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VISUAL CUE REQUIREMENTS FOR TARGET ORIENTATION ASSESSMENT IN AIR COMBAT SIMULATION

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13. ABSTRACT (Maximum 200 words)

The primary objective of this investigation was to determine the visual cues pilots use in air-to-air combat engagements in order to specify the level of detail required for flight simulator training. Fighter pilots were presented 35mm slide images of 1/48-scale model target aircraft, and the pilots indicated the spatial orientation of the targets and specified the visual cues they used to determine orientation. The independent variables were: target orientation, target type, target distance, pilot experience, and pilot's own aircraft type. Eleven target cues were predominantly used, and the frequency of use varied as a function of target orientation, type, and distance. Orientation recognition accuracy was also evaluated and it was also influenced by target orientation, type, and distance. Differences in pilot experience and pilot's own aircraft type had little or no effect on response accuracy. When the orientations were not clearly discernible, the pilots often indicated the orientations that would most likely occur in air combat training. Additionally, the pilots often specified the illusory reverse target orientation.

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PREFACE

The present investigation was conducted at the Armstrong Laboratory's Aircrew Training Research Division to evaluate the visual cues pilots use to determine target orientation in air-to-air combat engagements and how accurately pilots can distinguish target orientation. This research effort was supported by the University of Dayton Research Institute, Contract No. F33615-90-C-0005, in conjunction with Work Unit Nos. 2743-25-17, Flying Training Research Support, and 1123-32-03, Scene Content Requirements for Tactical Simulation. Contract Monitor was Ms. Patricia A. Spears. Work Unit Monitor was Dr. Elizabeth L. Martin.

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VISUAL CUE REQUIREMENTS FOR TARGET ORIENTATION
ASSESSMENT IN AIR COMBAT SIMULATION

INTRODUCTION

In air-to-air combat engagements that are performed within visual range, pilots fly their aircraft at or near the limits of the performance envelope with little or no reference to inside instruments. Their attention is initially focused outside the cockpit to search for and acquire the threat aircraft in the visual environment. The pilots must then visually track and assess the adversary's orientation and range, which dictate the tactical maneuvers the pilots will execute.

Due to the intense visual demands imposed upon the pilots in air-to-air engagements, the effectiveness of a flight simulator for air combat training will largely depend on the characteristics of the visual system. Two of the most important of these characteristics in terms of air combat training are display resolution and the level of target detail. Ideally, the visual system should provide the visual cues pilots normally use in the target acquisition and the orientation and range assessment phases of the engagements at the simulated distances corresponding to real-world training operations. If these cues are not present or are not visible at the correct simulated distances, a pilot practicing air combat maneuvers will be forced to approach the simulated target aircraft unrealistically close, focus on alternative visual cues, or omit the training altogether.

The visual cues and distances involved in the target detection phase of air combat, as well as the factors influencing airborne target detection performance, have been the subject of numerous investigations. The current state of our knowledge concerning the specific visual cues that are used and the distances the cues are visible in the target orientation and range assessment phase of training is not nearly as comprehensive, however. A review of the technical literature pertaining to airborne target acquisition and a review of the literature concerned with target orientation and range assessment are provided below. Subsequently, the gaps in our knowledge base with respect to the latter phase of air combat simulation training are addressed, and the technical requirements for the development of realistic simulation are elucidated. These requirements constitute the impetus for the present investigation.

Visual Target Acquisition

The visual task in the target acquisition phase of air-to-air engagements requires pilots to discriminate the target aircraft from the background. Of 759 training engagements at the Naval Air Station Oceana Tactical Air Combat Training System (TACTS) range, it was observed (Hamilton & Monaco, 1986; Monaco & Hamilton, 1985) that pilots first sighted the target aircraft as a dot contrasting with the background in 624 engagements and that exhaust smoke, contrails, and glint (i.e., sun reflections) were the first target cues visible in 135 engagements. The TACTS is an instrumented range where fighter aircraft maneuvers can be trained and simulated weapons can be fired and scored. Some of the longer detection distances that were obtained resulted from sightings of the smoke, contrails, and glint. In fact, the average detection distance for the 122 engagements in which exhaust smoke was the primary target cue was 7.64 nmi whereas the average distance was 5.67 nmi for the 624 engagements for which the target first appeared as a contrasting dot.

Air-to-air target detection distances were measured by Temme and Still (1991) at the Naval Air Station Oceana TACTS range to compare detection performance between aviators who wore corrective eyeglasses and aviators who did not need glasses. The slant range between the pilot and the target aircraft was used as the measure of air-to-air target detection performance, and slant ranges were obtained from 18 pilots who used eyeglasses while flying and 131 pilots who used no glasses. The analysis of the data indicated that the pilots with glasses detected the target aircraft on the average approximately 9.5% closer (4.52 versus 4.99 nmi) than those without glasses when the slant ranges encompassed all sightings, including target glint, contrails, and exhaust smoke. This difference was not statistically significant ($p > 0.05$). When the slant ranges for aircraft detection alone were analyzed, the mean detection ranges for the pilots with glasses and the pilots without glasses were respectively 4.35 and 5.05 nmi, which were significantly different ($p < 0.05$). Because of the considerable difference in group size, follow-up analyses were conducted in which 18 pilots from the larger group who did not wear glasses were selected to match the pilots who wore glasses in terms of age, the number of jet hours flown, and the total number of flight hours. Significant differences in detection distance were found between the two groups when all sightings were compared and when the aircraft-only detections were evaluated ($p < 0.05$). For all sightings, the mean detection ranges were 4.52 and 5.64 nmi for the pilots who wore glasses and the pilots who did not wear glasses, respectively; the corresponding distances were 4.35 and 5.54 nmi for the aircraft-only detections.

Kress and Brictson (1983) analyzed 87 air-to-air training engagements conducted at the Yuma TACTS range by Navy fighter squadrons from Naval Air Station Miramar and found that the average target detection distance when no visual aids were used was 3.1 nmi. The detection distances were collected from F-14 and F-4 fighter aircrews, and the targets were F-5 and F-4 aircraft. When visual aids were used by the aircrews, the mean detection range was nearly doubled. The visual aids were symbols on the aircraft head-up display (HUD), which were positioned in the HUD where the target was located in the visual environment, and a riflescope. The mean detection distance when the HUD symbols were used to find the target was 6.8 nmi and 6.2 nmi when the riflescope was employed.

The initial visual acquisition distances in 45 air combat training engagements flown at the Air Combat Maneuvering Range (ACMR) were evaluated by Hutchins (1978). He found that the mean visual acquisition distance of A-4 aircraft by F-4 fighter pilots was 3.09 nmi with a range from 0.38 to 6.23 nmi. The ACMR was the earlier name of the TACTS.

Several investigators have evaluated the detection distances of aircraft by ground observers to compare contrast sensitivity and visual acuity in relation to target acquisition performance (Ginsburg, Easterly, & Evans, 1983; O'Neal & Miller, 1988) and to assess the effects of yellow ophthalmic filters on target acquisition distance (Provines, Rahe, Block, Pena, & Tredici, 1983). Ginsburg et al. observed that the mean detection distances for an approaching T-39 aircraft by pilots ranged from 0.38 to 10.26 mi over ten days of testing in which the meteorological visibility conditions changed from 0.5 mi to over 15 mi. In eight days of testing in which the weather varied from partly cloudy to cloudy with visibility conditions ranging from 7 to 10 mi, O'Neal and Miller found that the detection distances for an approaching T-38 aircraft by ground observers ranged from 4.77 to 6.73 mi. Provines et al. obtained 400 visual acquisitions of T-38 aircraft approaching from a distance of 9 mi. In half the acquisitions, the observers wore yellow ophthalmic filters; and the other half were made without filters. There was no statistically significant difference in acquisition performance associated with the use of the filters, and the mean acquisition distance for all observers combined was 4.55 mi.

Although the target detection distances represent the maximum visible distances of the target aircraft, it appears that the distances aviators can first detect target aircraft are considerably less than the theoretical detection distances. In the research mentioned previously (Hamilton & Monaco, 1986; Monaco & Hamilton, 1985), it was found that average exposed area of the targets at the moment of detection was about four times larger than the size predicted from the average visual detection and high-contrast acuity thresholds of the pilots that were obtained in two vision tests. The reduced detection distances observed in the investigation were attributed to a variety of environmental, vision, and flight performance factors.

In point of fact, there is a wide assortment of factors that may influence target detection. Consequently, to provide realistic simulation of the actual training environment, the factors that are anticipated in actual training should be incorporated in the simulation. A compilation of the factors that have been found to influence target detection performance in both laboratory and field investigations is provided in Table 1. These factors were extracted from reviews of the scientific literature on target acquisition performance (Bloomfield & Smith, 1982; Boff & Lincoln, 1988; Buffett, 1986; Costanza, Stacey, & Snyder, 1980; Hoffmann, 1976) and from the field evaluations that were cited above.

Target Orientation and Range Assessment

Following target acquisition in air-to-air combat engagements, the pilots must continuously monitor and analyze the target's orientation and range in order to anticipate the evolving engagement geometries and to initiate the proper combat maneuvers. Range is simply the distance the two aircraft are separated from each other, while target orientation encompasses the relative pitch and bank attitudes of the target, as well as the angular relationships that exist between the two aircraft. In air combat maneuvering within visual range, two angular relationships are used to specify the position of one aircraft relative to the other: aspect angle and heading crossing angle (also known as angle off).

Aspect angle is defined (Brown, 1984; Department of the Air Force, 1986; Murray, 1987) as the angle formed by the target's flight path and the line of sight from the attacker to the target when measured from the tail of the target aircraft (Fig. 1). Aspect angle can vary from 0 to 180 deg. For example, at 0-deg aspect, the target is tail-on to the attacker; at 180-deg aspect, the target is nose-on to the attacker; and at 90-deg aspect, the long axis of the target is perpendicular to the attacker's line of sight. Aspect angle changes as the target changes heading; it is not affected by the attacker's heading.

Heading crossing angle is the angular difference measured between the longitudinal axis of the attacker and the longitudinal axis of the target (Fig. 1). The angle varies between 0 and 180 deg, and the angle changes when either the attacker or the target heading changes. The aspect angle and heading crossing angle are equal whenever the attacker is pointing at the target.

The minimum distances pilots must be able to visually distinguish the adversary aircraft's orientation for various Basic Fighter Maneuvering (BFM) and Air Combat Maneuvering (ACM) tasks were determined by Brown (1984) and are provided in Table 2. The table also specifies the distance requirements of the offensive BFM tasks that begin with high aspect (180 to 135 deg), medium aspect (135 to 45 deg), and low aspect (45 to 0 deg) engagements. BFM is the initial phase of air combat training designed to develop proficiency in one-versus-one aircraft positioning. ACM follows

Table 1. Factors Governing Target Detectability

<u>Target features</u>
Size
Shape
Brightness
Coloring
Type of aircraft
Location in the visual field
Motion
Exposure time
Smoke
Contrails
Glint
Dynamics
Target-to-background contrast
<u>Environmental characteristics</u>
Background brightness
Atmospheric conditions, i.e., haze, smoke, dust
Cloud cover
Sun position
Background clutter
Glare
Cockpit structures
<u>Observer characteristics</u>
Visual acuity
Accommodation and myopia
Contrast sensitivity
Workload
Eye movements
Search/scan patterns
Miscellaneous factors, i.e., motivation, fatigue, anxiety, anticipation
Training
Individual differences
<u>Observer aircraft</u>
Dynamics
Cockpit physical structures
<u>Target and observer aircraft relationships</u>
Slant range
Target orientation

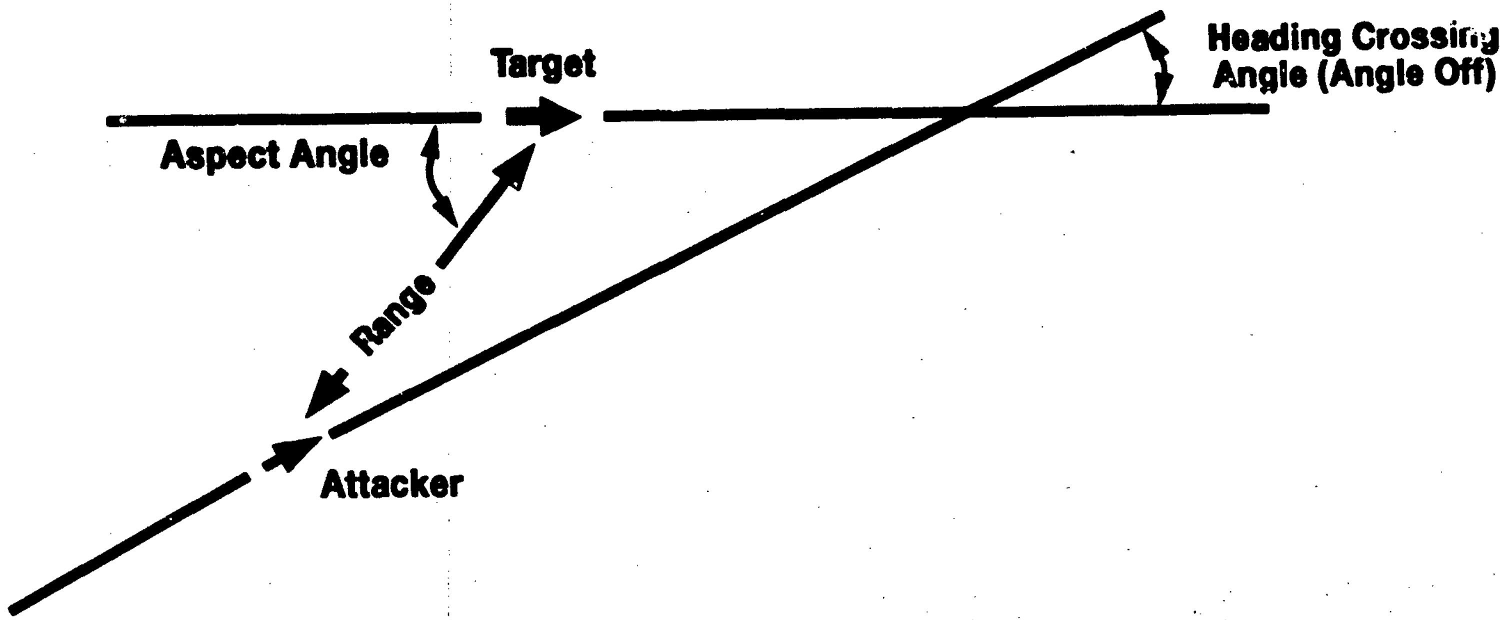

Figure 1
Geometrical Relationships Between Target and Attacker Aircraft

Table 2. Aircraft Orientation Assessment Distances for BFM and ACM Tasks (from Brown, 1984)

Task	Maneuver	Distance (ft)
	Neutral BFM	
Two circle		15,000 - 17,000
One circle		9,000 - 11,000
	Offensive BFM	
High aspect		
Immelmann		10,500 - 13,000
Medium aspect		
Barrel roll		10,500 - 12,000
High Yo-Yo		4,500 - 5,500
Vector roll		4,000 - 5,000
Low Yo-Yo		3,500 - 5,000
Quarter plane		2,500 - 3,500
Low aspect		
High Yo-Yo		3,000 - 4,000
Vector roll		3,500 - 4,500
Low Yo-Yo		3,000 - 4,000
Lag roll		2,500 - 3,500
Quarter plane		2,000 - 3,000
Gun tracking		1,500 - 2,500
Gun snap shots		4,000 - 5,500
Missile attacks		6,500 - 8,000
	Counteroffensive BFM	
Hard turns		9,000 - 10,000
Counter to Yo-Yo's		5,000 - 7,000
Break turns		6,000 - 7,500
Reversals/Scissors		2,500 - 3,000
High-g/Angle-of-Attack rolls		2,000 - 3,000
Guns defense		2,000 - 2,500
	Offensive ACM	
Co-Flow entries		13,000 - 18,000
Counter-Flow entries		13,000 - 18,000
High/Low entries		9,000 - 11,000
Cover wing		8,000 - 9,000
Fighting wing		2,000 - 3,000
	Counteroffensive ACM	
Counters to switch attacks		10,000 - 14,000
Element sandwich		9,000 - 10,000

the BFM phase of fighter aircraft training and encompasses the coordinated application of BFM by two or more aircraft to deliver ordnance against one or more target aircraft. The distances reported by Brown were extracted from Air Combat Maneuvering Instrumentation (ACMI) range data for F-15, F-4, and F-5 fighter aircraft. The ACMI is the Air Force equivalent of the Navy's TACTS.

In a previous experiment, Coward and Rupp (1982) investigated the visual cues pilots use in real-world, air-to-air combat training. The participants were 15 F-4 fighter pilots who had completed BFM and ACM training, and a questionnaire was used to solicit the visual cues the pilots used. The cues that were indicated and the percentage of pilots mentioning each of the cues are provided in Table 3. It may be seen in the table that the cues most frequently used to determine target position were wing planform, target nose position, relative motion across the attacker's canopy, and relative size/size changes.

Problem Statement

As the pilot maneuvers in air-to-air combat engagements to either attack or evade the adversary aircraft, the physical features of the adversary that are visible to the pilot are constantly changing. At any given moment, a variety of cues is in view, which the pilot uses to assess the adversary's spatial orientation and range. Although Brown (1984) specified the minimum distances at which the pilot must be able to determine target aircraft orientation, the visual cues that must be visible at these distances and orientations were not addressed. Coward and Rupp (1982), on the other hand, identified the array of cues that pilots use in real-world air combat training but not the distances at which the cues must be discernible. As a result, the target cues that must be discriminable at different distances for different target orientations are unknown. Because this information is essential to the development of visual simulation systems for air combat training, an investigation was conducted that focused on the visual cue requirements for target orientation assessment. The investigation that was accomplished is presented herein.

Purpose and Scope

The primary objectives of this investigation were to evaluate the visual cues pilots use and the distances the cues are discernible in the target orientation and range assessment phase of air-to-air combat engagements. The results will have application in the determination of the display resolution and the level of image detail requirements for flight simulator training. In the investigation, U.S. Air Force fighter pilots were asked to indicate the orientations of static target aircraft images, then to specify the visual cues they used to determine the orientations. The variables that were manipulated were: target orientation, target

Table 3. Visual Cues Used in Air-to-Air Combat Training (from Coward & Rupp, 1982)

	Percent of subjects		
Cues reported	Vital	Important	Desirable
Relative motion--on canopy	73.3	6.7	--
Relative motion--to outside ref. point	33.3	6.7	6.7
Wing planform	93.3	6.7	--
Target nose position	80.0	--	--
Relative size/size changes	53.3	6.7	--
Sun glint	6.7	26.7	13.3
Smoke	20.0	26.7	33.3
Afterburner plume	13.3	13.3	46.7
Wingtip contrails	--	20.0	40.0
High altitude contrails	6.7	20.0	20.0
Altitude cues	--	13.3	--
Weapon cues (missile plume etc.)	6.7	6.7	--
Color	13.3	13.3	20.0
Shading and shadows	6.7	6.7	6.7
Yaw movement	6.7	--	--
Distinction of top vs. bottom	6.7	--	--
Control surface movements	6.7	--	--
Vertical position	6.7	--	--
Shape (for target identification)	6.7	--	--
Fine target detail	--	6.7	6.7
Ground cues	13.3	--	--

type, target distance, pilot flight experience, and whether the pilots viewed the same or different target aircraft from their own aircraft. In addition, the responses were analyzed to evaluate the effects of the test conditions on target orientation recognition accuracy.

METHOD

Subjects

A total of 80 U.S. Air Force active duty and reserve fighter pilots participated. The pilots consisted of 20 instructor pilots (IPs), 20 TX/C-Course pilots, 20 B-Course pilots, and 20 operational pilots. Table 4 indicates the current aircraft of the pilots in each group, the average number of flight hours in the current aircraft, the average number of total fighter flight hours,

Table 4. Pilot Flight Experience

Pilots	No.	Current A/C F-15	F-16	A-7	Avg current aircraft hrs	Avg total aircraft hrs	Avg A/A sorties
IPs	20	10	9	1	635.5	2146.0	65.7
TX/C	30	10	6	4	132.5	1957.6	53.3
B	20	7	9	4	50.9	505.2	19.2
OPS	20	10	10	0	272.4	802.0	61.2

and the average number of air-to-air training sorties accomplished in the 12 months prior to the test. The air-to-air training sorties included BFM, ACM, air combat training (ACT), dissimilar air combat training (DACT), composite force training (CFT), and Red Flag sorties. The pilots were from the 405th Tactical Training Wing and 58th Tactical Training Wing, Luke Air Force Base, AZ; the 49th Tactical Fighter Wing, Holloman Air Force Base, NM; the 388th Tactical Fighter Wing, Hill Air Force Base, UT; and the 162nd Tactical Fighter Group, Tucson, AZ. If the pilots normally used eyeglasses or contact lenses when flying, they were asked to wear them during testing.

Visual Stimuli

The visual stimuli were photographic slide images of 1/48-scale, F-15 and F-16 aircraft models. A separate set of slides was produced for each model consisting of 8 demonstration slides, 8 practice slides, and 64 test slides. The spatial orientations of the models depicted in the test slides are presented in Table 5. Four images were produced for each aircraft orientation to simulate distances of 0.5, 1.0, 2.0, and 3.0 nmi. The factorial combination of the 16 orientations and four distances provided the 64 test slides. The same orientations and distances were used for both the F-15 and F-16 slide sets. The rationale for using these four distances is that they are representative of the distances involved in the target orientation and assessment phase of air combat training as specified by Brown (1984) and shown in Table 2.

For the sake of clarification, the aspect angles and directions of travel employed in the present investigation are illustrated in Figure 2. The heading crossing angle was always equal to the aspect angle (see definition of aspect angle and heading crossing angle above).

Table 5. Target Orientations

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
1	0	Tail-on	0	0
2	0	Tail-on	45 Up	0
3	180	Nose-on	0	0
4	180	Nose-on	45 Up	0
5	90	Left	45 Down	0
6	90	Left	0	60 Left
7	90	Right	0	60 Left
8	90	Right	45 Up	120 Left
9	45	Left	0	45 Left
10	45	Left	45 Down	0
11	135	Left	45 Up	45 Right
12	135	Left	0	45 Left
13	45	Right	0	45 Left
14	45	Right	45 Down	45 Right
15	135	Right	0	0
16	135	Right	45 Down	0

Guidance was obtained from a U.S. Air Force fighter pilot in the selection of the target orientations. Each of the aspect angle and direction of travel combinations was used twice in the 16 target orientations. Additionally, the number of pitched targets was the same as the number of nonpitched targets and the number of banked targets was equal to the number of nonbanked targets. A photograph of each of the 16 target orientations at 0.5 nmi is provided in Appendix A.

Each of the eight combined aspect angles and directions of travel employed in the test slides was presented in both the demonstration slides and the practice slides, and they were randomly combined with various pitch and bank angles. Also, two of the target orientations in both slide sets were randomly combined with each of the four simulated distances that were used in the test slides. None of the combinations of orientations and distances used in the demonstration and practice slides were the same as the combinations presented in the test slides.

The aircraft models used for the slides were assembled from commercially available kits, and the model paints were applied with an airbrush. Standard U.S. Air Force camouflage-gray, F-15 and F-16 color schemes were adopted. Both models were equipped with missiles, which were painted white. The F-16 was modeled with two

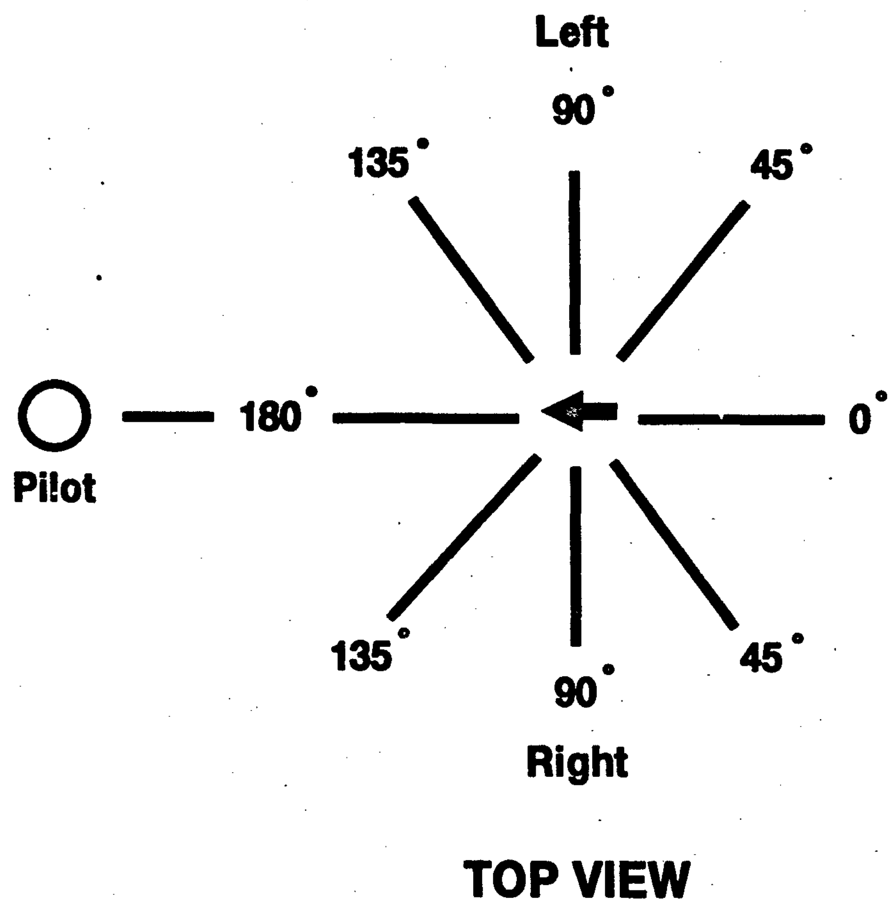

Figure 2
Aspect Angles and Directions of Travel

AIM-9 missiles, and the F-15 was equipped with four AIM-7 missiles and four AIM-9 missiles. Neither model had external fuel tanks nor landing gear.

The slides were taken in a studio using a 35mm single-lens reflex (SLR) camera with Kodachrome 25 color film. The models were suspended on lightweight monofilament fishing line, and a white background was used to simulate atmospheric haze or clouds. Several strobe lights were used to illuminate the aircraft models and the background. The camera was always level with the models and focused on the aircraft fuselage, midway between the nose and tail. The specific target orientations depicted in the slides were achieved by adjusting the position of the model, and the required distances were simulated by photographing the models at four discrete distances in the studio.

Apparatus

The stimuli were presented on an 18 in. by 18 in. rear-projection screen using a Gerbrands Corporation G1178 3-Field Projection Tachistoscope. The tachistoscope employed three Kodak Ektagraphic Model IIIB carousel projectors, three tachistoscopic shutters, a formica base, two beam splitters, a shutter drive control console, and a tachistoscope controller. The spatial relationships between the observer, projection screen, and slide projectors are illustrated in Figure 3.

Because of the distances at which the aircraft models were photographed, portions of the studio were unavoidably visible in the original slides. These unwanted features were eliminated with slide masks that were sandwiched in the slide mounts. The slide masks were transparent in the center and opaque in the periphery. Slide projector 1 in Figure 3 was used to present the aircraft images with the slide masks. To compensate for the reduction of the slide field of view from the masks, an equal number of slides of the aircraft background were produced with opposite masks, which were presented simultaneously with the aircraft images. These slides were presented using projector 2. The masks for the background were opaque in the center and transparent in the periphery, and the background completely filled the slide "window." Slide projector 3 was used to present an unmasked background image that provided constant screen illumination in the interval following the presentation of the stimuli. The shutter drive control console powered the projector shutters, and the duration and sequence of the shutter openings were controlled by the tachistoscope controller. The projectors were placed on the formica base, and the beam splitters were arranged as depicted in Figure 3.

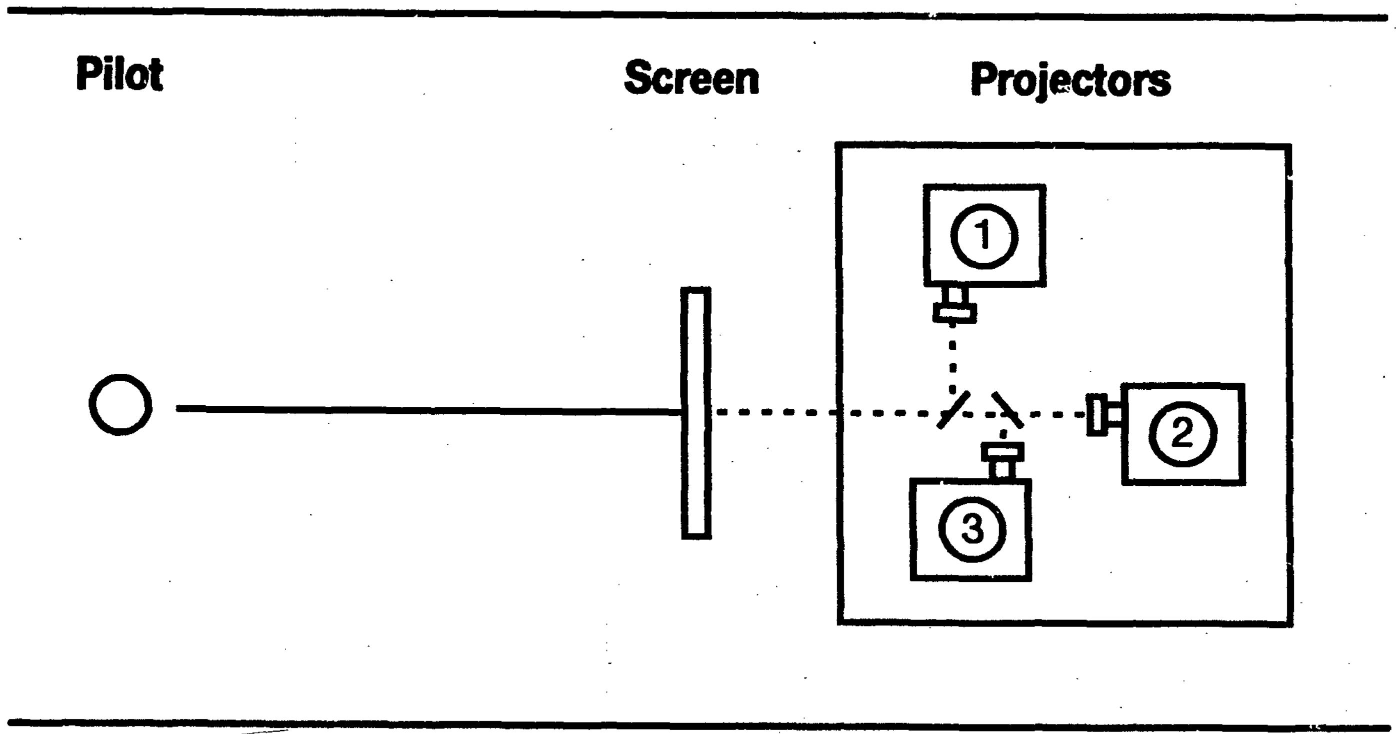

Figure 3
Equipment Layout

A pilot control console was provided that contained two precision telegraph keys. One key was used to concurrently trigger the tachistoscope controller and activate a digital timer, while the other key was used to stop the timer.

When the tachistoscope controller was triggered, the stimulus slides (i.e., an aircraft slide and the corresponding background slide) were simultaneously presented, the timer started, and the unmasked background slide was blanked. After 5 s had elapsed, the stimulus slides were blanked and the unmasked background slide was displayed until the tachistoscope controller was triggered again.

The tachistoscope controller was also used to activate a Gerbrands Corporation G1180A Slide Changer, which advanced the slides of the aircraft and corresponding background images. The slide changer was triggered immediately after the 5-s stimulus interval. The unmasked background slide image was not changed.

During data collection, the pilots were seated at a pilot station, which included a table, a chin rest, a standard office chair, and the pilot control console. The chin rest was adjusted so that the pilots' eyes were level with aircraft images on the screen. The viewing distance from the eye position to the screen was 12 ft.

Experimental Design

A five-factor experimental design was used, which consisted of three between-subject factors and two within-subject factors. The between-subject factors were (a) pilot type, (b) target type, and (c) pilot's aircraft; and the within-subject factors were (a) target orientation and (b) target distance. The levels associated with each factor are specified in Table 6. Under the pilot's aircraft factor in the table, "same" means that the pilots were current in the same aircraft as the target type they were presented, and "different" indicates that the pilots were current in an aircraft that was different from the type of targets they viewed.

Procedure

Data collection was accomplished on site at Luke Air Force Base, AZ; Holloman Air Force Base, NM; Hill Air Force Base, UT; and the Arizona Air National Guard, Tucson, AZ. The equipment was transported to each of the test sites, and the data were collected in a semidarkened private room. A test schedule was initially established at each of the sites visited, and then squadron personnel randomly assigned pilots to participate in the investigation from among those who were available at the scheduled times. The pilots were tested individually, and they were randomly assigned either the F-15 or F-16 target sets. Each session lasted between 45 and 75 min.

Table 6. Experimental Design

Between group factors (5 pilots per group)			Within group factors							
			Orientation							
			1			.....			16	
			Distance (nmi)							
Pilot type	Target type	Pilot's aircraft	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
IPs	F-15	Same Different								
	F-16	Same Different								
TX/C-Course	F-15	Same Different								
	F-16	Same Different								
B-Course	F-15	Same Different								
	F-16	Same Different								
OPs	F-15	Same Different								
	F-16	Same Different								

Ten operational F-15 pilots were used at Holloman Air Force Base and ten operational F-16 pilots were used at Hill Air Force Base. Half of the pilots at each location viewed the F-15 slide set and half viewed the F-16 set. The instructor pilots, TX/C-Course pilots, and B-Course pilots were obtained from Luke Air Force Base and the Arizona Air National Guard, and the pilots were tested in random order.

Prior to the start of the slide presentations, the pilots were provided a standard set of instructions, which described the purpose and scope of the research, the visual stimuli and target orientations, the pilot's task, and the procedures. The eight demonstration slides were then presented. The experimenter identified the aspect angle, direction of travel, pitch, bank, and simulated distance of the targets in each slide, as well as the salient visual cues, using the corresponding aircraft model. The slide exposures were controlled by the experimenter, and they were displayed until the pilot had assimilated the image.

The pilots were then presented the 8 practice slides and the 64 test slides, and both the practice and test trials were pilot-paced. When the pilots were ready to view a slide, they pressed the key on the pilot control console that triggered the tachistoscope and the digital timer. After the pilots had determined the orientation of the target in the slide, they first pressed the key on the control console to stop the clock and then they indicated the aspect angle, direction of travel, pitch attitude, and bank attitude of the aircraft and the visual cues they used on a response form. Feedback concerning the target orientation was provided for the practice slides.

The response form consisted of a nine-page booklet, one page for the practice slides and eight pages for the test slides. The slides were numbered sequentially on the pages, and there were eight slides to a page. For each slide, all eight combined aspect angles and directions of travel were listed, three response alternatives were provided for pitch attitude (i.e., high, level, and low), three response alternatives were provided for bank attitude (i.e., left, zero, and right), and space was provided for specifying the visual cues. The pilots were asked to circle the target conditions they felt were depicted on the screen.

The order in which the test slides were presented was fully randomized, and a different random sequence was used for each of the pilots. The practice and test slides were each presented for 5 s, and the pilots were requested to use the chin rest when they viewed the slides. The pilots were instructed to respond as rapidly as possible but that accuracy was more important than speed. Prior to each session, the pilot was administered a pilot experience form; and following the session, a debriefing questionnaire was administered. Each morning before the first pilot arrived, the equipment setup was calibrated.

The response time data were collected to permit the experimenters to ascertain whether the duration of the slide exposures was adequate. Because the response time data were not critical to the objectives of the investigation, they were not subjected to statistical analysis.

RESULTS

Visual Cue Usage

The visual cues the pilots indicated they used in conjunction with each of the 16 target orientations are summarized in Table 7. Each orientation encompasses the various target types, target distances, and types of pilots. The specific cues used with the two target types (i.e., F-15 and F-16 targets) at the four simulated distances are provided in Appendix B for each of the 16 target orientations. The data arrayed in the tables represent the percentage of the total number of correct target orientation responses in which the target cue was specified by the pilots. A correct target orientation response in the present context is defined as a correct aspect angle, direction of travel, pitch, and bank response. In some instances, the pilots provided more than one target cue for a target presentation, thus the column totals may exceed 100 percent. "No response" in the table signifies that the pilots did not specify any target cues, even though they correctly identified the target orientation.

The analyses of the target orientation responses, which are addressed in the following section, indicated that the differences in response accuracy between pilot types was negligible and that there was no effect of pilot's aircraft type on the response accuracy when the 16 target orientations were pooled. Consequently, the specific visual cues used in conjunction with the four pilot types and pilot's aircraft type were not tabulated.

In constructing Table 7 and the tables in Appendix B, all tail-related responses were combined within the "tail" target cue. These responses included: rudder, vertical stabilizer, stabilator, horizontal tail, tail fin(s), space between tails, and just tail. Conversely, "no tail" includes: no rudder, no stabilizer, no fin(s), no space between tails, and no tail. The cue "top of aircraft/wings" represents the combination of three responses: top, top of aircraft, and top of wings. "Entire aircraft" means that the target was so large on the screen that an array of cues too numerous to elucidate were simultaneously distinguishable. "Planform" and "silhouette" could have, possibly, been combined in the tables. Strictly speaking, the term silhouette refers to the outline or contour, whereas planform refers to the outline of an aircraft when looking at it such that the wing shape is distinguishable. "No planform" indicates the wing contour was not

Table 7. Summary of Target Cues Used in Relation to 16 Target Orientations

No.	Target cue	Target orientation 1	2	3	4	5	6	7	8
1	Tail	21.0	23.4	17.6	15.3	51.4	26.7	14.8	21.1
2	Wings	17.5	20.6	13.8	17.5	11.9	28.5	21.2	15.6
3	Nose	2.8	23.4	11.4	22.4	30.0	22.7	12.8	19.3
4	Intake(s)	3.5	1.6	47.6	50.8	8.3	1.1	29.6	23.9
5	Planform	-	31.5	-	13.7	21.0	29.2	19.7	23.9
6	Canopy	5.6	23.0	10.5	-	7.1	32.5	0.5	-
7	Belly	-	0.4	-	27.3	-	-	29.6	29.4
8	Missiles	-	-	-	16.4	5.5	0.7	26.1	32.1
9	Top of aircraft/ wings	-	22.6	-	0.6	-	18.4	0.5	0.9
10	Fuselage	2.8	13.2	2.9	6.0	19.0	13.0	7.9	6.4
11	Exhaust outlet(s)	40.6	5.9	0.5	-	0.4	0.7	1.0	0.9
12	Entire aircraft	-	2.0	1.4	1.1	1.6	4.0	4.4	0.9
13	Silhouette	11.2	-	14.8	-	-	-	-	-
14	No planform	7.0	-	6.7	-	9.1	-	-	-
15	No wings	-	-	-	-	15.0	-	-	-
16	No tail	0.7	2.0	1.4	4.4	2.4	0.4	3.5	3.7
17	No intake(s)	1.4	5.1	-	-	2.0	2.5	1.0	1.8
18	Color	1.4	2.3	0.5	2.2	-	1.8	2.0	2.8
19	No missiles	-	2.7	-	-	-	1.8	-	-
20	Dark dot	4.2	-	3.3	-	-	-	-	-
21	No canopy	0.7	0.8	-	-	-	-	1.5	2.8
22	Strakes	1.4	-	-	-	0.4	-	2.0	0.9
23	Side view	-	-	-	-	4.4	1.1	-	-
24	No exhaust outlet(s)	-	-	0.5	-	1.2	1.4	1.5	0.9
25	Aircraft size	-	-	-	0.6	-	-	-	-
26	No fuselage length	4.2	-	1.4	-	-	-	-	-
27	No nose	1.4	-	1.9	0.6	-	-	-	-
28	Cockpit	-	-	-	-	-	1.1	-	-
29	No shadows	-	-	-	-	0.4	-	-	-
30	No exhaust outlet metal	-	0.4	-	-	-	-	-	-
31	No strakes	-	0.4	-	-	-	-	-	-
32	No response	17.5	7.4	16.7	6.6	4.0	4.3	5.4	6.4

Notes. 1. Data represent percent of correct responses each cue was used.
2. Dash indicates cue was not used.
3. "No response" signifies that the pilots did not specify any cues.

Table 7. (concluded)

		Target orientation							
No.	Target cue	9	10	11	12	13	14	15	16
1	Tail	41.6	47.9	18.9	43.2	46.3	65.5	60.3	47.6
2	Wings	40.0	24.7	14.9	30.9	31.3	27.6	10.3	22.0
3	Nose	23.7	23.7	25.7	25.0	20.7	24.1	16.9	26.8
4	Intake(s)	-	14.0	41.9	18.6	19.8	1.2	45.6	11.0
5	Planform	23.7	17.7	16.2	15.9	8.8	18.4	-	20.7
6	Canopy	19.5	1.6	1.4	25.0	1.8	6.9	22.8	29.3
7	Belly	-	24.2	33.8	-	21.2	-	-	2.4
8	Missiles	0.4	11.3	33.8	-	16.7	-	3.7	-
9	Top of aircraft/ wings	17.6	-	1.4	22.3	0.4	10.3	-	24.4
10	Fuselage	9.2	7.5	5.4	9.1	7.9	9.2	10.3	6.1
11	Exhaust outlet(s)	9.2	14.0	-	0.5	11.0	10.3	-	-
12	Entire aircraft	3.4	2.2	2.7	2.3	1.8	3.5	1.5	8.5
13	Silhouette	-	-	-	-	-	-	6.6	-
14	No planform	-	-	-	-	-	-	2.9	-
15	No wings	-	0.5	-	-	-	4.6	4.4	-
16	No tail	0.4	0.5	4.1	-	0.9	-	-	-
17	No intake(s)	1.9	1.6	-	-	-	3.5	-	1.2
18	Color	1.9	2.2	1.4	0.9	1.8	-	-	-
19	No missiles	1.9	-	-	1.4	-	1.2	-	1.2
20	Dark dot	-	-	-	-	-	-	-	-
21	No canopy	0.4	0.5	-	-	0.4	-	-	-
22	Strakes	-	1.1	-	-	0.9	-	-	-
23	Side view	-	-	-	-	-	-	0.7	-
24	No exhaust outlet(s)	-	-	-	-	-	-	0.7	-
25	Aircraft size	-	-	-	-	-	-	-	-
26	No fuselage length	-	-	-	-	-	-	-	-
27	No nose	-	-	-	-	-	-	-	-
28	Cockpit	0.8	-	-	0.9	-	-	0.7	-
29	No shadows	-	-	-	-	-	-	-	-
30	No exhaust outlet metal	-	-	-	-	-	-	-	-
31	No strakes	-	-	-	-	-	-	-	-
32	No response	5.3	4.8	4.1	5.5	4.9	3.5	4.4	4.9

Notes. 1. Data represent percent of correct responses each cue was used.
2. Dash indicates cue was not used.
3. "No response" signifies that the pilots did not specify any cues.

visible, although the silhouette definitely was. When "no wing" was indicated, the wing was observed to be level with the fuselage, and its shape was not discernible. While "intake(s)" primarily refers to the intake opening(s), occasionally the pilots used it in reference to the bulge below the fuselage on the F-16 targets or on either side of the F-15 targets. That is why this cue was specified when the target was pointed away from the pilot and the intake opening was obviously not distinguishable. The remaining target cues are self-explanatory.

Response Accuracy

A series of statistical analyses was conducted to evaluate the effects of the various test conditions on response accuracy. A logistic analysis was used since the responses were dichotomous, i.e., correct or incorrect. This analysis provides the same type of information as an analysis of variance (ANOVA) without the normality assumption. The test statistic is the chi-square (χ^2). For more detailed information concerning logistic analysis, refer to Fienberg (1980).

Separate statistical analyses were performed to compare different combinations of treatment conditions and different types of scores. Fifteen analyses were run. In the first five analyses, various slide conditions were pooled to form the various levels of the treatment conditions. In the following 10 analyses, specific target orientations were compared to assess the differences in target aspect, direction of travel, pitch, or bank on recognition accuracy. The analyses that were accomplished and the results of the analyses are described along with the treatment conditions and scores that were employed in each analysis.

Response Accuracy as a Function of Target Type, Target Distance, Pilot Type, and Pilot's Aircraft Type. Four experimental conditions were compared in the initial analysis using a four-factor model. The factors were: target type, target distance, pilot type, and pilot's aircraft type. In this analysis, the response data were summed across the 16 target orientations. A correct response for a particular target presentation was defined as a correct aspect angle, direction of travel, pitch attitude, and bank attitude response. If any individual response was incorrect, the overall response was incorrect.

The analysis indicated that the main effect of target type was statistically significant ($\chi^2(1) = 173.78$, $p < 0.01$), as were the main effects of target distance ($\chi^2(3) = 449.48$, $p < 0.01$) and pilot type ($\chi^2(3) = 14.96$, $p < 0.01$). In addition, two two-way interactions were significant: (a) target type by target distance ($\chi^2(3) = 12.52$, $p < 0.01$) and (b) target type by pilot type ($\chi^2(3)$

= 10.82, $p < 0.05$). These two interactions are depicted in Figures 4 and 5, respectively.

Figure 4 shows that response accuracy was greater for the F-15 targets than for the F-16 targets and that accuracy diminished as the simulated distances of the targets increased. The rate of change in response accuracy across the four distances was not the same, however, for two target types. For the F-15 targets, response accuracy declined at a greater rate between 1.0 and 2.0 nmi, whereas accuracy decreased more rapidly between 0.5 and 1.0 nmi for the F-16 targets. Because the response data were summed across the 16 target orientations, this figure depicts the overall relationship between target type and target distance and is not necessarily indicative of the association for a specific target orientation.

In the target type by pilot type interaction, it can be seen (Fig. 5) that there was a small increase in response accuracy across pilot types for the F-16 targets and that for the F-15 targets the trend is the same except for the B-Course pilots who had slightly fewer correct responses. The interaction also indicates that response accuracy was consistently greater for the F-15 targets than the F-16 targets for each of the four pilot types.

Pilot's aircraft type was not a significant factor in the analysis, neither as a main effect nor in the interactions. This means that response accuracy was not influenced by the type of aircraft the pilot participants were currently flying. In other words, the F-15 pilots were not able to distinguish the F-15 targets any better than the F-16 and A-7 pilots, and the F-16 pilots could not discriminate the F-16 targets more accurately than the F-15 and A-7 pilots.

Because the differences in accuracy between pilot types were relatively minor and because accuracy was not significantly influenced by the pilot's aircraft type, these two variables were not treated as separate factors in the subsequent analyses. Instead, the response data were collapsed across both pilot type and pilot's aircraft type in each of the analyses.

Response Accuracy as a Function of Target Pitch, Target Type, and Target Distance. In the second analysis, a three-factor model was used to compare target pitch, target type, and target distance. The pitch factor consisted of three levels: pitch up, pitch down, and no pitch. The pilot's pitch response was used in this analysis.

Each of the three main effects was significant, as follows: (1) target pitch ($\chi^2(2) = 23.69$, $p < 0.01$), (2) target type ($\chi^2(1) = 24.85$, $p < 0.01$), and (3) target distance ($\chi^2(3) = 49.85$, $p <$

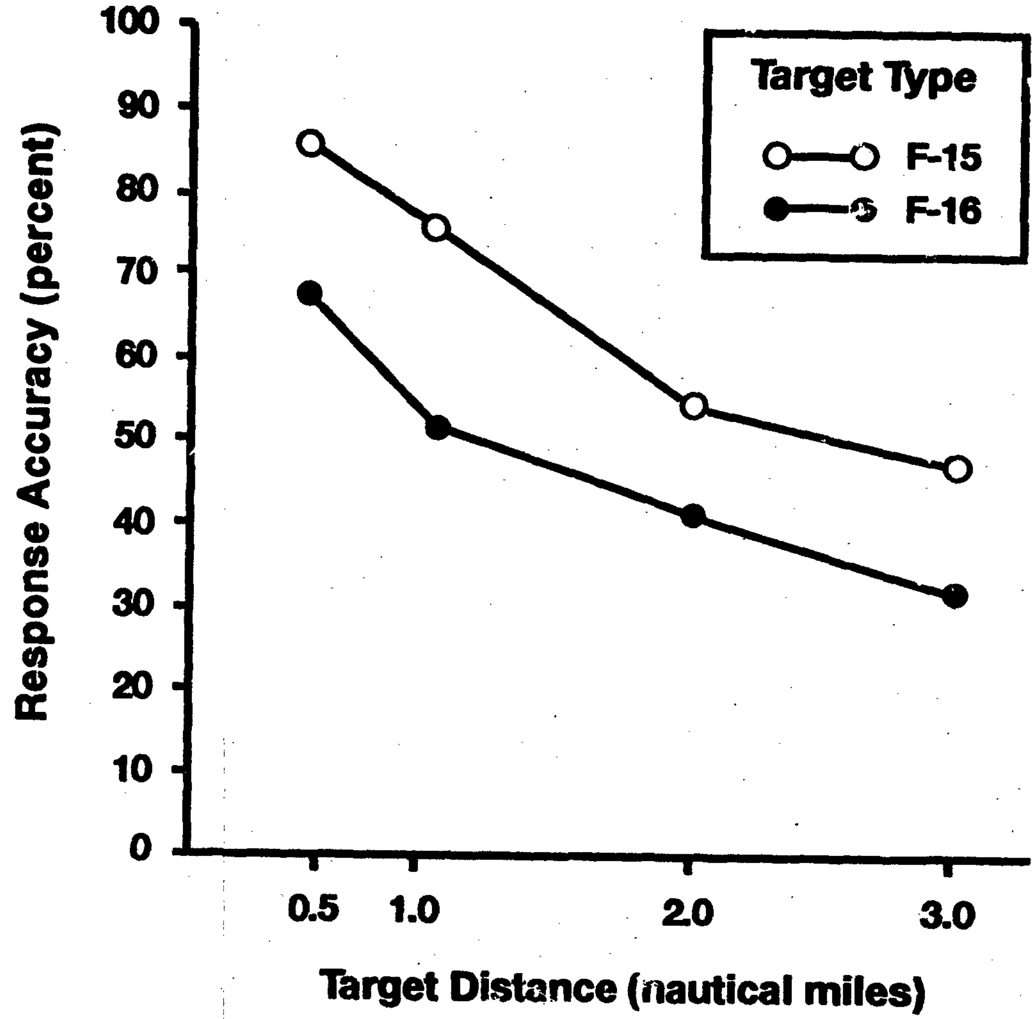

Figure 4
Response Accuracy as a Function of Target Type and Distance

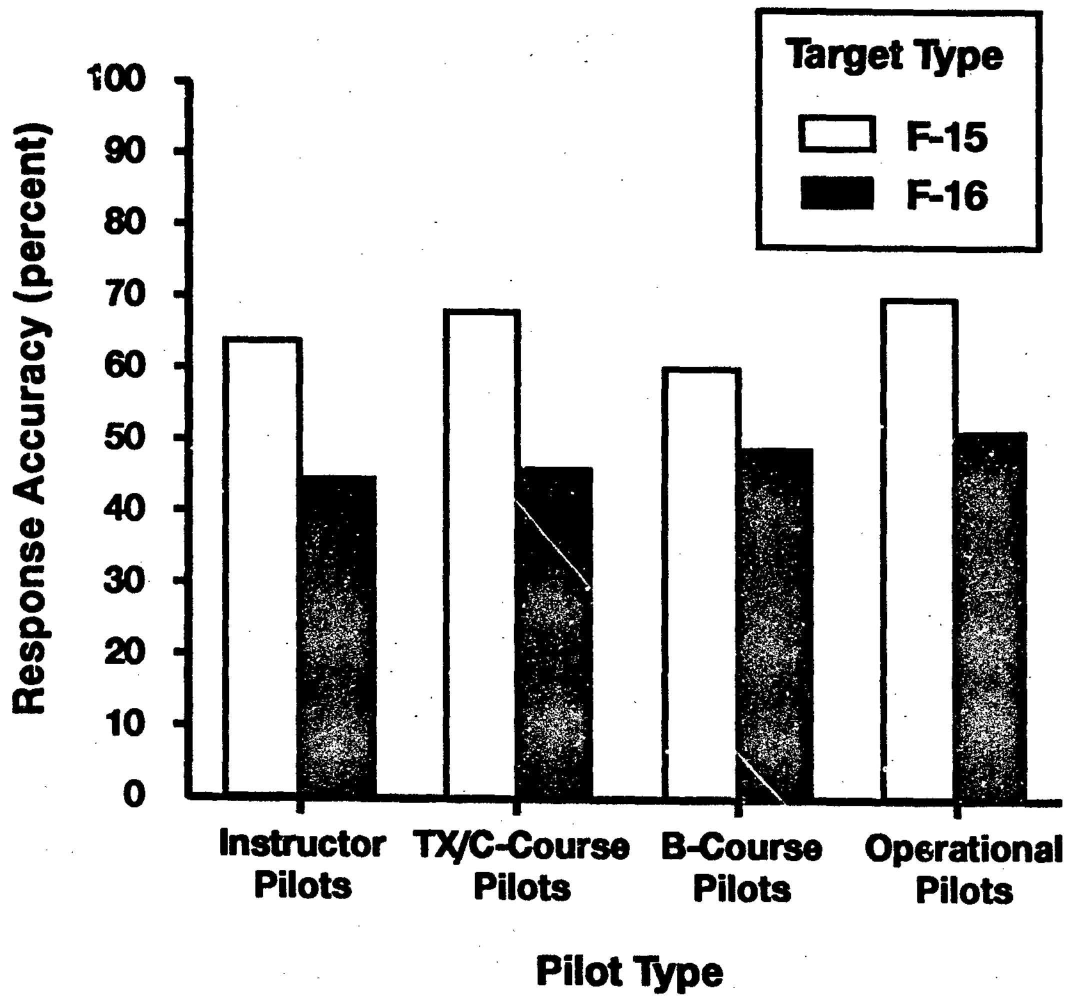

Figure 5
Response Accuracy as a Function of Target Type and Pilot Type

0.01). The correct response percentages for the three main effects are provided in Table 8. None of the interactions was statistically significant.

Table 8. Correct Responses for the Main Effects in the Analysis Comparing Target Pitch

Main effect	Correct responses (percent)
Target pitch	
Pitch up	98.75
Pitch down	98.34
No pitch	96.52
Target type	
F-15	98.59
F-16	96.48
Target distance (nmi)	
0.5	99.06
1.0	98.44
2.0	97.73
3.0	94.92

Comparison of the correct response percentages in Table 8 reveals that the pilots could distinguish the pitched targets with greater facility than the nonpitched targets, and that the nose-high and nose-low targets were about equally discriminable. As reflected in the target type and target distance main effects, pitch recognition accuracy was facilitated by the larger, F-15 targets in contrast to the F-16 targets and accuracy declined as the simulated distance of the targets increased.

Response Accuracy as a Function of Direction of Travel, Target Type, and Target Distance. The data were then subjected to a three-factor analysis to evaluate the relationship between direction of travel, target type, and target distance. There were three levels of the direction of travel factor: left, fore/aft, and right. The purpose of this analysis was to determine how well the pilots could distinguish whether the targets were turned left, turned right, or not turned (i.e., fore/aft). We were not concerned at this juncture with the pilots' ability to discern whether the targets were pointed toward or away from them, which is examined in subsequent analyses. Consequently, for this analysis, the 45-, 90-, and 135-deg aspect targets with the left direction of travel were combined; the 0- and 180-deg aspect targets were combined for the fore/aft direction of travel; and the 45-, 90-, and 135-deg aspect targets with the right direction of travel were combined. The pilot's direction of travel response was the score used in this analysis. For the fore/aft direction of travel, the pilot's response was also considered correct if he specified 180-deg aspect when the actual aspect angle was 0-deg and vice versa. The pilots were given credit for these responses because they correctly indicated that the target was not turned.

The direction of travel main effect was significant ($\chi^2(2) = 49.38$, $p < 0.01$), along with the main effects of target type ($\chi^2(1) = 15.09$, $p < 0.01$) and target distance ($\chi^2(3) = 127.09$, $p < 0.01$). The two-way direction of travel by target type interaction was also significant ($\chi^2(2) = 8.72$, $p < 0.05$). The correct response percentages associated with the four distances of the target distance main effect were respectively 99.79, 99.51, 96.84, and 93.32. The direction of travel by target type interaction is graphically illustrated in Figure 6.

Figure 6 distinctly shows that the left and right directions of travel were more discernible than the fore/aft direction and that the left and right directions were about equally discriminable. The figure also indicates that the direction of travel of the F-15 targets was more recognizable than the direction of the F-16 targets, although the difference between the two target types was not as large for the fore/aft direction of travel, which accounts for the significant interaction that was obtained.

Response Accuracy as a Function of Target Bank, Target Type, and Target Distance. Two three-factor analyses were subsequently conducted, and the factors in both analyses were target bank, target type, and target distance. All of the banked targets were combined and all of the targets that were not banked were combined to form two levels of the target bank factor: bank and no bank. A different set of bank scores was produced for each of the analyses; a set of "liberal" scores was used in one and a set of "strict" scores was used in the other. A response was considered correct according to the liberal scoring method if the pilot correctly identified whether the target was banked, without regard to the direction of bank, or not banked. For example, if a target with a right bank was presented and the pilot indicated a left bank, he obviously could distinguish that it was banked and was credited with a correct response. The purpose of the liberal scoring approach was to determine how efficiently pilots could discern whether the targets were simply banked. With the strict scoring method, the pilots' responses were considered correct only when they accurately identified the direction of bank of the banked targets and indicated that the nonbanked targets were not banked.

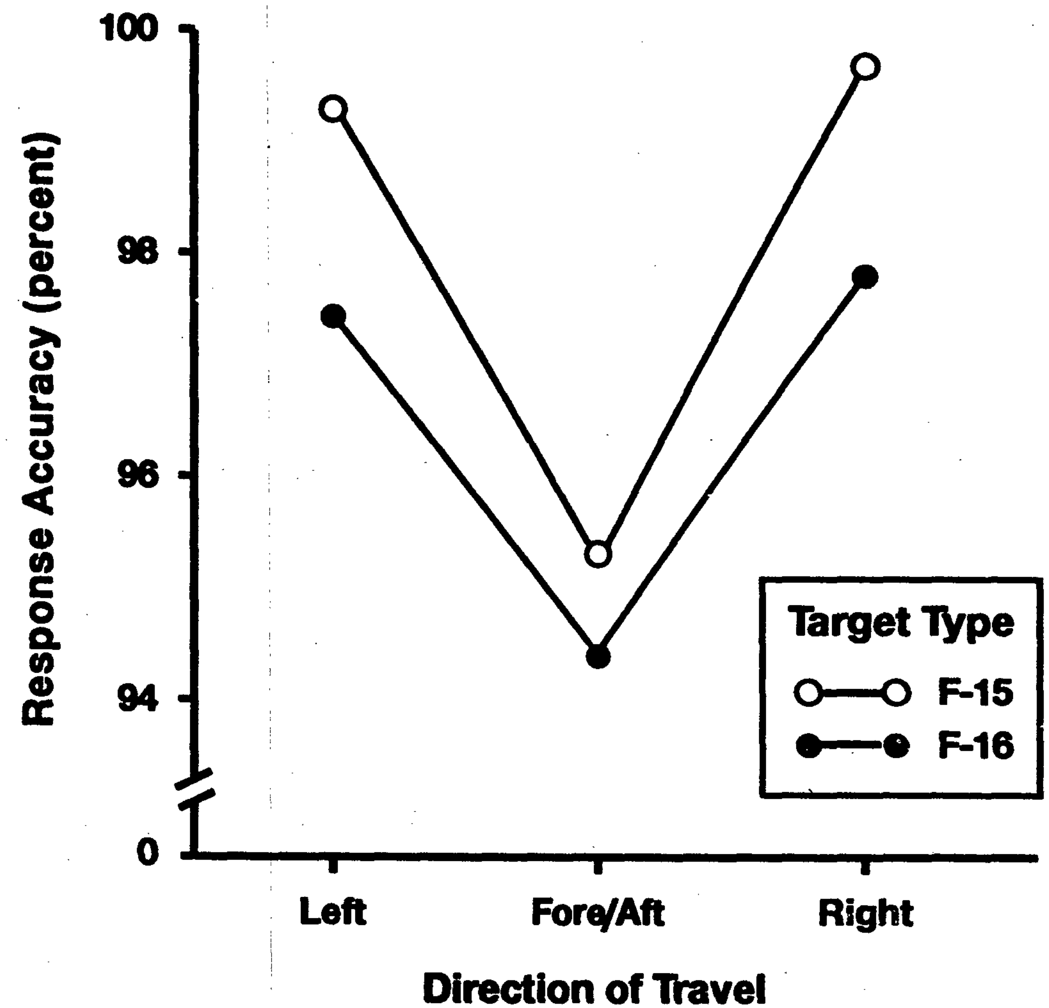

Figure 6
Response Accuracy as a Function of Target Type and
Direction of Travel

To illustrate, if the pilot indicated a left bank when a target with a right bank was presented, the response was incorrect. This scoring technique was implemented to determine the pilots' ability to recognize the direction the targets were banked.

In the analysis using the liberal bank scores, the main effect of target bank was significant ($\chi^2(1) = 59.36$, $p < 0.01$), along with the main effects of target type ($\chi^2(1) = 33.27$, $p < 0.01$) and target distance ($\chi^2(3) = 87.26$, $p < 0.01$). In addition, the two-way, target bank by target distance interaction was significant ($\chi^2(3) = 17.23$, $p < 0.01$) and the three-way, target bank by target type by target distance interaction was significant ($\chi^2(3) = 12.33$, $p < 0.01$).

When the strict bank scores were subjected to analysis, significant main effects were observed for target bank ($\chi^2(1) = 215.86$, $p < 0.01$), target-type ($\chi^2(1) = 93.82$, $p < 0.01$), and target distance ($\chi^2(3) = 352.49$, $p < 0.01$). Two two-way interactions were significant, target bank by target distance ($\chi^2(3) = 8.28$, $p < 0.05$) and target type by target distance ($\chi^2(3) = 18.44$, $p < 0.01$). The three-way interaction was also significant ($\chi^2(3) = 22.39$, $p < 0.01$).

The significant three-way interactions in the two analyses are depicted simultaneously in Figures 7 and 8. The response accuracy for the F-15 targets is presented in Figure 7, and Figure 8 shows the response accuracy corresponding to the F-16 targets. In both the liberal and strict scoring methods, the scores for the targets that were not banked were the same. For this reason, there is only one "no-bank" condition in each of the figures.

It can be observed in Figures 7 and 8 that the pilots could quite accurately discern when the F-15 and F-16 were banked, up to the maximum distance used in this investigation of 3 nmi. When the targets were not banked, bank recognition accuracy declined noticeably at the two greater distances. The strict bank scores indicate that the accuracy with which the left and right directions of bank could be distinguished decreased sharply as a function of distance and aircraft type.

<u>Response Accuracy as a Function of Aspect Angle, Target Type, and Target Distance</u>. Next, a three-factor analysis was conducted that encompassed target aspect, target type, and target distance. The target-aspect factor consisted of five aspect conditions, as follows:

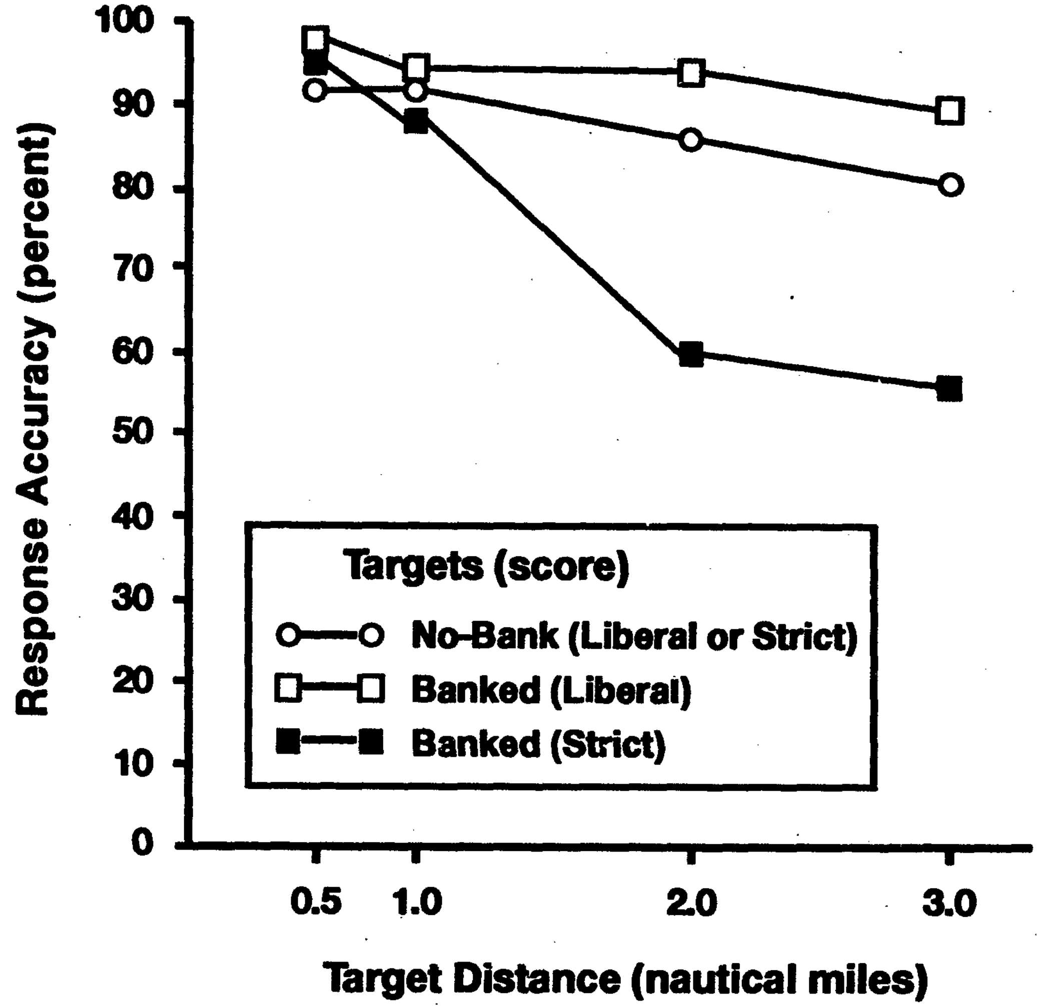

Figure 7
Response Accuracy as a Function of F-15 Target Bank and Distance

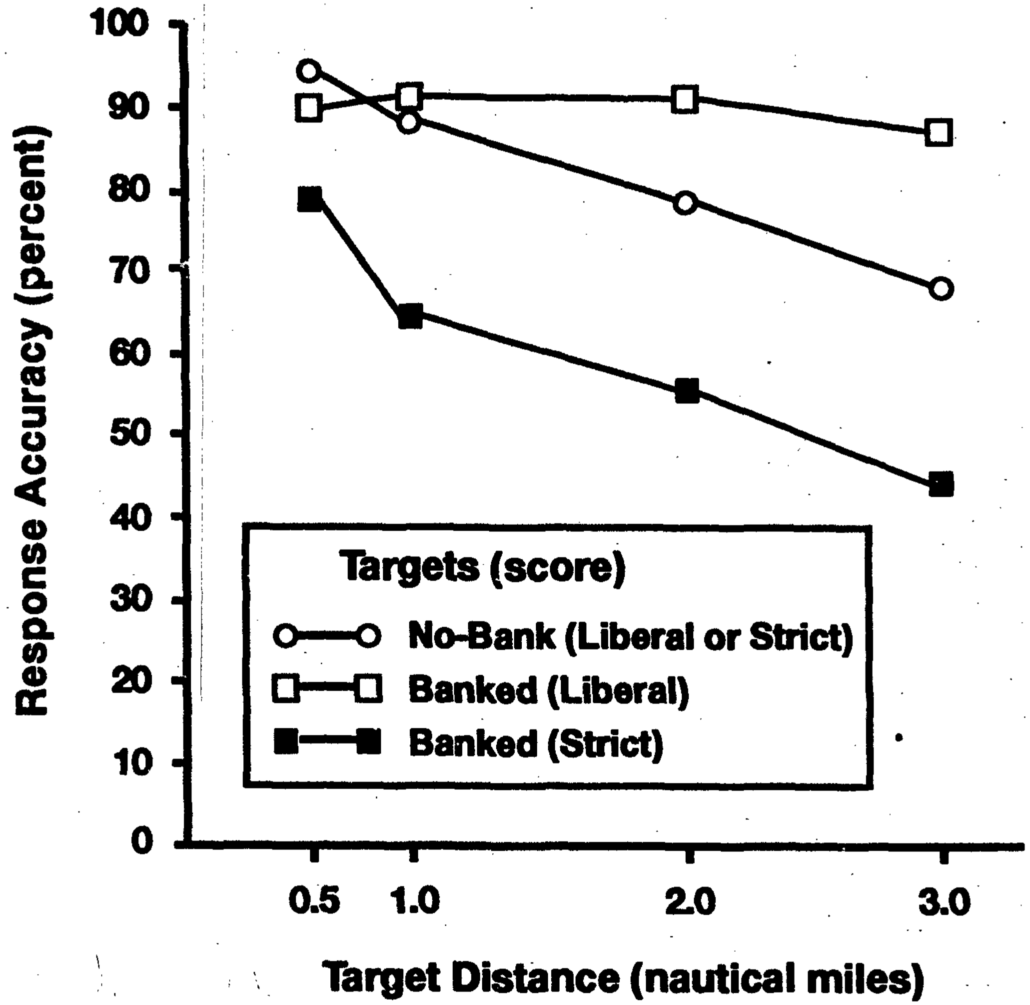

Figure 8
Response Accuracy as a Function of F-16 Target Bank and Distance

Aspect condition	Aspect angle (deg)
1	0
2	45
3	90
4	135
5	180

For this analysis, all the targets with the same aspect angle were combined. The score used in the analysis was the pilot's aspect angle response for each of the target presentations.

Significant main effects were obtained in the analysis for target aspect ($\chi^2(4) = 370.98$, $p < 0.01$), target type ($\chi^2(1) = 172.91$, $p < 0.01$), and target distance ($\chi^2(3) = 279.78$, $p < 0.01$). The two-way, target aspect by target type interaction was significant ($\chi^2(4) = 15.05$, $p < 0.01$), as well as the target aspect by target distance interaction ($\chi^2(12) = 123.92$, $p < 0.01$) and the target type by target distance interaction ($\chi^2(3) = 17.67$, $p < 0.01$). In addition, the three-way, target aspect by target type by target distance interaction was significant ($\chi^2(12) = 23.93$, $p < 0.05$). Figures 9 and 10 depict the three-way interaction. The correct response percentages associated with the F-15 targets are provided in Figure 9, and Figure 10 presents the percentages corresponding to the F-16 targets.

The errors that were made by the pilots when the aspect angles were incorrectly identified will be addressed in greater detail in the subsequent target orientation comparisons. Suffice to say that the predominant aspect response was 180 deg when the 0-deg aspect targets were misidentified, and vice versa. It was also observed that the aspect responses were almost exclusively 90 and/or 135 deg for the 45-deg aspect errors, 45 and/or 135 deg for the 90-deg aspect errors, and 45 and/or 90 deg for the 135-deg aspect errors.

<u>Response Accuracy as a Function of Target Orientation, Target Type, and Target Distance</u>. The specific target orientations were evaluated along with target type and target distance in the subsequent analyses. The response accuracy associated with the target type and target distance for each of the target orientations is provided in Table 9. The target orientations are rank ordered in the table in accordance with the total percentage of correct responses. The specific types of errors the pilots committed in relation to each of the target orientations are presented in Appendix C.

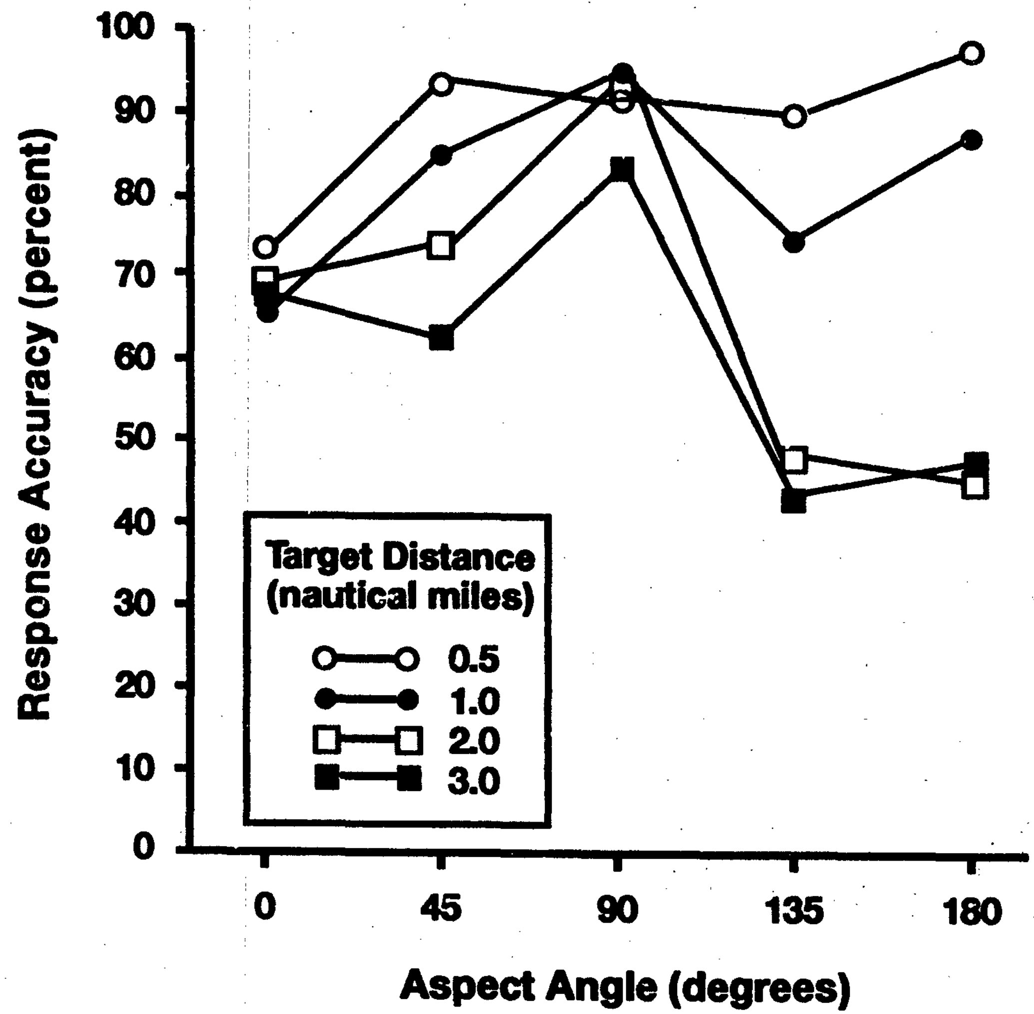

Figure 9
Response Accuracy for the F-15 Targets as a Function of Aspect Angle and Distance

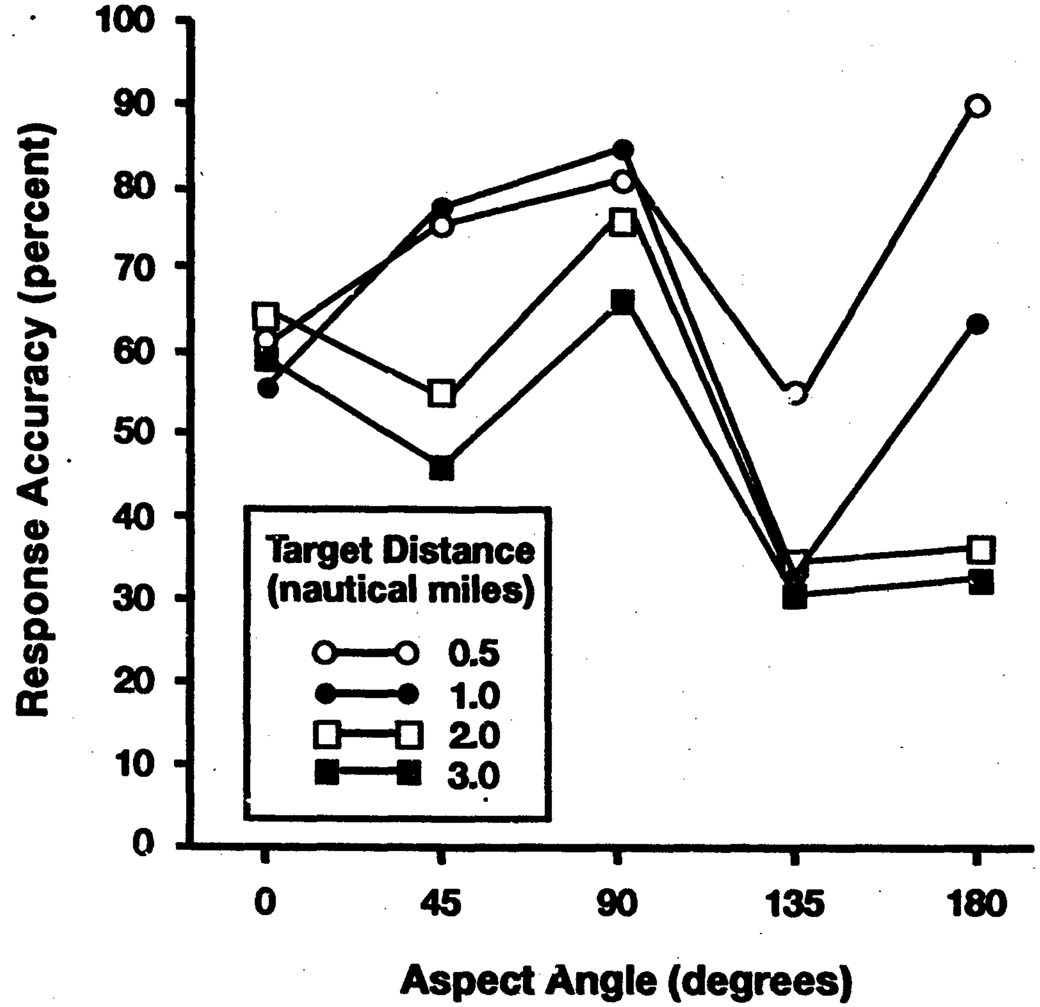

Figure 10
Response Accuracy for the F-16 Targets as a Function of Aspect Angle and Distance

Table 9. Percent Correct Responses as a Function of Target Orientation, Type, and Distance

Target orientation	F-15 Target distance (nmi)				F-16 Target distance (nmi)				
	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0	Mean
6	95.0	97.5	95.0	82.5	95.0	80.0	80.0	67.5	86.56
9	95.0	92.5	87.5	87.5	80.0	77.5	67.5	67.5	81.88
2	95.0	95.0	97.5	87.5	57.5	60.0	77.5	72.5	80.31
5	95.0	97.5	95.0	85.0	90.0	72.5	52.5	45.0	79.06
13	100.0	95.0	72.5	60.0	90.0	85.0	50.0	15.0	70.94
12	92.5	92.5	77.5	65.0	72.5	42.5	50.0	57.5	68.75
3	95.0	82.5	62.5	52.5	90.0	57.5	42.5	42.5	65.63
7	97.5	95.0	45.0	25.0	90.0	82.5	47.5	25.0	63.44
10	77.5	70.0	62.5	40.0	80.0	70.0	32.5	32.5	58.13
4	97.5	92.5	30.0	37.5	90.0	67.5	27.5	15.0	57.19
1	47.5	35.0	40.0	45.0	65.0	52.5	37.5	35.0	44.69
15	97.5	62.5	32.5	27.5	62.5	27.5	20.0	10.0	42.50
8	75.0	67.5	20.0	17.5	32.5	25.0	30.0	5.0	34.06
14	72.5	37.5	27.5	15.0	17.5	10.0	20.0	17.5	27.19
16	65.0	55.0	20.0	12.5	30.0	7.5	12.5	2.5	25.63
11	60.0	40.0	5.0	17.5	40.0	17.5	5.0	0	23.13
Mean	84.84	75.47	54.38	47.34	67.66	52.19	40.78	31.88	56.82

A total of 10 analyses was conducted, 6 three-factor analyses, 1 four-factor analysis, and 3 two-factor analyses. A correct response in these analyses was defined as a correct aspect angle, direction of travel, pitch attitude, and bank attitude response. The composite response was incorrect if any individual response was in error.

The target orientations that were compared in each analysis were selected in order to isolate the effects of the target characteristics on detection accuracy. In the first analysis, for example, where target orientations 3 and 15 were compared, the effect of rotating the nose of the target 45 deg to the right was evaluated when all the other target characteristics were held constant. In the second analysis, which involved a comparison between target orientations 15 and 16, the effect of pitching the nose down 45 deg was determined when the aspect angle, direction of travel, and bank angle were constant.

Target Orientation Analysis 1. The factors encompassed in the three-factor analyses were: (a) target orientation, (b) target type, and (c) target distance. The following target orientations were compared in the first of these analyses:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
3	180	Nose-on	0	0
15	135	Right	0	0

The target orientation main effect was statistically significant ($\chi^2(1) = 45.79$, $p < 0.01$), as were the main effects of target type ($\chi^2(1) = 35.45$, $p < 0.01$) and target distance ($\chi^2(3) = 132.85$, $p < 0.01$). The correct response percentages associated with each of the main effects are provided in Table 10, and the error responses for the two target orientations are provided in Tables 3 and 15 in Appendix C. None of the interactions was statistically significant.

The incorrect responses associated with the two target orientations were predominantly in the form of aspect recognition errors, rather than incorrect direction of travel, pitch, or bank responses. Of the aspect errors committed in response to target orientation 3, 0 deg was designated most often, while for target orientation 15, 45 deg was specified with the greatest regularity followed by 90 deg.

Table 10. Correct Responses for the Main Effects in the Analysis Comparing Target Orientations 3 and 15

Main effect	Correct responses (percent)
Target orientation	
3	65.63
15	42.50
Target type	
F-15	64.06
F-16	44.06
Target distance (nmi)	
0.5	86.25
1.0	57.50
2.0	39.38
3.0	33.13

<u>Target Orientation Analysis 2</u>. The target orientations compared in the second three-factor analysis were the following:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
15	135	Right	0	0
16	135	Right	45 Down	0

Significant main effects were observed for target orientation ($\chi^2(1) = 29.36$, $p < 0.01$), target type ($\chi^2(1) = 58.33$, $p < 0.01$), and target distance ($\chi^2(3) = 123.74$, $p < 0.01$). Table 11 presents the correct response percentages for each main effect, and the error responses corresponding to the two target orientations are provided in Tables 15 and 16 in Appendix C. None of the interactions attained statistical significance.

As previously noted, aspect errors were the most prevalent of the incorrect responses for target orientation 15. For target orientation 16, however, there was a large number of aspect errors as well as bank errors, even though the targets were not banked.

Table 11. Correct Responses for the Main Effects in the Analysis Comparing Target Orientations 15 and 16

Main effect	Correct responses (percent)
Target orientation	
15	42.50
16	25.63
Target type	
F-15	46.56
F-16	21.56
Target distance (nmi)	
0.5	63.75
1.0	38.13
2.0	21.25
3.0	13.13

The aspect angle designated with the highest frequency among the aspect errors was 45 deg, and both left and right bank angles were erroneously attributed to the target. A right bank was specified with the greatest regularity when only the bank angle was incorrect, and a left bank was usually indicated when the target was perceived as being at a 45-deg aspect and also in a bank attitude.

Target Orientation Analysis 3. The target orientations evaluated in the subsequent analysis consisted of:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
9	45	Left	0	45 Left
12	135	Left	0	45 Left

The main effects in the analysis were significant for target orientation ($\chi^2(1) = 16.44$, $p < 0.01$), target type ($\chi^2(1) = 44.33$, $p < 0.01$), and target distance ($\chi^2(3) = 15.05$, $p < 0.01$). The various interactions associated with this analysis were not statistically significant. The correct response percentages for the main effects are presented in Table 12, and Tables 9 and 12 in Appendix C indicate the corresponding response errors.

The response errors committed by the pilots in connection with target orientation 9 consisted principally of a mix of aspect, pitch, and bank angle errors. When the aspect angle and/or the direction of bank was incorrect, the pilots mainly indicated that the target aspect was 135 deg and the target was banked right. In all but one instance where the pilots incorrectly identified the pitch angle, a nose-high attitude was attributed to the target.

For target orientation 12, the incorrect responses were predominantly aspect and/or bank errors. The aspect angle specified most of the time among the aspect errors was 45 deg, and a right bank was designated with the greatest frequency when the bank was incorrect. The errors became more diverse as the target distance increased, which was characterized by the production of direction of travel and pitch errors. At this target orientation, the pilots primarily indicated a nose-low attitude when pitch was incorrect.

Target Orientation Analysis 4. In the fourth three-factor analysis, the following two target orientations were compared:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
5	90	Left	45 Down	0
10	45	Left	45 Down	0

This analysis yielded a significant main effect for target orientation ($\chi^2(1) = 38.37$, $p < 0.01$), target type ($\chi^2(1) = 30.22$, $p < 0.01$), and target distance ($\chi^2(3) = 64.04$, $p < 0.01$). In addition, the two-way target orientation by target type interaction was significant ($\chi^2(1) = 15.56$, $p < 0.01$). For the main effect of target distance, the response accuracy associated with each of the distances in ascending order was 85.63, 77.50, 60.63, and 50.63%. Figure 11 illustrates the response accuracy profiles in the target orientation by target type interaction. Tables 5 and 10 in Appendix C present the error responses corresponding to the two target orientations.

It is evident in Figure 11 that response accuracy was greater for the F-15 targets than the F-16 targets and that target orientation 5 was more conducive to accurate orientation recognition than target orientation 10. The decline in accuracy

Table 12. Correct Responses for the Main Effects in the Analysis Comparing Target Orientations 9 and 12

Main effect	Correct responses (percent)
Target orientation	
9	81.88
12	68.75
Target type	
F-15	86.25
F-16	64.38
Target distance (nmi)	
0.5	85.00
1.0	76.25
2.0	70.63
3.0	69.38

between the two target orientations, however, was much greater for the F-15 targets than the F-16 targets, which accounts for the significant interaction. The error responses for target orientation 5 and 10 indicate that when the pilots responded incorrectly, they primarily misjudged the target aspect angle and/or bank angle.

Target Orientation Analysis 5. The target orientations addressed in the subsequent analysis were:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
6	90	Left	0	60 Left
7	90	Right	0	60 Left

In addition to the significant main effect of target orientation ($\chi^2(1) = 57.86$, $p < 0.01$), the main effects were significant for target type ($\chi^2(1) = 9.73$, $p < 0.01$) and target distance ($\chi^2(3) = 124.28$, $p < 0.01$). The two-way, target orientation by target distance interaction was also significant

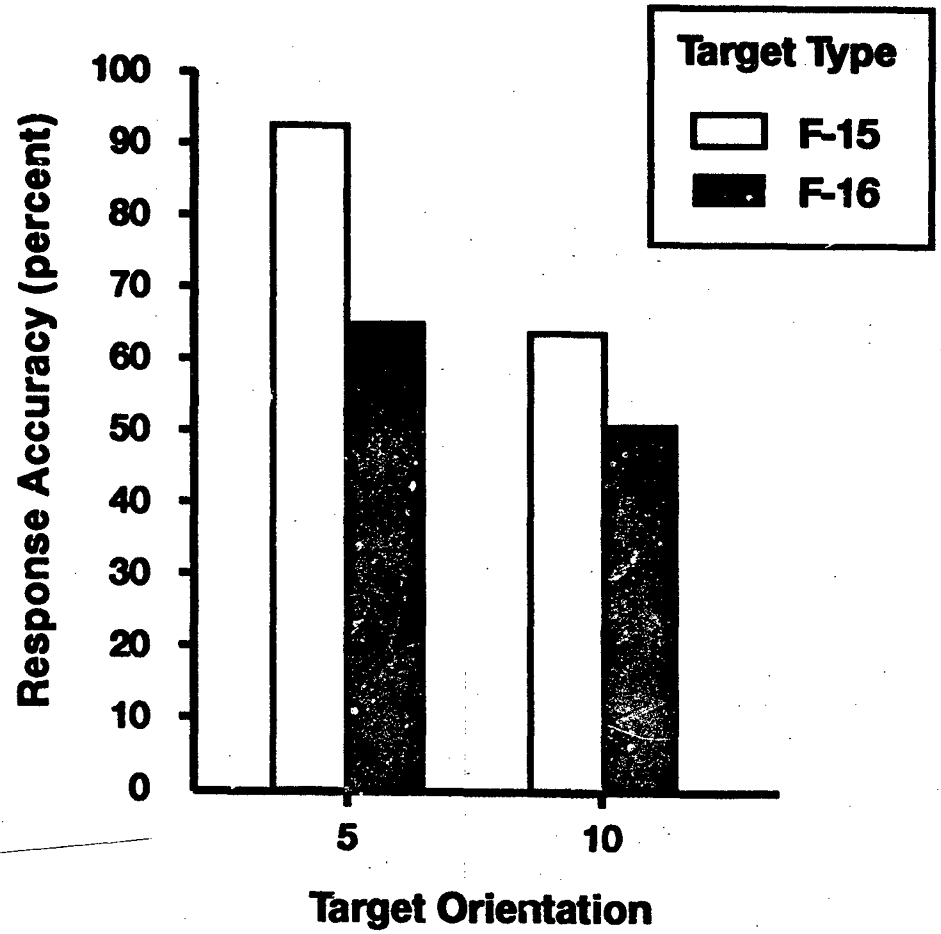

Figure 11
Response Accuracy as a Function of Target Type
and Target Orientations 5 and 10

($\chi^2(3) = 13.41$, $p < 0.01$). The correct response percentages corresponding to the F-15 and F-16 targets in the main effect of target type were 79.06 and 70.94, respectively, and the percentages for the target orientation by target distance interaction are presented in Figure 12. The errors made by the pilots relative to the target orientations are provided in Tables 6 and 7 in Appendix C.

Figure 12 shows that response accuracy for target orientation 6 decreased as a function of target distance and that the largest decline occurred when the distance increased from 2.0 to 3.0 nmi. Response accuracy for target orientation 7 at the 0.5 and 1.0 nmi distances was very nearly identical to the accuracy at the corresponding distances for target orientation 6. Accuracy decreased very abruptly, however, for target orientation 7 when the distance increased from 1.0 to 2.0 nmi. This was followed by a smaller decline from 2.0 to 3.0 nmi. Most of the response errors that were committed were due to a misidentification of the direction of bank.

<u>Target Orientation Analysis 6</u>. The next analysis encompassed the following target orientations:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
9	45	Left	0	45 Left
13	45	Right	0	45 Left

In this analysis, the main effect of target orientation was significant ($\chi^2(1) = 13.37$, $p < 0.01$), as well as the main effect of target type ($\chi^2(1) = 40.41$, $p < 0.01$) and target distance ($\chi^2(3) = 74.14$, $p < 0.01$). There was one significant two-way interaction, which occurred between target orientation and target distance ($\chi^2(3) = 27.81$, $p < 0.01$). In the main effect of target type, response accuracy was 86.25% for the F-15 targets and 66.56% for the F-16 targets. The correct response percentages associated with the target orientation by target distance interaction are depicted in Figure 13, and the response errors are presented in Tables 9 and 13 in Appendix C.

Response accuracy for target orientation 9 decreased only slightly across the four simulated distances employed in the present investigation (Fig. 13), with the largest reduction occurring when the distance increased from 1.0 to 2.0 nmi. There was no difference in accuracy between the 2.0 and 3.0 nmi distances. The nature of the response errors pertaining to target

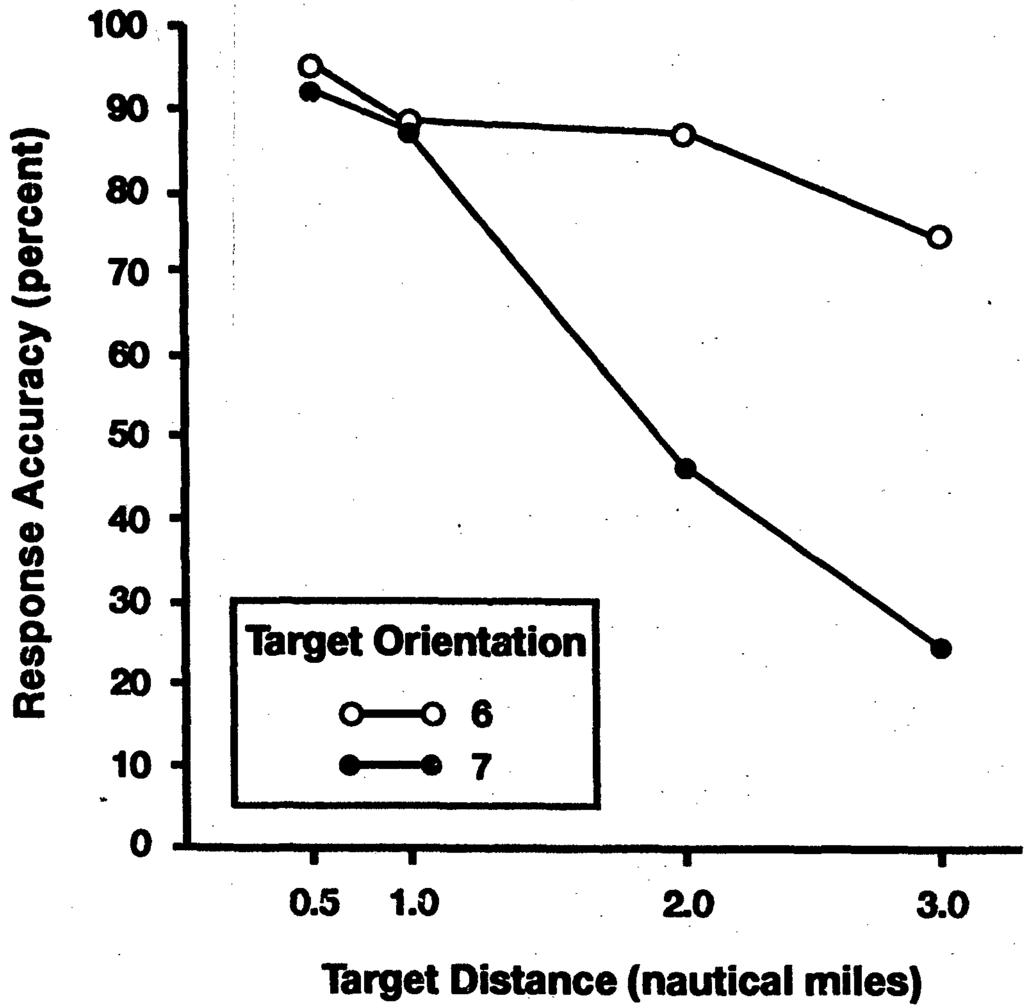

Figure 12
Response Accuracy as a Function of Target Distance
and Target Orientations 6 and 7

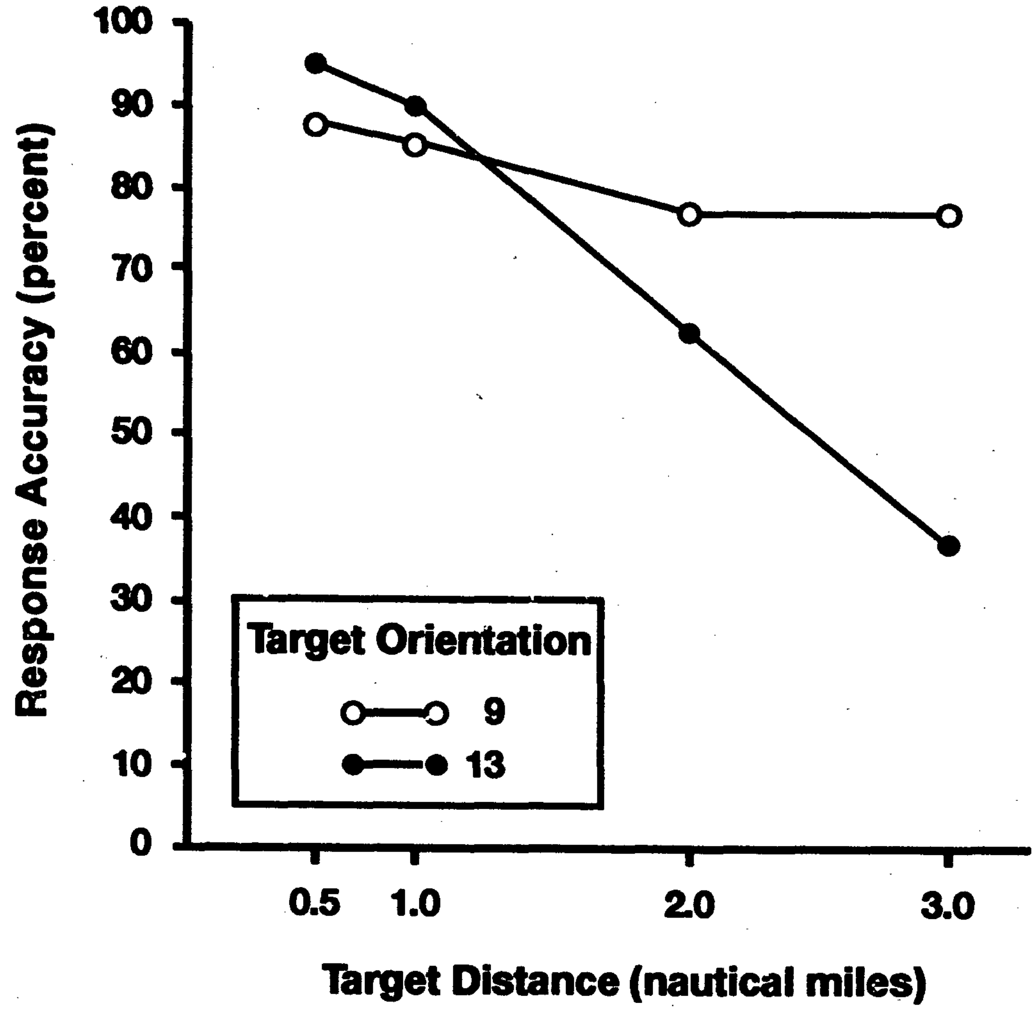

Figure 13
Response Accuracy as a Function of Target Distance
and Target Orientations 9 and 13

orientation 9 have been examined previously in the comparison between target orientations 9 and 12.

Response accuracy for target orientation 13 dropped precipitously when the simulated target distance increased from 1.0 to 2.0 nmi, and there was a further sharp decline in accuracy when the target distance was increased to 3.0 nmi. There was a wide range of orientation errors, which included incorrect aspect angles, directions of travel, pitch attitudes, and directions of bank. The most common orientation designated when an error was committed was a 135-deg aspect with a right bank, and a 90-deg aspect was the next most frequent error.

Target Orientation Analysis 7. In the four-factor analysis that was conducted, the factors were target aspect, target pitch, target type, and target distance. There were two target aspect conditions, 0 and 180 deg, and two target pitch conditions, nose-level and nose-high. The target aspect and target pitch conditions were formed in this analysis using the following four target orientations:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
1	0	Tail-on	0	0
2	0	Tail-on	45 Up	0
3	180	Nose-on	0	0
4	180	Nose-on	45 Up	0

In the analysis, three main effects, three two-way interactions, and two three-way interactions were statistically significant. The significant main effects were: (a) target pitch ($\chi^2(1) = 27.68$, $p < 0.01$), (b) target type ($\chi^2(1) = 24.09$, $p < 0.01$), and (c) target distance ($\chi^2(3) = 92.53$, $p < 0.01$). The two-way interactions were: (a) target aspect by target pitch ($\chi^2(1) = 69.61$, $p < 0.01$), (b) target pitch by target type ($\chi^2(1) = 14.36$, $p < 0.01$), and (c) target aspect by target distance ($\chi^2(3) = 76.63$, $p < 0.01$). The three-way interactions consisted of: (a) target aspect by target pitch by target type ($\chi^2(1) = 7.47$, $p < 0.01$) and (b) target aspect by target pitch by target distance ($\chi^2(3) = 17.07$, $p < 0.01$).

The three-way interactions are illustrated in Figures 14 and 15. The four target orientations that comprise the four target-aspect by target-pitch combinations are specified in the figures. Comparison of target orientations 1 and 2 in the figures shows the

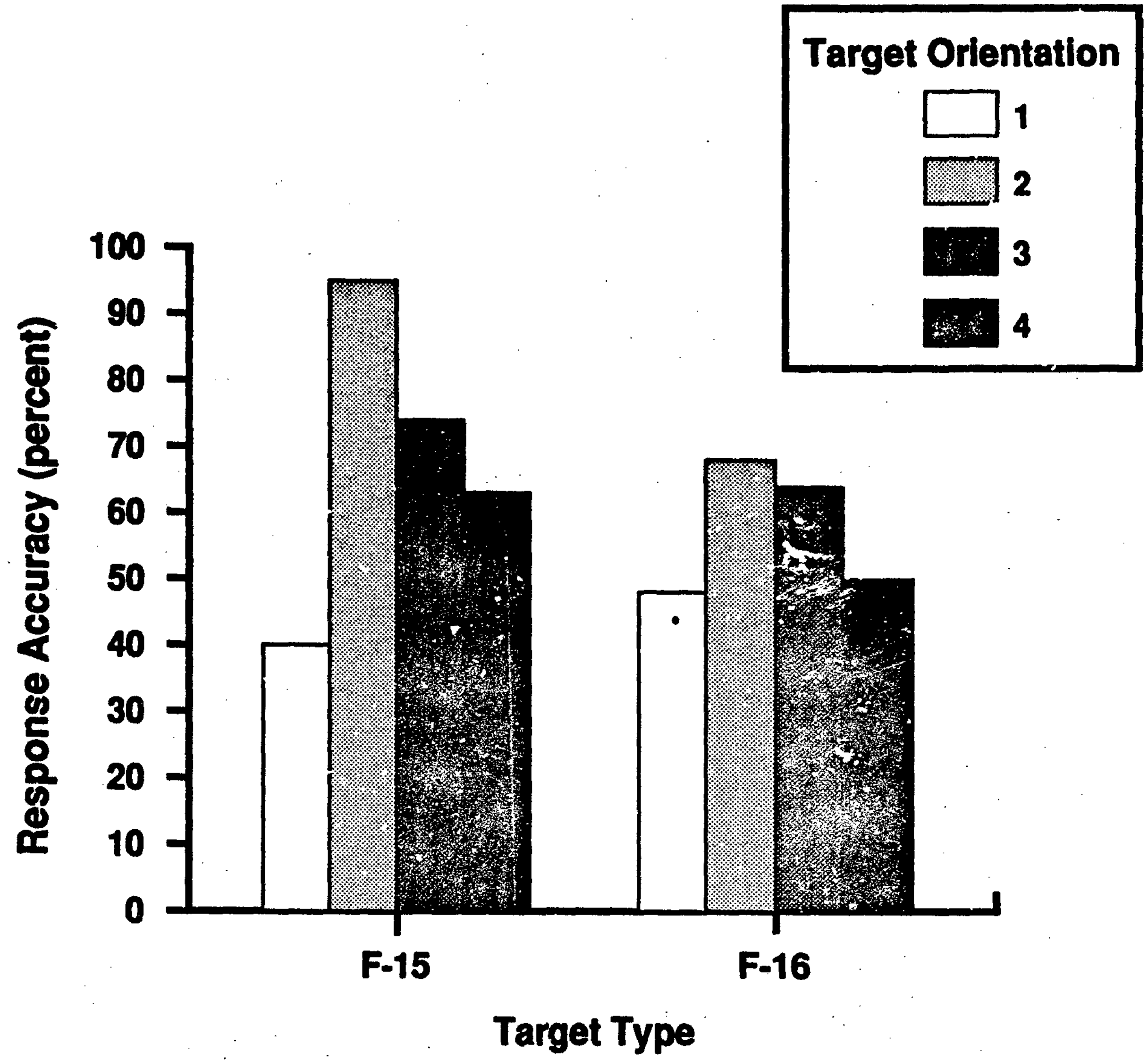

Figure 14
Response Accuracy as a Function of Target Type and Target Orientations 1, 2, 3, and 4

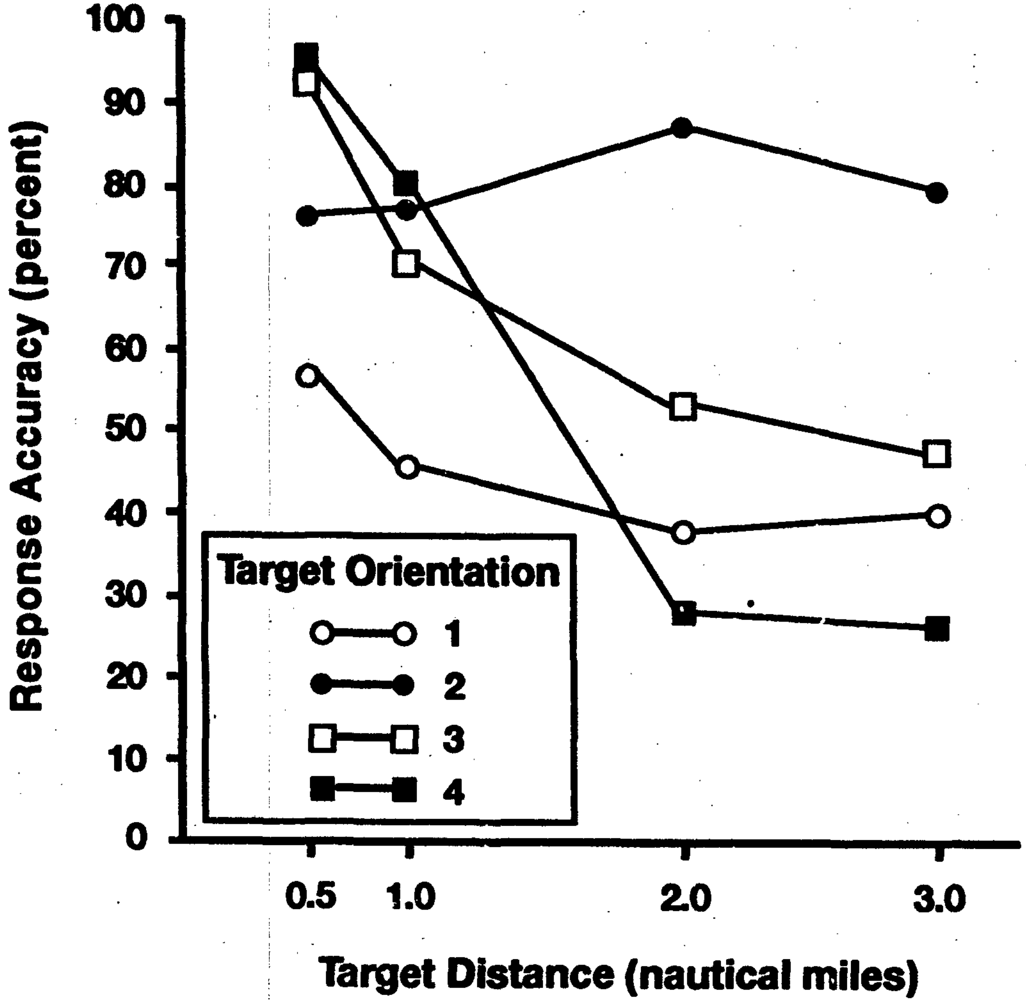

Figure 15
Response Accuracy as a Function of Target Distance
and Target Orientations 1, 2, 3, and 4

effects of changing target pitch on response accuracy when the targets are tail-on, and comparison of orientations 3 and 4 reflects the effects of pitch when the targets are nose-on. The difference in response accuracy between target orientations 1 and 3 is indicative of a nose-on to tail-on target aspect change with 0-deg pitch, and the difference between target orientations 2 and 4 quantifies the influence of the aspect change when the targets are pitched up.

The error responses induced by the four target orientations are presented in Tables 1, 2, 3, and 4 in Appendix C. In most cases, the pilots designated the opposite aspect angle when an error occurred, i.e., 0 deg for 180-deg targets and 180 deg for 0-deg targets. As the simulated target distances increased, the errors became more diverse, resulting in aspect angle, direction of travel, target pitch, and target bank errors.

<u>Target Orientation Analysis 8</u>. In the last three analyses, the effects of three different target orientations on recognition accuracy were separately evaluated. A two-factor model was used in each of these analyses, and the factors were target type and target distance.

The target orientation in the first of the two-factor analyses was as follows:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
8	90	Right	45 Up	120 Left

In this analysis, the target type main effect was significant ($\chi^2(1) = 19.89$, $p < 0.01$), as well as the target distance main effect ($\chi^2(3) = 46.00$, $p < 0.01$) and the target type by target distance interaction ($\chi^2(3) = 14.51$, $p < 0.01$). The interaction is portrayed in Figure 16, where it can be observed that there was a large difference in response accuracy between the two target types at 0.5 and 1.0 nmi and a very small difference at 2.0 and 3.0 nmi. At 2.0 nmi, response accuracy for the F-16 targets was actually better than the accuracy for the F-15 targets, but this represents a difference of only four errors.

Table 8 in Appendix C presents the error responses for target orientation 8. The pilots missed mainly the aspect angle and the direction of bank. A right bank was almost exclusively specified when the bank was incorrect, and a 45-deg aspect was designated most often when the target aspect was incorrectly identified.

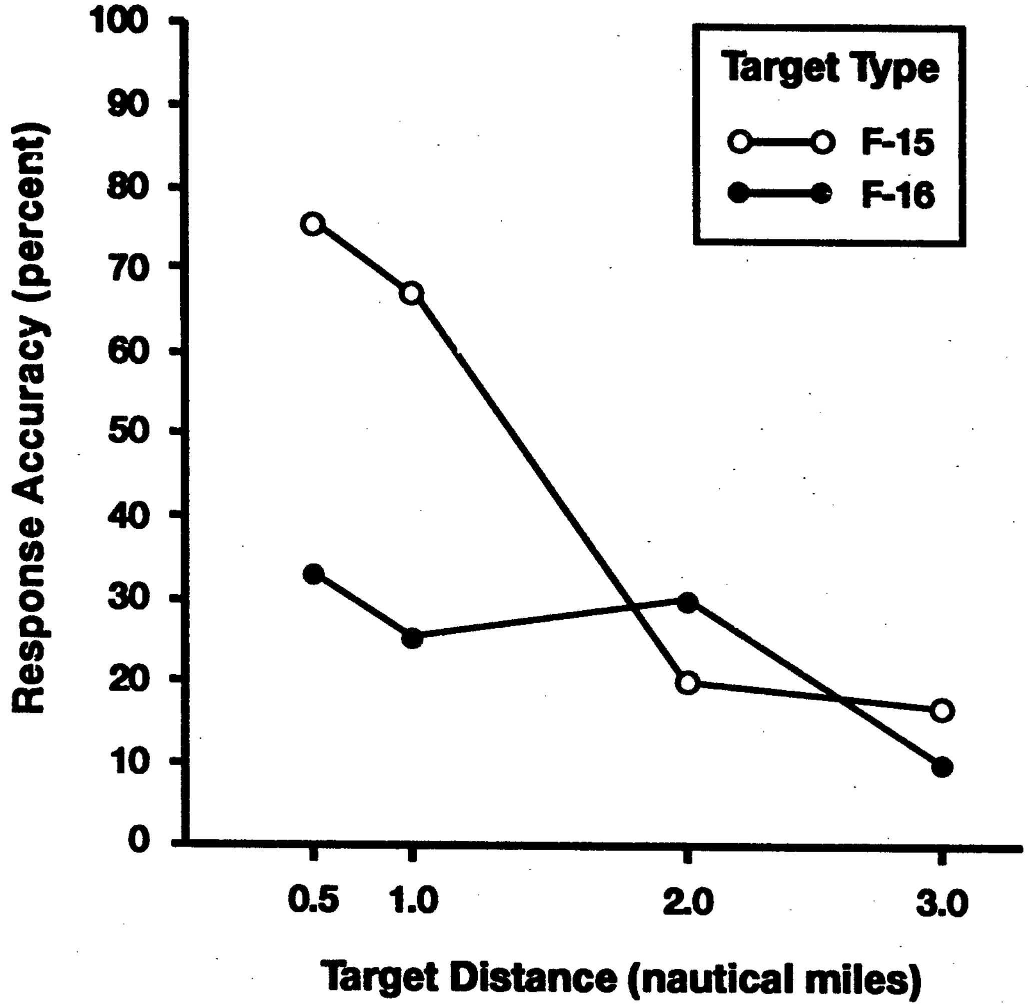

Figure 16
Response Accuracy for Target Orientation 8 as a Function of Target Type and Distance

Target Orientation Analysis 9. In the second two-factor analysis, the following target orientation was used:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
11	135	Left	45 Up	45 Right

The main effect of target type was significant ($\chi^2(1) = 12.61$, $p < 0.01$) and the target distance main effect was significant ($\chi^2(3) = 62.31$, $p < 0.01$) in this analysis. There was no statistically significant interaction. The response accuracy associated with F-15 and F-16 targets was 30.63 and 15.63%, respectively, and the response accuracy corresponding to the four distances was respectively 50.00, 28.75, 5.00, and 8.75%.

The error responses in conjunction with target orientation 11 are presented in Table 11 in Appendix C. The pilots typically felt the target aspect was either 45 or 90 deg and the target was banked left when the target aspect and/or target bank was incorrectly identified.

Target Orientation Analysis 10. The target orientation encompassed in the final two-factor analysis was as follows:

Target orientation	Aspect angle (deg)	Direction of travel	Pitch angle (deg)	Bank angle (deg)
14	45	Right	45 Down	45 Right

A significant target type main effect ($\chi^2(1) = 21.06$, $p < 0.01$), target distance main effect ($\chi^2(3) = 19.24$, $p < 0.01$), and target type by target distance interaction ($\chi^2(3) = 14.39$, $p < 0.01$) were observed in this analysis. Figure 17 illustrates the interaction, and it may be seen that the difference in response accuracy between the two target types decreased as the simulated distance of the targets increased. Examination of the error responses, which are provided in Table 14 in Appendix C, shows that the target was primarily interpreted as being in a wings-level attitude (0-deg bank) and that the target aspect was 90 or 135 deg when the bank and/or target aspect were incorrect.

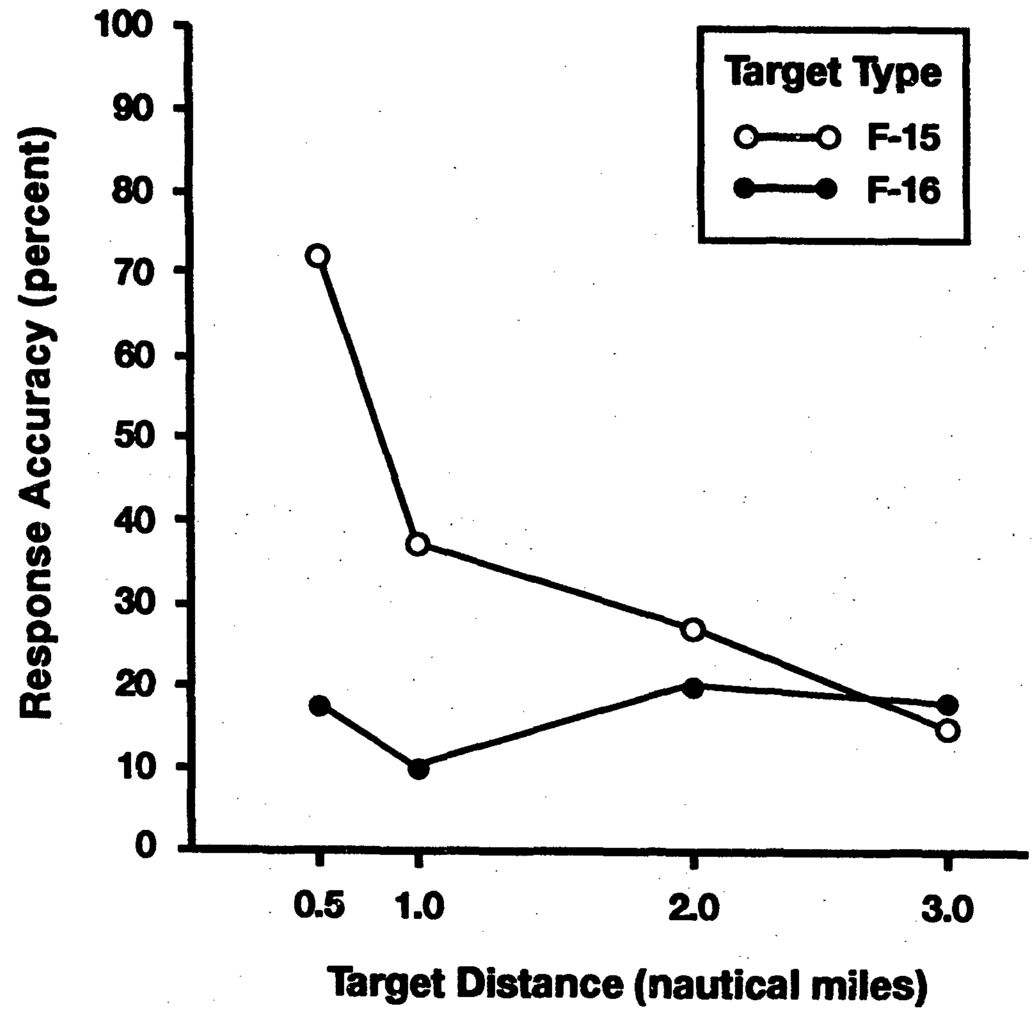

Figure 17
Response Accuracy for Target Orientation 14 as a Function of Target Type and Distance

Debriefing Questionnaire

The debriefing questionnaire was administered mainly to determine if the slides provided a realistic simulation of the target orientation assessment task in air-to-air combat and if the procedures used in the investigation may have influenced the pilots' responses. The specific questions that were contained in the questionnaire, the pilots' responses, and the explanations provided by the pilots for their responses are presented in Appendix D. With only a few exceptions, the pilots felt that the target images and the simulated target distances were realistic. Half the pilots, however, indicated that there were visual cues missing that they normally use to determine target orientation, including target motion, exhaust smoke, wingtip vortices, canopy and tail glint, and target shadows and shading.

The questionnaire revealed that only 10% of the pilots thought the task used in the present investigation was easier than actual target orientation assessment, 18.75% felt it was about the same, and 71.25% concluded it was more difficult. Some of the reasons given when the task was judged to be easier were that the targets were always at the same location and the missiles were white. The lack of target motion was almost always given as the reason why the task was felt to be more difficult. It may be recalled that target motion across the cockpit canopy, along with the relative size/size changes of the target, were two of the most important cues in air-to-air combat training reported by the pilots in the evaluation conducted by Coward and Rupp (1982).

The target background in the slide presentations appeared realistic for two-thirds of the pilots, but unrealistic for one-third. The primary reason for not being realistic was that the background never changed. In real-world flight conditions, the background may be a blue sky, clouds, or ground. The background was not varied in the present investigation to avoid confounding the target variables with the background.

The pilots expressed relatively few objections to the conduct of the investigation. The only problems deserving mention were that 9 of the 80 pilots experienced some fatigue during the slide presentations and 8 of the pilots felt that the slide presentations were either too long or too short.

DISCUSSION

Visual Cue Usage

Based on the percentages of the correct target orientation responses in which the various visual cues were used, as shown in Table 7, the most important cues for discerning the orientation of the targets were:

1. tail
2. wings
3. nose
4. intake(s)
5. planform
6. canopy
7. belly
8. missiles
9. top of aircraft or wings
10. fuselage
11. exhaust outlet(s)

The balance of the target cues that were indicated were either infrequently used or they represented the absence of cues (e.g., no tail).

In the survey conducted by Coward and Rupp (1982), the four most important visual cues for air-to-air combat training reported by the pilots were: wing planform, nose position, relative motion across the canopy, and relative size/size changes. The former two visual cues were among the most frequently designated by pilots in the present investigation, especially at the greater simulated distances. Since static target images were used in this investigation, the latter two motion-related cues identified by Coward and Rupp were not available to the pilots in the current research.

Comparison of the pilot responses in Table 7 and Tables 1 through 16 in Appendix B clearly shows that the target cues that were used and the extent they were used were a function of: (a) the orientation of the target, (b) the type of target, and (c) the distance of the target. The influence of target orientation on cue usage is exemplified by comparing target orientation 2 and target orientation 4. In target orientation 2, where the target was pointed directly away with a nose-high pitch attitude, the canopy was on the observer's side of the target fuselage, and the canopy was used as a target cue for orientation in 22.96% of the correct responses. In target orientation 4, in which the target was nose-high and pointed directly toward the observer, the canopy was on the opposite side of the target and was not available as an orientation cue. Consequently, the canopy was not reported as a cue used for target orientation 4.

It may be noted that in a few instances the pilots indicated they used target cues that would not have been visible to them. For example, the intake of the F-16 target was not visible in target orientation 2, yet a couple of times the pilots reported using the intake as a cue. Either this was simply erroneous or they meant that they could not see it, and to them "intake" was synonymous with "no intake."

The effect of target type on cue usage is exemplified by contrasting the use of the missiles. The missiles were on the underside of the F-15 target, and were comprised of four AIM-7 and four AIM-9 missiles. For the F-16 targets, one AIM-9 missile was on either wingtip. The observers frequently reported using the missiles as an orientation cue for the F-15 targets when the underside of the targets was in view. The missiles were rarely used in conjunction with the F-16 targets.

It must be pointed out, though, that the missiles were painted white and provided excellent contrast with the belly of the F-15 targets. In present-day air combat training, the missiles are a grayish color, which reduces contrast, and a full missile load is not used. Therefore, the use of missiles as a cue for target orientation in the present investigation may overestimate the role of missiles as a target orientation cue in training.

Target distance had a pronounced influence on the cues that were used. For the most part, the smaller, more detailed cues were used less frequently as distance increased because the pilots were increasingly less able to visually resolve the finer details, whereas the larger, more global cues increased in usage as distance increased. For example, the relatively small missiles were frequently reported as an F-15 target orientation cue at the closer distances, but not at the farther distances. In contrast, the target planform was indicated more often as distance increased.

Because static target images were used in this research, none of the dynamic cues to target orientation were available to the pilots. In normal training situations, targets may move vertically and horizontally relative to the attacker, as well as toward and away from the attacker. Furthermore, targets may produce vapor trails, exhaust smoke, canopy glint, and afterburner illumination, along with other dynamic visual cues. The investigation reported by Coward and Rupp (1982) suggests that these dynamic cues are important sources of target orientation information. Therefore, it is likely that target orientation response accuracy would be greater in a high-fidelity, dynamic environment than under the static conditions employed in this investigation, particularly at the longest distances.

Response Accuracy

The analyses indicated that the orientation recognition accuracy associated with the F-15 targets was usually greater than the accuracy obtained with the F-16 targets. The reasons for this are that the F-15 fighter is much larger and is configured differently than the F-16 fighter. The F-15 is 63 ft, 9 in. in length and 42 ft, 10 in. in width from wingtip to wingtip. It has two tail fins, an air inlet on either side of the fuselage, and two side-by-side exhaust outlets in the tail section. The F-16 fighter, on the other hand, is 49 ft, 3 in. long (including nose probe) and 32 ft, 10 in. wide (including missile fins), and it has a single tail fin, one air inlet under the nose, and one exhaust outlet below the tail fin. There were various other differences between the two targets. For example, the camouflage color schemes were dissimilar and the weapons loads were different (i.e., the F-16 was equipped with a missile on either wingtip, whereas the armament for the F-15 was located under the wings and consisted of eight missiles).

In the bulk of the analyses, target orientation recognition accuracy declined when the target distance increased. This reduction in accuracy occurred because as the size of the targets on the screen diminished as distance increased, the physical features that provided cues to orientation became more difficult to visually resolve and, therefore, less visible. The instances in which response accuracy was not influenced by target distance, as well as the exceptions corresponding to target type, will be addressed later in the discussion.

The differences in response accuracy between the four types of pilots used in the present investigation were dependent on the type of targets the pilots viewed, as evidenced by the significant pilot type by target type interaction that was obtained in the initial analysis where the 16 target orientations were pooled. The differences in response accuracy were relatively small, however; consequently, the response data were summed across the four pilot types in the subsequent analyses. The distribution of the percent correct responses associated with the interaction revealed (Fig. 5) that response accuracy was nearly the same between the pilots who viewed the F-16 targets, and except for the B-Course pilots, the accuracy was very similar between the pilots who were presented the F-15 targets. The B-Course pilots were slightly less accurate in judging the orientations of the F-15 targets, which accounted for the significant interaction. These findings suggest that the B-Course pilots had learned to discriminate the orientations of the F-16 targets about as well as the other pilots, but not the orientations of the F-15 targets. Inspection of the pilots' flight experience in Table 4 shows that the B-Course pilots had flown between 64.04 and 70.83% fewer air-to-air training sorties than the other pilots.

The type of aircraft the pilots were flying had no bearing on target orientation recognition accuracy when the 16 target orientations were pooled, as witnessed by the absence of a difference between the "same" and "different" pilot's aircraft types. "Same" signifies that the targets the pilots viewed were the same as the fighter they flew, and "different" denotes the opposite. The lack of a difference in response accuracy means that they were no better at determining the orientation of the targets that were the same as their own fighter and no worse when the targets were different from their own fighter. Because there were no differences, the response data were summed across the two pilot aircraft types in the remaining analyses.

Both target direction of travel and target pitch were comparatively easy for the pilots to discern in the slide presentations. Since there was very little deterioration in response accuracy as target distance increased, it is surmised that the visual cues the pilots reported using at the longer distances, mainly the nose, tail, and planform, were the primary cues used to determine the left and right directions of travel and pitch. The absence of these cues and the presence of a mere circular spot were the chief indicators of the direction of travel and pitch when the target was either nose-on or tail-on and at 0-deg pitch at the longer distances. At the closer distances, the pilots could distinguish the finer cues, such as the air inlet, canopy, and exhaust, which were undoubtedly the principal cues used to determine whether the target was pointed toward or away from the pilot. Thus, to provide a realistic flight simulator visual environment, the pilot should be able to discriminate the left and right directions of travel and the pitch of a simulated target up to at least 3.0 nmi. The distance at which the pilot should be able to distinguish whether the target is nose-on or tail-on will be discussed later.

The analysis of the bank error scores revealed that the pilots could fairly easily distinguish when the targets were banked, and that bank recognition accuracy did not vary substantially across the four simulated target distances used. It is, therefore, essential that the pilots are able to recognize a banked target up to at least 3.0 nmi in a flight simulator to provide an environment comparable to actual training. The target wings and planform are the dominant indicators of target bank. Determining the direction of bank (i.e., left or right) proved to be far more error inducing than just determining whether or not the targets were banked, but this was dependent upon the type of target portrayed on the screen. For the F-15 targets, the direction of bank was more difficult to distinguish only at 2.0 and 3.0 nmi where response accuracy was near the chance level. For the F-16 targets, discriminating the direction of bank was more difficult than just determining whether the target was banked across the four target distances, although the difference was much smaller at 0.5 nmi. The rationale for this occurrence is simply that the pilots could not reliably distinguish the top of the target from the bottom. Based on these observations, the distance at which the pilots should be capable of discriminating the direction of bank of a simulated target should be at least 1.0 nmi for an F-15 target and between 0.5 and 1.0 nmi for an F-16 target.

Aspect recognition accuracy varied considerably between the aspect angles used in the present investigation. The significant three-way, aspect angle by target type by target distance interaction indicated that aspect recognition accuracy was also influenced by target type and target distance. Comparisons of the individual target orientations, which are discussed below, indicate that target pitch and bank attitude also contributed to the differences in aspect recognition accuracy.

Of the various aspect angles evaluated, the number of just aspect recognition errors was lowest for target orientations 6 and 7, as shown in Tables 6 and 7 in Appendix C. If the bank errors are omitted in the tables, it can be seen that there were relatively few aspect recognition errors at these orientations. Therefore, to provide real-world, target aspect recognition in a flight simulator, the pilots should be able to discriminate 90-deg aspect up to 3.0 nmi when the target is not pitched and is banked 60 deg relative to the pilot. It is conjectured that if the pilot can recognize the aspect of target orientations 6 and 7 at 3.0 nmi, the other aspect conditions used in the present investigation will also be recognizable at their real-world distances, so long as the cues the pilots used to determine the aspect angles at those distances are visible.

The specific target orientations were compared in the analyses to isolate the effects of changes in target aspect, pitch, or bank on orientation recognition accuracy. In the comparison of target orientations 3 and 15, the influence of the difference in target aspect between 180 deg and 135 deg was evaluated. Except for the F-15 target at 0.5 nmi, target orientation 15 promoted far more orientation recognition errors than orientation 3. The errors for target orientation 15 indicated that the elevated error rate was primarily due to the pilots assuming that the target was oriented away from them at a 45-deg aspect. This suggests that they could distinguish, for the most part, that the target was oriented diagonally to their line of sight, and that they assumed the target was most likely going away from them rather than toward them.

Target orientations 15 and 16 were compared to identify the effect of a change in target pitch on orientation recognition accuracy. It was found that orientation 16, in which the target was pitched down, resulted in significantly more errors than orientation 15, where the target was not pitched. Just as with target orientation 15, the pilots incorrectly identified most often the aspect of orientation 16 as 45 deg. The pilots also misidentified the bank angle of orientation 16 fairly frequently, even though the targets were not banked, which primarily accounted for the higher error rate. Among the bank errors, a right bank was the most common error. This suggests when the pilots could see the top of the target or thought they were viewing the top, they frequently surmised that it was in a right bank. It is also probable that they assumed that if the target were not banked, the wingtip would be even with the fuselage.

The effect of a change in target aspect in conjunction with a left target bank on response accuracy was evaluated in the target orientation 9 and 12 comparison. Overall, response accuracy for target orientation 9, which entailed a 45-deg aspect was second highest of the target orientations evaluated and sixth highest for target orientation 12, where the aspect angle was 135 deg. A large part of the increased error rate associated with orientation 12 was due to a tendency to interpret the 135-deg aspect angle as 45 deg, as explained abo e for target orientation 15, and to interpret the left bank as a right bank.

Target orientations 5 and 10 provided a comparison of the effect of a change in aspect with a nose-down attitude on response accuracy. In this comparison, a significant interaction was observed between target orientation and target type. For target orientation 5 in which the aspect angle was 90 deg, orientation recognition was much more efficient in connection with the F-15 targets than with the F-16 targets. The pilots rarely misidentified the F-15 target orientations, and of the incorrect responses associated with the F-16 targets, aspect and/or bank angle were the predominant errors. Response accuracy was lower for target orientation 10, which employed a 45-deg aspect, and the reduction in accuracy was far greater for the F-15 targets compared to orientation 5. The pilots mainly misinterpreted aspect and/or bank relative to target orientation 10.

Based on the difference in response accuracy between these target orientations, it is evident that the full-length side view provided by orientation 5 afforded better orientation cuing than the belly view and shorter physical screen size of the targets corresponding to target orientation 10. Furthermore, since the difference in response accuracy between the F-15 and F-16 targets was not as great for orientation 10 as for orientation 5, it can be asserted that the enhanced orientation cuing provided by the larger F-15 is degraded when the target is angled 45 deg away from the perpendicular with a nose-down attitude.

The comparison between target orientations 6 and 7 addressed the effects on response accuracy of a change in direction of travel from left to right, when the target aspect was 90 deg and the targets were in a left bank. In target orientation 6, with the left direction of travel, the top of the targets faced the pilots, and the bottom of the targets faced the pilots in target orientation 7. In the analysis, a significant interaction was obtained between target orientation and target distance. For target orientation 6, response accuracy declined slightly between 0.5 and 1.0 nmi, then remained essentially constant between 1.0 and 2.0 nmi, and fell again between 2.0 and 3.0 nmi. The response accuracy for target orientation 7 was nearly identical to the accuracy for orientation 6 at 0.5 and 1.0 nmi, but between 1.0 and 3.0 nmi, it dropped precipitously. Almost all of the errors the pilots committed were incorrect bank responses.

The explanation for this occurrence is relatively simple. At 0.5 and 1.0 nmi, both target orientations were fairly easily and equally distinguishable. At 2.0 and 3.0 nmi, however, the pilots could not discern the top from the bottom of the target as efficiently, which provide the left and right angle of bank cues. Therefore, based on their past experience, the pilots assumed that the targets were turning toward them and that the top of the target was facing them when they could not discriminate the top from the bottom. This was the correct interpretation of target orientation 6, but not orientation 7.

Target orientations 9 and 13 permitted a comparison of a left and right direction of travel when the target aspect was 45 deg and the targets were in a left bank. In target orientation 9, which simulated a left direction of travel, the top of the target was toward the pilots, and the pilots had a bottom view in target orientation 13, which portrayed a right direction of travel. A significant interaction was observed in the analysis between target orientation and target distance, which is depicted in Figure 13. The relationship between the two target orientations across the four target distances was the same as the relationship between target orientations 6 and 7, which was described previously.

It can be seen in Figure 13 that both target orientations 9 and 13 were about equally discernible and reasonably easy to distinguish at 0.5 and 1.0 nmi. Although it seems that the pilots were also able to fairly accurately recognize target orientation 9 at 2.0 and 3.0 nmi, but not target orientation 13, an alternative explanation is more tenable, which is based on the illusory reverse target orientation. In the present investigation, the 45- and 135-deg target aspect angles were reversible when the finer target details could not be visually resolved. For example, a target with a 45-deg aspect, a right direction of travel, and a left bank could appear as a target orientation with a 135-deg aspect, a right direction of travel, and right bank. This can be demonstrated by viewing one of the 45- or 135-deg aspect slides in Appendix A at a sufficient distance so that the smaller details cannot be seen.

It is the authors' contention that, based on the pilots' prior flight experience, the reverse orientation for target orientation 9 in the present investigation was less likely than the actual orientation, therefore, their responses were mostly correct. For target orientation 13, however, the reverse orientation was more likely as the finer target details became more difficult to resolve, which prompted them to incorrectly specify the reverse orientation with greater regularity. This assumption is corroborated by the error responses that were made in conjunction with target orientation 13. The reverse target orientation concept also provides an explanation for the consistently incorrect responses that occurred in relation to the various other target orientations used in the investigation.

Target orientations 1 through 4 provided a comparison between the nose-on and tail-on targets when they were pitched and not pitched. In this evaluation, two three-way interactions were significant, target aspect angle by pitch by type (Fig. 14) and target aspect angle by pitch by distance (Fig. 15). The first interaction (Fig. 14) revealed that response accuracy was greater for the F-15 targets than the F-16 targets, except with target orientation 1. A review of the incorrect responses in Appendix C corresponding to target orientation 1 shows that the errors for the F-15 targets were greater than the errors for the F-16 targets at 0.5 and 1.0 nmi. Although the targets were actually tail-on, the pilots invariably indicated that the targets were nose-on at these two distances when the F-15 target orientations were incorrectly identified. This signifies that the tail-on orientation of the F-15 targets was slightly more difficult to distinguish than tail-on orientation of the F-16 targets at the two closer distances.

In the second interaction (Fig. 15), the two most critical comparisons are between target orientation 1 and 3 and between orientations 2 and 4. It is evident in Figure 15 that the pilots could efficiently identify target orientation 3 at 0.5 nmi where the target was nose-on to the pilot. Then, as the distance increased, response accuracy correspondingly declined. The pilots were not as accurate interpreting the direction of travel in target orientation 1 as in orientation 3, and the elevated error rates occurred across the four simulated distances used in the investigation. Due to the shape of the response distributions over the four distances, it would appear that when the pilots were unable to accurately interpret the direction of travel, they basically guessed that it was either nose-on or tail-on. Had they employed a decision rule based on their previous flight experience where, for example, they may have indicated that the target was nose-on whenever they could not distinguish target direction, then response accuracy would have been much higher over the four distances for target orientation 3 and much lower for orientation 1.

In the comparison between target orientations 2 and 4, it is clearly evident that such a decision rule was implemented, which resulted in the characteristic response distributions. At 0.5 and 1.0 nmi, the visual cues provided reasonable orientation cuing and response accuracy was relatively good. At 2.0 and 3.0 nmi, however, the majority of pilots could not clearly distinguish whether the pitched up target was nose-on or tail-on. Consequently, they indicated a tail-on orientation based on their previous flight experience, which was correct for target orientation 2 but not orientation 4. Of the errors that were made in conjunction with target orientation 4, the pilots primarily indicated that the target aspect was 0 deg, which is the reverse target orientation of orientation 4.

Target orientations 8 and 14 proved to be among the most difficult for the pilots to interpret. For both these target orientations, there was a significant target type by target distance interaction, as shown in Figures 16 and 17, respectively. At 0.5 and 1.0 nmi, response accuracy was superior for the F-15 targets, and at the longer distances, the differences between the target types were negligible. These interactions suggest that the physical features and larger size of the F-15 targets provided more effective orientation cuing at the closer distances for target orientations 8 and 14, but the cuing advantages of the F-15 targets were eliminated by the longer distances.

Target orientation 8 was primarily conducive to aspect and/or direction of bank errors. The pilots specified a right bank almost exclusively when the target bank was incorrectly identified. This is consistent with the nature of the errors observed for target orientation 7, which provided the same 90-deg aspect and direction of bank. As previously stated, it is apparent that the pilots assumed the targets were turning toward them when they were unable to distinguish the top from the bottom of the targets. The target aspect designated most often when the aspect was misinterpreted was 45 deg. In contrast, there were hardly any aspect errors associated with target orientation 7. It would therefore appear that the larger angle of bank (i.e., 120 deg) coupled with the nose-high attitude creates a strong false impression of the target aspect.

In target orientation 14, the banked wing was in line with the target fuselage, which the pilots frequently interpreted as no bank. In addition, the pilots often indicated erroneously that target aspect was 90 deg with no bank. In this orientation, the wing would be in line with the fuselage, the same as target orientation 14. The pilots also specified the reverse target aspect (i.e., 135 deg) numerous times.

Of the various target orientations evaluated in this investigation, target orientation 11 was the most difficult to interpret correctly. A variety of errors was made, although the reverse target orientation was most commonly specified. The pilots rarely misinterpreted only the direction of bank; they either incorrectly identified the aspect or the aspect and bank. It is of interest to note that among the errors committed in relation to target orientation 12, which also portrayed a 135-deg aspect, the pilots rarely indicated that the aspect was 90 deg. In contrast, a 90-deg aspect was frequently designated in response to target orientation 11. This would seem to suggest that the nose-high attitude in orientation 11 had a heavy influence on the perception of target aspect.

RECOMMENDATIONS

In order to facilitate the practical application of the results of the present investigation, a set of recommendations was produced for use in the visual simulation of air-to-air combat. Because target motion was not simulated in this investigation, these recommendations are applicable to static image presentations. The recommendations that were developed are provided here.

Target Distance

Air-to-air combat engagements within visual range are performed at various slant range distances up to about 3.0 nmi. At these distances, different target cue arrays will be visible due to the decreasing power of the eyes to resolve finer details as distance increases. Therefore, to provide high-fidelity simulation, the visual cues pilots use for target orientation assessment should be resolvable at the distances corresponding to real-world training operations.

Target Detail

Simulated target aircraft should be modeled to resemble as closely as possible the targets that are anticipated in the actual training environment. Generally speaking, when greater target detail is provided, target orientation assessment is facilitated. The nose, wings, tail, and fuselage are essential cues, especially from 2.0 to 3.0 nmi. At 0.5 and 1.0 nmi, smaller target details provide additional orientation cues. These cues include the canopy, missiles, air intakes, and exhaust outlets. The simulated target paint scheme is also critical because it will determine how well the target contrasts with the background and it may influence the pilots' ability to distinguish the top and the bottom of the target. In the debriefing questionnaire, the pilots indicated that they use a number of other visual cues, including canopy glint, engine smoke, contrails, and afterburner glow. Therefore, these cues should be provided when feasible for the simulation system and appropriate for the simulated target.

Target Type

The size and configuration of the target aircraft will have a significant influence on target orientation recognition accuracy in air-to-air combat engagements. At a given distance, larger targets with richer details will promote greater orientation recognition accuracy. Therefore, it may be advisable to introduce larger, richly detailed targets during initial simulation training phases to permit the pilots to develop and refine their target orientation assessment skills. As they progress, these targets can be eliminated in favor of the target types that will be encountered in actual flight training.

Target Pitch

The visual display should allow pilots to differentiate whether a target aircraft is pitched upward or downward at a simulated distance of at least 3.0 nmi. To accurately recognize target pitch at this distance, the edges of the target must be sharply defined and the target must contrast sufficiently with the background. Because the direction the nose is pointed, the relative position of the nose and tail, and the sweep of the wings are the primary determinants of target pitch, these cues must be distinctly visible.

Target Bank

Pilots should be able to distinguish whether a target is banked at a simulated distance of at least 3.0 nmi. Since the wings and planform are the dominant cues for bank, the wings should be discriminable from the fuselage and background at this distance. The direction of bank (i.e., left and right) is far more difficult to determine than merely whether the target is banked. To accurately specify the direction of bank, the pilot must be able to discriminate the top from the bottom of the target, which is influenced by the difference in coloring and detail, such as missiles and canopy. For F-15 and F-16 simulated targets modeled in the fashion used in this investigation, the direction of bank of the F-15 targets should be recognizable at a minimum of 1.0 nmi, and between 0.5 and 1.0 nmi for the F-16 targets.

Left and Right Target Direction of Travel

The left and right target directions of travel should be discriminable up to at least 3.0 nmi. The direction the nose is pointed, the relative positioning of the nose and tail, and the sweep of the wings constitute the main direction-of-travel cues. Consequently, sharply defined edges of the target aircraft and a suprathreshold level of contrast are required to accurately identify the direction of travel at this distance.

Target Aspect

The simulation should permit pilots to accurately recognize a target aspect of 90 deg (i.e., the target is perpendicular to the line of sight) up to at least 3.0 nmi when the target is not pitched and is banked 60 deg relative to the observer. It is surmised that if the pilots can accurately recognize this target orientation at 3.0 nmi, the other target orientations will be recognizable at their real-world detection distances. The physical relationship between the nose and the wings and between the wings and tail are the principal determinants of aspect. Consequently, a clearly defined aircraft outline is essential to accurate aspect recognition at 3.0 nmi.

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APPENDIX A

TARGET AIRCRAFT ORIENTATIONS AT 0.5 NAUTICAL MILE

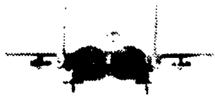

Figure 1. Target Orientation 1 - F-15 Target.

Figure 2. Target Orientation 1 - F-16 Target.

Figure 3. Target Orientation 2 - F-15 Target

Figure 4. Target Orientation 2 - F-16 Target

Figure 5. Target Orientation 3 - F-15 Target

Figure 6. Target Orientation 3 - F-16 Target.

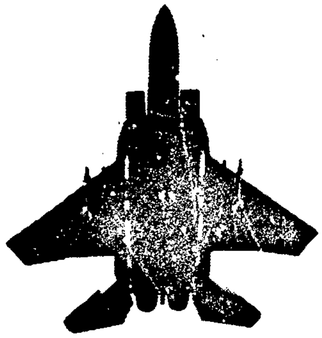

Figure 7. Target Orientation 4 -
F-15 Target.

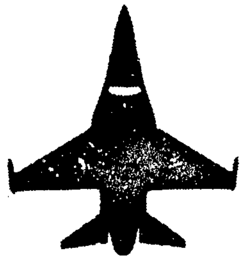

Figure 8. Target Orientation 4 -
F-16 Target.

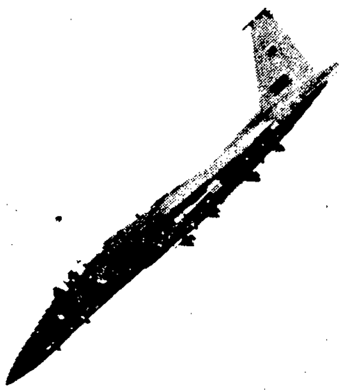

Figure 9. Target Orientation 5 -
F-15 Target.

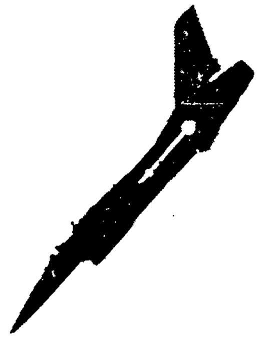

Figure 10. Target Orientation 5 -
F-16 Target.

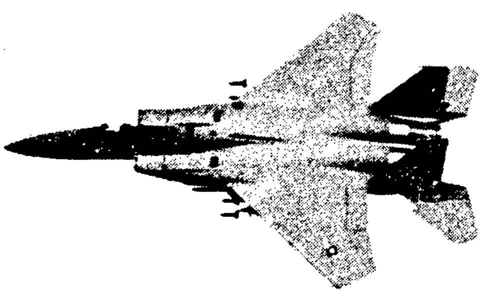

Figure 11. Target Orientation 6 -
F-15 Target.

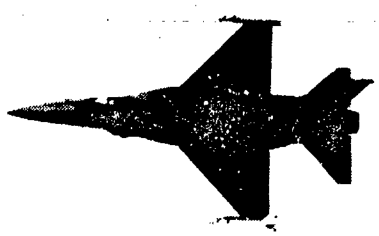

Figure 12. Target Orientation 6 -
F-16 Target.

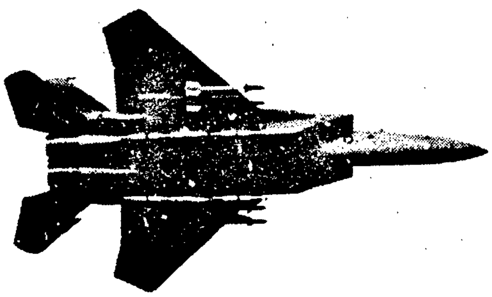

Figure 13. Target Orientation 7 - F-15 Target.

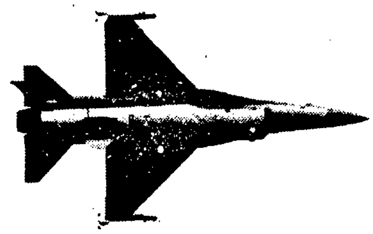

Figure 14. Target Orientation 7 - F-16 Target.

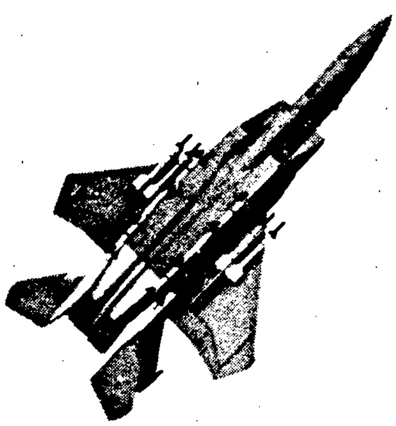

Figure 15. Target Orientation 8 - F-15 Target.

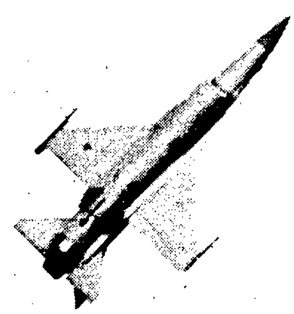

Figure 16. Target Orientation 8 - F-16 Target.

Figure 17. Target Orientation 9 - F-15 Target.

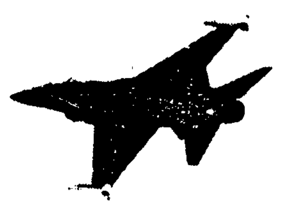

Figure 18. Target Orientation 9 - F-16 Target.

Figure 19. Target Orientation 10 -
F-15 Target.

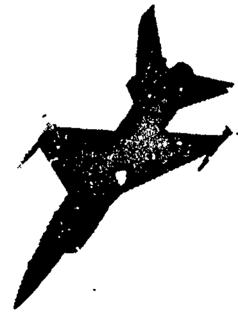

Figure 20. Target Orientation 10 -
F-16 Target.

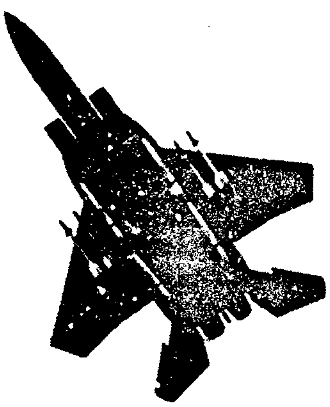

Figure 21. Target Orientation 11 -
F-15 Target.

Figure 22. Target Orientation 11 -
F-16 Target.

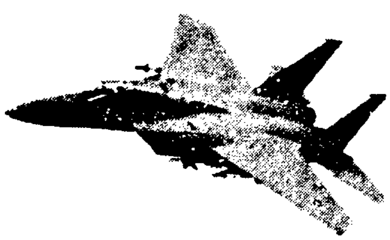

Figure 23. Target Orientation 12 -
F-15 Target.

Figure 24. Target Orientation 12 -
F-16 Target.

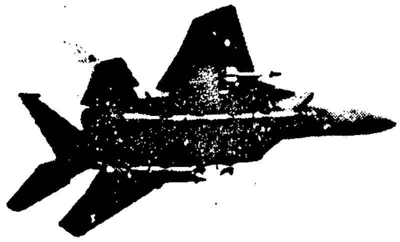

Figure 25. Target Orientation 13 - F-15 Target.

Figure 26. Target Orientation 13 - F-16 Target.

Figure 27. Target Orientation 14 - F-15 Target.

Figure 28. Target Orientation 14 - F-16 Target.

Figure 29. Target Orientation 15 - F-15 Target.

Figure 30. Target Orientation 15 - F-16 Target.

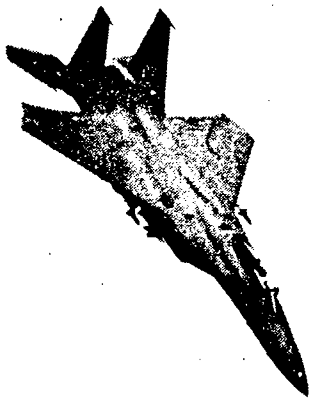

Figure 31. Target Orientation 16 -
F-15 Target.

Figure 32. Target Orientation 16 -
F-16 Target.

APPENDIX B

VISUAL CUES USED FOR 16 TARGET ORIENTATIONS

Table 1. Target Cues Used in Relation to Target Orientation 1

No.	Target cue	F-15 Target distance (nmi) 0.5	1.0	2.0	3.0	F-16 Target distance (nmi) 0.5	1.0	2.0	3.0
1	Exhaust outlet(s)	89.5	50.0	31.3	11.1	46.2	57.1	20.0	-
2	Tail	31.6	21.4	12.6	-	38.5	28.6	6.7	14.3
3	Wings	5.3	14.3	12.5	22.2	11.5	23.8	40.0	14.3
4	Silhouette	-	21.4	25.0	16.7	7.7	4.8	6.7	14.3
5	No planform	10.5	7.1	6.3	27.8	-	-	-	7.1
6	Intake(s)	5.3	7.1	6.3	5.6	3.9	-	-	-
7	Canopy	5.3	14.3	6.3	-	11.5	4.8	-	-
8	Dark dot	-	-	-	-	-	-	20.0	21.4
9	No fuselage length	-	-	18.8	11.1	-	4.8	-	-
10	Nose	-	7.1	6.3	5.6	-	4.8	-	-
11	Fuselage	-	7.1	6.3	-	7.7	-	-	-
12	No nose	-	-	-	5.6	-	-	-	7.1
13	No intake(s)	-	-	6.3	5.5	-	-	-	-
14	Color	-	-	-	5.6	-	4.8	-	-
15	Strakes	-	-	-	-	3.9	4.8	-	-
16	No tail	-	-	-	5.6	-	-	-	-
17	No canopy	-	-	-	-	3.9	-	-	-
18	No response	-	-	12.5	33.3	7.7	19.1	33.3	42.9

<u>Notes</u>. 1. Data represent percent of the correct responses each cue was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilots did not specify any cues.

Table 2. Target Cues Used in Relation to Target Orientation 2

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Planform	26.3	34.2	43.6	37.1	13.0	25.0	25.8	37.9
2	Nose	18.4	23.7	28.2	22.9	26.1	25.0	16.1	27.6
3	Canopy	34.2	31.6	30.8	11.4	52.2	16.7	6.5	-
4	Tail	29.0	23.7	35.9	25.7	17.4	25.0	9.7	13.8
5	Top of aircraft/wings	36.8	36.8	28.2	28.6	8.7	8.3	12.9	3.5
6	Wings	13.2	7.9	28.2	30.8	21.7	16.7	19.4	24.1
7	Fuselage	-	2.6	2.6	5.7	13.0	12.5	12.9	17.2
8	No intake(s)	2.63	5.3	-	-	4.4	12.5	16.1	3.5
9	Exhaust outlet(s)	13.1	15.8	2.6	-	4.4	4.2	3.2	-
10	Color	-	-	-	-	8.7	4.2	3.2	6.9
11	No missiles	5.3	5.3	5.1	2.9	-	-	-	-
12	No tail	2.6	2.6	-	2.9	4.4	4.2	-	-
13	Intake(s)	-	-	2.6	-	8.7	4.2	-	-
14	Entire aircraft	7.9	2.6	-	-	4.4	-	-	-
15	No canopy	-	-	-	-	-	8.3	-	-
16	No strakes	-	-	-	-	4.4	-	-	-
17	Belly	-	-	-	-	-	4.2	-	-
18	No exhaust outlet metal	-	2.6	-	-	-	-	-	-
19	No response	5.3	2.6	5.1	5.7	4.4	8.3	19.4	10.3

Notes.
1. Data represent percent of the correct responses each cue was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilots did not specify any cues.

Table 3. Target Cues Used in Relation to Target Orientation 3

No.	Target cue	F-15 Target distance (nmi) 0.5	1.0	2.0	3.0	F-16 Target distance (nmi) 0.5	1.0	2.0	3.0
1	Intake(s)	84.2	84.9	40.0	14.3	47.2	30.4	17.7	-
2	Silhouette	7.9	18.2	20.0	23.8	11.1	17.4	17.7	5.9
3	Tail	26.3	18.2	12.0	4.8	36.1	8.7	-	11.8
4	Wings	13.2	12.1	4.0	-	25.0	26.1	5.9	17.7
5	Nose	13.2	3.0	4.0	-	13.9	26.1	5.9	29.4
6	Canopy	13.2	3.0	-	-	25.0	13.0	17.7	5.9
7	No planform	7.9	3.0	12.0	28.6	-	-	-	5.9
8	Dark dot	-	-	12.0	4.8	-	-	5.9	11.8
9	Fuselage	2.6	3.0	-	4.8	5.6	4.4	-	-
10	No nose	2.6	3.0	-	-	-	4.4	5.9	-
11	No tail	-	-	4.0	4.8	-	-	-	5.9
12	No fuselage length	-	-	8.0	4.8	-	-	-	-
13	Entire aircraft	2.6	-	-	4.8	2.8	-	-	-
14	Exhaust outlet(s)	-	-	-	-	-	-	5.9	-
15	Color	-	-	-	-	-	4.4	-	-
16	No exhaust outlet(s)	-	-	-	-	2.8	-	-	-
17	No response	2.6	3.0	28.0	33.3	5.6	21.7	29.4	41.2

Notes. 1. Data represent percent of the correct responses each cue was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilots did not specify any cues.

Table 4. Target Cues Used in Relation to Target Orientation 4

No.	Target cue	F-15 Target distance (nmi) 0.5	1.0	2.0	3.0	F-16 Target distance (nmi) 0.5	1.0	2.0	3.0
1	Intake(s)	53.9	56.8	25.0	13.3	80.6	59.3	9.1	-
2	Nose	25.6	16.2	25.0	46.7	16.7	18.5	33.3	-
3	Belly	43.6	35.1	-	26.7	19.4	26.0	18.2	-
4	Tail	10.3	10.8	33.3	33.3	8.3	11.1	36.4	16.7
5	Wings	15.4	16.2	8.3	6.7	25.0	14.8	36.4	16.7
6	Planform	10.3	21.6	16.7	20.0	8.3	11.1	9.1	16.7
7	Missiles	41.0	32.4	8.3	6.7	-	-	-	-
8	Fuselage	2.6	5.4	8.3	-	13.9	3.7	-	16.7
9	No tail	5.1	5.4	8.3	6.7	-	7.4	-	-
10	Color	-	-	-	-	2.8	7.4	9.1	-
11	Top of aircraft/wings	-	-	-	-	-	-	-	16.7
12	Aircraft size	-	-	-	6.7	-	-	-	-
13	Entire aircraft	2.6	-	-	-	2.8	-	-	-
14	No nose	2.6	-	-	-	-	-	-	-
15	No response	2.6	-	25.0	6.7	-	11.1	27.3	16.7

Notes. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 5. Target Cues Used in Relation to Target Orientation 5

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Tail	63.2	46.2	57.9	58.8	33.3	55.2	38.1	55.6
2	Nose	31.6	25.6	31.6	32.4	22.2	27.6	42.9	33.3
3	Fuselage	10.5	10.3	13.2	17.7	25.0	27.6	33.3	27.8
4	Planform	23.7	30.8	26.3	23.5	11.1	6.9	23.8	16.7
5	No wings	13.2	10.3	13.2	11.8	16.7	13.8	28.6	22.2
6	Wings	10.5	15.4	7.9	5.9	11.1	17.2	4.8	27.8
7	Intake(s)	5.3	5.1	-	-	19.4	24.1	9.5	5.6
8	No planform	15.8	12.88	15.8	14.7	-	-	-	5.6
9	Canopy	7.9	2.6	2.6	2.9	25.0	10.3	-	-
10	Missiles	5.3	2.6	-	-	25.0	6.9	-	-
11	Side view	7.9	7.7	5.3	8.8	-	-	-	-
12	No tail	-	5.1	2.6	5.9	-	-	4.8	-
13	No intake(s)	5.3	2.6	-	2.9	-	3.5	-	-
14	Entire aircraft	5.3	-	-	-	5.6	-	-	-
15	No exhaust outlet(s)	2.6	2.6	-	2.9	-	-	-	-
16	Exhaust outlet(s)	-	-	-	-	2.8	-	-	-
17	Strakes	-	-	-	-	2.8	-	-	-
18	No shadows	2.6	-	-	-	-	-	-	-
19	No response	2.6	5.1	2.6	-	8.3	6.9	4.8	-

Notes.
1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 6. Target Cues Used in Relation to Target Orientation 6

No.	Target cue	F-15 Target distance (nmi) 0.5	1.0	2.0	3.0	F-16 Target distance (nmi) 0.5	1.0	2.0	3.0
1	Canopy	47.4	41.0	34.2	15.2	52.6	50.0	6.3	-
2	Planform	26.3	33.3	34.2	36.4	15.8	25.0	25.0	40.7
3	Wings	23.7	33.3	23.7	15.2	29.0	31.3	37.5	37.0
4	Tail	31.6	38.5	31.6	36.4	23.7	21.9	12.5	11.1
5	Nose	21.1	28.2	21.1	33.3	15.8	18.8	21.9	22.2
6	Top of aircraft/wings	26.3	23.1	29.0	30.3	18.4	3.1	6.3	3.7
7	Fuselage	2.6	10.3	5.3	3.0	21.1	15.6	21.9	29.6
8	Entire aircraft	13.2	7.7	-	-	2.6	6.3	-	-
9	No intake(s)	-	5.1	5.3	-	2.6	-	6.3	-
10	Color	-	-	2.6	-	2.6	3.1	6.3	-
11	No missiles	-	2.6	2.6	9.1	-	-	-	-
12	No exhaust outlet(s)	-	5.1	5.3	-	-	-	-	-
13	Side view	-	-	2.6	-	2.6	-	-	3.7
14	Cockpit	-	-	-	-	5.3	3.1	-	-
15	Intake(s)	2.6	-	-	3.0	2.6	-	-	-
16	Missiles	-	2.6	-	-	-	3.1	-	-
17	Exhaust outlet(s)	2.6	-	-	-	2.6	-	-	-
18	No tail	-	-	-	-	-	3.1	-	-
19	No response	-	-	-	9.1	5.3	3.1	9.4	11.1

Notes. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 7. Target Cues Used in Relation to Target Orientation 7

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Belly	41.0	29.0	50.0	10.0	19.4	33.3	26.3	-
2	Intake(s)	15.4	23.7	11.1	-	55.6	57.6	21.1	10.0
3	Planform	18.0	21.1	33.3	30.0	13.9	15.2	26.3	10.0
4	Wings	12.8	26.3	11.1	-	25.0	21.2	36.8	30.0
5	Tail	7.7	10.5	11.1	40.0	8.3	18.2	15.8	50.0
6	Missiles	66.7	52.6	38.9	-	-	-	-	-
7	Nose	18.0	15.8	11.1	20.0	5.6	15.2	5.3	10.0
8	Fuselage	-	5.3	5.6	10.0	8.3	9.1	26.3	10.0
9	Entire aircraft	10.3	5.3	5.6	-	2.8	3.0	-	-
10	No tail	2.6	7.9	-	-	2.8	3.0	-	10.0
11	Color	-	-	-	-	-	6.1	5.3	10.0
12	Strakes	-	-	-	-	5.6	3.0	5.3	-
13	No exhaust outlet(s)	2.6	-	11.1	-	-	-	-	-
14	No intake(s)	2.6	-	-	10.0	-	-	-	-
15	Top of aircraft/wings	-	-	-	10.0	-	-	-	-
16	Canopy	-	-	-	10.0	-	-	-	-
17	No canopy	2.6	2.6	-	-	2.8	-	-	-
18	Exhaust outlet(s)	-	2.6	-	-	2.8	-	-	-
19	No response	2.6	-	-	20.0	13.9	3.0	-	20.0

Notes. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 8. Target Cues Used in Relation to Target Orientation 8

No.	Target cue	F-15 Target distance (nmi) 0.5	1.0	2.0	3.0	F-16 Target distance (nmi) 0.5	1.0	2.0	3.0
1	Belly	26.7	37.0	25.0	57.1	30.8	40.0	-	-
2	Planform	16.7	25.9	63.0	28.6	7.7	30.0	25.0	-
3	Intake(s)	13.3	14.8	13.0	-	53.9	70.0	25.0	-
4	Tail	30.0	11.1	50.0	14.3	-	30.0	25.0	-
5	Nose	16.7	25.9	38.0	14.3	-	20.0	25.0	-
6	Missiles	66.7	51.9	13.0	-	-	-	-	-
7	Wings	23.3	7.4	13.0	-	15.4	10.0	33.3	-
8	No intake(s)	-	-	13.0	-	-	-	-	50.0
9	Fuselage	6.7	-	-	-	-	10.0	33.3	-
10	No tail	3.3	3.7	-	28.6	-	-	-	-
11	No canopy	-	-	-	14.3	-	10.0	8.3	-
12	Color	-	3.7	-	-	-	20.0	-	-
13	Top of aircraft/wings	-	-	-	14.3	-	-	-	-
14	Strakes	-	-	-	-	7.7	-	-	-
15	Exhaust outlet(s)	-	3.7	-	-	-	-	-	-
16	No exhaust outlet(s)	3.3	-	-	-	-	-	-	-
17	Entire aircraft	3.3	-	-	-	-	-	-	-
18	No response	3.3	3.7	13.0	14.3	15.4	-	-	50.0

Notes.
1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 9. Target Cues Used in Relation to Target Orientation 9

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Wings	29.0	32.4	31.4	34.3	46.9	51.6	59.3	44.4
2	Tail	42.1	48.7	45.7	42.9	40.6	41.9	44.4	22.2
3	Nose	15.8	21.6	22.9	22.9	28.1	22.6	37.0	22.2
4	Planform	21.1	18.9	34.3	25.7	12.5	19.4	22.2	22.2
5	Canopy	34.2	29.7	14.3	8.6	38.0	12.9	11.1	-
6	Top of aircraft/wings	29.0	24.3	31.4	25.7	12.5	-	3.7	3.7
7	Fuselage	2.6	8.1	2.9	2.9	9.4	19.4	11.1	22.2
8	Exhaust outlet(s)	21.1	13.5	11.4	8.6	3.1	6.5	-	3.7
9	Entire aircraft	7.9	5.4	-	-	9.4	3.2	-	-
10	No intake(s)	2.6	-	-	2.9	3.1	3.2	7.4	-
11	Color	-	-	-	-	6.3	3.3	3.7	3.7
12	No missiles	2.6	5.4	2.9	2.9	-	-	-	-
13	Cockpit	-	-	-	-	3.1	3.2	-	-
14	Missiles	-	-	2.9	-	-	-	-	-
15	No canopy	-	2.7	-	-	-	-	-	-
16	No tail	2.6	-	-	-	-	-	-	-
17	No response	7.9	8.1	2.9	5.7	-	6.5	3.7	7.4

Notes. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 10. Target Cues Used in Relation to Target Orientation 10

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Tail	48.4	50.0	72.0	68.8	18.8	42.9	53.9	46.2
2	Wings	19.4	17.9	28.0	6.3	28.1	35.7	30.8	30.8
3	Nose	25.8	17.9	28.0	18.8	21.9	21.4	23.1	38.5
4	Belly	51.6	28.6	28.0	18.8	15.6	7.1	23.1	7.7
5	Planform	9.7	17.9	28.0	43.8	9.4	17.9	7.7	15.4
6	Missiles	32.3	28.6	8.0	6.3	-	-	-	-
7	Exhaust outlet(s)	16.2	14.3	4.0	25.0	21.9	14.3	-	7.7
8	Intake(s)	6.5	-	4.0	-	40.6	25.0	15.4	7.7
9	Fuselage	-	3.6	4.0	12.5	12.5	14.3	7.7	7.7
10	Color	-	3.6	4.0	-	3.1	-	7.7	-
11	Entire aircraft	6.5	-	-	-	6.3	-	-	-
12	Strakes	-	-	-	-	3.1	-	-	7.7
13	Canopy	-	-	4.0	-	3.1	3.6	-	-
14	No intake(s)	3.2	3.6	-	-	-	3.6	-	-
15	No wings	-	-	-	6.3	-	-	-	-
16	No canopy	-	3.6	-	-	-	-	-	-
17	No tail	-	3.6	-	-	-	-	-	-
18	No response	3.2	3.6	8.0	-	6.3	3.6	7.7	7.7

Notes. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 11. Target Cues Used in Relation to Target Orientation 11

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Intake(s)	12.5	31.3	50.0	14.3	93.8	85.7	-	-
2	Belly	33.3	56.3	50.0	28.6	12.5	42.9	-	-
3	Nose	20.8	43.8	50.0	28.6	18.8	-	50.0	-
4	Missiles	50.0	62.5	50.0	14.3	-	14.3	-	-
5	Tail	25.0	18.8	-	28.6	6.3	14.3	50.0	-
6	Wings	16.7	18.8	-	-	6.3	28.6	50.0	-
7	Planform	20.8	37.5	-	14.3	-	-	-	-
8	Canopy	-	-	-	-	-	-	50.0	-
9	No tail	-	6.3	-	-	6.3	14.3	-	-
10	Fuselage	4.2	6.3	-	-	12.5	-	-	-
11	Entire aircraft	4.2	-	-	-	6.3	-	-	-
12	Color	-	-	-	-	6.3	-	-	-
13	Top of aircraft/wings	4.2	-	-	-	-	-	-	-
14	No response	-	-	-	28.6	-	-	50.0	-

Notes. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 12. Target Cues Used in Relation to Target Orientation 12

No.	Target cue	F-15 Target distance (nmi) 0.5	1.0	2.0	3.0	F-16 Target distance (nmi) 0.5	1.0	2.0	3.0
1	Tail	40.5	48.7	54.8	73.1	24.1	47.1	20.0	30.4
2	Wings	27.0	37.8	35.8	23.1	20.7	23.5	50.0	30.4
3	Nose	27.0	18.9	35.5	19.2	20.7	35.3	20.0	26.1
4	Canopy	43.2	35.1	25.8	11.5	44.8	5.9	-	4.4
5	Top of aircraft/wings	40.5	35.1	29.0	15.4	10.3	11.8	10.0	4.4
6	Intake(s)	24.3	21.6	3.2	19.2	31.0	41.2	5.0	4.4
7	Planform	10.8	21.6	19.4	7.7	10.3	11.8	20.0	26.1
8	Fuselage	-	8.1	-	7.7	3.5	11.8	25.0	30.4
9	Entire aircraft	8.1	-	-	-	6.9	-	-	-
10	No missiles	2.7	2.7	3.2	-	-	-	-	-
11	Cockpit	-	-	-	-	3.5	-	5.0	-
12	Color	-	-	-	-	3.5	-	5.0	-
13	Exhaust outlet(s)	-	-	3.2	-	-	-	-	-
14	No response	2.7	-	6.5	7.7	13.8	-	5.0	8.7

Notes. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 13. Target Cues Used in Relation to Target Orientation 13

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Tail	35.0	60.5	72.4	54.2	22.2	32.4	70.0	16.7
2	Wings	32.5	29.0	20.7	41.7	33.3	23.5	45.0	33.3
3	Nose	20.0	18.4	27.6	25.0	19.4	20.6	20.0	-
4	Belly	40.0	31.6	24.1	25.0	13.9	5.9	-	-
5	Intake(s)	2.5	5.3	6.9	-	61.1	50.0	5.0	-
6	Missiles	55.0	31.6	10.3	4.2	-	-	-	-
7	Planform	5.0	5.3	10.3	12.5	8.3	17.7	5.0	33.3
8	Exhaust outlet(s)	25.0	15.8	13.8	-	11.1	2.9	-	-
9	Fuselage	5.0	5.3	10.3	4.2	2.8	17.7	15.0	-
10	Color	-	-	-	4.2	8.3	-	-	-
11	Canopy	-	-	-	-	5.6	5.9	-	-
12	Entire aircraft	2.5	2.6	-	-	5.6	-	-	-
13	Strakes	-	-	-	-	5.6	-	-	-
14	No tail	2.5	2.6	-	-	-	-	-	-
15	Top of aircraft/wings	-	-	-	4.2	-	-	-	-
16	No canopy	-	-	-	-	2.8	-	-	-
17	No response	5.0	-	6.9	16.7	2.8	2.9	5.0	-

Notes.
1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 14. Target Cues Used in Relation to Target Orientation 14

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Tail	62.1	66.7	100.0	50.0	42.9	50.0	50.0	57.1
2	Wings	20.7	33.4	-	50.0	28.6	25.0	50.0	42.9
3	Nose	13.8	33.3	18.2	33.3	42.9	50.0	25.0	14.3
4	Fuselage	6.9	-	-	-	-	50.0	25.0	28.6
5	Planform	24.1	46.7	9.1	-	-	-	-	14.3
6	Intake(s)	-	-	-	-	14.3	-	-	-
7	Exhaust outlet(s)	13.8	13.3	9.1	-	-	-	25.0	-
8	Top of aircraft/wings	24.1	6.7	-	16.7	-	-	-	-
9	Entire aircraft	3.5	-	-	-	28.6	-	-	-
10	Canopy	17.2	-	-	-	-	-	12.5	-
11	No wings	3.5	-	-	-	14.3	50.0	-	-
12	No intake(s)	6.9	6.7	-	-	-	-	-	-
13	No missiles	3.5	-	-	-	-	-	-	-
14	No response	3.5	6.7	-	16.7	-	-	-	-

Notes.
1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 15. Target Cues Used in Relation to Target Orientation 15

		F-15				F-16			
		Target distance (nmi)				Target distance (nmi)			
No.	Target cue	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
1	Tail	56.4	80.0	92.3	81.8	36.0	45.5	37.5	50.0
2	Intake(s)	64.1	56.0	7.7	9.1	56.0	54.6	12.5	-
3	Fuselage	5.1	8.0	15.4	9.1	4.0	9.1	37.5	50.0
4	Canopy	30.8	28.0	7.7	-	36.0	9.1	12.5	-
5	Nose	15.4	16.0	23.1	18.2	20.0	18.2	12.5	-
6	Wings	12.8	8.0	7.7	-	12.0	18.2	12.5	-
7	Silhouette	7.7	4.0	7.7	18.2	4.0	-	-	25.0
8	No wings	2.6	4.0	7.7	-	8.0	9.1	-	-
9	No planform	2.6	8.0	-	9.1	-	-	-	-
10	Missiles	7.7	4.0	-	-	4.0	-	-	-
11	No exhaust outlet(s)	-	-	-	9.1	-	-	-	-
12	Entire aircraft	2.5	-	-	-	4.0	-	-	-
13	Cockpit	-	-	-	-	4.0	-	-	-
14	Side view	-	4.0	-	-	-	-	-	-
15	No response	-	-	7.7	-	8.0	9.1	25.0	-

<u>Notes</u>. 1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

Table 16. Target Cues Used in Relation to Target Orientation 16

No.	Target cue	F-15 Target distance (nmi) 0.5	1.0	2.0	3.0	F-16 Target distance (nmi) 0.5	1.0	2.0	3.0
1	Tail	46.2	68.2	37.5	60.0	25.0	33.3	40.0	-
2	Planform	23.1	9.1	25.0	40.0	8.3	33.3	40.0	100.0
3	Nose	30.8	27.3	37.5	20.0	16.7	33.3	20.0	-
4	Canopy	34.6	36.4	12.5	-	41.7	33.3	-	-
5	Wings	19.2	27.3	37.5	20.0	25.0	-	20.0	-
6	Top of aircraft/wings	26.9	31.8	62.5	-	8.3	-	-	-
7	Intake(s)	11.5	13.6	12.5	-	-	33.3	20.0	-
8	Fuselage	-	9.1	12.5	-	8.3	-	20.0	-
9	Entire aircraft	11.5	9.1	-	-	16.7	-	-	-
10	Belly	-	-	-	20.0	8.3	-	-	-
11	No missiles	-	-	12.5	-	-	-	-	-
12	No intake(s)	-	4.6	-	-	-	-	-	-
13	No response	3.9	-	-	20.0	8.3	33.3	-	-

Notes.
1. Data represent percent of the correct responses each visual was used.
2. Correct response is defined as a correct aspect angle, direction of travel, pitch, and bank response.
3. "No response" signifies that the pilot did not specify any cues.

APPENDIX C

RESPONSE ERRORS

The tables in this appendix show the various types of errors that were made in conjunction with each of the target orientations, and the frequency of each type of error is also provided in the tables. An example will suffice to explain these tables. Table 1 presents the response errors for target orientation 1. In target orientation 1, the targets were tail-on to the pilot observers and the targets were neither pitched nor banked. Some of the pilots felt, however, that the targets were nose-on and so they indicated a 180-deg aspect, which is represented by error number 1 in the tables. They correctly indicated that the targets were not pitched or banked, therefore a dash was placed in the tables. The number of pilots that interpreted the targets as being nose-on for each of the four distances is shown in the tables.

Table 1. Response Errors for Target Orientation 1

Target type	Error no.	Response error: Aspect angle (deg)	Response error: Direction of travel	Response error: Pitch	Response error: Bank	Target distance (nmi): 0.5	Target distance (nmi): 1.0	Target distance (nmi): 2.0	Target distance (nmi): 3.0	Total
F-15	1	180		-	-	21	26	13	14	74
	2	90	Right	-	-			5		5
	3	45	Right	-	-			1	3	4
	4	90	Left	-	-			2		2
	5	135	Right	-	-				2	2
	6	90	Right	-	Right			2		2
	7	135	Left	-	-			1	1	2
	8	45	Right	-	Right				1	1
	9		No response						1	1
				F-15 Total		21	26	24	22	93
F-16	1	180		-	-	14	18	18	11	61
	2	-		Up	-				3	3
	3	180		-	Left				2	2
	4	180		Up	-			1	1	2
	5	90	Right	-	-			1	1	2
	6	45	Left	Down	Right				1	1
	7	45	Left	Up	-				1	1
	8	45	Left	Up	Right				1	1
	9	45	Left	-	Left				1	1
	10	45	Left	Up	Left				1	1
	11	45	Right	-	Left				1	1
	12	90	Left	-	-			1		1
	13	90	Left	Down	Left				1	1
	14	90	Right	-	Right				1	1
	15	135	Left	Up	Left				1	1
	16	135	Left	Down	Left		1			1
	17	180		-	Right				1	1
	18	-		-	Left			1		1
	19		No response						1	1
				F-16 Total		14	19	25	26	84
				Grand Total		35	45	49	48	177

Note. Dash indicates correct response.

Table 2. Response Errors for Target Orientation 2

		Response error				Target distance (nmi)				
Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
F-15	1	180		-	-	1	2	1	3	7
	2	-		-	Right				2	2
	3	-		Level	-	1				1
				F-15	Total	2	2	1	5	10
F-16	1	180		-	-	17	15	8	4	44
	2	-		-	Right		1		4	5
	3	-		-	Left				1	1
	4	45	Right	-	Right			1		1
	5	45	Right	Level	Right				1	1
	6	45	Left	Level	Left				1	1
				F-16 Total		17	16	9	11	53
				Grand Total		19	18	10	16	63

Note. Dash indicates correct response.

Table 3. Response Errors for Target Orientation 3

		Response error				Target distance (nmi)				
Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
F-15	1	0		-	-	2	7	11	12	32
	2	45	Right	-	-				2	2
	3	135	Right	-	-			2		2
	4	90	Right	-	-				1	1
	5	90	Right	Up	Left				1	1
	6	90	Left	-	-				1	1
	7	45	Left	-	Left			1		1
	8	135	Left	-	-			1		1
	9	-		-	Left				1	1
	10	No response							1	1
				F-15 Total		2	7	15	19	43
F-16	1	0		-	-	4	16	17	11	48
	2	135	Right	-	Right				3	3
	3	45	Right	-	Left				2	2
	4	90	Right	-	Right			1	1	2
	5	No response						1	1	2
	6	45	Left	Down	Right		1			1
	7	135	Right	Down	Right			1		1
	8	135	Left	Up	Left			1		1
	9	-		-	Left				1	1
	10	135	Left	-	Left			1		1
	11	0		Up	-			1		1
	12	135	Left	Down	-				1	1
	13	0		Down	-				1	1
	14	135	Left	-	-				1	1
	15	90	Left	-	-				1	1
				F-16 Total		4	17	23	23	67
				Grand Total		6	24	38	42	110

Note. Dash indicates correct response.

Table 4. Response Errors for Target Orientation 4

Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	Target distance (nmi) 0.5	1.0	2.0	3.0	Total
		Response error								
F-15	1	0		-	-		3	27	23	53
	2	0		-	Left			1		1
	3	0		-	Right				1	1
	4	-		-	Left				1	1
	5	-		Level	-	1				1
				F-15	Total	1	3	28	25	57
F-16	1	0		-	-	4	13	27	25	69
	2	0		-	Left			2	1	3
	3	-		Level	-				3	3
	4	0		-	Right				2	2
	5	45	Right	-	Right				1	1
	6	45	Right	Level	Right				1	1
		135	Right	Level	Right				1	1
				F-16 Total		4	13	29	34	80
				Grand Total		5	16	57	59	137

Note. Dash indicates correct response.

Table 5. Response Errors for Target Orientation 5

Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
		Response error				Target distance (nmi)				
F-15	1	-	-	-	Left			1	2	3
	2	45	-	-	-			1	1	2
	3	45	-	-	Right				1	1
	4	135	-	-	-	1				1
	5	135	-	-	Left	1				1
	6	135	-	-	Right		1			1
	7	135	Right	Level	Left				1	1
	8	-	-	Level	-				1	1
				F-15 Total		2	1	2	6	11
F-16	1	45	-	-	Left		1	3	8	12
	2	45	-	-	-	1	1	4	5	11
	3	-	-	-	Left	2	1	3	2	8
	4	135	-	-	-	1	2	1	2	6
	5	135	-	-	Left			4	1	5
	6	135	-	-	Right		1	1	2	4
	7	-	-	-	Right		2		2	4
	8	45	-	-	Right		2	1		3
	9	45	-	Level	-			1		1
	10	45	-	Level	Right			1		1
	11	-	-	Level	-		1			1
				F-16 Total		4	11	19	22	56
				Grand Total		6	12	21	28	67

Note. Dash indicates correct response.

Table 6. Response Errors for Target Orientation 6

Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
		Response error				Target distance (nmi)				
F-15	1	-	-	-	Right	1	1	1	2	5
	2	45	-	-	-	1			3	4
	3	135	-	-	-			1	1	2
	4	45	-	-	Right				1	1
				F-15 Total		2	1	2	7	12
F-16	1	-	-	-	Right		7	5	7	19
	2	135	-	-	-	1			3	4
	3	45	-	-	-		1	2	1	4
	4	45	-	-	Right	1				1
	5	135	-	-	Right				1	1
	6	-	-	-	Level			1		1
	7	0	-	-	Right				1	1
				F-16 Total		2	8	8	13	31
				Grand Total		4	9	10	20	43

Note. Dash indicates correct response.

Table 7. Response Errors for Target Orientation 7

Target type	Error no.	Response error: Aspect angle (deg)	Response error: Direction of travel	Response error: Pitch	Response error: Bank	Target distance (nmi): 0.5	1.0	2.0	3.0	Total
F-15	1	-	-	-	Right			20	24	44
	2	45	-	-	-		1		2	3
	3	135	-	-	Right			1	2	3
	4	135	-	-	-	1		1		2
	5	45	-	-	Right				1	1
	6	45	-	Down	Right				1	1
	7	-	-	-	Level		1			1
				F-15 Total		1	2	22	30	55
F-16	1	-	-	-	Right	2	6	20	25	53
	2	-	-	-	Level	1			2	3
	3	45	-	-	-	1		1	1	3
	4	135	-	-	Right				2	2
	5	90	Left	-	-		1			1
				F-16 Total		4	7	21	30	62
				Grand Total		5	9	43	60	117

Note. Dash indicates correct response.

Table 8. Response Errors for Target Orientation 8

		Response error				Target distance (nmi)				
Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
F-15	1	-	-	-	Right		2	23	20	45
	2	45	-	-	Right	1	1	5	9	16
	3	45	-	-	-	4	6	1		11
	4	135	-	-	-	4	3	1		8
	5	135	-	-	Right			1	3	4
	6	-	-	-	Level		1			1
	7	45	-	-	Level			1		1
	8	45	-	Level	Right				1	1
	9	135	Left	-	-	1				1
					F-15 Total	10	13	32	33	88
F-16	1	-	-	-	Right	3	16	11	10	40
	2	45	-	-	-	12	7	8	10	37
	3	45	-	-	Right	2	4	9	14	29
	4	135	-	-	-	5			1	6
	5	135	-	-	Right	1	2		2	5
	6	45	-	-	Level	3				3
	7	45	-	Level	Right	1				1
	8	90	Left	-	Right		1			1
	9	135	Left	Level	-				1	1
					F-16 Total	27	30	28	38	123
					Grand Total	37	43	60	71	211

Note. Dash indicates correct response.

Table 9. Response Errors for Target Orientation 9

Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
		Response error				Target distance (nmi)				
F-15	1	-	-	-	Right	1	1	2		4
	2	-	-	Up	-		1	2	1	4
	3	90	-	-	-	1			1	2
	4	135	-	-	-			1	1	2
	5	135	-	-	Right				1	1
	6	135	-	Up	Right		1			1
	7	90	Right	Up	Left				1	1
				F-15 Total		2	3	5	5	15
F-16	1	-	-	Up	-	4	7	5	2	18
	2	135	-	-	Right	1	1	3	4	9
	3	135	-	Up	Right		1	2	1	4
	4	-	-	-	Right	1		1	1	3
	5	90	-	-	-	2		1		3
	6	135	-	-	-				2	2
	7	135	-	Down	Level				1	1
	8	135	Right	-	Right				1	1
	9	90	-	-	Right			1		1
	10	-	-	Up	Level				1	1
				F-16 Total		8	9	13	13	43
				Grand Total		10	12	18	18	58

Note. Dash indicates correct response.

Table 10. Response Errors for Target Orientation 10

		Response error				Target distance (nmi)				
Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
F-15	1	-	-	-	Right	6	6	7	8	27
	2	135	-	-	Left		1	5	8	14
	3	135	-	-	-		3	2	5	10
	4	-	-	-	Left	2	1	1	1	5
	5	90	-	-	Right	1			1	2
	6	135	-	-	Right		1			1
	7	0		Level	Left				1	1
				F-15 Total		9	12	15	24	60
F-16	1	135	-	-	Left	1	1	13	9	24
	2	-	-	-	Right	4	6	4	3	17
	3	135	-	-	-	1	1	4	4	10
	4	-	-	-	Left		2	2	3	7
	5	135	-	-	Right	2	1	1	1	5
	6	90	-	-	Left			2	1	3
	7	90	-	-	Right				2	2
	8	90	Right	Level	Left				1	1
	9	135	Right	-	Left				1	1
	10	135	Right	-	Right			1		1
	11	45	Right	Level	Right		1			1
	12	45	Right	Up	Left				1	1
	13	-	-	Level	Left				1	1
				F-16 Total		8	12	27	27	74
				Grand Total		17	24	42	51	134

Note. Dash indicates correct response.

Table 11. Response Errors for Target Orientation 11

Target type	Error no.	Response error: Aspect angle (deg)	Direction of travel	Pitch	Bank	Target distance (nmi): 0.5	1.0	2.0	3.0	Total
F-15	1	45	-	-	Left		2	21	18	41
	2	90	-	-	-	9	11	3	4	27
	3	90	-	-	Left		1	7	6	14
	4	45	-	-	-	2	3	2	2	9
	5	90	-	-	Level	2	2	1		5
	6	-	-	-	Left	1	2	1		4
	7	-	-	-	Level	1	2			3
	8	45	-	-	Level			1	2	3
	9	-	-	Level	-			1		1
	10	-	-	Level	Level	1				1
	11	180	-	-	-		1			1
	12	0		-	Left			1		1
	13	45	-	Down	-				1	1
				F-15 Total		16	24	38	33	111
F-16	1	45	-	-	Left	3	10	20	25	58
	2	90	-	-	-	10	8	1	2	21
	3	45	-	-	-	5	4	5	2	16
	4	90	-	-	Left	3	4	7	2	16
	5	45	-	-	Level	1	4	1	1	7
	6	-	-	-	Left		1	1	4	6
	7	0		-	Left			1	2	3
	8	90	-	-	Level	1	2			3
	9	-	-	-	Level	1		1		2
	10	0		-	Level			1		1
	11	45	Right	Down	-				1	1
	12	90	Right	Down	Left				1	1
				F-16 Total		24	33	38	40	135
				Grand Total		40	57	76	73	246

Note. Dash indicates correct response.

Table 12. Response Errors for Target Orientation 12

Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
	Response error					Target distance (nmi)				
F-15	1	45	-	-	Right			5	3	8
	2	-	-	-	Right	2	1	1	3	7
	3	45	-	-	-				3	3
	4	90	-	-	-		1	2		3
	5	-	-	Down	-		1	1		2
	6	-	-	Down	Right	1			1	2
	7	135	Right	Down	Level				2	2
	8	45	Right	Down	Level				1	1
	9	-	-	Up	-				1	1
				F-15 Total		3	3	9	14	29
F-16	1	45	-	-	Right	8	15	11	3	37
	2	90	-	-	-			3	2	5
	3	-	-	-	Right		4			4
	4	-	-	-	Level	1		1	1	3
	5	45	-	-	-		1	1	1	3
	6	90	-	-	Right	1	2			3
	7	45	Right	-	Right	1		1		2
	8	45	Right	-	Level				2	2
	9	45	Right	-	-			1	1	2
	10	45	-	Down	Right		1	1		2
	11	45	Right	Down	-				1	1
	12	45	Right	Down	Level				1	1
	13	45	Right	Down	Right				1	1
	14	45	-	Up	Right			1		1
	15	135	Right	Down	Level				1	1
	16	135	Right	Down	Right				1	1
	17	90	-	-	Level				1	1
	18	-	-	Down	-				1	1
				F-16 Total		11	23	20	17	71
				Grand Total		14	26	29	31	100

Note. Dash indicates correct response.

Table 13. Response Errors for Target Orientation 13

Target type	Error no.	Response error: Aspect angle (deg)	Direction of travel	Pitch	Bank	Target distance (nmi): 0.5	1.0	2.0	3.0	Total
F-15	1	135	-	-	Right		1	9	4	14
	2	135	-	-	-			1	3	4
	3	135	-	Down	Right			1	1	2
	4	90	-	-	-				2	2
	5	-	-	-	Level				2	2
	6	90	-	-	Right				1	1
	7	135	-	Down	Level				1	1
	8	135	Left	-	-				1	1
	9	-	-	Up	-		1			1
	10	-	-	Down	-				1	1
				F-15 Total		0	2	11	16	29
F-16	1	135	-	-	Right		2	9	16	27
	2	90	-	-	-	3	2	4	4	13
	3	-	-	-	Right			1	3	4
	4	90	-	-	Right				3	3
	5	135	-	-	-		1	2		3
	6	135	-	Down	Right			2		2
	7	45	Left	Down	Right				2	2
	8	45	Left	-	-	1				1
	9	45	Left	-	Level				1	1
	10	135	Left	-	Right			1		1
	11	135	Left	Down	Right				1	1
	12	135	Left	Down	-				1	1
	13	135	-	Down	Level				1	1
	14	90	-	-	Level				1	1
	15	90	-	Down	-			1		1
	16	-	-	-	Level				1	1
	17	-	-	Up	-		1			1
				F-16 Total		4	6	20	34	64
				Grand Total		4	8	31	50	93

Note. Dash indicates correct response.

Table 14. Response Errors for Target Orientation 14

		Response error				Target distance (nmi)				
Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
F-15	1	90	-	-	Level		1	8	20	29
	2	-	-	-	Level	3	7	6	5	21
	3	90	-	-	-	3	6	3	5	17
	4	135	-	-	Level	3	5	6	1	15
	5	135	-	-	-	1	2	3	2	8
	6	135	-	-	Left		2	3		5
	7	-	-	Level	-	1	1			2
	8	-	-	-	Left				1	1
	9	-	-	Up	Level		1			1
				F-15 Total		11	25	29	34	99
F-16	1	90	-	-	Level	17	17	13	12	59
	2	-	-	-	Level	1	7	6	6	20
	3	135	-	-	Level	7	3	4	2	16
	4	135	-	-	-	2	1	2	5	10
	5	-	-	-	Left	2	4	1	2	9
	6	135	-	-	Left	2	2	2	3	9
	7	90	-	-	-	1	2	3	1	7
	8	90	-	-	Left	1		1	1	3
	9	45	Left	-	Left				1	1
				F-16 Total		33	36	32	33	134
				Grand Total		44	61	61	67	233

Note. Dash indicates correct response.

Table 15. Response Errors for Target Orientation 15

Target type	Error no.	Response error: Aspect angle (deg)	Direction of travel	Pitch	Bank	Target distance (nmi): 0.5	1.0	2.0	3.0	Total
F-15	1	45	-	-	-	1	15	26	19	61
	2	90	-	-	-			1	9	10
	3	45	-	-	Right				1	1
				F-15 Total		1	15	27	29	72
F-16	1	45	-	-	-	14	28	22	13	77
	2	90	-	-	-	1	1	7	14	23
	3	45	-	-	Left			2		2
	4	45	-	-	Right				2	2
	5	-		-	Right			1	1	2
	6	-		-	Left				1	1
	7	45	Left	-	-				1	1
	8	45	-	Up	Right				1	1
	9	90	-	-	Right				1	1
	10	0		-	-				1	1
	11	135	Left	Down	Right				1	1
				F-16 Total		15	29	32	36	112
				Grand Total		16	44	59	65	184

Note. Dash indicates correct response.

Table 16. Response Errors for Target Orientation 16

Target type	Error no.	Aspect angle (deg)	Direction of travel	Pitch	Bank	0.5	1.0	2.0	3.0	Total
		Response error				Target distance (nmi)				
F-15	1	-	-	-	Right	12	12	19	13	56
	2	45	-	-	-		3	6	8	17
	3	45	-	-	Left	1	1	4	4	10
	4	90	-	-	Right	1	2	2	2	7
	5	90	-	-	Left				2	2
	6	45	-	-	Right				2	2
	7	-	-	-	Left			1	1	2
	8	-	-	-	Level				1	1
	9	45	-	Up	Right				1	1
	10	135	Left	-	-				1	1
				F-15 Total		14	18	32	35	99
F-16	1	45	-	-	-	12	16	11	8	47
	2	-	-	-	Right	6	6	9	13	34
	3	45	-	-	Left	5	12	5	4	26
	4	-	-	-	Left		2	4	2	8
	5	45	-	-	Right	2			4	6
	6	135	Left	-	-			2	1	3
	7	135	Left	Level	Left				3	3
	8	90	-	-	Right	2			1	3
	9	90	-	-	Left	1	1	1		3
	10	90	-	-	-			1	2	3
	11	45	Left	-	-			1		1
	12	135	-	Level	Right			1		1
	13	-	-	Level	-				1	1
				F-16 Total		28	37	35	39	139
				Grand Total		42	55	67	74	238

Note. Dash indicates correct response.

APPENDIX D

DEBRIEFING QUESTIONNAIRE RESPONSES

1. Did the target images appear realistic?

Response	Total
"Yes"	72
"No"	7
No response	1

Explanations for the "No" responses:

Frequency	Explanation
2	No target movement.
2	Target features were not distinct enough.
1	No glint or glare from natural lighting.
1	Too much detail. Too clear.
1	Never have seen a full missile load. No detail is normally present on F-15 belly.

2. Did the simulated target distances appear realistic?

Response	Total
"Yes"	77
"No"	2
No response	1

Explanations for the "No" responses:

Frequency	Explanation
1	The 0.5 nmi target seemed closer. The other distances were realistic.
1	No reason given.

3. Were any cues missing that you normally use to determine target orientation?

Response	Total
"Yes"	40
"No"	39
No response	1

Explanations for the "Yes" responses:

Frequency	Explanation
16	No target motion.
1	No target motion or canopy glare.
1	No target movement or shadows.
1	No target line-of-sight rates.
1	No horizon, clouds, atmospheric conditions, or target contrails.
2	No target smoke trail.
3	No target color shading and/or shadows.
1	No target wingtip vortices.
1	No target canopy flashes or refueling markings.
1	No target motion, smoke trails, etc.
1	No target smoke trails or sun glint.
1	No target line-of-sight rates, turn cues, situational awareness, etc.
1	No target external centerline fuel tank.
1	No situational awareness.
1	No glare from the target canopy or off the tail.
1	No target motion, situational awareness, horizon, etc.
2	No exhaust smoke or contrails.
1	No shiny exhaust outlets.
1	No target motion or line-of-sight rates.
1	No head-up display (HUD) aspect angle indicator.
1	No target vapor trails at high angle of attack.

4. How does this task compare to actual target orientation assessment?

Response	Total
"Easier"	8
"About the same"	15
"More difficult"	57

Explanations for the "Easier" responses:

Frequency	Explanation
1	Viewing distance to the targets was constant.
3	Location of the targets was constant.
1	Targets were clearer.
1	Location of the targets was predictable and no workload from flying own aircraft.
1	Missiles on the targets were white. Have seen only gray-colored missiles.
1	Learned to look for certain visual cues. Aircraft motion in the real world does not allow time for extended looking.

Explanations for the "more difficult" responses:

Frequency	Explanation
29	No target motion cues.
2	No target motion cues and the coloring was difficult to distinguish.
2	No target motion, rate of change information exhaust trails, or previous position.
1	No target smoke trail or previous position.
3	No target motion or line-of-sight rate.
2	No target motion, line-of-sight rate, or contrast with the terrain or atmospheric conditions.
3	No line-of-sight rate.
2	No target motion or glare.
1	No target motion or radar information.
2	No situational awareness.

2	No target motion or situational awareness.
2	No target motion or previous position.
1	No line-of-sight rate or previous position.
1	No target motion or horizon.
1	Target visual cues are normally more distinct.
1	No target motion, smoke trail, vapor trail, or afterburner light.
1	No developing trend of target position.
1	No target motion, line-of-sight rates, or rolling motion.

5. Did the target background appear realistic?

Response	Total
"Yes"	53
"No"	27

Explanations for the "No" responses:

Frequency	Explanation
19	The background was always the same. Sometimes dark blue sky, clouds, and ground are visible.
1	No target smoke trail.
3	The background was too bright.
2	No horizon, clouds, or atmospheric conditions.
2	No reason given.

6. Were the targets obscured or degraded in any way?

Response	Total
"Yes"	4
"No"	76

Explanations for the "Yes" responses:

Frequency	Explanation
1	Some targets appeared fuzzier than others.
2	Increased simulated distance reduced cue clarity.
1	There were some scratches and specks on the slides but they didn't affect the target images.

7. Were there any outside distractions during the slide presentations?

Response	Total
"Yes"	0
"No"	80

Explanations for the "Yes" responses: Not applicable.

8. Were you able to predict the orientation of the target at any time?

Response	Total
"Yes"	0
"No"	80

Explanations for the "Yes" responses: Not applicable.

9. Were there any cues in the slides, other than the target, that indicated the target orientation?

Response	Total
"Yes"	0
"No"	80

Explanations for the "Yes" responses: Not applicable.

10. What is your opinion as to the duration of the slide presentations?

Response	Total
"Too short"	6
"About right"	72
"Too long"	2

Explanation for the "Too short" responses:

Frequency	Explanation
1	Too short for the greater simulated distances.
1	Without line-of-sight rate, about two more seconds are required.
1	Try to keep in view longer in real aircraft to determine target aspect angle.
1	Too short for greater target distances and too long for closer distances.
1	Too short due to lack of aircraft motion.
1	No reason given.

Explanation for the "Too long" responses:

Frequency	Explanation
1	Pilots would see the motion of the target in real flight at this target duration.
1	Too long when a lot of time is spent on listing the cues used.

11. Did you experience any fatigue during the slide presentations?

Response	Total
"Yes"	9
"No"	71

Explanation for the "Yes" responses:

Frequency	Explanation
5	Some eye fatigue.
2	Got a little tired toward end of session.
1	Looking from slide to paper and back was tiring.
1	No reason given.

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