VISUAL DISPLAY RESOLUTION AND CONTRAST REQUIREMENTS FOR AIR COMBAT SIMULATION: AN APPLICATION OF COMPUTER MODELING

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ABSTRACT

A study on the effects of target resolution and contrast in air combat engagements was conducted to determine the potential impact of visual display characteristics on the effectiveness of air combat simulation training. A large-scale computer model of air combat engagements was used to investigate the effects of 2 and 4 arc min. of target resolution and target/background contrast ratios of 0.5 and 9.0. The study results are discussed in the context of the benefits of enhanced visual display characteristics in practicing the skills required in air combat.

INTRODUCTION

The requirement for a high degree of realism in the generation of visual scenes in the displays of manned flight simulators has been a major factor in increasing the unit cost of simulators used in aircrew training. The training benefits that result from each successive advance in visual display technology must be weighed against the cost increase associated with that technology if simulation is to remain a viable option for aircrew training. Agencies tasked with the procurement of aircrew training systems are repeatedly tasked with the problem of cost-benefit trade-offs but have little or no objective means by which to assess the extent to which training will be affected by a given improvement in a device's fidelity with actual aircraft operations.

An area where flight simulation is likely to play an increasing role in training is in air-to-air combat. Success in air-to-air combat depends on the skilled execution of basic fighter maneuvers and on the awareness and understanding of the tactical situation.

Simulation training has, to date, stressed basic fighter maneuvering, that is, instruction in the limits of an aircraft's flight envelope, weapons envelope recognition and pre-planned offensive and defensive fighter maneuvers. The Air Force's Simulator for Air-to-Air Combat (SAAC) is an example of this kind of simulation training for air combat. However, the type of training that is likely to have the greatest benefit for real-world combat success involves flight vs flight force-level engagements where many aircraft are simultaneously involved in the same gaming area. Only exercises involving large numbers of operational aircraft can currently provide realistic training in these force-level combat environments. The costs of such exercises in fuel consumed, airframe and engine wear, and potential for aircraft and aircrew losses make it difficult to conduct this training. The alternative to providing training in combat environments likely to be encountered by pilots is through ground-based simulators. In addition to reducing costs, simulation would provide virtually unlimited flexibility in preparing pilots for performance with and against different numbers and types of aircraft and, therefore, permit training in key areas such as situation awareness, communication and control, and energy management. However, simulation technology has not achieved the state where visual scene generation of this type of environment can provide the necessary degree of realism within the practical limits of cost. For example, the brightness requirements for presenting a full field of view, daylight scene is 1000 ft-L or greater but dome visual displays such as the Navy's VTRS and F-14 Wide Angle Visual Systems (WAVS) provide a brightness of only about 4 ft-L and 0.4 ft-L, respectively.

Display resolution limits are of even greater concern since even a realistic brightness level will be of little value if the display resolution is not sufficient to provide target acquisition and identification of target attitude changes at realistic ranges. Ideally, visual perception of targets in simulators should be limited only by the optics of eye and not by the simulator display. Unfortunately, the optimal resolution of current displays is in the range of 6-8 arc min. compared to 1-2 arc min resolution capacity of the eye. Producing displays with very high resolution is technically feasible(1) but the cost associated with very high resolution systems is substantial. More important from the viewpoint of training management is the degree to which training effectiveness of the simulator is improved by advances in display quality. In the majority of cases, the real training value of a simulator is only known well after the device is procured and an operational test conducted. Design specifications for successful training of certain tasks can, of course, be done to a limited extent on research devices. But even these devices are constrained by available technology as well as the considerable difficulty in conducting controlled transfer-of-training studies to determine the cost-effectiveness of even one of a variety of display improvements.

This paper will describe an alternative method for determining the potential impact of visual display characteristics on air combat simulation training effectiveness as well as presenting initial data from this ongoing research. Our objective is to provide reliable data on the kinds of training that will be possible under specific visual display conditions for a tactical air combat simulator training system. For the sake of simplicity and brevity we have focused on resolution and contrast characteristics. Investigations into other display characteristics such as field-of-view/area-of-interest are in the planning stage.

METHOD

The method employed in this study had to meet the requirements of any useful applied research, i.e., control of the variables of interest and valid generalizability of the results to the operational environment. Additional constraints of time to conduct the needed studies also were considered. Data must be available at the time in which decisions on a systems training value are being made if such data are to have any impact on design specifications.

The advances in the field of computer simulation modeling in the last two decades are of such a scope that the utility of using such models in addressing manned flight simulator design issues deserved investigation. A computer model as a research tool has the potential to meet all of the criteria previously mentioned.

TAC BRAWLER

A key element in utilizing a computer model to investigate the general problem of simulation fidelity and the specific problem of visual display requirements is that the model accurately depict the human component of the task at hand. Few tasks in the flight regime depend more on pilot perception and decision-making than air-to-air combat. The engagement model that was ultimately chosen met the need to simulate this human component of realistic force-level air combat engagements. The model chosen for this research, TAC BRAWLER, is a cooperative air combat engagement model developed under the auspices of the Assistant Chief of Staff, Studies and Analyses, HQ USAF. BRAWLER was designed to model flight vs flight engagements for a variety of fighter aircraft types and weapons systems. Continual interaction with experienced air combat pilots in the model's development assured that the simulated pilot responses in each of the aircraft involved in the engagement accurately depicted skilled, but not perfect, pilot combat performance. Further validation of BRAWLER has been carried out in conjunction with AIMVAL/ACEVAL exercise.

A detailed description of BRAWLER is beyond the scope of this paper. However, a brief discussion of the model architecture of BRAWLER (Figure 1) emphasizing the visual modeling will aid in understanding the procedures and results that follow. The architecture of BRAWLER is divided into two major information arrays, a Central Status Array which describes the physical parameters of the engagement and a Mental Status Array which describes each pilot's perception of the engagement. The Central Status Array maintains information on each aircraft's position and velocity, missile launches, etc. for all aircraft in the engagement. The Mental Status Array maintains only the information available to a pilot based upon that pilot's (imperfect) knowledge of the situation. A pilot's awareness of the actions of other aircraft in the engagement is based upon information available visually (either directly or by radar) and information from flight members or ground control. The decisions trade by each pilot in the engagement are, therefore, based on information that would be available to that pilot in a real-life engagement. This approach to the modeling of pilot behavior in BRAWLER allows for the simulation of air combat skill expected of experience, but not perfect, pilots.

Pilot Visual Perception.

Since this report addresses the issue of visual display effects in a manned flight simulator, a detailed description of how BRAWLER models the visual perception of pilots in air combat engagements is necessary. The visual processes of the simulated pilot in BRAWLER were systematically varied to emulate the effects of differing display characteristics of resolution and contrast. Target inherent contrast values of 0.5 and 9.0 were used in this study where inherent contrast is computed by the formula:

$$C = |L_t - L_b| / L_b$$

where: L_t = target luminance,
L_b = background luminance.

The effect of target contrast on the likelihood of detection depends on the position of the target in the pilot's visual field. As a consequence, BRAWLER models the effect of target contrast utilizing a visual detection lobe.[4] The lobe delineates the threshold contrast values that a target must meet in order to be detectable. The equation used to describe the detection lobe for foveal vision is:

$$C_t = 1.55 + 15.2/\beta^2, \ (\theta < 0.8 \text{ deg})$$

The equation for parafoveal vision is:

$$C_t = 1.75\ \theta^{1/2} + 19\theta/\beta^2, \ (\theta > 0.8 \text{ deg})$$

where β is the angle subtended by the target (arc min.), θ is the off-axis angle, and C_t is percent contrast at threshold. It is clear from these formulae that the effects of target contrast depend to a great extent on the position within the pilot's visual field. However, atmospheric visibility will markedly affect the level of target contrast that is actually perceived by the pilot. The level of target contrast that actually reaches the pilot's eyes is the effective, as opposed to the inherent, contrast of the target. Effective contrast in BRAWLER is modeled as an exponential function of inherent target contrast as follows:

$$c = c_o\, e^{-3.912\, R/V}$$

where: c = effective target contrast,
c_o = inherent target contrast,
R = range of target,
V = atmospheric visibility.

Inherent target contrast values of 0.5 and 9.0

were used in this study. Atmospheric visibility was set at 20 nm for all engagements. Given that the effective contrast of the target is sufficient for detection to occur, BRAWLER estimates the probability of detection in a single glimpse to be a normal ogive function of the ratio of effective to threshold contrast for targets subtending any given visual angle.[5]

Simulation of resolution effects in BRAWLER is based on the apparent size of the target derived from the angle subtended by the target at a given range. If the total surface area of the target is not sufficient to subtend the minimum visual angle (resolution values) used, the target would remain undetected. Note that the value β (angle subtended) in the formula for contrast threshold will have an inverse effect on threshold detection probability. The higher the visual angle subtended by the target, the lower the contrast threshold required for target detection.

Visual search characteristics will also affect the likelihood that a target within visual range will be detected. BRAWLER models the pilot's visual search pattern by dividing the total visual field (excluding areas masked by the cockpit) into eight sectors. Sectors are searched essentially at random with the constraint that the same sector is not searched again until at least one other sector is sampled. The simulated pilot searches each sector for 2.5 sec. with no more than 150 msec. per fixation. Once the target is detected, a visual tracking algorithm based upon the optimum control model[6] is initiated while the target is in view.

Procedure

The purpose of using BRAWLER was to determine the kinds of effects display resolution might have on engagements in a manned flight simulator and, therefore, the kinds of skills that could be trained. Since display resolution in effect limits what the pilots will see in an engagement, the *visual acuity of the "pilots"* in BRAWLER was altered to simulate resolution acuities of 2 and 4 arc min. These values were chosen to permit comparison of resolution effects for display systems of the future where 2 arc min. may be considered the ultimate goal of a system designer. Target inherent contrast values of 0.5 and 9.0 were also simulated in this study. The contrast value of 0.5 approximates the expected contrast of targets in the real-life engagements. A high contrast of 9.0 was chosen to investigate potential trade-offs between resolution and contrast in display design. All engagements were run as within visual range (WVR) scenarios, i.e., radar intercept was not possible.

Engagement Scenarios

For the sake of simplicity, only BRAWLER data on a one vs one engagement will be presented here. The aircraft simulated were Air Force F-15 fighters equipped with radar and infrared guided missiles and guns. At the start of each engagement the aircraft were situated with reciprocal headings (head-on approach) and offset by 1 nm, with a slant range of 8 nm. Visual acuity values for a given engagement scenario were either 2 or 4 arc min. for both pilots. All scenarios assumed daylight, unlimited visibility conditions. As with real life engagements, some variability in performance is expected from one engagement to the next. To assure reliability of the results, 25 engagements were run for each factorial combination of resolution and contrast under each of the two (Head-On or Right-Angle) intercept conditions.

RESULTS

Results of the BRAWLER engagement runs were analyzed for effects of differences in simulated system resolution and target inherent contrast on average detection range, opportunities for early shots, advantage of first sighter, and the type of weapons used. These measurements were chosen because they would reflect the general nature of the engagements and are reasonably accurate indicators of the types of skills that would be excercised. The results were analyzed separately for the Head-On and Right-Angle engagement scenarios.

Detection Range

The average range at which an opponent was detected under the four conditions of system resolution and target contrast are shown in Figure 2 for the two engagement scenarios. The average Head-On detection range for the 2 arc min. case is 14,800 ft. (S.D. = 3,200 ft.) and for the 4 arc min. case it is 11,100 ft. (S.D. = 1,300 ft.) with a target contrast at 0.5. When the target contrast is very high (9.0), the average detection increases to 20,300 ft. (S.D. = 1,200 ft.) for the 2 arc min. resolution case but has little effect on the 4 arc min. case. A similar pattern of results occurs in the Right-Angle engagement scenarios. The increase in target contrast did not, as might be expected, improve initial target detection in the poor resolution runs. A doubling of resolution from 2 to 4 arc min. improves detection but only by an average of 3,700 ft. in the low contrast conditions. The effects of resolution and contrast on detection range are reflected in the opportunity for early shots.

Early Shots

The proportion of engagements in which weapons were fired in the first phase of the engagement is shown in Figure 3. The improvement in detection range within increased acuity accounts for an increase of only 12% in shots fired during the initial phase of the Head-On engagement with low contrast. With increased target contrast from 0.5 to 9.0, early shots rise dramatically from 16% to 80% of the engagements in the 2 arc min. case. As expected from the data on detection range, improved contrast had no significant effect on early shot opportunities in the Head-On engagements. The pattern of results for early shots as with detection range data is similar for both scenario types run.

The relatively small effects on detection range and early shot opportunities resulting from a doubling of target resolution suggest that only a small gain in training utility is achieved for this critical phase of air combat engagements. Attaining positional and energy advantage over an opponent aircraft early in an engagement are often the most important factors in determining the outcome of an engagement. The increases in the range of target detection in this study which resulted from improved target resolution were not of sufficient magnitude to markedly affect the positional advantage of either combatant. As a result, the opportunities to fire weapons early in the engagement are roughly equivalent for all engagements run.

Advantage of First Sighter

In general, air combat engagement outcomes favor the pilot who sights his opponent first. This first sighter advantage is reflected in the frequency of engagement kills shown in Figure 4. Note that these kills occur in the secondary phase of the engagements, i.e., after the aircraft have passed each other. The high kill frequency in the secondary phase is due to the low proportion of early shot opportunities in the initial phase of combat.

Poorer target resolution had the effect of increasing the advantage to the first sighter in the Head-On engagements. For the low target contrast condition, the proportion of kills by the first sighter increases from 64% for 2 arc min. of resolution to 79% for 4 arc min. of resolution. In the high contrast condition, the effect of poorer resolution is even greater. The proportion of kills increases from 54% for 2 arc min. to 100% for 4 arc min. Target contrast effects had generally little effect on first sighter advantage for 2 arc min. case but substantially increased the advantage for 4 arc min. of resolution.

The differential effects of target resolution and contrast for the two types of engagement scenarios on the relative advantage to the first sighter are due to several factors. The nature of a Head-On intercept is such that, at the longer detection ranges occurring with 2 arc min. the difference in detection time for both combatants is sufficiently small to permit defensive maneuvering by the second aircraft, thus lowering the advantage to the first sighter. With the decreased detection range at the lower resolution (4 arc min.), a higher proportion of engagements occur in which only one aircraft sights the other. The higher contrast increases the frequency of this occurrence. In the Right-Angle scenario overall detection range is much less with an increased frequency of cases in which only one aircraft sights the other. This is due to the tail-chase maneuver that is typically executed by the first sighter in these engagements. Higher resolution in the type of engagement had the effect of *increasing the time that the first sighter has* to achieve a positional advantage (tail-chase) over his opponent. This resulted in a higher proportion of cases in which the first sighter was never detected in the engagements run with 2 arc min. of target resolution. Improved target contrast offset the advantage to the first sighter by permitting a higher probability that the first sighter would be detected by the second aircraft. The improved detection by the second aircraft resulted in defensive maneuvering and a lower lethality of early shots fired by the first sighter.

Weapons Selection

These differential effects of target resolution and contrast for the two scenarios are also found in the selection of weapons during the engagements. In Figure 5, the proportion of missile kills for target contrast and resolution values are shown for the two scenarios. In the Head-On engagements the proportion of kills due to missiles increases substantially as target resolution is reduced from 2 arc min. to 4 arc min. The difficulties in achieving positional advantage with reduced target resolution results in a higher frequency of selecting a missile over a gun solution in these engagements. In general, the shorter detection associated with the Right-Angle scenario eliminated any influence of target resolution on weapons selection. That is to say, the vast majority of engagements were missiles. Increased target contrast has the same effect on weapons selection for both types of engage- ments. An increased frequency of missile selection occurred consistently with increased target contrast. Engagements run with high target contrast resulted in much shorter differences in time required for the two aircraft to detect one another. This reduced time differential generally favors a missile shot.

DISCUSSION

The purpose of this study was to investigate variations in target resolution and contrast in simulated air combat engagements with the intent of deriving information which would assist in the design of visual displays for manned flight simulators in air combat training programs. The results of the study indicate that increased target resolution had only a small effect on initial target detection. Despite the fact that these resolution values are representative of design goals in simulators, the differences in the critical early phase of an air combat engagement that result from improved target resolution are small. The training value for display configurations with a resolution beyond 4 arc min. is doubtful but increased resolution to 2 arc min. does not result in substantial gains in the early phase of engagements when measured by average detection range or early shot opportunities. A substantially greater benefit results from improved target contrast in the initial phase of air combat. This is largely due to the fact that initial detection of an opponent aircraft will more likely occur in the pilot's visual periphery where acuity is poorer but responsiveness to contrast is much greater.

In subsequent phases of air combat engagements, resolution plays a more important role. Poorer resolution clearly results in some scenarios in which the first sighter will have an overwhelming advantage. The advantage is so large as to allow little opportunity for defensive maneuvering. Poorer resolution also resulted in an unreasonably high frequency of missile engagements, in some cases eliminating the gun as a viable option. In training for positional advantage and weapons selection, a lower resolution display would seem to be a poor choice. However, in some engagements such as the Right-Angle intercept resolution, differences have little impact.

Target contrast enhancement can be a useful device to improve initial detection and thereby permit some training with poorer resolution displays. Despite the substantially different contrast values used in this study, the effects of enhanced target contrast on the qualitative nature of the engagements after initial detection is not great. In general, the contribution of target contrast in air combat training will depend upon the extent to which location of targets in visual periphery (as in initial detection) is deemed critical.

This study has demonstrated the advantage of examining the potential impact of simulator display characteristics on air combat training by using computer modeling techniques. The changes in the nature of air combat engagements with variations on target resolution and context is useful in determining the type of skills that can be trained in simulators having these display features. The use of computer modeling techniques in studying simulation fidelity requirements has the potential to provide procurement agencies with objective data on the benefits of training devices as a part of cost-benefit analysis prior to purchase.

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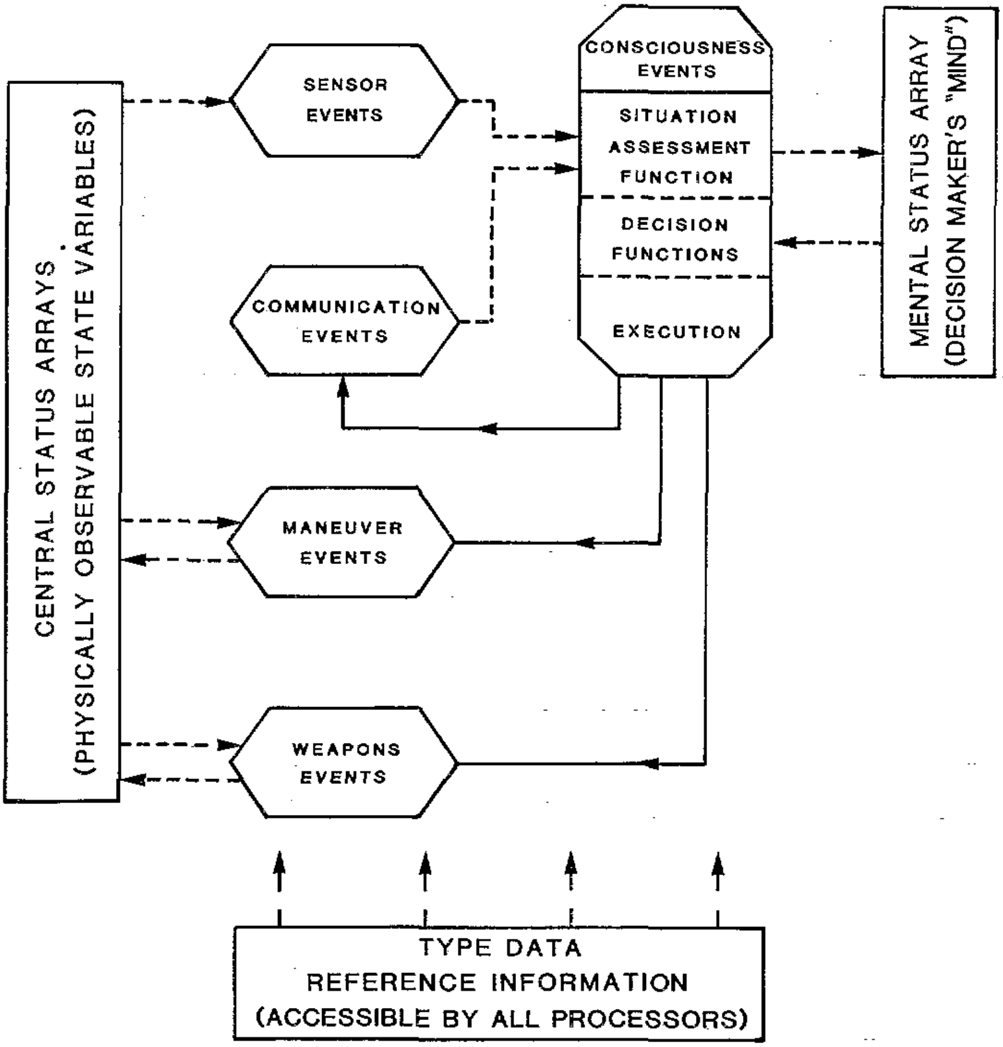

Figure 1. Conceptual Representation of Information Flow

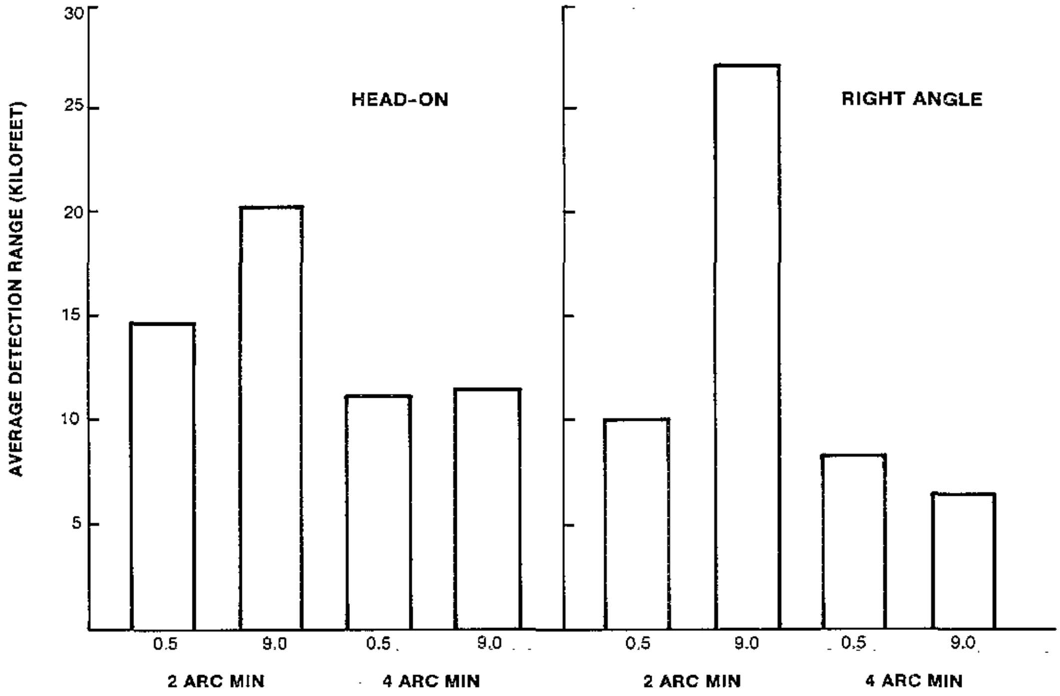

Figure 2. Average detection range for Head-on and Right Angle engagement scenarios as a function of pilot acuity and target inherent contrast.

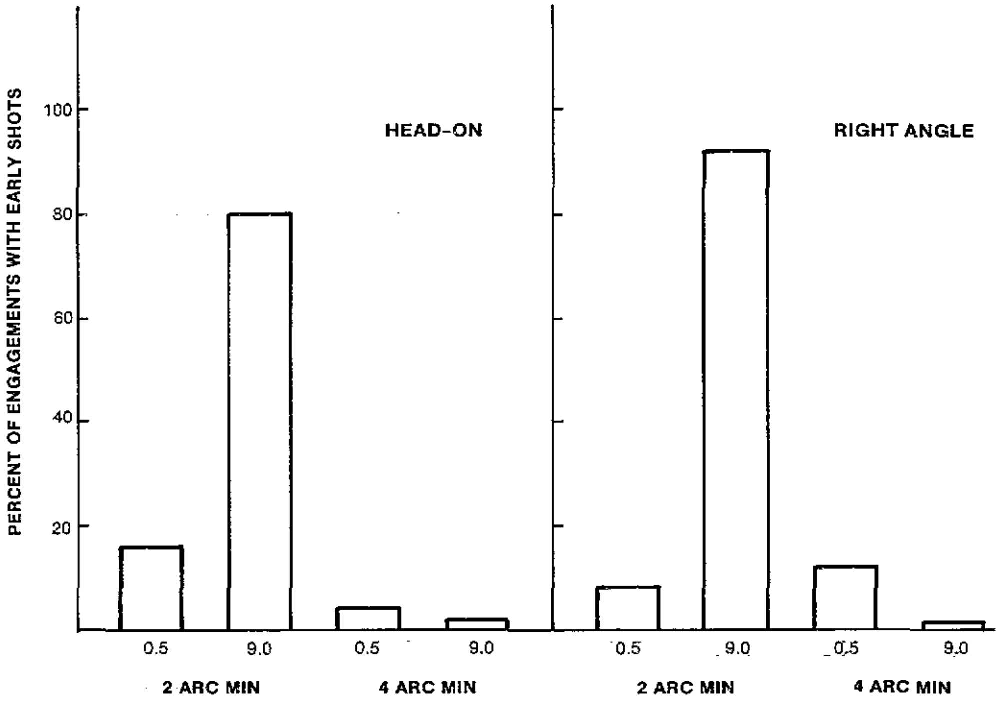

Figure 3. Percent engagements with weapons fired during first phase (early shots) as a function of pilot acuity and target inherent contrast.

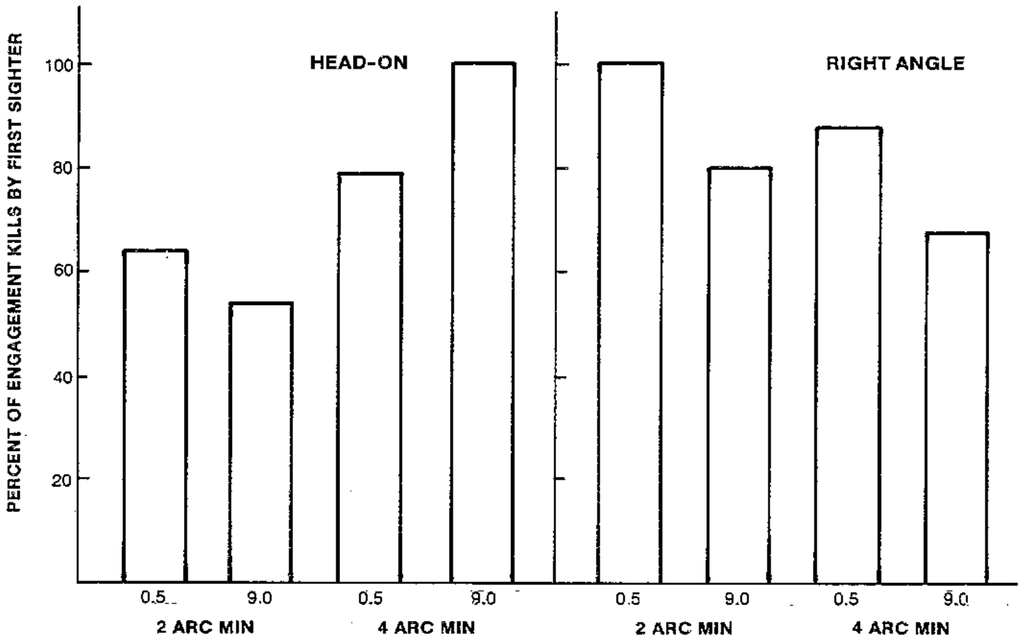

Figure 4. Percent of engagement kills by first sighter as a function of pilot acuity and target inherent contrast.

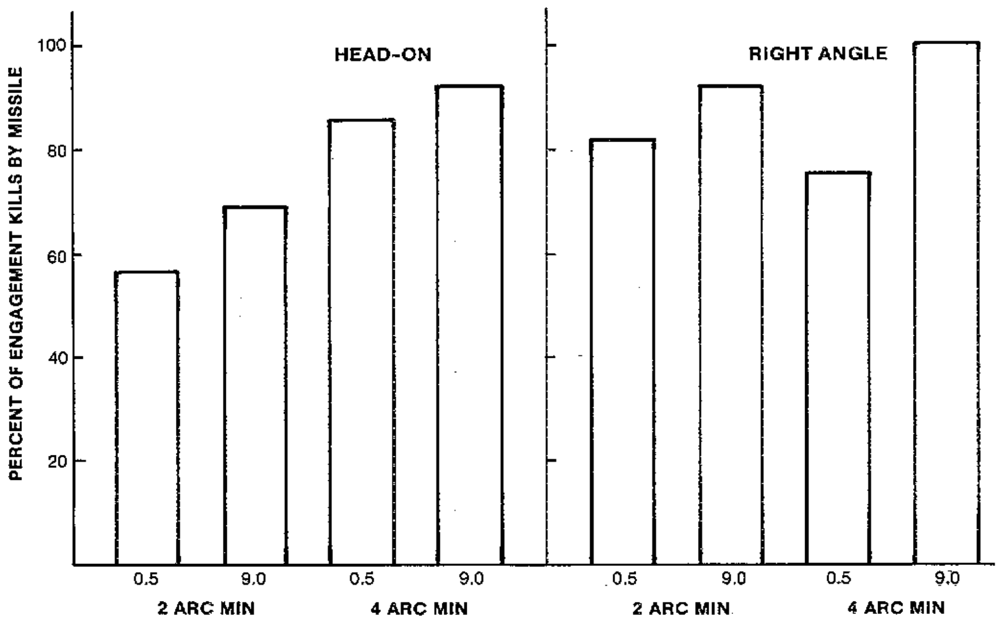

Figure 5. Percent of kills in engagements due to missiles as a function of pilot acuity and target inherent contrast.