THE EFFECT OF STATIONARY AND HEAD-DRIVEN FIELD-OF-VIEW SIZES ON POP-UP WEAPONS DELIVERY

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ABSTRACT

It is commonly believed that flight simulators capable of supporting tactical combat tasks should possess full field-of-view visual displays with high levels of brightness and resolution. The problem of designing such a visual system is that the three factors (field-of-view, brightness, resolution) are not independent. For instance, as field-of-view is increased brightness and resolution decrease. An attempt to overcome this dilemma uses head-driven visual displays with limited instantaneous field-of-view. Head-driven systems overcome the full field-of-view problem by providing a full field-of-regard for the head-driven instantaneous field-of-view. Important considerations for head-driven systems are the horizontal and vertical dimensions of the instantaneous field-of-view. This study examines the effect of the instantaneous field-of-view size on pilots' ability to perform pop-up weapons deliveries using both stationary and head-driven visual displays. The field-of-view sizes used were 127°H by 36°V, 160°H by 80°V, 160°H by 88° V, and 180°H by 88°V. A 300°H by 150°V size provided a full FOV control condition. An A-10 dodecahedron simulator configured with a seven window color light valve display, computer generated imagery, and a Polhemus magnetic head tracker provided the cockpit and display apparatus. Aircraft performance measures (altitude, airspeed, etc.) and head position data were the dependent measures. Ten F-5 instructor pilots from Williams AFB Arizona served as subjects for the study. The results did not confirm initial hypothesis that performance would be better for head-driven conditions and larger fields-of-view. This may be due to an increased use of instruments in the smaller field-of-view conditions to maintain performance levels. This conclusion is difficult to verify, because no eye position data is available. However, it is clear that the smallest condition (127°H X 36°V) is inadequate to support training.

INTRODUCTION

The design of current flight simulator visual systems must take into account the interaction between field-of-view size, brightness, and resolution in order to ensure training effectiveness. The final design of a visual system depends on the type of task to be trained and level of image detail needed. For example, a simulator designed to train low level flight may need a full field-of-view visual display and high levels of brightness and resolution so that pilots can determine altitude or locate objects on the surface. The task of designing such a system is difficult because as field-of-view size increases, brightness and resolution decrease. Researchers, designers, and engineers must determine what levels of the three variables effectively meet the training requirements. Three approaches that have been investigated are head-slaved display systems with instantaneous field-of-view sizes, full field-of-view domes or window based displays, and limited field-of-view domes or window based displays.

The first research involving the use of an instantaneous FOV was in 1976 (Hutton, Burke, Englehard, Wilson, Rumaglia, and Scheider, 1976). The objective of this research was to determine if a head-slaved instantaneous field-of-view display could help satisfy full FOV requirements for air-to-surface tasks. The results of this study revealed that a 60° horizontal instantaneous field-of-view is inadequate for air-to-surface tasks and further experimentation was needed to determine the effects of such systems on pilot performance.(3)

One of the main questions to be addressed is what horizontal and vertical dimensions are needed for the instantaneous FOV size. This question can be addressed by systematically changing the instantaneous FOV size for a number of tasks and determining its effect on pilot performance and/or head movement. Air-to-ground tasks have received the most attention with respect to experimental studies to determine instantaneous FOV size. LeMaster and Longridge (1978) examined the effects of various FOV sizes on conventional gunnery range weapons delivery in a tactical environment. The results indicated that a head-driven instantaneous FOV size as small as 90°H X 70°V could be used without seriously degrading performance.(4) Another research effort conducted by Warner (1981) investigated instantaneous FOV size in conjunction with a visual overlap field (high resolution inset). The results of Dr Warner's study found that a 80°H X 66°V head-driven instantaneous FOV with a 20° visual overlap area did not adversely effect 30° manual dive bombing performance. Other findings included that horizontal head movement decreased as the instantaneous FOV increased. The increased horizontal head movement in the smallest FOV conditions is thought to be associated with pilots compensating for the lack of peripheral information in the smallest conditions. The above studies indicate that head-slaved FOV systems can be effectively used to perform high angle (30°) weapons delivery with an instantaneous FOV size of 80°H X 66°V.(5)

Low level flight is another important tactical task that may benefit from head-slaved systems. Hughes and Hubbard (1985) performed a study in which subjects were instructed to fly as low as they safely could through a marked route. Two instantaneous FOV conditions and a full FOV condition (300°H X 150°V) were tested using performance measures. The results indicate that altitude during turns was significantly affected when the peripheral information was occulded. The authors concluded that a head-slaved system is an effective option for various tasks, but control performance may be affected for those tasks that require a high degree of aircraft maneuvering.(2) Another effort performed by Dixon, Krueger, Rojas, and Hubbard (1989) examined the effects of head-slaved instantaneous FOV size on low level flight and 30° manual dive bombing tasks. The results indicated that larger instantaneous FOV sizes may be needed for skill acquisition applications and as the instantaneous FOV size was increased pilots needed fewer trials to reach criterion level of performance. The implications from the research presented above suggest that further research is needed using both inexperienced and experienced pilots on a number of different tasks.(1)

The present study attempts to further define instantaneous FOV size requirements for a previously unexamined task (pop-up weapon delivery). The study used both head-slaved FOV's and static FOV's to determine the relationship between the various configurations. The selected FOV sizes are based on current stationary FOV dimensions and proposed helmet-mounted FOV dimensions. The results of the study should provide a clearer understanding of performance differences between static and head-driven FOV's and differences with respect to head movement.

The pop-up weapons delivery was selected due to its unique flight pattern and requirement for out-of-the-window visual cues. The basic pop-up is illustrated in Figure 1. It involves a low level approach to a pull-up point selected on the basis of target position. At the pull-up point, a climb angle is established that will allow the pilot to gain enough altitude to acquire the target and set up the bomb run. At the appropriate altitude, the pilot rolls in on the target, apexes, rolls out, establishes the correct dive angle, and flies the aircraft to the release point. After delivering the ordinance, the pilot takes evasive action to avoid ground threats and returns to low level. The purpose of the pop-up is to minimize the amount of time that a pilot is vulnerable to ground threats. One consideration that made the pop-up delivery desirable for the study was the requirement to use the vertical dimension of the field-of-view during rolling phases to locate the target. Correct performance of this maneuver requires both instruments and out-of-the-window visual cues. The task can be performed with reliance on instruments, if necessary.

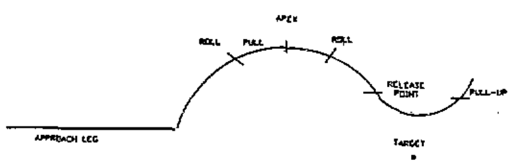

FIGURE 1: POP-UP WEAPON DELIVERY PROFILE

Objective

The objective of this effort was to determine the pilot performance and head movement tradeoffs for display type (head-tracked systems and stationary display systems) and various FOV sizes. Based on prior studies, we felt that as FOV size increases 1) performance would be closer to the ideal flight parameters, 2) head movement would decrease, and 3) head-driven displays would produce superior performance.

Method

Subjects

Ten F-5 instructor pilots from the 425th Tactical Fighter Training Squadron at Williams AFB, Arizona, participated in the study. The mean total number of flight hours was 1982, with a range of 1000 - 4500.

Apparatus

This research effort was conducted in an A-10 Dodecahedron simulator which provides computer-generated imagery for out-of-the-window visual cues. The field of regard for this simulator is 300°H and 150°V. The visual system produces day, dusk, and night scenes through seven channels with seven color light valves on seven 36" windows. The Advanced Visual Technology System (comparable to Compuscene IV) image generator is capable of producing approximately 8000 faces and 2000 point features simultaneously. Additional features include a resolution of six arc minutes, an average brightness of two foot lamberts, a full color display, and cell texturing.

The imagery can be electronically masked and a Polhemus magnetic head-tracker used to move the masked out display thus providing various FOV sizes for research purposes. The head tracker uses a 3-space system to compute gaze position and angle outputs. The four field-of-view sizes and the simulator field of regard are shown in Figure 2.

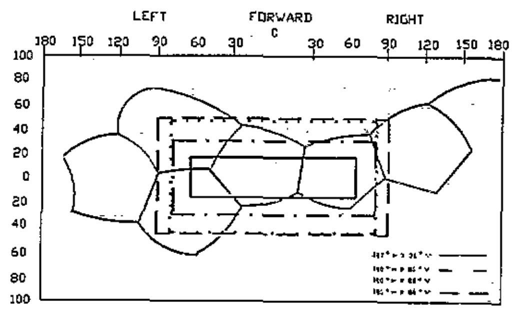

FIGURE 2: INSTANTANEOUS FIELD-OF-VIEW SIZES

Experimental Design

This study was a full factorial, within subjects, repeated measures design. The independent variables were field-of-view size, whether the FOV was head-driven or static, and initial headings.

The five instantaneous and stationary FOV sizes are as follows:

a. 127^{o}H x 36^{o}V
b. 160^{o}H x 80^{o}V
c. 160^{o}H x 88^{o}V
d. 180^{o}H x 88^{o}V
e. 300^{o}H x 150^{o}V

The field-of-regard was 300^{o}H x 150^{o}V for the instantaneous FOV sizes and control conditions. The 300^{o}H x 150^{o}V was repeated to give 10 display type conditions.

The dependent variables included missed distance, flight parameters (i.e., altitude, airspeed, bank angle) and head movement variables (head pitch, head yaw, head roll).

Procedure

Each pilot was given a handout describing the parameters and headings for the pop-up trials. The experimenter also went through the handout with the subjects and answered any questions concerning the task.

The pilots were given five minutes to familiarize themselves with the A-10 cockpit configuration and the simulator's flight characteristics. Following the orientation, each subject performed five practice pop-up trials; one at each initial condition point with the 300^{o}H x 150^{o}V FOV.

During the test portion, the subjects performed 50 pop-up trials. The trials were randomly selected from the 10 possible FOV conditions and five initial conditions until all combinations were completed.

Data Analysis

For analysis purposes the data were analyzed by mission segment. The approach, pull-up to roll 1, roll 1 to apex, apex to roll 2, release point, and bomb impact point comprised the six parts examined. The segments were defined by states of the aircraft parameters. The files were separated into discrete data at the break points and continuous data collected at a 10 hertz update rate. The discrete data were used for bomb score analysis and deviations from ideal parameters. The continuous data were used to calculate the Root Mean Squares for head pitch, head roll, and head yaw. The data were analyzed using the SAS GLM program.

RESULTS

Bombing Score Error

There were no significant effects ($p > .05$) noted for miss distance as a function of FOV size, display type, or the FOV size by display type interaction. The mean bombing error for each FOV size in conjunction with display type (stationary or head-driven) is plotted in Figure 3. The plot displays the associated changes in bomb score as both the horizontal and vertical field is varied. The best scores were obtained in the 160^{o}H X 60^{o}V stationary FOV and the 180^{o}H X 88^{o}V head driven instantaneous FOV. Although there were no significant effects, the relationship between stationary and head-driven conditions is better performance in the static states except for the 180^{o}H X 88^{o}V head-driven condition.

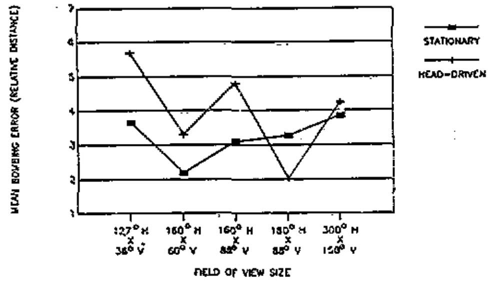

FIGURE 3: BOMBING ERROR AS A FUNCTION OF FIELD-OF-VIEW AND DISPLAY TYPE

RMS Head Movement

Significant effects were found for head roll, head pitch, head yaw in the various segments for FOV size. The most consistent effects were found for RMS of head pitch. This effect can be attributed to the large differences between the smallest static FOV (127^{o}H X 36^{o}V) condition and the remaining conditions. The smallest static FOV condition displayed significantly less degrees of movement. For conditions greater than 127^{o}H X 36^{o}V RMS head pitch was essentially identical. Other effects found for RMS head roll and RMS head yaw occurred in the pull-up and roll segments and followed the same trend as RMS head roll. Figure 4 shows an example of the head movement data with respect to head pitch.

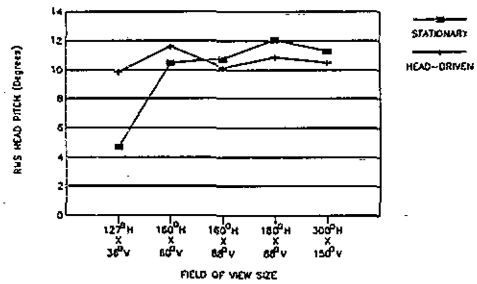

FIGURE 4: RMS HEAD PITCH FOR PULL-UP SEGMENT

Deviations from Ideal Parameters

The deviations from ideal were collected at various points along the flightpath. These points were pull-up, roll 1, apex, roll 2, and bomb release. None of the independent variables significantly affected the pull-up point. At the first rolling point, FOV size effects were found for airspeed, altitude, and roll rate. Other FOV size effects were found at apex (altitude, yaw rate), roll 2 (roll rate), and release (pitch). Table 1 displays the means for these effects by FOV size.

FIELD-OF-VIEW SIZES	126°H X 36°V	160°H X 60°V	160°H X 88°V	180°H X 88°V	300°H X 150°V
VARIABLES					
ROLL 1					
AIRSPEED	3.01	-1.55	[0.15]	-0.62	-1.55
ALTITUDE	-110.13	43.22	20.40	28.91	[15.08]
ROLL RATE	10.59	-6.38	-1.56	-2.50	[0.64]
APEX					
ALTITUDE	70.42	[-13.89]	-32.08	15.83	-44.42
YAW RATE	1.50	-0.48	-0.27	[-0.25]	-0.52
ROLL 2					
ROLL RATE	5.22	4.04	-3.61	[-2.37]	-3.64
BOMB RELEASE POINT					
PITCH	-0.63	0.04	[0.00]	-0.10	0.71

TABLE 1: SIGNIFICANT EFFECTS FOR DEVIATIONS FROM IDEAL PARAMETERS BY MISSION SEGMENT

[ ] INDICATES BEST PERFORMANCE

Display type (static vs head-driven) effects were found at apex for yaw rate, angle-of-attack, and G's. Table 2 displays the means for the display type effects. Three size by movement interactions were noted at roll 1 (roll rate), apex (pitch) and release (roll rate).

DISPLAY TYPE	STATIONARY	HEAD DRIVEN
VARIABLES		
APEX		
YAW RATE	-0.39	0.39
AOA	0.19	-0.19
G	0.09	-0.09

TABLE 2: SIGNIFICANT DISPLAY TYPE EFFECTS FOR DEVIATIONS FROM IDEAL PARAMETERS BY MISSION SEGMENT

CONCLUSIONS

The purpose of the present study was to compare various instantaneous field-of-view sizes against stationary field-of-view sizes of the same dimensions. It was anticipated that performance differences would be found between display type (stationary and head-driven) and size. The effect of field-of-view size was found more frequently than effects for display type or the FOV size by display type interaction. The effects found for FOV size have more statistical significance than practical significance. However, the significant differences associated with RMS of head movement in the smallest FOV condition indicate that head movement is related to FOV size and display type. The authors believe that this suggests the pilots are relying more on instruments in conditions where appropriate information is not available. This is most evident in the smallest stationary FOV size (127°H X 36°V). In this condition, there is significantly less head movement and the head is remaining relatively stationary (See Figure 4). It is difficult to draw conclusions on the remaining conditions because the changes are not statistically significant. The importance of the differences in head movement behavior is unknown at this time. Overall, the results show that pilots can quickly adapt to the various configurations and perform equally well whether or not the FOV is moving or stationary except in the smallest stationary FOV.

The pilots that served as subjects in this experiment were highly experienced in performing the selected task. Presumably, the manner in which they performed the task in the full FOV condition was much the same as would be performed in the aircraft. The use of head position data allows us to directly assess head movement in all FOV conditions. The results of this data show that head movement remained relatively constant between all conditions except the smallest FOV size. This size (127°H X 36°V) showed significant differences with respect to stationary or moving FOV for head movement variables and flightpath deviations. Therefore, this FOV size is unacceptable for performing pop-up weapons delivery. Other conclusions based on results suggest that the pop-up weapons delivery could be performed in FOV sizes as small as 160°H X 60°V without serious detriments to flightpath adherence or bomb scores. A further conclusion is that head-tracked FOV systems can be used in the performance of air-to-ground maneuvers.

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