conditions did not differ significantly. These results are like those of the preceding experiments with regard to the differences between motion and no-motion conditions, except here they are demonstrated with a part-task and single-axis motion (pitch).

Also of importance is the non-significant difference between correct and reverse motion for each of the dependent measures in the study. This suggests that motion may provide a "cue" or "clue" that "something happened" but does not support the hypothesis that direction of motion is obtained through motion information. This is supported by self-report from the test subjects. Eight of the 10 subjects reported that they could not tell whether motion was correct or reversed on a particular trial.

The fixation time distributions obtained in the present experiment were found to be much like those obtained in Experiments 1 and 2. The differences between the no-motion distribution and the distributions for the two motion conditions are similar in magnitude and direction to the differences observed between motion and no-motion in Experiments 1 and 2.

2. A measure of new fixation latency, or the elapsed time from the beginning of a trial to the first change in fixation position, showed no significant differences across the experimental conditions. This is an important finding because it suggests that motion onset did not prompt a "quicker" first transition to a new fixation point, as would be expected if action of the VOR was uniquely responsible for fixation time changes with motion.

3. Initial control movement latency, defined as the response time from trial onset to initial movement of the control column, indicated no significant differences across the experimental conditions. Likewise, each of three methods of assessing control activity showed no significant differences across the experimental conditions.

4. Mathematical curve fitting, particularly the use of a transformed Normal density function, was found to be applicable to both describing fixation time distributions and significance testing between such distributions. Such a technique may be employed in situations in which the analysis of distribution means would be inappropriate, and is especially useful for the evaluation of data sets with small sample sizes.

Table 22

Mean Fixation Time
Table of Means
(Milliseconds)

| | CORRECT MOTION | NO-MOTION | REVERSE MOTION |
|---|---|---|---|
| All Subjects | 702 | 989 | 715 |
| All Pilots | 750 | 1084 | 801 |
| Pilot 1 | 766 | 1098 | 844 |
| 2 | 1061 | 1086 | 1290 |
| 3 | 1338 | 1493 | 1152 |
| 4 | 521 | 1148 | 711 |
| 5 | 360 | 752 | 412 |
| 6 | 572 | 999 | 503 |
| 7 | 630 | 1012 | 695 |
| All Non-Pilots | 590 | 767 | 512 |
| Non-Pilot 1 | 658 | 825 | 704 |
| 2 | 565 | 811 | 392 |
| 3 | 546 | 666 | 441 |

Table 23

New Fixation Latency
Table of Means
(Milliseconds)

| | | CORRECT MOTION | NO-MOTION | REVERSE MOTION |
|---|---|---|---|---|
| All Subjects | | 653 | 743 | 592 |
| All Pilots | | 741 | 774 | 604 |
| Pilot | 1 | 798 | 911 | 1047 |
| | 2 | 656 | 969 | 544 |
| | 3 | 1273 | 989 | 709 |
| | 4 | 580 | 416 | 333 |
| | 5 | 504 | 411 | 227 |
| | 6 | 636 | 871 | 611 |
| | 7 | 742 | 853 | 758 |
| All Non-Pilots | | 447 | 668 | 565 |
| Non-Pilot | 1 | 304 | 437 | 562 |
| | 2 | 600 | 804 | 676 |
| | 3 | 438 | 764 | 456 |

Table 24

Initial Control Movement Latency
Table of Means
(Milliseconds)

| | CORRECT MOTION | NO-MOTION | REVERSE MOTION |
|---|---|---|---|
| All Subjects | 1304 | 1334 | 1236 |
| All Pilots | 1370 | 1382 | 1311 |
| Pilot 1 | 1196 | 1144 | 1062 |
| 2 | 1211 | 1242 | 1356 |
| 3 | 904 | 1062 | 902 |
| 4 | 1609 | 1696 | 1602 |
| 5 | 1358 | 1256 | 1165 |
| 6 | 1816 | 1869 | 1736 |
| 7 | 1498 | 1407 | 1351 |
| All Non-Pilots | 1149 | 1223 | 1064 |
| Non-Pilot 1 | 1093 | 1216 | 1062 |
| 2 | 1113 | 1091 | 1073 |
| 3 | 1242 | 1362 | 1056 |

Table 25

Mathematical Curve Fitting:
Results of the Kolmogorov-Smirnov Statistic
and Normal Function Parameters

7 PILOTS

| D(n) Values: | Correct Motion | No-Motion | Reverse Motion | |
|---|---|---|---|---|
| Correct Motion | .034 | .189 * | .047 | Data |
| No-Motion | .196 * | .032 | .167 + | |
| Reverse Motion | .039 | .176 + | .052 | |
| | Best-Fit Curve | | | |

Diagonal entries are tests between data and best-fit curve.

Critical Values for D(n):
(n=58)

+ $p < .10$, D(n) = .160
* $p < .05$, D(n) = .179
** $p < .01$, D(n) = .214

| Parameters: | Correct Motion | No-Motion | Reverse Motion |
|---|---|---|---|
| Mean | 3.91 | 5.02 | 4.89 |
| Variance | 15.93 | 21.02 | 13.69 |

Parameter units: Sampling Rate / 2 (66.667 msec)
(These are transformed values.)

Table 26

Mathematical Curve Fitting:
Results of the Kolmogorov-Smirnov Statistic
and Normal Function Parameters

3 NON-PILOTS

| D(n) Values: | Correct Motion | No-Motion | Reverse Motion |
|---|---|---|---|
| Correct Motion | .066 | .187 * | .043 |
| No-Motion | .199 * | .062 | .211 * |
| Reverse Motion | .036 | .231 ** | .060 |

Upper triangle: Data. Lower triangle: Best-Fit Curve.

Diagonal entries are tests between data and best-fit curve.

Critical Values for D(n):
(n=58)

+ $p < .10$, $D(n) = .160$
* $p < .05$, $D(n) = .179$
** $p < .01$, $D(n) = .214$

| Parameters: | Correct Motion | No-Motion | Reverse Motion |
|---|---|---|---|
| Mean | 4.56 | 4.38 | 4.34 |
| Variance | 11.52 | 19.86 | 11.13 |

Parameter units: Sampling Rate / 2 (66.667 msec)
(These are transformed values.)

## General Discussion

"Fixation Time," defined as the time the eyes spend at a particular place before moving on to another fixation point, was found to be an oculometric measure sensitive to motion effects in each of the three experiments reported here. For the purposes of the present study, a fixation was defined mathematically as a series of lookpoints having X and Y coordinates that did not exceed a selected boundary limit (typically a radius) from the centroid of prior X and Y coordinates (Details were reported in the section on "Measurement of eye movement").

When employing fixation time as a dependent measure, the distribution of fixation times can be obtained and examined as either a frequency or cumulative frequency plot. The distribution of fixation times on (a) the Flight Director in the simulator motion versus no-motion study (Experiment 1), (b) the Electronic Attitude Display Indicator in the aircraft versus simulator study (Experiment 2), and (c) the Command Bar task in the single-axis part-task study (Experiment 3), each show similarities between motion and no-motion. In each case, an increase in fixation time (decreased fixation rate) was noted for the no-motion condition.

Explanatory hypotheses

Three general hypotheses offer plausible explanations of the results of the present series of experiments:

1. Attentional or arousal factors. The first hypothesis would explain increased fixation rate with motion as the product of heightening of generalized attention or arousal in the presence of motion. Motion may represent a series of powerful sensory events adding to the subjects attentional or arousal level. This hypothesis can be discounted by the present series of experiments for several reasons. Initially, attentional or arousal factors do not appear to have been a factor in Experiment 1, as significantly greater pitch control activity was noted when motion was not employed. Secondly, in Experiment 3, no significant differences were found in control movement or in the elapsed time until the beginning of a new fixation, two measures that should have been sensitive to subject attentional or arousal level. Thirdly, no differences were noted in accuracy of approach (approach error) in Experiment 1. Given this evidence, it is difficult to support the first hypothesis.

2. Motion conveys direction information. The second hypothesis would explain decreased fixation time for motion conditions as the result of information conveyed through the motion itself, perhaps leading to a decreased need for visual information. Experiment 3 was designed, in part, to answer this question. The results of Experiment 3 suggest that

subjects are not able to discern directional information from motion in the pitch dimension, and are not able to report whether motion was correct or reversed on a trial. Likewise, with respect to the correct motion condition, reversed motion did not significantly change control activity measures or fixation time distributions.

3. Motion serving an alerting function. The third hypothesis would explain increased fixation rate with motion as the result of motion providing a "cue" or "clue" that "something happened" leading to visual search to determine what it was. This hypothesis offers the best explanation of the three.

Longer fixations, such as found in the no-motion condition, may be attributable to supplanting the alerting function of motion information. It has been argued (Russo, 1978, p. 108) that eye movements have a "cost" in terms of temporal gaps in the incoming visual information. To reduce such gaps saccades may be suppressed leading to longer fixation times. That this process is accomplished, perhaps providing more of a continuous visual image, is supported by eye-scan data recorded at the point of landing flare, where a single fixation of from five to seven seconds is often observed. This situation is obviously one in which a continuous visual picture with constant updating is necessary.

In a no-motion condition, all indicators of deviation from flight path and verification of corrective actions are visually presented. A gap in visual information represents a total loss of available information. On the contrary, when motion is present, additional information is available, as motion may act to warn of a change, or to confirm a control input, even if directional information is not conveyed.

Implications

1. Given the goal of providing a simulation environment that matches the actual flight environment as closely as possible, it becomes apparent that motion effects cannot be ignored. The present study suggests that there are differing visual demands placed on the pilot between motion and no-motion conditions, as reflected by differences in fixation rate between these conditions. The most compelling hypothesis is that motion serves an alerting function. Given this function, simulation without motion cues may represent an understatement of the true capacity of the pilot, although differences in performance of the man-aircraft system may only be found when the pilot is heavily loaded. Since none of the present experiments loaded the pilot, questions of performance under loaded conditions remain to be answered. Research conducted in this area would provide an answer to the question of whether differences in eye movement are directly related to performance of the piloting task.

The question of how much motion is needed also remains, as each of the motion conditions in the present study included an approximation of actual motion and not levels or degrees of motion. It should be noted that motion onset can also be produced in stationary simulators through "G" suits or other pressurized cuffs or seats. If the alerting function of motion is adequately provided by these devices, then fixation time distributions similar to those observed with motion base simulation would be expected. Research on alternative motion techniques that incorporate eye-movement measures would provide a test of the fidelity of these motion devices.

2. The measure of "dwell time" has been found to be quite variable from subject to subject and even within the same subject. The uniformity of fixation time was shown by similarities in fixation time distributions across the three experiments and between the pilot and non-pilot groups in the third experiment. The uniformity of fixation time suggests that fixations are well developed from other contexts, and the flying task does little to alter them. How the fixations are combined into dwells seems to be where the variability enters.

3. Mathematical curve-fitting and the analysis of the shape of the fixation time distribution has advantages in describing and testing such distributions, and is recommended as a technique to use in future studies in the area. The primary advantage is that tests between distributions can be performed on data from a single subject.

## Reference Notes

1. Harris, R. L., Sr. Flight Operations Research Branch, NASA Langley Research Center

2. Spady, A. A., Jr. Flight Operations Research Branch, NASA Langley Research Center

# References


Andersson, S., & Gernandt, B. E. Cortical projection of vestibular nerve in cat. Acta oto-laryngol., Stockh., Suppl. 116, 1954, 10-18. In Geldard, F. A. The Human Senses (Second Edition). New York: John Wiley & Sons, Inc., 1972.

Baker, R., Evinger, C., & McCrea, R. A. Some thoughts about the three neurons in the Vestibular Ocular Reflex. In Cohen, B. (Ed.) Vestibular and Oculomotor Physiology: International Meeting of the Barany Society. New York: Annals of the New York Academy of Sciences, 1981, 374, 171-188.

Bray, R. S. A study of vertical motion requirements for landing simulation. Human Factors, 1973, 15(6), 561-568.

Brown, B. P., Johnson, H. I., & Mungall, R. G. Simulator motion effects on a pilot's ability to perform a precise longitudinal flying task. NASA TN-D-367, 1960.

Carpenter, R. H. S. Movement of the eyes, London: Pion Limited, 1977.

Clark, B., & Stewart, J. D. Relationship between motion sickness experiences and tests of the perception of rotation in pilots and nonpilots. Aerospace Medicine, 1973, 44, 393-396.

Clark, B., Stewart, J. D., & Phillips, N. H. Thresholds for detection of constant rotary acceleration during vibratory rotary acceleration. Aviation, Space, and Environmental Medicine, 1980, 51, 603-606.

Cohen, B. (Ed.) Vestibular and Oculomotor Physiology: International Meeting of the Barany Society. New York: Annals of the New York Academy of Sciences, 1981, 374.

de No, Lorente (1933) Cited in: Cohen, B. (Ed.) Vestibular and Oculomotor Physiology: International Meeting of the Barany Society. New York: Annals of the New York Academy of Sciences, 1981, 374.

Geldard, F. A. The Human Senses (Second Edition). New York: John Wiley & Sons, Inc., 1972.

Gibino, D. J. Effects of presence or absence of cockpit motion in instrument flight trainers and flight simulators. Wright-Patterson AFB, Aeronautical Systems Division, ASD-TR-68-24, 1968.

Hayes, J. G. Numerical Approximation to Functions and Data. New York: Oxford University Press, Inc., 1970, 12-13.

Hoel, P. G. Introduction to Mathematical Statistics. New York: John Wiley Sons, Inc., 1971, 324-331.

Huff, E. M., & Nagel, D. C. Psychological aspects of aeronautical flight simulation. American Psychologist, 1975, 30(3), 426-439.

Hunter, J. Observations on certain parts of the animal economy. London: 1786, In Woellner, R. C., & Graybiel, A. Counterrolling of the eyes and its dependence on the magnitude of gravitational or inertial force acting laterally on the body. _Journal of Applied Physiology_, 1959, _14_, 632-634.

Merchant, J., & Morrisette, R. Remote measurement of eye direction allowing subject motion over one cubic foot of space. _IEEE Transactions on Biomedical Engineering_, 1974, BME-21, 309-317.

Ringland, R. F., & Stapleford, R. L. Motion cue effects on pilot tracking. _Proceedings of Seventh Conference on Manual Control_, National Aeronautics and Space Administration, 1971, SP-281.

Ruocco, J. N., Vitale, P. A., & Benfari, R. C. _Kinetic cueing in simulated carrier approaches_. U. S. Naval Training Device Center, NAVTRADEVCEN-1432-1, 1965.

Russo, J. E. Adaptation of cognitive processes to the eye movement system. In Senders, J. W., Fisher, D. F., & Monty, R. A. (Eds.) _Eye Movements and the Higher Psychological Functions_. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1978.

Spady, Jr., A. A. _Airline Pilot Scan Patterns During Simulated ILS Approaches_. NASA TP-1250, October 1978.

Tole, J. R., Stephens, A. T., Harris, R. L., Sr., Ephrath, A. R. Visual scanning behavior and mental workload in aircraft pilots. *Aviation, Space, and Environmental Medicine*, 1982, 53(1), 54-61.

Winer, B. J. *Statistical Principles in Experimental Design (Second Edition)*. New York: McGraw-Hill Book Company, 1971.

Young, L. R., & Sheena, D. Survey of eye movement recording methods. *Behavior Research Methods & Instrumentation*, 1975, *7*, 397-429.

# APPENDIX A

## Experiment 1:

## Analysis of Variance Summary Tables

Table A-1

Fixation Time (All Tracked Instruments):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 1275848.0 | 4 | 318961.9 | |
| Motion (M) | 241802.5 | 1 | 241802.5 | 9.092 * |
| Segment (G) | 24030.0 | 3 | 8010.0 | .418 |
| Replic (R) | 26890.0 | 3 | 8963.3 | 1.262 |
| SM | 106385.0 | 4 | 26596.3 | |
| SG | 229782.5 | 12 | 19148.5 | |
| MG | 127.5 | 3 | 42.5 | .011 |
| SR | 85222.5 | 12 | 7101.9 | |
| MR | 11067.5 | 3 | 3689.2 | .159 |
| GR | 16050.0 | 9 | 1783.3 | .564 |
| SMG | 44635.0 | 12 | 3719.6 | |
| SMR | 279295.0 | 12 | 23274.6 | |
| SGR | 113787.5 | 36 | 3160.8 | |
| MGR | 11622.5 | 9 | 1291.4 | .461 |
| SMGR | 100765.0 | 36 | 2799.0 | |

* $p < .05$

Table A-2

Fixation Rate (All Tracked Instruments):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 24.96828 | 4 | 6.24207 | |
| Motion (M) | 5.01618 | 1 | 5.01618 | 13.071 * |
| Segment (G) | .39873 | 3 | .13291 | .457 |
| Replic (R) | .59916 | 3 | .19972 | 1.379 |
| SM | 1.53502 | 4 | .38375 | |
| SG | 3.49100 | 12 | .29092 | |
| MG | .08097 | 3 | .02699 | .271 |
| SR | 1.73822 | 12 | .14485 | |
| MR | .03336 | 3 | .01112 | .034 |
| GR | .34955 | 9 | .03884 | .813 |
| SMG | 1.19749 | 12 | .09979 | |
| SMR | 3.90800 | 12 | .32567 | |
| SGR | 1.71990 | 36 | .04777 | |
| MGR | .34244 | 9 | .03805 | .556 |
| SMGR | 2.46128 | 36 | .06836 | |

* $p < .05$

Table A-3

Saccade Length (All Tracked Instruments):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 6.85411 | 4 | 1.71353 | |
| Motion (M) | .00945 | 1 | .00945 | .081 |
| Segment (G) | 12.15992 | 3 | 4.05330 | 13.542 ** |
| Replic (R) | .04838 | 3 | .01613 | .152 |
| SM | .46625 | 4 | .11656 | |
| SG | 3.59182 | 12 | .29932 | |
| MG | .19202 | 3 | .06401 | .455 |
| SR | 1.27177 | 12 | .10598 | |
| MR | .52796 | 3 | .17598 | 1.507 |
| GR | .31155 | 9 | .03462 | .283 |
| SMG | 1.68734 | 12 | .14061 | |
| SMR | 1.40125 | 12 | .11677 | |
| SGR | 4.40043 | 36 | .12223 | |
| MGR | .18420 | 9 | .02047 | .336 |
| SMGR | 2.19278 | 36 | .06091 | |

** $p < .01$

Table A-4

Glideslope Error:
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 1.617630 | 4 | .404408 | |
| Motion (M) | .101304 | 1 | .101304 | 1.243 |
| Segment (G) | 91.527130 | 3 | 30.509040 | 257.005 ** |
| Replic (R) | .070305 | 3 | .022343 | 1.108 |
| SM | .326091 | 4 | .081523 | |
| SG | 1.424521 | 12 | .118710 | |
| MG | .338335 | 3 | .112778 | 2.667 |
| SR | .253731 | 12 | .021144 | |
| MR | .105668 | 3 | .035223 | .832 |
| GR | .404266 | 9 | .044918 | 1.909 |
| SMG | .507525 | 12 | .042294 | |
| SMR | .508307 | 12 | .042359 | |
| SGR | .847042 | 36 | .023529 | |
| MGR | .170716 | 9 | .018968 | .782 |
| SMGR | .873391 | 36 | .024261 | |

** $p < .01$

Table A-5

Localizer Error:
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | .1087453 | 4 | .2718634E-01 | |
| Motion (M) | .9950059E-03 | 1 | .9950059E-03 | .198 |
| Segment (G) | .2738432E-01 | 3 | .9128106E-02 | 1.384 |
| Replic (R) | .1447792E-01 | 3 | .4825973E-02 | 1.714 |
| SM | .2014034E-01 | 4 | .5035085E-02 | |
| SG | .7916322E-01 | 12 | .6596935E-02 | |
| MG | .3991122E-02 | 3 | .1330374E-02 | .283 |
| SR | .3379236E-01 | 12 | .2816030E-02 | |
| MR | .3423820E-02 | 3 | .1141273E-02 | .153 |
| GR | .2132466E-01 | 9 | .2369407E-02 | .531 |
| SMG | .5635140E-01 | 12 | .4695950E-02 | |
| SMR | .8956597E-01 | 12 | .7463830E-02 | |
| SGR | .1606367 | 36 | .4462130E-02 | |
| MGR | .1478015E-01 | 9 | .1642239E-02 | .561 |
| SMGR | .1054047 | 36 | .2927908E-02 | |

Table A-6

Elevator Control Inputs
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 132771700. | 4 | 33192930. | |
| Motion (M) | 7590523. | 1 | 7590523. | 7.774 * |
| Segment (G) | 114244100. | 3 | 38081360. | 25.587 ** |
| Replic (R) | 8357313. | 3 | 2785771. | 1.341 |
| SM | 3905640. | 4 | 976410. | |
| SG | 17859760. | 12 | 1488313. | |
| MG | 942648. | 3 | 314216. | 1.747 |
| SR | 24922260. | 12 | 2076855. | |
| MR | 6552008. | 3 | 2184003. | 1.257 |
| GR | 7693586. | 9 | 854843. | 1.359 |
| SMG | 2157937. | 12 | 179828. | |
| SMR | 20856510. | 12 | 1738042. | |
| SGR | 22649290. | 36 | 629147. | |
| MGR | 6814045. | 9 | 757116. | 1.000 |
| SMGR | 27263910. | 36 | 757331. | |

* $p < .05$
** $p < .01$

Table A-7

Wheel Control Inputs
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | .4877959E+10 | 4 | .1219490E+10 | |
| Motion (M) | .1323395E+10 | 1 | .1323395E+10 | 1.602 |
| Segment (G) | .1621391E+11 | 3 | .5404636E+10 | 5.011 * |
| Replic (R) | .3750907E+10 | 3 | .1250302E+10 | 4.000 * |
| SM | .3305193E+10 | 4 | .8262984E+09 | |
| SG | .1294202E+11 | 12 | .1078502E+10 | |
| MG | .5669645E+09 | 3 | .1889882E+09 | 1.550 |
| SR | .3751125E+10 | 12 | .3125938E+09 | |
| MR | .4268131E+09 | 3 | .1422710E+09 | .249 |
| GR | .2286997E+10 | 9 | .2541107E+09 | .976 |
| SMG | .1462815E+10 | 12 | .1219012E+09 | |
| SMR | .6855075E+10 | 12 | .5712563E+09 | |
| SGR | .9373312E+10 | 36 | .2603698E+09 | |
| MGR | .1894990E+10 | 9 | .2105545E+09 | .465 |
| SMGR | .1631233E+11 | 36 | .4531203E+09 | |

* $p < .05$

Table A-8

Throttle Control Inputs
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | .4069427E+10 | 4 | .1017357E+10 | |
| Motion (M) | .5782985E+07 | 1 | .5782985E+07 | .904 |
| Segment (G) | .5472604E+09 | 3 | .1824201E+09 | 1.702 |
| Replic (R) | .2496782E+09 | 3 | .8322606E+08 | 3.182 |
| SM | .2559906E+08 | 4 | .6399766E+07 | |
| SG | .1286220E+10 | 12 | .1071850E+09 | |
| MG | .2276196E+09 | 3 | .7587320E+08 | 2.241 |
| SR | .3138547E+09 | 12 | .2615456E+08 | |
| MR | .2417142E+09 | 3 | .8057141E+08 | .841 |
| GR | .5583590E+09 | 9 | .6203989E+08 | .943 |
| SMG | .4062166E+09 | 12 | .3385139E+08 | |
| SMR | .1149160E+10 | 12 | .9576333E+08 | |
| SGR | .2369512E+10 | 36 | .6581976E+08 | |
| MGR | .2294529E+09 | 9 | .2549476E+08 | .638 |
| SMGR | .1438107E+10 | 36 | .3994742E+08 | |

Table A-9

Fixation Time (Flight Director):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 1821451.0 | 4 | 455362.7 | |
| Motion (M) | 299097.7 | 1 | 299097.7 | 7.354 * |
| Segment (G) | 4884.1 | 2 | 2442.0 | .265 |
| Replic (R) | 49648.5 | 3 | 16549.5 | 1.573 |
| SM | 162682.8 | 4 | 40670.7 | |
| SG | 73869.3 | 8 | 9233.7 | |
| MG | 1842.6 | 2 | 921.3 | .224 |
| SR | 126270.9 | 12 | 10522.6 | |
| MR | 6711.7 | 3 | 2237.2 | .097 |
| GR | 29617.9 | 6 | 4936.3 | 1.121 |
| SMG | 32930.7 | 8 | 4116.3 | |
| SMR | 275629.8 | 12 | 22969.2 | |
| SGR | 105692.6 | 24 | 4403.9 | |
| MGR | 37439.8 | 6 | 6240.0 | 2.034 |
| SMGR | 73630.7 | 24 | 3067.9 | |

* $p < .053$

Table A-10

Fixation Time (Airspeed):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 76643.81 | 4 | 19160.95 | |
| Motion (M) | 13161.90 | 1 | 13161.90 | 2.955 |
| Segment (G) | 27660.95 | 2 | 13830.48 | 1.229 |
| Replic (R) | 26632.77 | 3 | 8877.59 | 1.081 |
| SM | 17813.66 | 4 | 4453.41 | |
| SG | 90018.54 | 8 | 11252.32 | |
| MG | 10576.48 | 2 | 5288.24 | 1.655 |
| SR | 98555.50 | 12 | 8212.96 | |
| MR | 16357.89 | 3 | 5452.63 | .643 |
| GR | 42979.83 | 6 | 7163.30 | 2.306 |
| SMG | 25558.71 | 8 | 3194.84 | |
| SMR | 101692.60 | 12 | 8474.38 | |
| SGR | 74544.75 | 24 | 3106.03 | |
| MGR | 66803.11 | 6 | 11133.85 | 1.348 |
| SMGR | 198291.80 | 24 | 8262.16 | |

Table A-11

Fixation Time (VSI):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 328270.8 | 4 | 82067.7 | |
| Motion (M) | 30884.2 | 1 | 30884.2 | 2.484 |
| Segment (G) | 148250.4 | 2 | 74125.2 | 8.549 * |
| Replic (R) | 13615.6 | 3 | 4538.5 | .437 |
| SM | 49738.3 | 4 | 12434.6 | |
| SG | 69367.0 | 8 | 8670.9 | |
| MG | 7393.2 | 2 | 3696.6 | .128 |
| SR | 124726.4 | 12 | 10393.9 | |
| MR | 23693.8 | 3 | 7897.9 | .847 |
| GR | 55950.3 | 6 | 9325.1 | .893 |
| SMG | 230885.4 | 8 | 28860.7 | |
| SMR | 111874.2 | 12 | 9322.9 | |
| SGR | 250710.6 | 24 | 10446.3 | |
| MGR | 55285.6 | 6 | 9214.3 | 1.047 |
| SMGR | 211108.8 | 24 | 8796.2 | |

* $p < .05$

Table A-12

Fixation Time (Barometric Altimeter):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 147449.9 | 4 | 36862.5 | |
| Motion (M) | 18584.7 | 1 | 18584.7 | 3.329 |
| Segment (G) | 34098.5 | 2 | 17049.2 | 1.695 |
| Replic (R) | 53927.3 | 3 | 17975.8 | 1.413 |
| SM | 22328.2 | 4 | 5582.1 | |
| SG | 80468.1 | 8 | 10058.5 | |
| MG | 7815.4 | 2 | 3907.7 | .256 |
| SR | 152643.2 | 12 | 12720.3 | |
| MR | 12590.6 | 3 | 4196.9 | .404 |
| GR | 67101.2 | 6 | 11183.5 | 1.140 |
| SMG | 122102.4 | 8 | 15262.8 | |
| SMR | 124551.7 | 12 | 10379.3 | |
| SGR | 235447.1 | 24 | 9810.3 | |
| MGR | 16164.7 | 6 | 2694.1 | .286 |
| SMGR | 226012.6 | 24 | 9417.2 | |

Table A-13

Fixation Time (HSI):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 454014.7 | 4 | 113503.7 | |
| Motion (M) | 58099.2 | 1 | 58099.2 | 2.609 |
| Segment (G) | 2183.0 | 2 | 1091.5 | .099 |
| Replic (R) | 18539.1 | 3 | 6179.7 | .899 |
| SM | 89057.7 | 4 | 22264.4 | |
| SG | 87757.9 | 8 | 10969.7 | |
| MG | 177.3 | 2 | 88.6 | .009 |
| SR | 82488.1 | 12 | 6874.0 | |
| MR | 47107.7 | 3 | 15702.6 | 1.661 |
| GR | 52251.5 | 6 | 8708.6 | .888 |
| SMG | 80258.3 | 8 | 10032.3 | |
| SMR | 113463.0 | 12 | 9455.2 | |
| SGR | 235460.9 | 24 | 9810.9 | |
| MGR | 33246.0 | 6 | 5541.0 | 1.190 |
| SMGR | 111716.7 | 24 | 4654.9 | |

Table A-14

Percentage of Oculometer Track Time:
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
| --- | --- | --- | --- | --- |
| Pilot (S) | 1422.591 | 4 | 355.648 | |
| Motion (M) | 66.645 | 1 | 66.645 | .366 |
| Segment (G) | 317.010 | 3 | 105.670 | 2.073 |
| Replic (R) | 381.835 | 3 | 127.278 | 1.973 |
| SM | 728.635 | 4 | 182.159 | |
| SG | 611.788 | 12 | 50.982 | |
| MG | 27.534 | 3 | 9.178 | .376 |
| SR | 773.942 | 12 | 64.495 | |
| MR | 619.795 | 3 | 206.598 | 3.905 * |
| GR | 425.941 | 9 | 47.327 | 1.465 |
| SMG | 293.222 | 12 | 24.435 | |
| SMR | 634.813 | 12 | 52.901 | |
| SGR | 1162.930 | 36 | 32.304 | |
| MGR | 255.049 | 9 | 28.339 | .792 |
| SMGR | 1288.782 | 36 | 35.799 | |

* $p < .05$

Table A-15

Ratio of Transition Times
For Two Selected Radii
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 1.073441 | 4 | .268360 | |
| Motion (M) | .001235 | 1 | .001235 | .004 |
| Segment (G) | .368384 | 2 | .184192 | .592 |
| Replic (R) | .658480 | 3 | .219493 | 2.303 |
| SM | 1.226586 | 4 | .306646 | |
| SG | 2.487976 | 8 | .310997 | |
| MG | .899132 | 2 | .449566 | 2.264 |
| SR | 1.143693 | 12 | .095308 | |
| MR | .180328 | 3 | .060109 | .250 |
| GR | .793411 | 6 | .132235 | 1.015 |
| SMG | 1.588521 | 8 | .198565 | |
| SMR | 2.886252 | 12 | .240521 | |
| SGR | 3.126064 | 24 | .130253 | |
| MGR | .160790 | 6 | .026798 | .251 |
| SMGR | 2.559126 | 24 | .106630 | |

Table A-16

Fixation Rate (All Tracked Instruments)
Based on Enlarged Algorithm Radius (1.91 cm):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (S) | 26.725540 | 4 | 6.681384 | |
| Motion (M) | 2.026960 | 1 | 2.026960 | 14.280 * |
| Segment (G) | 1.091152 | 2 | .545576 | 2.600 |
| Replic (R) | .807180 | 3 | .269060 | 1.561 |
| SM | .567789 | 4 | .141947 | |
| SG | 1.678445 | 8 | .209806 | |
| MG | .128520 | 2 | .064260 | .812 |
| SR | 2.068542 | 12 | .172378 | |
| MR | .222600 | 3 | .074200 | .479 |
| GR | .475737 | 6 | .079290 | 1.032 |
| SMG | .632970 | 8 | .071212 | |
| SMR | 1.859285 | 12 | .154940 | |
| SGR | 1.843573 | 24 | .076815 | |
| MGR | .260152 | 6 | .043359 | .444 |
| SMGR | 2.343736 | 24 | .097656 | |

$* \; p < .05$

# APPENDIX B

## Experiment 1:

## Skew of fixation time distributions

Skew of fixation time distributions

| Instrument | Motion | No-motion |
|---|---|---|
| Airspeed | 0.147 | 0.847 |
| Flight Director | 1.468 | 0.949 |
| Barometric Altimeter | -0.347 | -0.109 |
| HSI | 0.960 | 0.733 |
| VSI | -0.178 | -0.006 |

# APPENDIX C

## Experiment 2:

## Analysis of Variance Summary Tables

Table C-1

Fixation Time (All Tracked Instruments):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 3175841.0 | 2 | 1587920.0 | |
| Motion (M) | 2049507.0 | 1 | 2049507.0 | 35.160 * |
| Replic (R) | 424875.5 | 19 | 22361.9 | 2.166 * |
| Segment (S) | 40023.1 | 3 | 13341.0 | 4.986 * |
| PM | 116581.7 | 2 | 58290.8 | |
| PR | 392255.2 | 38 | 10322.5 | |
| MR | 129609.9 | 19 | 6821.6 | .778 |
| PS | 16054.9 | 6 | 2675.8 | |
| MS | 125585.3 | 3 | 41861.8 | 1.382 |
| RS | 248615.6 | 57 | 4361.7 | 1.405 |
| PMR | 333099.1 | 38 | 8765.8 | |
| PMS | 181684.4 | 6 | 30280.7 | |
| PRS | 353865.3 | 114 | 3104.1 | |
| MRS | 286143.5 | 57 | 5020.1 | 1.204 |
| PMRS | 475353.2 | 114 | 4169.8 | |

* $p < .05$

Table C-2

Fixation Rate (All Tracked Instruments):
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 88.12525 | 2 | 44.06262 | |
| Motion (M) | 89.52854 | 1 | 89.52854 | 19.515 * |
| Replic (R) | 8.11413 | 19 | .42706 | 2.435 * |
| Segment (S) | 1.07959 | 3 | .35986 | 4.986 * |
| PM | 9.17560 | 2 | 4.58780 | |
| PR | 6.66464 | 38 | .17539 | |
| MR | 2.74705 | 19 | .14458 | .699 |
| PS | .43301 | 6 | .07217 | |
| MS | 3.20751 | 3 | 1.06917 | 3.968 |
| RS | 7.17737 | 57 | .12592 | 1.437 |
| PMR | 7.85508 | 38 | .20671 | |
| PMS | 1.61675 | 6 | .26946 | |
| PRS | 9.98761 | 114 | .08761 | |
| MRS | 7.09573 | 57 | .12449 | 1.218 |
| PMRS | 11.65470 | 114 | .10223 | |

* $p < .05$

Table C-3

Fixation Time ( EADI Segments 3 and 4 )
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 822883.1 | 2 | 411441.6 | |
| Motion (M) | 441955.8 | 1 | 441955.8 | 14.030 |
| Replic (R) | 169677.1 | 19 | 8930.4 | 1.475 |
| Segment (S) | 649896.3 | 1 | 649896.3 | 8.902 |
| PM | 63000.7 | 2 | 31500.3 | |
| PR | 230101.9 | 38 | 6055.3 | |
| MR | 111338.8 | 19 | 5859.9 | .496 |
| PS | 146004.8 | 2 | 73002.4 | |
| MS | 81585.9 | 1 | 81585.9 | 6743.941 * |
| RS | 101572.3 | 19 | 5345.9 | 1.268 |
| PMR | 448652.0 | 38 | 11806.6 | |
| PMS | 24.2 | 2 | 12.1 | |
| PRS | 160162.9 | 38 | 4214.8 | |
| MRS | 75264.6 | 19 | 3819.2 | .858 |
| PMRS | 169216.4 | 38 | 4453.1 | |

* $p < .05$

Table C-4

Percentage of Track Time on EADI
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 9869.93 | 2 | 4934.96 | |
| Motion (M) | 2585.92 | 1 | 2585.92 | .444 |
| Replic (R) | 10395.85 | 19 | 547.15 | 1.797 |
| Segment (S) | 180901.20 | 3 | 60300.39 | 39.742 ** |
| PM | 11645.59 | 2 | 5822.79 | |
| PR | 11567.32 | 38 | 304.40 | |
| MR | 4164.10 | 19 | 219.16 | .681 |
| PS | 9103.86 | 6 | 1517.31 | |
| MS | 12594.21 | 3 | 4198.07 | 8.153 * |
| RS | 9654.46 | 57 | 169.38 | 1.880 |
| PMR | 12225.17 | 38 | 321.72 | |
| PMS | 3089.62 | 6 | 514.94 | |
| PRS | 10270.95 | 114 | 90.10 | |
| MRS | 8117.39 | 57 | 142.41 | 1.288 |
| PMRS | 12604.23 | 114 | 110.56 | |

* p < .05
** p < .01

Table C-5

Percentage of Track Time on EHSI
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 6818.57 | 2 | 3409.29 | |
| Motion (M) | 4743.41 | 1 | 4743.41 | 1.993 |
| Replic (R) | 3194.79 | 19 | 168.15 | 1.701 |
| Segment (S) | 133884.60 | 3 | 44628.19 | 32.153 ** |
| PM | 4760.95 | 2 | 2380.48 | |
| PR | 3756.96 | 38 | 98.87 | |
| MR | 4399.81 | 19 | 231.57 | 2.048 |
| PS | 8328.02 | 6 | 1388.00 | |
| MS | 10741.09 | 3 | 3580.36 | 6.840 * |
| RS | 5626.33 | 57 | 98.71 | 1.685 |
| PMR | 4296.34 | 38 | 113.06 | |
| PMS | 3140.52 | 6 | 523.42 | |
| PRS | 6678.22 | 114 | 58.58 | |
| MRS | 5699.76 | 57 | 100.00 | 1.515 |
| PMRS | 7523.56 | 114 | 66.00 | |

* $p < .05$
** $p < .01$

APPENDIX D

Experiment 3:

Analysis of Variance Summary Tables

Table D-1

Mean Fixation Time (7 Pilots)
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 20822840. | 6 | 3470473. | |
| Motion (M) | 6803758. | 2 | 3401879. | 12.294 ** |
| Replic (R) | 5487291. | 14 | 391949. | 1.387 |
| PM | 3320490. | 12 | 276707. | |
| PR | 23741210. | 84 | 282633. | |
| MR | 6312258. | 28 | 225438. | 1.108 |
| PMR | 34174140. | 168 | 203417. | |

** p < .01

Table D-2

Mean Fixation Time (3 Non-Pilots)
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 790398.5 | 2 | 395199.2 | |
| Motion (M) | 1536934.0 | 2 | 768467.0 | 7.791 * |
| Replic (R) | 1451148.0 | 14 | 103653.4 | 2.023 |
| PM | 394544.6 | 4 | 98636.1 | |
| PR | 1434457.0 | 28 | 51230.6 | |
| MR | 1368251.0 | 28 | 48866.1 | .962 |
| PMR | 2845317.0 | 56 | 50809.2 | |

* $p < .05$

Table D-3

New Fixation Latency
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 13835320. | 6 | 2305887. | |
| Motion (M) | 1709822. | 2 | 854911. | 2.332 |
| Replic (R) | 5371322. | 14 | 383665. | .838 |
| PM | 4398613. | 12 | 366551. | |
| PR | 38476840. | 84 | 458058. | |
| MR | 10225950. | 28 | 365212. | .746 |
| PMR | 82237620. | 168 | 489510. | |

Table D-4

Initial Control Movement Latency
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
| --- | --- | --- | --- | --- |
| Pilot (P) | 22991880. | 6 | 3831979. | |
| Motion (M) | 309922. | 2 | 154961. | 2.036 |
| Replic (R) | 1990845. | 14 | 142203. | 1.435 |
| PM | 913287. | 12 | 76107. | |
| PR | 8326197. | 84 | 99121. | |
| MR | 1703831. | 28 | 60851. | .633 |
| PMR | 16150790. | 168 | 96136. | |

Table D-5

Control Activity "Plateaus"
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 6785.949 | 6 | 1130.992 | |
| Motion (M) | 281.187 | 2 | 140.594 | 1.273 |
| Replic (R) | 825.511 | 14 | 58.965 | 1.815 |
| PM | 1325.479 | 12 | 110.457 | |
| PR | 2729.289 | 84 | 32.492 | |
| MR | 948.717 | 28 | 33.883 | 1.655 |
| PMR | 3439.282 | 168 | 20.472 | |

Table D-6

Control Activity Time Measure
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 199943.8 | 6 | 33323.97 | |
| Motion (M) | 8913.2 | 2 | 4456.62 | 1.871 |
| Replic (R) | 15412.3 | 14 | 1100.88 | .582 |
| PM | 28577.9 | 12 | 2381.49 | |
| PR | 158905.1 | 84 | 1891.73 | |
| MR | 63966.8 | 28 | 2284.53 | 1.562 |
| PMR | 245686.7 | 168 | 1462.42 | |

Table D-7

Control Activity Rate Measure
ANOVA Summary Table

| Source of Variation | Sum of Squares | df | Mean Square | F Ratio |
|---|---|---|---|---|
| Pilot (P) | 3304427. | 6 | 550737.8 | |
| Motion (M) | 197901. | 2 | 98950.8 | 1.866 |
| Replic (R) | 555149. | 14 | 39653.5 | 2.598 |
| PM | 636347. | 12 | 53028.9 | |
| PR | 1282190. | 84 | 15264.2 | |
| MR | 363373. | 28 | 12977.6 | .978 |
| PMR | 2230209. | 168 | 13275.1 | |

# VITA

James Raymond Comstock, Jr. 6/84

PERSONAL DATA:

| | |
|---|---|
| Birthdate: | November 13, 1953 |
| Married: | March 5, 1977, to Ellen Garrett Warren |
| Child: | February 18, 1983, Patrick Warren Comstock |

EDUCATION:

| | | |
|---|---|---|
| B.A. | 1976 | College of William and Mary, Williamsburg Virginia |
| M.S. | 1980 | Old Dominion University, Norfolk, Virginia General/Experimental Psychology |
| Ph.D. | 1983 | Old Dominion University, Norfolk, Virginia Industrial/Organizational Psychology |

PRESENT APPOINTMENT:

| | |
|---|---|
| Feb. 1984 - present | Research Assistant Professor<br>Department of Psychology<br>Old Dominion University, Norfolk, Virginia<br>20% Teaching, 80% Research at NASA Langley Research Center (NASA Grant NAG-1-451) |

EXPERIENCE:

| | |
|---|---|
| July 1981 - Sept. 1983 | NASA Graduate Student Researchers Program<br>Langley Research Center, Hampton, Virginia<br>(NASA Grant NGT 47-003-800) |
| 1982 - 1983 | Instructor: Department of Psychology<br>Old Dominion University, Norfolk, VA |
| 1980 - 1983 | Statistical Consultant and Data Analyst<br>Department of Special Services<br>Portsmouth Public Schools, Portsmouth, VA |
| 1980 - 1981 | Graduate Teaching Assistant, Department of Psychology, Old Dominion University |
| 1979 - 1980 | Master's Thesis: "The effect of tone frequency spacing on perception of order in repeating tone sequences." |
| 1978 - 1979 | Research Assistant, Performance Assessment Laboratory, Old Dominion University |
| 1976 - 1978 | Rehabilitation Counselor, Drug Treatment Clinic<br>Portsmouth Health Department, Portsmouth, VA |

PROFESSIONAL MEMBERSHIP:

Tidewater Chapter, Human Factors Society (THF)
Human Factors Society (HFS)
Virginia Psychological Association (VPA)
Southeastern Psychological Association (SEPA)
Southern Society for Philosophy and Psychology (SSPP)
Association of Aviation Psychologists (AAP)

PROFESSIONAL ORGANIZATION ACTIVITIES:

Chair: Audio/Visual Subcommittee for the October 1983 Annual Meeting of the Human Factors Society, Norfolk, Virginia.

Secretary-Treasurer: Tidewater Chapter, Human Factors Society Elected to the position for 1983.

Editor: Newsletter, Tidewater Chapter, Human Factors Society 1982-1983.

Judge: Virginia Junior Academy of Science - 1981 Psychology Division, Norfolk, Virginia

PAPERS, MANUSCRIPTS, AND PRESENTATIONS:

Comstock, J. R., Jr. Oculometric indices of simulator and aircraft motion. NASA Contractor Report 3801 (NASA Grant NGT 47-003-800), June 1984.

Spady, A. A., Jr., Harris, R. L., Sr., Comstock, J. R., Jr. Flight versus simulator scan behavior. Proceedings of the Second Symposium on Aviation Psychology, Columbus Ohio, April 25-28, 1983.

Comstock, J. R., Jr. Perception of order in repeating tone sequences: The effect of frequency spacing. Paper presented at the Seventy-Fourth Annual Meeting of the Southern Society for Philosophy and Psychology, Fort Worth, Texas, April 1982.

Comstock, J. R., Jr. The effect of tone frequency spacing on perception of order in repeating tone sequences. Unpublished Master's Thesis, August 1980.

DeBiasi, G. L., Comstock, J. R., Jr., & MacKinnon, C. E. Determinants and Consequences of Student Motivation. Paper presented at the Southern Society for Philosophy and Psychology, Norfolk, Virginia, April 1979. Abstract appears in College Student Personnel Abstracts, 15(4), 1980.

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August 13, 1984

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Sincerely yours,

J. Raymond Comstock Jr.

J. Raymond Comstock, Jr., Ph.D.