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WEAPONS DELIVERY TRAINING: EFFECTS OF SCENE CONTENT AND FIELD OF VIEW

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13. ABSTRACT (Maximum 200 words)

Two of the issues faced by designers of modern high-performance aircraft simulators are: (a) the level of visual scene realism required to adequately train complex tasks within the simulator; and (b) the field of view (FOV) required for such training. The experiment described in this paper was designed to study both of these problems as they relate to the training of manual dive bombing in the F-16 aircraft. The experiment was performed in two separate simulators using the same visual image generators and data base. The first simulator was a Fiber Optic Helmet-Mounted Display (FOHMD) System with a full 360-degree field of regard; the second used wide-angle collimated (WAC) windows to provide a more restricted FOV. Subjects with no previous fighter aircraft experience were trained to perform 10°, 20°, and 30° dive bomb attacks on either a simulated bombing range, a low-detail airfield target scene, or a high-detail simulation of the same scene. The transfer/test condition was a different high-detail airfield scene.

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This publication is primarily a working paper. It is published solely to document work performed.

SUMMARY

An experiment was conducted to determine the effects of simulator scene content and field of view on the acquisition of manual dive bombing skill. These factors directly affect the cost of a visual system. A higher scene content requires additional computer capacity, whereas a larger field of view requires larger displays and a more expensive image generator.

Thirty-six T-38 instructor pilots performed manual dive bombing tasks at 10°, 20°, and 30° dive angles using two different field-of-view configurations and three levels of scene content. After reaching a criterion level of performance for each dive angle, subjects were tested on a high-detail scene. Analyses showed that performance was closer to the desired flight profile for shallower dive angles, higher scene content, and wider fields of view. Therefore, for tasks requiring a close adherence to a flight profile, a full field of view and a high level of scene content should be considered requirements by simulator designers.

Further testing is needed to validate these results on a variety of tasks with varying levels of scene content and differing fields of view to verify that the conclusions can be generalized across all tasks. Future testing involving investigations into aircraft transfer should be planned.

PREFACE

The present effort was conducted in support of the Air Force Human Resources Laboratory's Research Planning Objective 4.2, Simulator Component Research and Development. The goal of this program is to develop guidelines for visual systems designers and users. This experiment was conducted under work unit 1123-32-04, Field-of-View Requirements.

The goal of this experiment was to determine if varying scene content and field of view would affect performance on manual dive bombing. Results showed that performance was better for those conditions that used a larger field of view and a higher level of scene content.

The authors would like to thank Roseann Perchinelli for graphic support and the 82 FTW from Williams AFB, Arizona, for providing the pilots who served as subjects for the experiment.

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I. INTRODUCTION

The simulator can provide an ideal training ground for a wide variety of piloting tasks. In years past, the tasks considered for simulator training fell mostly in the realm of procedures training, cockpit layout familiarization, and basic contact/transition skills. As flight simulators have become more complex and visual image generators more powerful, many new and previously unconsidered tasks can be trained in the simulator. For many such tasks, the simulator may prove to be a better initial trainer than the actual aircraft, particularly for those tasks involving large amounts of set-up time or high degrees of risk. An ideal task for such training is precision ground attack, for the actual aircraft can carry only a limited number of practice bombs and each pass requires considerable positioning time.

If such tasks are to be trained within the simulator, two questions are of major importance: (a) How much detail must the visual scene contain? (b) What size field of view (FOV) does the pilot require to perform the task? More complex visual scenes require powerful and expensive image generators. Full-FOV systems (360° Horizontal x > 150° Vertical) are much more complex and approximately five times as expensive as those with more limited fields of view. Using a minimal, yet effective, capability for simulators is important for cost savings in both acquisition and maintenance.

II. BACKGROUND

Scene Content

Investigations of scene content variables and their effects on pilot performance are relatively few in number, and for the most part have concentrated on approach and landing and low-altitude flight. Buckland, Monroe, and Mehrer (1980) placed checkerboard textural patterns of various sizes directly on a simulated runway. Increased texture density in the simulator display produced greater control of the aircraft at touchdown, as indicated by slower vertical velocity, less displacement from the centerline, and touchdown closer to the desired touchdown point. Kraft, Anderson, and Elsworth (1980) evaluated the effects of a complex visual scene which included peripheral cues located adjacent to the runway. The complex scene resulted in less vertical deviation from the glideslope for straight-in approach segments, and less lateral deviation from the centerline at touchdown. Additional research performed by Westra, Simon, Collyer, and Chambers (1981, 1982) suggested that performance is enhanced in the approach and landing segments of simulated flight when additional cues are presented. It seems that further increases in scene complexity--particularly vertical object development along the approach and landing path--would result in further improvement in performance of this type of task.

Another task that has shown performance improvement with vertical objects in the simulator scene is low-level flight. Martin and Rinalducci (1983) used three terrain cue configurations: (a) all black, inverted 35-foot-high tetrahedrons; (b) inverted tetrahedrons of the same type, with black bottoms and white tops; and (c) flat, white triangles (of the same density as the cues in conditions (a) and (b)) placed directly on the ground. The study showed that pilots performed closer to the ideal flight path with cues that had vertical development. Another simulator study of low-level flight was performed by Buckland, Edwards, and Stephens (1981), who examined the effect of vertical cues and checkerboard textural patterns on flight performance. Their results showed less deviation from the ideal flight parameters for those conditions involving vertical objects or textural cues.

Another interesting study was performed by Westra et al. (1985), who investigated the effect of scene content on performance for carrier landings and 30° dive bombing attacks. They manipulated the scene content, using a simulated day carrier scene for the high-detail condition and a simulated night carrier scene for the low-detail condition. They found no significant difference in transfer of training to the aircraft between individuals trained with the high-detail scene and those trained with the low-detail scene. These findings suggest that a low-detail scene could be used to train Navy pilots for carrier landings. Lintern, Thomley-Yates, Nelson, and Roscoe (1987) employed the same approach to study 30° dive bombing attacks. He used a complex day scene--a bombing range with vertical objects--for the high-detail condition, and a dusk scene--a bombing range with fewer terrain features--for the low-detail condition. The experiment found no significant performance differences in the simulator between the two conditions; however, he alluded to methodological problems in the comparisons that may have confounded the data.

Objective - Scene Content

The present experiment was concerned primarily with the addition of two- and three-dimensional cues of known size to an otherwise simple scene. All three of the data bases used irregular texturing to represent fields and other ground cues. The low- and high-detail training data bases included two-dimensional objects representing airport runways and three-dimensional cues representing associated structures. The high-detail testing data base used essentially the same two- and three-dimensional cues as did the high-detail training data base (see Figures 1 through 4).

Figure 1. **Standard Air Force Gunnery Range.**

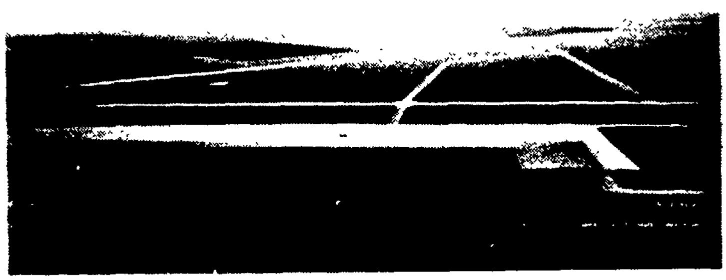


Figure 2. **Training Condition: Low-Detail Representation of Standard Air Force Runway (Cannon AFB, NM).**

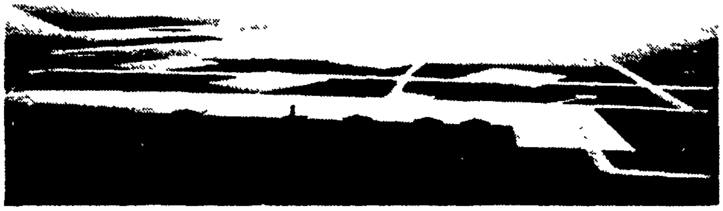


Figure 3. **Training Condition: High-Detail Representation of Standard Air Force Runway (Cannon AFB, NM).**

Figure 4. **Test Condition: High-Detail Representation of Standard Air Force Runway (China Lake NAS, CA).**

Field of View

For the present effort, FOV was defined as the instantaneous field displayed by the system from the pilot's eyepoint; therefore, all FOV dimensions will be defined in degrees, with the pilot's eyepoint considered 0,0.

Many researchers have attempted to define FOV requirements. These early attempts focused almost exclusively on using the aircraft as the primary tool for providing data on FOV requirements (Weaver, Loikith, & Jordan, 1978), and incorporated either pilot subjective data or video techniques such as mounting in the cockpit a camera that followed the pilot's eye-track (Yeend & Carico, 1978). More recent attempts have focused on using the simulator as the primary research tool.

Early investigations using the simulator as a research tool concentrated on determining the FOV requirements for straight-in takeoffs and landings using experienced pilots. The results of such investigations were summarized by Collyer, Ricard, Anderson, Westra, and Perry (1980) as follows: Safe and acceptable takeoffs and landings can be performed in the simulator using various FOV configurations (e.g., with dimensions of 10° horizontal by 10° vertical, 21.5° horizontal by 21.5° vertical, and 5.7° horizontal by 30° vertical). The most important findings were that the FOV configurations used were significantly smaller than those that were currently being used in simulation and that these configurations could be used successfully.

Other early FOV research investigated the use of simulators for training basic contact maneuvers, as an alternative for Undergraduate Pilot Training since fuel and aircraft costs had risen considerably. Several studies (Irish, Grunzke, Gray, & Waters, 1977; Irish & Buckland, 1978; Nataupsky, Waag, Weyer, McFadden, & McDowell, 1979) explored basic contact maneuvers such as aileron rolls, barrel rolls, and the 360° overhead (OVHD) landing pattern. In the three studies above, FOV was used as an independent variable in conjunction with various other environmental factors. These studies showed that FOV requirements are extremely maneuver-specific, but that maneuver performance improved in the simulator as the FOV increased.

The significant technological advances of the last decade in simulator design and visual display technology have driven FOV research toward defining more complex tasks to be accomplished in the simulator (e.g., air-to-ground attacks, aerial refueling, carrier landings, and close air support). A number of studies (Collyer et al., 1980; Hughes & Brown, 1985; Westra et al., 1981, 1982; Wightman & Chambers, 1985) have examined the effect of various FOV configurations on experienced pilots for each of these maneuvers. Each has shown that a smaller FOV than that of the actual aircraft could be used by experienced pilots to practice these tasks. Significant results of these investigations were summarized by Wiekhorst and Vaccaro (1986) as follows: (a) Flying tasks can be performed in the simulator with a limited field of view (LFOV) or area-of-interest, and (b) the FOV requirement is very task-specific. Future FOV research should concentrate on in-simulator transfer-of-training studies using inexperienced pilots and larger sample sizes than those employed in previous efforts.

The present investigation examined the effects of FOV on skill acquisition and in-simulator transfer. The study employed two display media: a wide-angle collimated (WAC) window display and a Fiber Optic Helmet-Mounted Display (FOHMD). The WAC windows provided a 125° Horizontal (H) by 30° Vertical (V) fixed FOV (see Figure 5). The FOHMD provided a 126° H x 60° V instantaneous FOV and nearly a full 360° field of regard (see Figure 6).

III. METHODOLOGY

Hypothesis

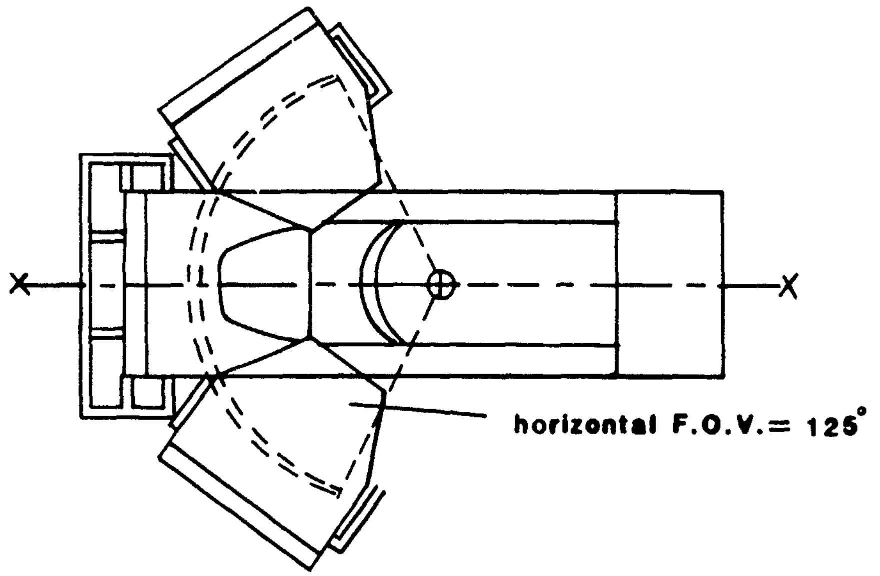
The overall hypothesis for the present research was that increased scene content and FOV size would significantly affect performance on manual dive bombing tasks in the simulator. A secondary hypothesis was that the use of familiar objects (taxiways, aprons, and runways) would also improve manual dive bombing task performance.

Subjects

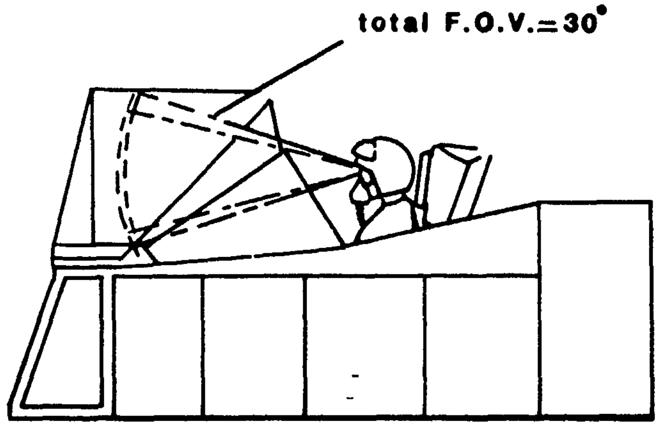
Thirty-six Air Force pilots with high performance ratings in Fighter/Attack/Reconnaissance (FAR) aircraft were used as subjects. None of the subjects had previous flight experience in the F-16 aircraft or previous dive bombing experience. All were currently flying the Northrop T-38 aircraft, a supersonic jet trainer.

Apparatus

The present investigation was conducted in an F-16C flight simulator with two visual display systems. The first was a window-type display using three wide-angle collimated (WAC) windows with an approximate field of view of 125° horizontally and 30° vertically. The second display was a Fiber Optic Helmet-Mounted Display (FOHMD) which allowed an unrestricted field of view in all directions (cockpit, wings, nose, and tail were computer-masked) and an instantaneous FOV of 126° horizontally and 60° vertically, with the only restricted visual area being that occupied by the simulated aircraft itself. Imagery in both cases was provided by a Singer-Link Digital Image Generation System (DIGS). Identical data bases were used under both of the display conditions. The cockpit itself was fully instrumented, with the head-up display (HUD) targeting system set for the manual bombing mode. All information necessary to perform the dive bombing tasks (dive angle, airspeed, g-factor, altitude, flight path marker, targeting reticle, and compass heading) was presented to the subject in the HUD, thus lessening the distraction caused by having to perform complex cross-checks with an unfamiliar cockpit layout.



(A) Plan view of display heads showing F.O.V. .



(B) Cross-section through x-x showing vertical F.O.V. .

Figure 5. **WAC Window Field-of-View Size.**

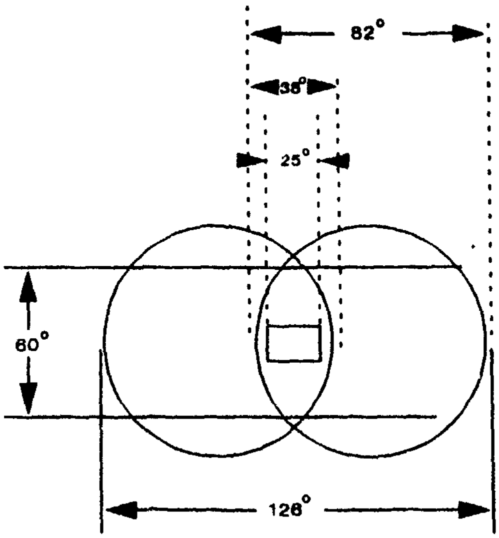


Figure 6. **FOHMD Instantaneous Field-of-View Size.**

Experimental Design

This study employed a mixed design (see Scheffe, 1959, Chapter 8). Each subject received one of three scene content conditions, one of two FOV sizes, and one of six presentation orders. Independent variables and their treatments were as follows:

1. Field of View:

   (a) WAC Window (125° x 30°)
   (b) FOHMD (360° field of regard)

2. Scene Content (Data Base):

   (a) Low-Detail Bombing Range
   (b) Low-Detail Airfield
   (c) High-Detail Airfield

3. Dive Angle:

   (a) 10°
   (b) 20°
   (c) 30°

4. Presentation Order:

   (a) 10°, 20°, 30°
   (b) 20°, 30°, 10°
   (c) 30°, 20°, 10°
   (d) 30°, 10°, 20°
   (e) 20°, 10°, 30°
   (f) 10°, 30°, 20°

The training data bases in this study varied as to the amount of visual information presented to the pilot. The lowest level of detail was a standard Air Force gunnery range with minimal visual information, consisting primarily of a target circle with three down-range distance markers at 600, 1,250, and 2,000 feet. The second data base was a two-dimensional representation of Cannon AFB, New Mexico, including all runways, taxiways, parking aprons, etc. The third data base differed from the second only by the addition of three-dimensional cues around the airfield (buildings, hangars, a control tower, etc.). The target in both of the airfield conditions was located at the intersection of a taxiway and the main runway. (See Figures 1 through 4.) Each subject performed attacks at dive angles of 10°, 20°, and 30°. The order of presentation of these angles was balanced across subjects, with each subject completing all passes at a given dive angle before proceeding to the next. Dive angles were investigated within subjects; data bases, fields of view, and dive angle presentation order were investigated across subjects.

Procedure

Each subject was randomly assigned to one of two visual displays (WAC windows or FOHMD) and one of three levels of scene content. Each subject was given a checklist-driven 1/2-hour briefing on the nature of the experiment and on the techniques for performing a manual dive bomb attack in the F-16 aircraft. This briefing included information on both optimum delivery patterns and parameters, as well as correction factors for variations from optimum. During this briefing, the subject was also familiarized with the HUD and instrument cockpit. Following this, the subject was taken to the simulator and instructed to practice the material he had learned. A practice pass consisted of the simulated aircraft being placed on the base leg of the bombing run 11,800 feet back and 12,000 feet outboard from the target, and initialized at an altitude commensurate with the dive angle to be used in the attack (2,500 feet, 4,500 feet, or 7,000 feet). Ideally, the subject was to maintain straight-and-level flight until reaching a parallel to the target and then make a 90° turn toward the target, rolling out of the turn at the prescribed dive angle. During the dive, he was to accelerate to 450 knots, align the target reticle with the target (bombing circle or tank on runway), and release the bomb at the proper altitude (500 feet, 1,600 feet or 3,000 feet, depending on the dive angle). Figures 7 and 8 show the final leg parameters and ideal flight paths for the various dive angles.

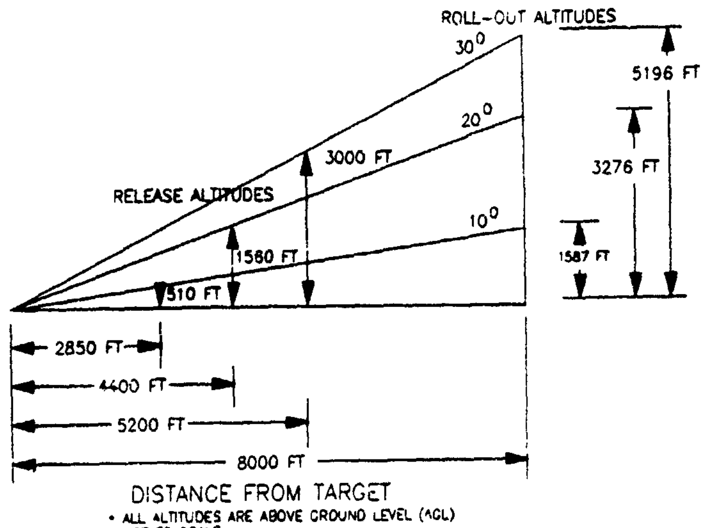


Figure 7. **Final Leg Parameters for Dive Bomb Tasks.**

Following each training pass, verbal feedback was provided to the subject on: how well he had followed the flight profile; bomb miss distance; the angle at which the bomb landed with respect to the target; deviation from ideal release parameters (dive angle, airspeed, and release altitude); and possible corrective actions which might have been taken. The subject continued flying training passes until reaching a criterion level of performance defined as three successive training passes resulting in bombs falling within a specified distance from the target. Once this level of proficiency was attained, the subject was transitioned to a test condition which consisted of a series of six simulated attacks on a second high-detail airfield (China Lake Naval Air Station, California). In this condition, the subject was provided with feedback only on his miss distance and miss angle. Each dive angle was both trained and tested before the subject proceeded to the next dive angle.

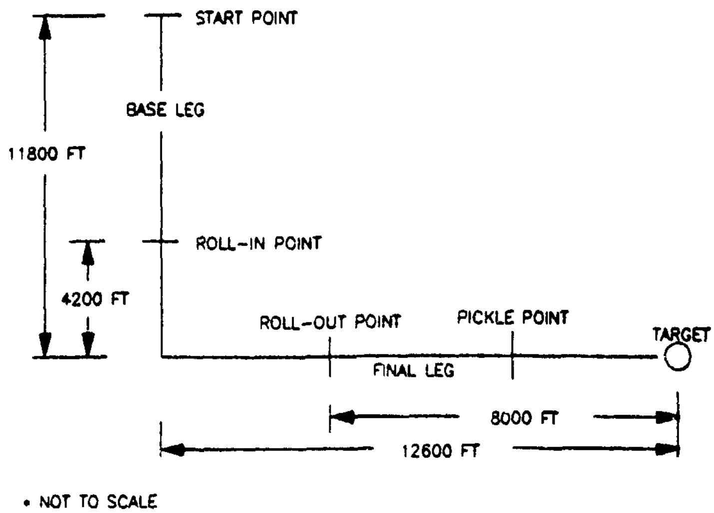


Figure 8. **Ideal Flightpath.**

Data Analysis

Data were initially examined using the SPSSX-MANOVA program. In cases where the Multivariate Analysis of Variance (MANOVA) indicated significant results, the univariate ANOVAs were examined and residuals were analyzed using the RUMMAGE statistical package. With the MANOVA procedure, the Wilks F-statistic was used to determine whether a multivariate effect had reached a significance level of .05. The following comparisons were made: (a) comparison of both of the data bases containing no vertical development (the bombing range and the low-detail Cannon AFB data base); (b) comparison of the two Cannon AFB data bases to determine the effect of adding the three-dimensional cues; and (c) comparison of the bombing range and the high-detail Cannon data base.

Data from the experiment were divided into three categories. The first set included the number of practice trials needed by the subject to reach the required minimum level of proficiency. The second set included data relating to the subject's approach profile during the series of test attacks. The final set was composed of the instantaneous parameters from the aircraft at the moment the bomb was released.

All dependent variables investigated are listed below:

A. Training trials:

1. Total number of training passes across all dive angles.
2. Number of training passes required for 10° proficiency.
3. Number of training passes required for 20° proficiency.
4. Number of training passes required for 30° proficiency.

B. Approach to the target:

1. Mean and standard deviation of roll.
2. Mean and standard deviation of pitch.
3. Mean and standard deviation of g's.
4. Mean and standard deviation of the horizontal flight path error.
5. Mean and standard deviation of the altitude error.
6. Mean and standard deviation of airspeed.

C. Bomb release parameters:

1. Roll.
2. Pitch error.
3. g factor.
4. Horizontal deviation from ideal flight path.
5. Deviation from ideal bomb release altitude.
6. Airspeed.
7. Bomb miss distance.

IV. RESULTS

Comparison I: Bombing Range Versus Low-Detail Cannon AFB

A. Trials Data: No significant effects were noted for any of the training trials metrics.

B. Approach Data: The FOV by dive angle and the data base by dive angle interactions were both significant (F (24,58) = 1.69, p = .050 and F (24, 58) = 1.89, p = .025, respectively), as was the dive angle effect (F (24,58) = 32.80, p = .0005). For the FOV by dive angle interaction, the univariate F-tests showed significant effects in the mean altitude deviation and standard deviation of roll metrics (F (2,40) = 3.87, p = .029 and F (2,40) = 3.42, p = .049, respectively). These data are depicted graphically in Figures 9 and 10. For the data base by dive angle interaction, only the mean altitude deviation metric reached significance (F (2,40) = 4.35, p = .019). This effect is shown in Figure 11. All metrics for the dive angle effect were significant with the exception of mean airspeed and the standard deviation of the horizontal flight path error (see Table 1).

C. Release Data: Analysis of the release data showed significant effects for FOV (F (7,14) = 3.26, p = .028), data base (F (7,14) = 4.90, p = .006), and dive angle (F (14,68) = 10.27, p = .0005). For the FOV effect, the univariate F-tests showed the main effect was in the roll metric and the horizontal flight path error metric (F (1,20) = 6.38, p = .020 and F (1,20) = 9.645, p = .006, respectively). Pilots with limited fields of view exhibited an average of 3° of right roll and were almost 420 feet to the left of the ideal ground track at bomb release, whereas those with full fields of view averaged 2° of left roll and were only 110 feet off track, also to the left. These results are summarized in Table 2. The significant metrics for the data base effects were roll (F (1,20) = 7.25, p = .014), pitch (F (1,20) = 7.75, p = .011), and horizontal deviation (F (1,20) = 6.54, p = .019). Pilots trained on the bombing range averaged 2° of left roll, were pitched 1.7° shallower than optimum, and were 136 feet off and to the left at bomb release. Pilots trained on the low-detail Cannon AFB data base averaged 3° of right roll, .35° of pitch error, and 390 feet of horizontal deviation at this point (see Table 3). For the dive angle effect, all metrics other than roll were significant. Results for this effect are summarized in Table 4.

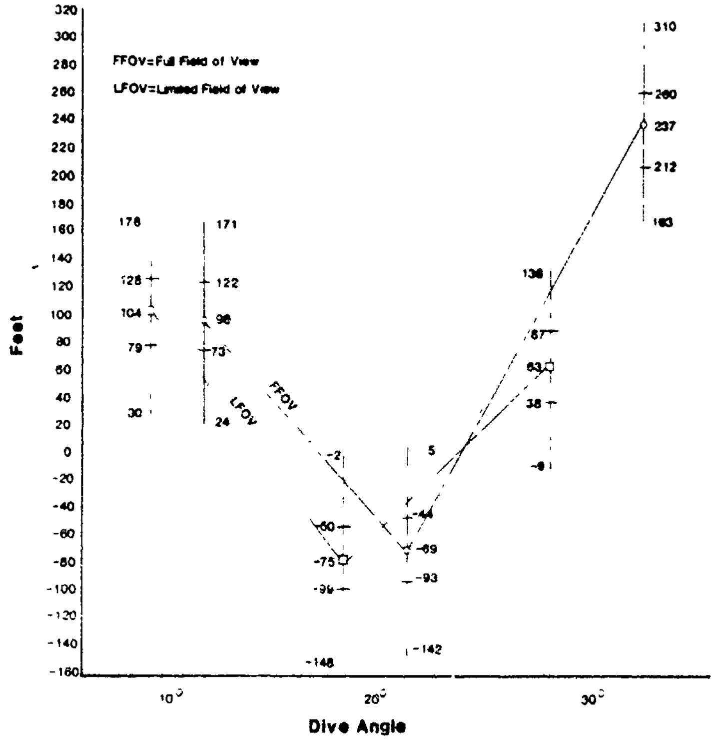


Figure 9. Field of View by Dive Angle Interaction Mean Altitude Deviation.

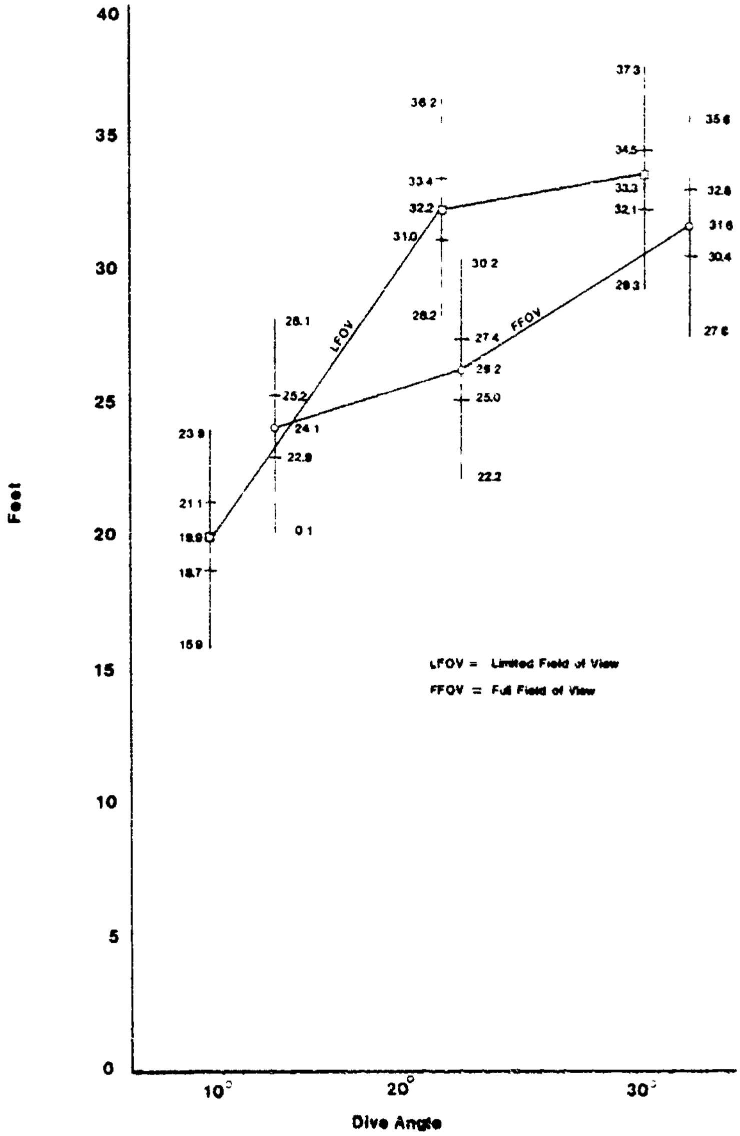


Figure 10. Field of View by Dive Angle Interaction Standard Deviation of Roll.

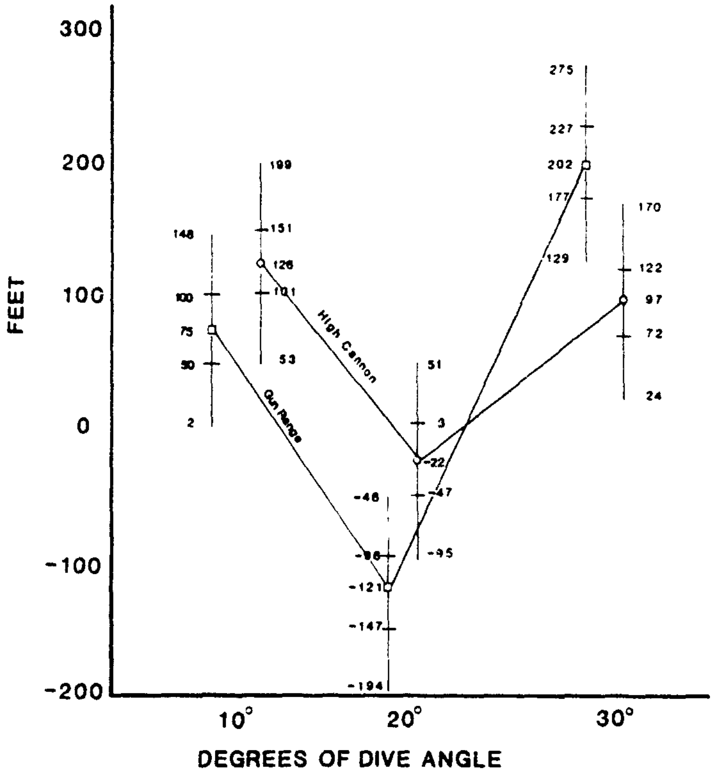


Figure 11. **Data Base by Dive Angle Interaction, Mean Altitude Deviation.**

Table 1. **Effect of Dive Angle on Approach**

	10°	20°	30°
Mean Roll	-7.3 deg	-8.6 deg	-12.0 deg
Mean Pitch	.9 deg	6.5 deg	7.8 deg
Mean G's	1.30 G	1.69 G	1.99 G
Mean Horizontal Deviation	426 ft	361 ft	612 ft
Mean Glideslope Error	101 ft	-71 ft	150 ft
Standard Deviation Roll	22.0 deg	29.2 deg	32.4
Standard Deviation Pitch	3.2 deg	8.0 deg	11.4 deg
Standard Deviation G	1.10 G	1.81 G	2.30
Standard Deviation Altitude Error	128 ft	234 ft	364 ft
Standard Deviation Airspeed	17 kt	17 kt	24 kt

Table 2. **Effect of Field of View on Bomb Release Parameters**

	Limited FOV	Full FOV
Roll	-3.1 deg	1.9 deg
Horizontal Deviation	419 ft	109 ft

Table 3. **Effect of Data Base on Bomb Release Parameters**

	Bombing range	Low-detail cannon
Roll	2.0 deg	-3.3 deg
Pitch Error	1.7 deg	.3 deg
Horizontal Deviation	136 ft	392 ft

Table 4. **Effect of Dive Angle on Bomb Release Parameters**

	10°	20°	30°
Airspeed	450 kts	456 kts	471 kts
Pitch Error	-1.0 deg	2.5 deg	1.5 deg
G Factor	.86 G	1.16 G	1.19 G
Horizontal Deviation	-180 ft	220 ft	405 ft
Release Altitude Deviation	-4 ft	224 ft	321 ft
Bomb Miss Distance	46 m	65 m	66 m

Comparison II: Low-Detail Versus High-Detail Cannon AFB

A. Trials Data: No significant effects were noted for any of the training trials metrics.

B. Approach Data: Significant effects were found for FOV (F (12,9) = 9.95, p = .001), data base (F (12,9) = 3.39, p = .038), and dive angle (F (24,60) = 18.76, p = .0005). For the FOV effect, the univariate F-tests showed the effect was concentrated in the roll and the horizontal deviation from the flight path (F (1,20) = 12.72, p = .002 and F (1,20) = 32.72, p = .0005, respectively). For the roll metric, pilots with a limited FOV averaged 15.5° of right roll, whereas those with a full FOV averaged only 6°. For the horizontal deviation metric, limited FOVs produced an average deviation of 925 feet from the ideal path, while full FOVs resulted in just over 40 feet of deviation on the average (see Table 5). For the data base effect, significance was found on the g-factor metric (F (1,20) = 4.67, p = .043) and the horizontal deviation metric (F (1,20) = 10.79, p = .038). For the g-factor metric, it was found that trainees in the high-detail condition averaged 1.81 g's, whereas those trained in the low-detail condition averaged 1.55 g's. On the horizontal deviation metric, those trained in the high-detail condition were an average of 230 feet off the flight path, whereas those trained in the low-detail condition showed an average deviation of almost 740 feet. The standard deviations of airspeed were 22.5 knots for the high-detail scene and 18.5 knots for the low-detail scene. These results are shown in Table 6. All metrics for the dive angle effect were significant with the exception of mean roll, mean airspeed, and horizontal flight path error standard deviation (see Table 7). Performance decreased as dive angle increased.

Table 5. **Effect of Field of View on Bomb Release Parameters**

	Limited FOV	Full FOV
Roll	-15.5 deg	-6.0 deg
Horizontal Deviation	925 ft	41 ft

Table 6. **Effect of Data Base on Bomb Release Parameters**

	Low-detail Cannon	High-detail Cannon
G Factor	1.55G	1.81 G
Airspeed	19 kt	23 kt
Horizontal Deviation	737 ft	230 ft

Table 7. **Effect of Dive Angle on Approach**

	10°	20°	30°
Mean Pitch Error	1.0 deg	6.5 deg	7.3 deg
Mean G's	1.36 G	1.72 G	1.96 G
Mean Horizontal Deviation	472 ft	326 ft	652 ft
Mean Glideslope Error	89 ft	-61 ft	107 ft
Standard Deviation Roll	23.2 deg	30.6 deg	35.0 deg
Standard Deviation Pitch	3.6 deg	8.0 deg	11.0 deg
Standard Deviation G	1.14 G	1.87 G	2.31 G
Standard Deviation Altitude Error	153 ft	233 ft	385 ft
Standard Deviation Airspeed	18 kt	20 kt	24 kt

C. Release Data: Examination of the instantaneous release point data showed significant effects for FOV (F (7,14) = 5.16, p = .004), data base (F (7,14) = 2.98, p = .039), and dive angle (F (14,68) = 10.60, p = .0005). For the FOV effect, significance was found for the horizontal flight path deviation metric only (F (1,20) = 27 27, p = .0005), with full FOVs producing 45 feet of error at release versus 490 feet for the limited FOV. For the data base effect, the airspeed and horizontal deviation metrics were significant (F (1,20) = 5.04, p = .036 and F (1,20) = 8.72, p = .008, respectively). Pilots in the low-detail condition averaged 8 knots faster than optimum at release and were about 393 feet off and to the left of optimum. High-detail-condition pilots were approximately 17 knots faster than optimum, but only 140 feet wider. All of the dive angle metrics except roll were significant (see Table 8).

Table 8. **Effect of Dive Angle on Bomb Release Parameters**

	10°	20°	30°
Airspeed	451 kts	463 kts	473 kts
Pitch Error	0.7 deg	2.4 deg	1 4 deg
G Factor	.91 G	1.21 G	1.11 G
Horizontal Deviation	-176 ft	-205 ft	-414 ft
Release Altitude Deviation	13 ft	261 ft	491 ft
Bomb Miss Distance	50m	64m	70m

Comparison III: Bombing Range Versus High-Detail Cannon AFB

A. Trials Data: Again, none of the training trials data showed significant results.

B. Approach Data: The only significant treatment effect found was for dive angle (F (24,60) = 21.50, p = .0005), with all metrics other than mean roll, mean airspeeo, and standard deviation of horizontal flight path deviation reaching significance (see Table 9). Results in general followed the previously observed pattern of better performance at shallower dive angles.

Table 9. **Effect of Dive Angle on Approach**

	10°	20°	30°
Mean Pitch Error	1.3 deg	7.0 deg	7.7 deg
Mean G's	1.43 G	1.87 G	2.06 G
Mean Horizontal Deviation	219 ft	90 ft	329 ft
Mean Glideslope Error	64 ft	-1.10 ft	160 ft
Standard Deviation Roll	22.9 deg	31.3 deg	33.3 deg
Standard Deviation Pitch	3.9 deg	8.7 deg	12.0 deg
Standard Deviation G	1.21 G	1.84 G	2.35 G
Standard Deviation Altitude Error	137 ft	256 ft	373 ft
Standard Deviation Airspeed	18 kt	21 kt	25 kt

C. Release Data: The FOV by data base interaction and dive angle effects were both found to be significant in this condition F (7,14) = 3.17, p = .031 and F (14,68) = 7.51, p = .0005, respectively). For the FOV by data base interaction, significance was concentrated in the roll and miss distance metrics (F (1,20) = 15.90, p = .001 and F (1,20) = 5.37, p = .031, respectively). These interactions are shown in Figures 1l2 and 13. For the dive angle effect, all of the metrics other than roll and miss distance were significant. These results are summarized in Table 10.

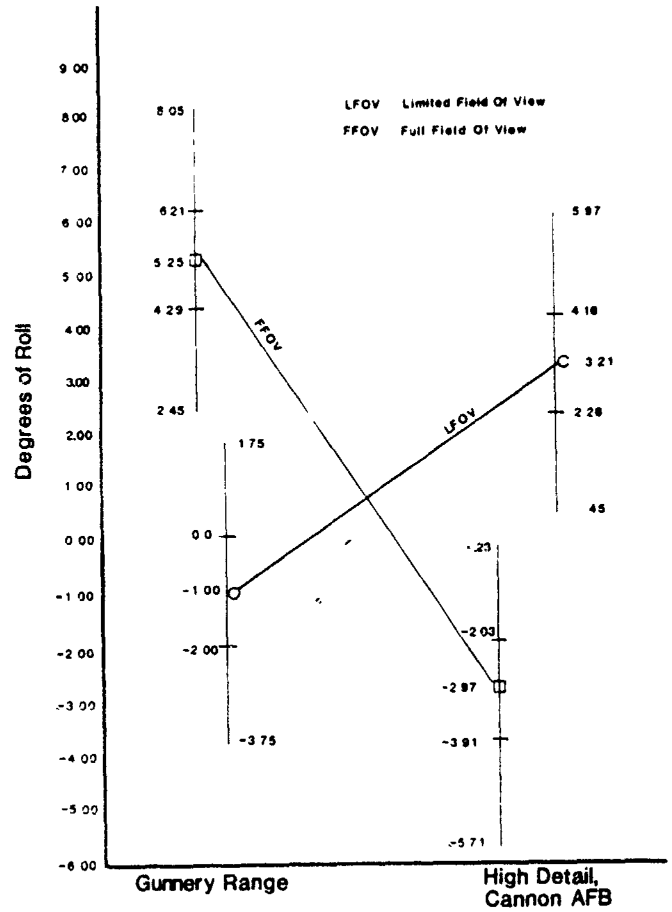


Figure 12. **Field of View by Data Base Interaction, Roll Metric.**

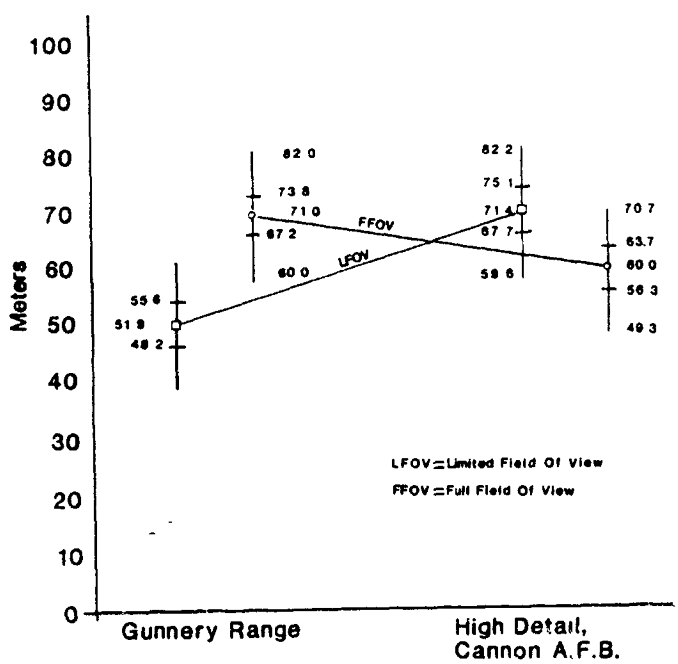


Figure 13. **Field of View by Data Base Interaction, Bomb Miss Distance.**

Table 10. **Effect of Dive Angle on Bomb Release Parameters**

	10°	20°	30°
Airspeed	453 kts	463 kts	474 kts
Pitch Error	0.0 deg	3.4 deg	1.7 deg
G Factor	.85 G	1.18 G	1.10 G
Horizontal Deviation	107 ft	62 ft	246 ft
Release Altitude Deviation	-1 ft	287 ft	395 ft
Bomb Miss Distance	54 m	65 m	71 m

V. DISCUSSION

The present investigation was conducted to determine the effect of scene content and field of view on weapons delivery training. Neither the scene content nor the FOV variable affected the number of trials required to reach proficiency. The approach data results revealed significant effects and interactions on a number of variables. There was a significant main effect associated with the task factor (10°, 20°, and 30° dive angle tasks) for approach and release data. In general, overall flight performance was better with shallower dive angles. This can be attributed to the fact that the steeper dive angles are generally considered more difficult because release distances and altitudes are displaced further from the target.

Other significant main effects were noted for FOV and scene content in (a) the approach and release data for the high- versus low-detail Cannon AFB comparison and (b) the release data for the bombing range versus low-detail Cannon AFB comparison. For FOV, this effect was reflected in a 10% larger horizontal deviation in the limited FOV condition. This is probably due to the difficulty associated with finding the proper roll-out cues, which are not visible at the turn point in the limited FOV condition. For scene content, the high-detail airfield (with vertical development) was associated with a 70% decrease in horizontal deviations. The presence of buildings provided more precise cues for judging roll-out and run-in lines. The high-detail airfield was also associated with higher g's at pull-out. This effect may be due to the pilots' ability to better detect ground proximity with the addition of vertical development.

The main interaction effects for the approach data were FOV by dive angle and data base (scene content) by dive angle in the bombing range versus low-detail Cannon AFB comparison. The FOV by dive angle effect was concentrated in mean altitude deviation and standard deviation of roll (see Figures 9 and 10). These effects are not easily interpreted. This interaction effect did not appear in any of the other comparisons, and this was the only comparison involving scenes with no vertical development. It is possible, however, that some other differences between the scenes manifest themselves in the absence of visible cues. The data base by dive angle interaction was due to differences in mean altitude deviation, but the pattern, although consistent, allows no readily interpretable explanations (refer to Figure 11).

The other main interaction effect was FOV by data base in the release data for the bombing range versus high-detail Cannon AFB comparison. The effect was due to the mean roll and mean bomb miss distance variables (refer to Figures 12 and 13). Full FOV was associated with significantly more roll deviation for the gunnery range and less for the high-detail airfield. We believe this is caused by pilots maneuvering more in an attempt to locate cues in the bombing range. The presence of vertical development in the high-detail scene gave the pilot the appropriate cues, and degrees of roll deviations decreased.

Even though there were no strong and consistent effects in bomb scores, the overall performance of subjects was better in training conditions that incorporated familiar objects (taxiways, aprons, and runway width) and vertical development in that greater adherence to the desired flight profile occurred in the test condition (high-detail China Lake Naval Air Station) for pilots trained in those conditions. There was also better performance for the full-FOV display. This leads us to believe that tasks requiring close adherence to a flight profile should use full-FOV displays and incorporate vertically developed cues. Further testing is planned to validate this finding with additional air-to-ground maneuvers and varied scene content. Other follow-on investigations will include training in air-to-air and formation flight in limited-FOV displays and testing in full-FOV displays. This will help determine the amount of training transfer between these FOV configurations.

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