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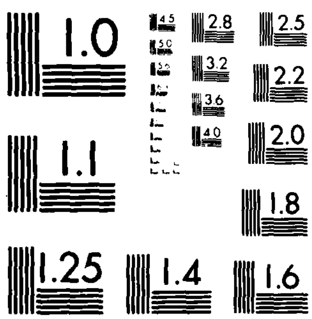
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SIMULATOR FOR AIR-TO-AIR COMBAT VERSUS REAL WORLD:
VISUAL CUE ANALYSIS FOR SIMULATED AIR-TO-AIR COMBAT TRAINING

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Flying an aircraft requires a continuous interpretation of the visual environment in which the pilot uses visual information from outside the cockpit and from the flight instruments inside the cockpit to develop and maintain an awareness of the status of the aircraft and its location in space. Flying a high-speed/high-performance aircraft in an air-to-air combat environment vastly increases the complexity of the pilot's task. The pilot must also keep track of and evaluate the performance of any opposing aircraft. To maintain a dynamic awareness of the situation and ultimately to be successful in the airborne arena, the pilot depends heavily on interpretation of out-of-the-cockpit visual cues. Usually training of the necessary visual skills for air-to-air combat takes place entirely in the aircraft . . . a high stress environment where the student pilot quickly can become overwhelmed with visual information. In addition, the

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training is severely limited by both rules of engagement and aircraft safety limitations that prevent the student pilot from experiencing and practicing maximum performance tactics. Often the result is inadequate air combat skills, so that additional training is required once the pilot is assigned to an operational squadron. New technology that provides visual display systems for flight simulators now makes it possible for many flying tasks to be more safely and more effectively trained than in the past. However, many simulator training programs have suffered from the erroneous assumption that transfer of training to the aircraft depends on the degree of realism provided by the simulator. The purpose of this study was to determine the "out-of-the-cockpit" visual cues that are essential for air-to-air combat training, and to evaluate the adequacy of visual cues provided by the Simulator for Air-to-Air Combat (SAAC).

SUMMARY

Objectives

The objectives were (a) to collect opinions of combat-ready fighter pilots concerning the training adequacy of the visual cues provided by the opposing enemy aircraft image (i.e., target) in the Simulator for Air-to-Air Combat (SAAC), and (b) to identify critical visual enhancements required to improve the effectiveness of the SAAC for Air Combat Maneuvering (ACM) training.

Background/Rationale

Flying an aircraft requires a continuous interpretation of the outside visual environment, as well as of the flight instruments inside the cockpit. Flying a high-speed/high-performance aircraft in an air-to-air combat environment vastly increases the complexity of the pilot's task since the pilot must also keep track of and evaluate the performance of the opposing aircraft. Usually, training of the necessary visual skills for air-to-air combat takes place entirely in the aircraft, a high stress environment where the student pilot can quickly become overwhelmed with visual information. In addition, the training is severely limited by both the peacetime rules of engagement and aircraft safety limitations that prevent the student pilot from experiencing and practicing maximum performance tactics.

The current state-of-the-art in wide-angle visual display systems now makes it possible for many combat flying tasks to be trained more safely and effectively in a ground-based simulator. For example, the SAAC was designed for training Tactical Air Command (TAC) pilots in basic air-to-air combat maneuvers and tactics. The simulator consists of two F-4E cockpits and a computer interface that allows two pilots to fly against each other or against the computer in air combat engagements. The visual displays are provided by eight cathode ray tubes (CRTs) that are combined to provide a field of view of 148 degrees horizontal and 150 degrees vertical. The result is a field of view almost identical to that of F-4 aircraft. However, because of the early technology CRTs being used, the visual scene inside the simulator appears as a monochromatic green background with a ghost-like white aircraft image. Consequently, the visual scene lacks much of the realism found in actual air-to-air combat. This study was focused on the current and potential out-of-the-cockpit visual cues associated with the target aircraft that appear to be most crucial for ACM training.

Approach

A structured interview technique was used to gather data from the F-4 fighter pilots who had experienced 4 days of training in the SAAC. Each of the 15 pilots was requested to provide information in the following areas: visual cues used in actual airborne ACM training, impressions of the target image generated by the SAAC, inputs about confusing visual cues in the SAAC, and recommended modifications to improve SAAC training effectiveness.

Specifics

The subjects' impressions about visual cues required during airborne ACM were used as baseline data for comparison to visual images generated by the SAAC. Five visual cues were reported as most important in ACM training: wing planform, target aircraft nose position, relative motion (across the canopy), relative size, and relative size changes.

The SAAC target image was judged to be generally acceptable as a presentation of an opposing aircraft by all of the subjects. However, only 33% listed the target as depicting the front-quarter pass as realistic, and only 20% listed the target as performing maneuvers realistically. Three deficient areas accounted for this condition: abrupt wing rock, target transition across the visual display, and inappropriate maneuvers (maneuvers that cannot be made by any existing fighter aircraft). The most prominent deficiency noted was the inability to determine target aspect adequately when the target represented an aircraft at a distance greater than 6000 feet. Four visual cues were reported as not being realistic. In all four cases, the lack of realism resulted from conditions peculiar to projection methods and computer logic of the SAAC subsystem. Only one cue, the sun image (when used as a wingman or target aircraft) was reported as unrealistic by more than half of the subjects. Of the nine visual cues reported as candidates for improvement in the SAAC, only two (improved target definition and improved ground image) were recommended by more than 50% of the subjects.

Conclusions/Recommendations

In general, the SAAC was judged to provide a reasonable state-of-the-art simulation of air-to-air combat when used in the one versus one (1v1) and two versus one (2v1) modes. The lessons learned certainly should be applied to future simulator developments and engineering studies. With respect to the SAAC itself, the following changes are recommended to improve its effectiveness for ACM training:

1. Improve target definition (beyond 6000 feet).
2. Improve target turn-around during passing and overtake maneuvers.
3. Improve the third aircraft image for 2v1 training.
4. Maintain optics alignment to limit loss of target.
5. Update the Automated Maneuvering Logic program.
6. Improve low-level ground cues.
7. Re-evaluate the concept for target projection.

PREFACE

This research was conducted under Project 1123, United States Air Force Flying Training Development; Task 1123-12, Tactical Combat Aircrew R&D. Dr. Edward E. Eddowes was the Task Scientist, and Mr. Robert E. Coward was the Principal Investigator.

The data collection and initial cue analysis were conducted by Cadet First Class Alexander M. Rupp of the United States Air Force Academy sponsored by the Frank J. Seiler Research Laboratory, as a Summer Research Project.

The authors express special appreciation for the assistance and advice provided by Lt Col Joe E. Robinson, 57FWW/OLAA/CC and the Instructor Pilots assigned to the TAC ACES Training Program at Luke AFB. Additionally, it is appropriate to acknowledge the professional and helpful attitude of the TAC ACES students who contributed to this report. Support provided by the SAAC Operations and Maintenance Contractor, Link Division of the Singer Company, was of considerable assistance to this research effort.

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SIMULATOR FOR AIR-TO-AIR COMBAT VERSUS REAL WORLD: VISUAL CUE ANALYSIS FOR SIMULATED AIR-TO-AIR COMBAT TRAINING

I. INTRODUCTION

Flying an aircraft requires a continuous interpretation of the visual environment in which the pilot uses visual information from outside the cockpit and from the flight instruments inside the cockpit to develop and maintain an awareness of the status of the aircraft and its location in space. Flying a high-speed/high-performance aircraft in an air-to-air combat environment vastly increases the complexity of the pilot's task. The pilot must also keep track of and evaluate the performance of any opposing aircraft. To maintain a dynamic awareness of the situation and ultimately to be successful in the airborne arena, the pilot depends heavily on interpretation of out-of-the-cockpit visual cues. Usually training of the necessary visual skills for air-to-air combat takes place entirely in the aircraft ... a high stress environment where the student pilot quickly can become overwhelmed with visual information. In addition, the training is severely limited by both rules of engagement and aircraft safety limitations that prevent the student pilot from experiencing and practicing maximum performance tactics. Often the result is inadequate air combat skills, requiring additional training once the pilot is assigned to an operational squadron.

New technology that provides visual display systems for flight simulators now makes it possible for many flying tasks to be more safely and more effectively trained than in the past. "It is now possible to perform in simulators many of the complex tasks required during operational missions, and tests have shown that simulators can be used effectively to develop many of the skills underlying these tasks" (Caro, 1977a). The Federal Aviation Administration recognized this when it allowed American Airlines to upgrade 40 Captains to DC 727 type aircraft in an experimental program extensively using simulators instead of non-revenue flights dedicated to training ... at a significant cost savings. "It also proved that simulators could provide training at least equal to, and in some cases, better than traditional aircraft training for airline ratings" (Kemmerling, 1975).

However, many simulator training programs have suffered from the erroneous assumption that transfer of training to the aircraft depends on the degree of realism provided by the simulator. Instead, Caro has stated "... the goal of a simulator training program should not be to replicate a visual scene, but only to provide those cognitive and visual cues essential to the training objectives" (Caro, 1977b).

In a classic study, Fitts identified three stages of sensory-motor learning: the cognitive stage, the fixation stage, and the automatic stage. During the cognitive stage, understanding of the task is gained; during the fixation stage, motor skills are learned by using the controls to respond to the visual display as defined in the cognitive stage. Finally, during the automatic stage, the motor skills are practiced to the point that they can be accomplished without adverse effect or intervention (Fitts, 1964). By presenting only the essential visual cues in a simulator (thereby eliminating the nonessential cues), the critical cognitive and fixation stages are simplified, and learning is enhanced. Then, by ensuring that these cues relate to the real world, transfer of training can result (Stark, Bennett, & Borst, 1977).

The purpose of this study was to determine the "out-of-the-cockpit" visual cues that are essential for air-to-air combat training, and to evaluate the adequacy of visual cues provided by the Simulator for Air-to-Air Combat (SAAC).

Background

The SAAC, located at Luke AFB, Arizona, was designed for training Tactical Air Command (TAC) pilots in basic combat maneuvers (ACM) and tactics. Figure 1 shows an illustration of the overall SAAC system. The simulator consists of two F-4E cockpits and a computer interface that allows the pilots to train against each other or against the computer in air combat engagements. The visual displays are provided by eight cathode ray tubes (CRTs) that are combined to provide a field of view of ± 148 degrees horizontal and +150 degrees, -30 degrees vertical (Kelly, Brown, Van Arsdall & Lee, 1979). A Farrand infinity optics system transforms the CRT images to a surface focused at infinity (Marr & Shaffer, 1978). The result, from the student pilot's viewpoint, is a field of view almost identical to that of the F-4 aircraft.

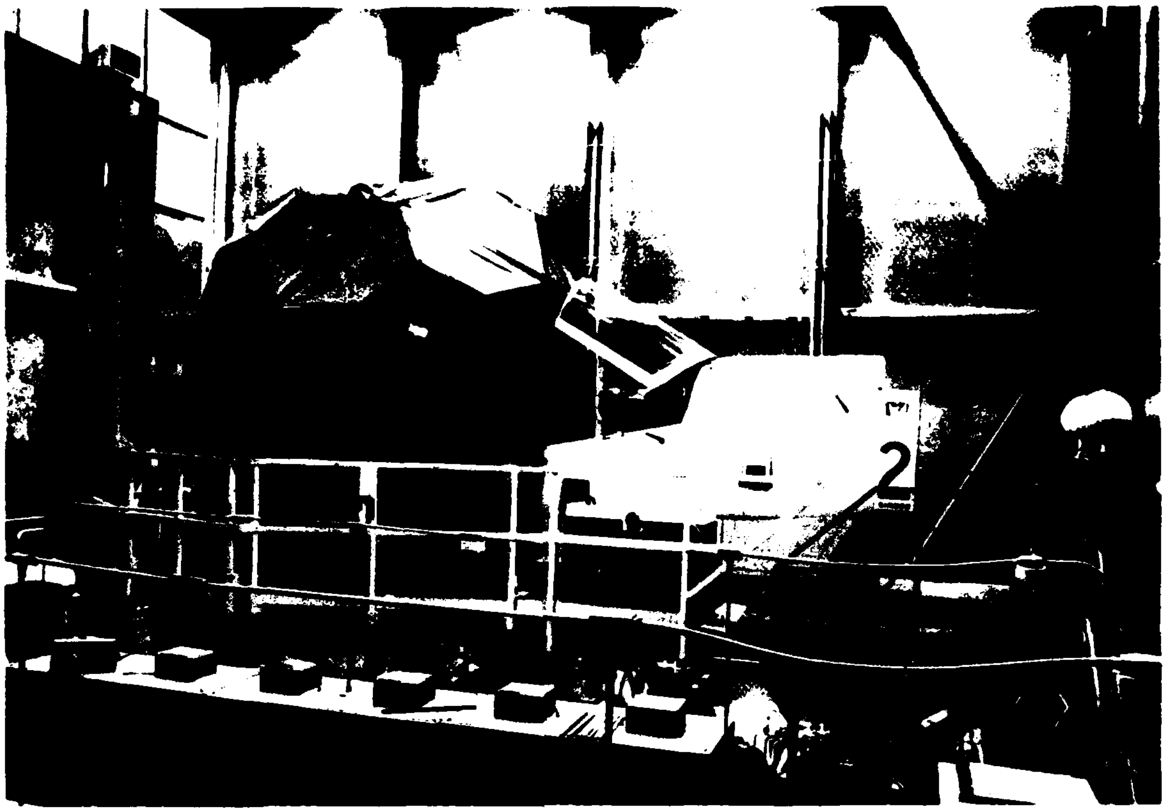

Figure 1a. **Cockpit open.**

Figure 1b. Cockpit closed — ready for entry.

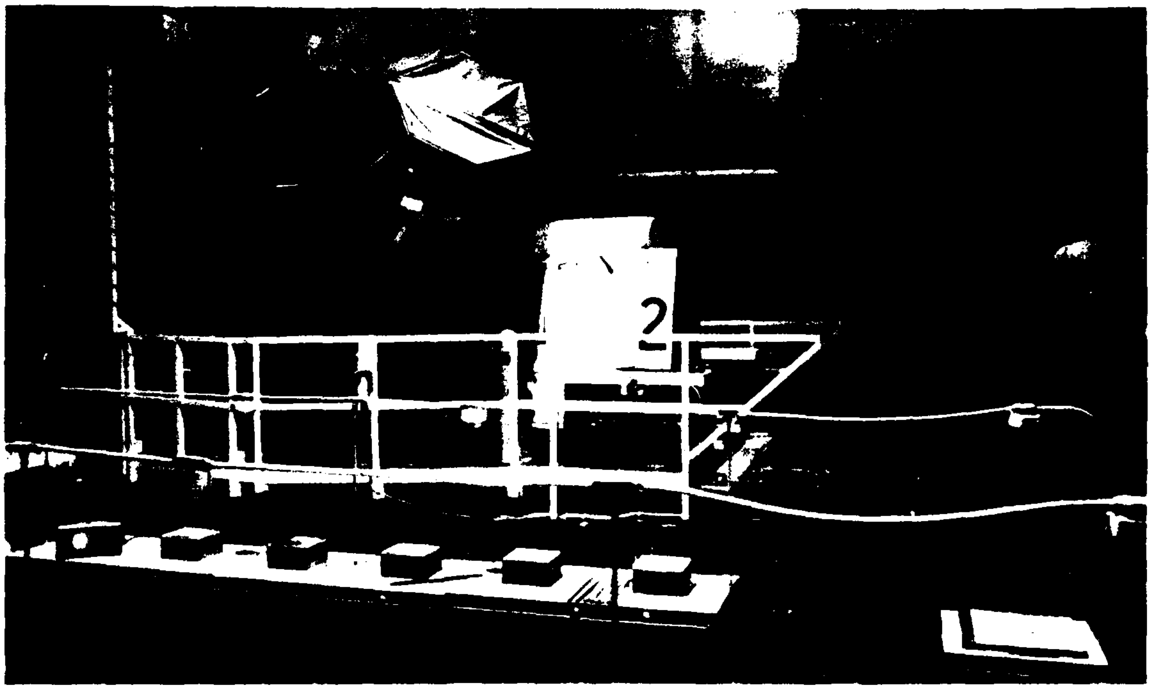

Figure 1c. Cockpit entry completed.

Figure 1. **Simulator for air-to-air combat.**

Visual information is provided in two alternating scans of the CRTs. The first scan (*time* = 8.3 *ms*) provides terrain information from the synthetic terrain generator (STG). The STG produces an irregular checkerboard ground pattern (the smallest division being 1/4 mile on a side), a haze layer (horizon), a sky, and a sun image (Figure 2). All of the images from the STG are totally computer generated. The second scan (time = 8.3 *ms*) provides target information from the aircraft image generator (AIG) (Figure 3). The AIG uses a video camera to photograph a slaved aircraft model mounted on gimbals for complete freedom on its pitch, roll, and yaw axes. The computer operates the gimbals, adds range information, and properly positions the aircraft image on the CRTs. A time sharing system is used so that while one cockpit is receiving target information, the other is receiving terrain information. The total time for both scans is 16.6 ms (or 60 cps), which appears as a continuously integrated image to the pilot.

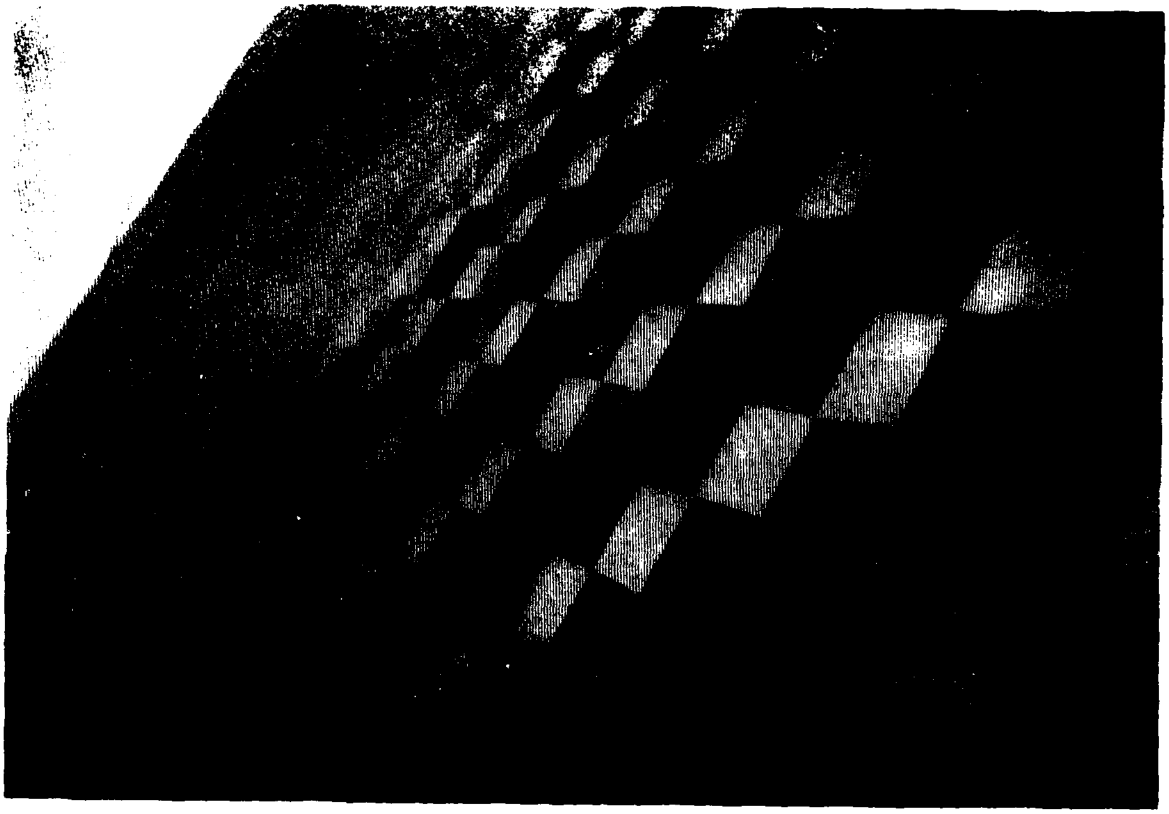

Figure 2. **Simulated terrain — SAAC.**

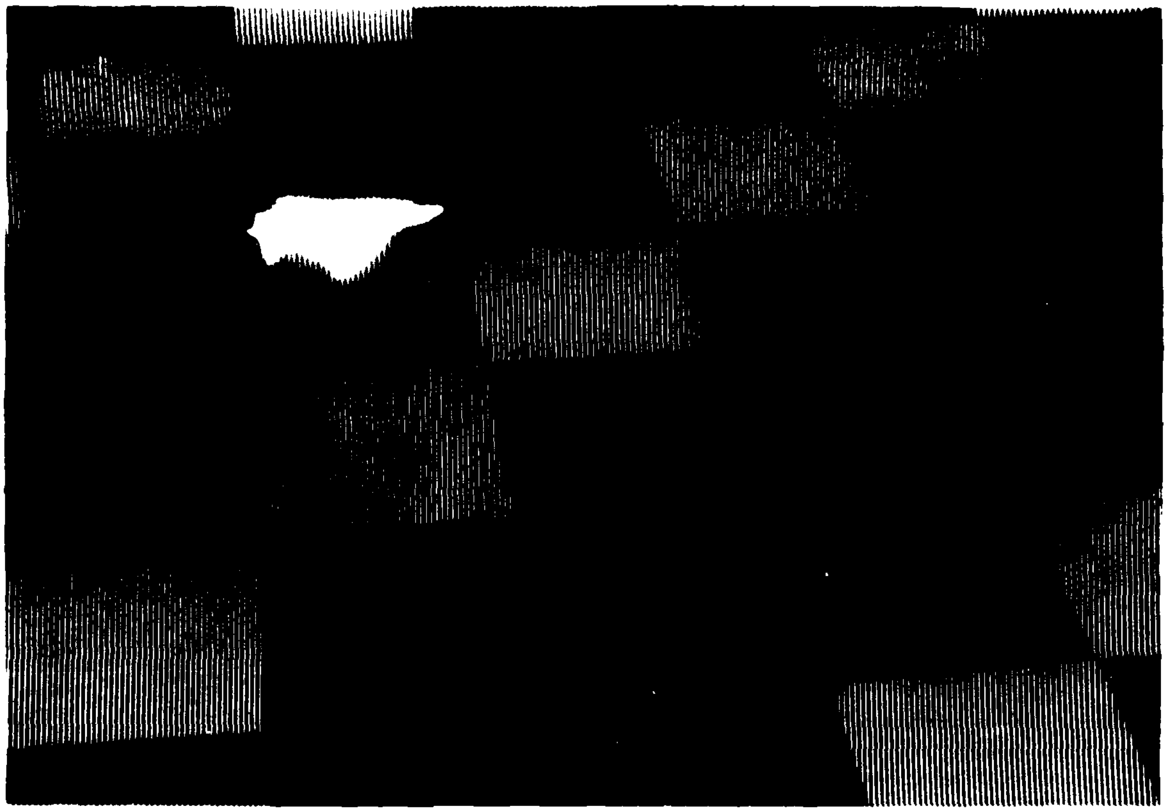

Figure 3. **Aircraft image — SAAC.**

Because of the early technology CRTs being used, the visual scene inside the simulator appears as a monochromatic green background with a ghost-like white aircraft image. Presently the simulator provides visual cues such as size, shape, relative speed, and relative flightpath for determining the opposing aircraft's performance. Consequently, the visual scene lacks much of the realism of an actual air-to-air combat environment (Figure 2); however, the technology presently exists to add detailed visual cues such as improved ground images, weapon flightpaths, operational flight controls, smoke, contrails, and so forth, by adding a digital image generator to the system. This study was focused on the current and potential out-of-the-cockpit visual cues, associated with the target aircraft, that may be used to provide improved training potential.

II. METHOD

Research on visual cues was conducted through a guided interview format. Subjects (Ss) were questioned in three broad areas. First, their level of training; second, what real-world visual cues they use in air-to-air combat; and third, their rating of the visual cues presently available from the AIG. The population was defined as F-4 fighter pilots who were assigned to units with an air combat mission.

Subjects

A clustered-group sample of the population consisted of students and instructors in the TAC Air Combat Engagement Simulator II (TAC ACES II) course (F-4000Z 00 AL) during the period 11 June to 13 July 1979. These Ss, 15 male fighter pilots, were selected in an attempt to interview all the available personnel attending the course during the data collection period. At a minimum, all Ss had completed F-4 transition training, Basic Fighter Maneuvers (BFM) training, and ACM training. The flying experience of the Ss ranged from less than 300 hours total flying time to more than 3000 hours flying time in high performance fighters. In addition, all of the Ss had obtained at least a bachelor degree, and several had completed advanced degrees. Table 1 provides a complete summary of their experience and training.

Table 1. **Aircrew Experience Data**

	% of Subjects
F-4 Flying Experience	
300 Hours or less	6.7
300 to 500 Hours	20.0
More than 500 Hours	73.3
Training Experience	
RTU * and BFM	100
ACM	100
Fighter Lead-In	73.3
Dissimilar Fighter Exercises	46.7
TAC ACES I (Vought Contract)	13.3
Red Flag	40.0
Fighter Weapons School	13.3
Combat Mission in Vietnam	26.7
Educational Experience	
BA/BS	100
MA/MS	33.3
PhD	0.0
SOS**	60.0
CS***	13.3

*Replacement Training Unit
**Squadron Officers' School
***Air Command and Staff College

Apparatus

A questionnaire (see Appendix A) was developed for use by the investigator during taped (audio) sessions. Two questionnaires were used for each S.

Procedure

The Ss were interviewed during a break in their training on the fourth day of the five-day training course. At this point in the training, the Ss had become familiar with the visual displays of the SAAC. The interviews were conducted in a separate briefing room to insure privacy. As the investigator asked questions following the questionnaire format, guided the discussion, and recorded the responses, the Ss followed the progress using a copy of the questionnaire. The second copy was used later to provide supplemental data after the Ss returned to their duty stations the next week. Interview sessions lasted between 30 and 45 minutes.

III. RESULTS

The results of this study have been broken down into four sections: an analysis of the visual cues in actual air-to-air combat training, impressions of the target image generated by the SAAC, an analysis of the confusing visual cues in the SAAC, and suggested improvements to the visual scene.

Actual Visual Cues Used

Four visual cues were reported as most important for air-to-air combat training (Table 2). Those cues used most frequently by experienced pilots to determine the target aircraft position are wing planform, target aircraft nose position, relative motion (across the canopy), and relative size/size changes. Being able to clearly see the planform of the target aircraft was reported by 93% of Ss as vital information for making a decision about the airborne fight. Target aircraft nose position was listed by 80% of the Ss as being vital for air-to-air combat as was relative motion across the canopy by 73%. An additional 7% considered the motion cue as important. Relative size and size changes were reported by 53% as vital and by 7% as important information.

Table 2. **Cues Used in Actual Air-to-Air Training**

Cues Reported	% of Subjects		
	Vital	Important	Desirable
Relative Motion—on canopy	73.3	6.7	—
Relative Motion—to outside reference 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	—	—

Aircraft Image Generator (AIG) Cues

As depicted in Table 3, the AIG cue was shown to be acceptable as a presentation of an opposing (target) aircraft by all of the Ss. However, only 33% listed the AIG as depicting the front-quarter pass as realistic and only 20% listed the target as performing maneuvers realistically. A majority of the Ss reported that the target does not always maneuver realistically. Three deficient areas accounted for this condition: abrupt wing rock, target transition across the visual display, and inappropriate maneuvers (maneuvers that cannot be made by any existing fighter aircraft).

Table 3. **Aircraft Image Generator Cues (Impressions)**

Cues Analyzed	% of Subjects			
	Yes	Generally	Can't Compare	No
Target as an Opposing Aircraft	80.0	20.0	—	—
Front-Quarter Pass Realistic	33.3	46.7	13.3	6.7
Target Maneuvers Realistically	20.0	80.0	—	—
Stern Overtake/Pass Realistic	53.3	40.0	—	6.7
Target Realistic	53.3	46.7	—	—
SAAC Depicts an A/A Encounter	80.0	6.7	—	13.3

Slightly more than half the Ss accepted the stern overtake/pass and the target itself as realistic. Although there were some reservations, 80% of the Ss reported the SAAC visual system as depicting a realistic air-to-air engagement.

Confusing Visual Cues

Four confusing cues were reported as not being typical of the real-world scene (Table 4). Only one, the *Sun Image* (when used as a wingman or target aircraft), was reported by more than half the Ss. However, all of the confusing cues represent a negative influence that deserves further attention. These are discussed later.

Table 4. **Confusing Cues**

Cues Reported	% of Subjects
Sun Image as Wingman/Target	66.7
Panel-to-Panel Shift	40.0
Low-Level Ground Image	26.7
Target Image	26.7

Candidate Cues for Improvement

The visual cues listed in Table 5 represent those reported as essential for improving the SAAC. Improved target image and improvement of the ground image (representation of the earth surface) were recommended by most of the Ss. The other cues were regarded as nice to have but not essential.

Table 5. **Candidate Cues for Improvement**

Cues Analyzed	% of Subjects
Improved Target Definition	93.3
Improved Ground Image	66.7
Exhaust Smoke/Afterburner Plume	26.7
Color	20.0
Collision Indication	13.3
Improved Sun Image	13.3
Improved Aircraft Features	6.7
Contrails	6.7
Sun Glint/Shadows/Clouds	6.7

IV. DISCUSSION

The most important finding of this study is that, in general, the SAAC presented an acceptable visual presentation for simulated air-to-air combat training. The visual cues identified as essential for training (planform, nose position, relative motion across the canopy, and relative size/size changes) are all readily provided by subsystems of the SAAC. Some other finite visual cues, listed in Table 5, may well enhance the detail and realism of the simulation, but as stated earlier by Caro (1977b) and Stark, Bennett & Borst (1977), such detail was not found by this study to be essential for training. This was further supported by the Ss' evaluations of existing visual cues as being generally acceptable representations of reality. As demonstrated during the study, pilots in training readily accepted the simulated target as an opposing aircraft and engaged the opponent using previously learned maneuvers with realistic results.

In general, the SAAC provides a reasonable state-of-the-art simulation of air-to-air combat when used in the one versus one (1v1) and two versus one (2v1) modes. There are, however, areas that this study indicate should be improved.

Visual Cues Currently Being Used

The most prominent visual cue commented on during the study and during daily training activities focuses on the definition and interpretation of the wing planform of the opposing aircraft (target). Briefly stated, planform is represented by the amount of wing area a pilot can see of the opponent aircraft and is used to determine aspect. This information, along with nose position, defines the direction the opponent is moving (closing or departing) and whether the opponent is turning, rolling, climbing, or diving. Adding the relative motion of the target image, as it traverses the visual scene, a pilot can determine how the opponent is moving in relation to defined fixed points (canopy code) on the nearby canopy bow and instrument panel reference points (Figure 4). This comparison of flightpaths is an essential cue to the fighter pilot during an airborne engagement. Changes in relative size of the target, in reference to the defined points and gunsight displays, provide the pilot necessary information about range to the target aircraft and the rate of closure. All of these cues are provided by the SAAC displays.

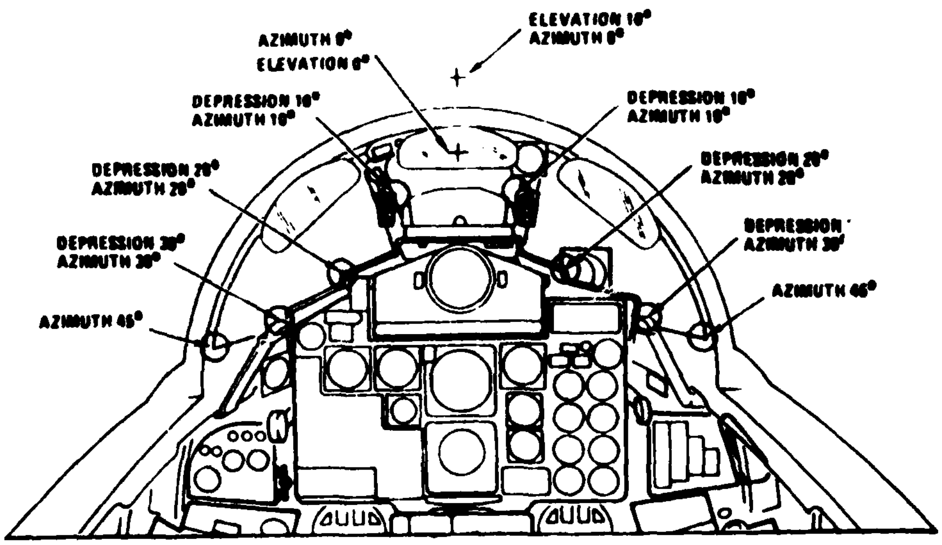

Figure 4. **F-4 Canopy code, front cockpit.**

Some areas were not comparable to real-world conditions or did not readily depict a totally acceptable presentation to the study group. The most prominent deficiency was in the ability of Ss to adequately determine target aspect during display of the target representing an aircraft at more than 6,000 feet distance. (Although this study did not pinpoint the distance stated here, subsequent trials by viewing the target at various distances established that an "apparent 6000 foot distance and further" was the point that pilots could no longer determine target aspect and planform. Comparison data from viewing of airborne target aircraft were not made.) Only 20% of the Ss were satisfied with the simulated image. Loss of target definition left the Ss doubtful of target maneuvers since aspect and direction were difficult to determine. This situation does not exist at closer distances.

Additionally, presentation of a front-quarter pass, two aircraft approaching and passing at high speed, is not totally realistic for two reasons associated with the presentation method and mounting method for the target aircraft image. The image is dynamically photographed by a video camera. An aircraft model, 72:1 scale, is mounted in a gimbal ring and moves based on inputs from one of the F-4 cockpit controls. As the image projection depicts closure and passing of the aircraft, the model must rapidly be turned 180° so the camera will then be viewing the aft end of the model as the target moves away to the rear of the viewing pilot. As the target image passes by the cockpit, the SAAC computer blanks out the visual image for the instant that the model is turning. Although this action is closely timed, the pilot sees two inappropriate actions: wing rock and a loss of the visual image when it is at a distance equivalent to about 200 feet in front. This rocking of the model's wing and the disappearance of the visual is the computer's way of turning the model around. Delayed for a second or so, this action would occur after the target had passed, and the action would not be as readily perceived by the pilot. The combination of these deficiencies also affects overtake of the target from the rear. Lack of target definition at long range prevents adequate interpretation of the direction the target is moving, and, upon overtake and passing, the wing rock and blanking of the target provides the pilot confusing cues of the movements being made by the target aircraft. At that time, an opponent may be expected to execute certain defensive moves. The rocking and blanking of the model at the time of overtake provides an unexpected reaction and resulted in 47% of Ss being less than satisfied with the stern overtake pass.

Along with the wing rock and disappearing target described above, 80% of the Ss were only generally satisfied with the maneuvering of the target aircraft. The unique SAAC visual display system is composed of eight large CRTs surrounding each simulator cockpit, integrated through infinity optics to portray the visual scene to the pilot. To minimize distortion in the visual presentation of the horizon and ground pattern and avoid abrupt movement of the target image as it transitions between adjacent CRTs, a concerted effort is required to insure that proper alignment of each tube in the system is maintained. Smoothing of the computer generated scene minimizes edge distortion. However, as the target image traverses the visual scene, it transitions abruptly as it moves from one CRT to the next. This slightly distracting move can be minimized by detailed alignment of the display optics and is an ongoing part of routine tuning and maintenance of the visual system.

The target was reported also to make unusual moves that are not realistic. This has nothing to do with the image display. The target aircraft image can be driven by inputs from a computer-modeled software program that emulates inputs from a human operator. The Automated Maneuvering Logic (AML), developed by Decision Sciences, Incorporated (Burgin, Fogel & Phelps, 1975), positions the target aircraft based on a series of decision statements. Sometimes the resulting move of the target is different from a maneuver that a human pilot would make. Ongoing update of the AML software program continues to improve target responses in the AML mode and has reduced this problem.

Although 80% of the Ss responded that, overall, the SAAC fulfilled their expectations of what an airborne engagement would be like, some said it was not realistic. Generally, the explanation given was that ACM in the SAAC was much harder than in the real world. The Ss related the difference to the lack of threat of a fatal encounter and that the tendency is to continue to the extremes of man and machine limits. However, the consensus was that by exercising those moves and judgmental decisions in the SAAC that must be prohibited in actual airborne missions, the student can graphically experience the result of the maneuver and learn exactly the limits that must be respected in the aircraft.

Visual Cues that Confuse Training

Original specifications for the SAAC provided that a capability must exist to train 1v1 air combat maneuvers (Kelly et al. 1979). Evolution of the subsystems resulting from lessons learned in training, applied research and technological developments have permitted expansion of training to include 2v1 ACM as a basic part of the TAC ACES II training program. Limitations of the AIG system, at present, allow only two aircraft images to be projected at any one time (only two AIGs are available). To provide a third aircraft in the visual scene, a computer-generated image is maneuvered through the visual scene as though it were a wingman for the student in training. Actually, the computer captures an image of the sun, used in BFM and 1v1 training and maneuvers this image as though it were another aircraft. System limitations currently prevent development of details that would give shape, size, and character to the image. As a result, the wingman image provides only limited cues during 2v1 training. Routine radio communications that would exist in combat provide the student readily usable information about the wingman and his location in the simulated fight. This limited aircraft image projection capability resulted in 67% of Ss reporting dissatisfaction with use of the sun image as a wingman. These were appropriate concerns since the student was not provided the performance cues (planform, nose position, relative size) that are needed to determine direction and closure of the wingman image.

Again, Ss reported the abrupt target motions and loss of the target image as it shifts from one CRT to the next as confusing visual cues. This is caused by masking of the optics where CRTs are aligned so the visual scene readily moves from one CRT to the next. Technology limitations of the system prevent total correction of this problem, however, proper optics alignment provides a minimum amount of target loss. Most students tend to readily adjust to the problem by moving their head to another vantage point. No one, however, found this to be an overwhelming problem.

Low level cues of the ground scene (below 500 feet) were reported as considerably confusing. The STG subsystem that generates the ground, haze, horizon, and sky does not produce the images, buildings, streets, and other objects that are provided by new technology visual systems ... nor are these required for the ACM training. The broad view of a platted earth image and clear sky separated by a layer of haze at the horizon provide a highly acceptable emulation of the air combat arena. However, as the training requires the student to practice low-level defensive and offensive moves, it becomes necessary to maneuver the simulated aircraft at very low altitudes ... as low as 200 to 500 feet. When the aircraft recovers or reacts very close to ground contact conditions, the SAAC subsystems cue any ground impact with a loud (adversive) Klaxon sound. It is important to note here that although only two Ss (13%) thought the altitude and ground cues were vital/important (Table 2), 27% reported the low level ground images as confusing (Table 4). The student soon learns to interpret the limited visual cues and, with use of the radar altimeter, becomes proficient using the available visual cues.

Several Ss reported the target image as a confusing cue. Basically, their concern was expressed as an objection to the bright, white, aircraft image against the dark background of the visual scene. They contrasted this to the real world situation of a brightly lighted sky and surround where the target aircraft appears as a dark object. The SAAC target image may well be characterized then as appearing like a photo negative where dark is light and light objects appear dark. This presentation is a function of the technology of green phosphorus CRTs and projection of the target image from a video input. Although the Ss reported the concept as confusing upon initial introduction, they readily adapted to the computer-generated scene and target and reported (80%) the target as being an acceptable presentation of an opposing aircraft.

Some Improved Cues for Consideration

During early portions of the interviews, the Ss discussed various visual cues that occur within the real world and those that exist within the SAAC visual scene. Later in the interview Ss were asked to recommend visual cues that are essential for improving TAC ACES program's training potential. Of those recommended (see Table 5), only two were reported by more than one-half of those interviewed. The others were generally reported as nice to have but not essential to training (compares to suggestions of Caro, 1977b, and Stark, Bennett & Borst, 1977).

Improvement of the target definition deals with the three problems (aspect, direction, and closure). Improvement of the ground image deals specifically with the detail of the ground scene when the aircraft are at altitudes lower than 500 feet. Some comments about improving the existing conditions are presented in the next section.

V. RECOMMENDATIONS

The recommendations provided here are oriented to the current training requirements of the TAC ACES training program using the SAAC as the training device.

1. *Improve target definition (beyond 6,000 feet).* As in the real world, the TAC ACES student should be able to interpret the visual image and accurately determine the aircraft's aspect angle, direction, maneuver being performed, and a fair estimation of closure rate. Although the SAAC target image far exceeds most computer-generated aircraft images, there is room for improvement. An ongoing research project has been initiated as a result of this study to evaluate candidate methods for improving the target. Definition of the extent to which TAC will pursue such improvements is underway by the Tactical Fighter Weapon Center (TFWC).

2. *Improve target turn-around during passing and overtake maneuvers.* This software modification can be achieved by the Operation and Maintenance (O&M) contractor.

3. *Improve the image for a third aircraft during 2vl training.* Since the present sun image (used as a wingman) does not provide aircraft performance cues, the students cannot interpret the wingman's maneuvers and cooperate in the fight. This restricts the potentially beneficial 2vl training. Several candidate methods for improvement are under study.

4. *Maintain optics alignment to limit loss of target as it traverses the visual scene.* This condition develops from change of the CRTs, during maintenance and as a function of age of the CRTs. Alignment of the optics is a time consuming problem. The results of this study indicate that the priority of optics alignment is sufficient to eliminate misalignment as a factor in reduced training effectiveness.

5. *Update the AML program.* Considerable changes have been made to the original AML program and as such have provided a useful subsystem for the TAC ACES training program. However, based on uses of the AML during this study and comments from the Ss, the program should be updated. The presence of a third aircraft in the training scenario has proven to be an exciting challenge to the students. It seems appropriate that some assistance should be provided toward attaining improved maneuvering as a timely way of improving the SAAC training capability.

6. *Improve the low-level ground cues.* The STG graphically depicts ground closure as the grid scene of the ground grows larger based on loss of altitude. However, from an indicated ceiling of 500 feet and lower, the change of the visual scene is not apparent, and in fact, the low-level scene resembles flying in a fog. The haze layer between ground and sky obscures the horizon, and the ground grid pattern appears too large and indistinct to be useful. Potential improvements should be tested where practical. One method, used in another training system, is to flash a bright (red) light in the visual scene area anytime the aircraft

is operating below 200 feet (or any other preselected altitude). Currently the crash Klaxon sounds upon simulated ground contact. However, avoiding the ground is a response best cued by visual signals (trees, hills, buildings, etc.). The flashing light in the visual dome could provide a visual cue, as opposed to the auditory cue upon impact, until a programming solution is developed.

7. *Re-evaluate the concept for target projection.* The negative-like image of the target aircraft is rather unrealistic but was a low-cost solution at the time of SAAC's development. Significant technological developments have occurred in programming and computer sciences that can improve the target image. Moving to a microprocessor or mini-computer to present the target would be costly. However, such alternatives should be investigated since significant fall-out benefits may result. Should such advancements be beyond TAC's investment strategy, continued analysis should occur as to potential methods for follow-on air combat simulator designs.

VI. APPLICATION

A great deal has been said by simulation experts, flying training managers, policy makers, and manufacturers about the pros and cons of visual fidelity in an aircraft simulator. Although much of the literature deals with the "whistles and bells" approach to designing engineering solutions to training requirements, there has been little work documented that compared what students see in the real world visual scene versus what is needed in the computer-generated visual scene. Along with this, most studies have dealt broadly with visual requirements for an extensive range of flying ... most generally from takeoff to landing.

The effort reported here was carried out with a very limited opportunity to analyze visual cues student pilots identify as essential to training BFMs for the 1v1 and 2v1 air combat engagement. Analysis of the visual cues available in the SAAC visual scene also was provided. The result has been a significant opportunity to document the effort for others to benefit from the experiences that occur during the TAC ACES training. The important point is that this study was concerned with the visual cues required by students receiving ACM training. Narrowing the scope to that limited area of training provides a specialized group of data that may generalize to other training requirements. All data reported here are from subjective evaluations of proficient pilots who received a specialized 1-week training course in SAAC. This training experience has been documented by the TAC ACES II Training Management as highly beneficial to TAC's mission readiness training. Additionally, the lessons learned here (not all of them can be documented in a technical report) should certainly be applied to future simulator developments and engineering studies.

The SAAC subsystems have now advanced to the point that useful data can be gathered and extracted for comparison to performance in the aircraft. Continued development of performance measurement concepts, tailored to ACM training, should well document the accepted notion that TAC ACES II training in the SAAC is highly valuable training that should be continued for future training of ACM concepts.

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APPENDIX A: QUESTIONNAIRE

VISUAL ACQUISITION OF ACM TARGETS SIMULATOR FOR AIR-TO-AIR COMBAT AIRCRAFT IMAGE GENERATOR REVIEW

This review is being conducted to obtain data about the Aircraft Image Generator (AIG) used to project a target image onto the SAAC visual scene. Your impressions will assist AFHRL in developing recommendations for improving the current target image.

PART I. Background Information:

1. Since entering your Air Force career you have accumulated (answer only one):

   a. 300 or fewer flying hours.
   b. More than 300 flying hours.
   c. More than 500 flying hours.

2. What command are you assigned to (circle the appropriate letter)?

   a. TAC
   b. USAFE
   c. PACAF
   d. AAC
   e. ANG
   f. Other (i.e., foreign service). Specify:

3. Have you completed any of the following (circle the letter(s) if you have)?

   a. BFM Training
   b. ACM Training
   c. Fighter Lead-in Course
   d. Dissimilar Fighter Exercises
   e. TAC ACES I Course (Vought Contract Program)
   f. Fighter Weapons Instructor Course
   g. Red Flag Exercise
   h. TAC Central Instructor School
   i. Instructor Pilot Instructors School (IPIS)
   j. Combat missions in Vietnam

4. Have you *completed* advanced educational training (circle the letter(s) if you have)?

   a. Bachelor Degree-Field ______________________________
   b. Master Degree-Field ______________________________
   c. Advanced Academic Degree Courses
   d. Squadron Officers School
   e. Command and Staff
   f. Other. Describe:

5. How recent is your airborne air combat training?

   a. Within last 6 weeks
   b. Within last 6 months
   c. Within last 12 months
   d. More than a year ago

6. What has your Directed Operational Capability (DOC) been?

a. Air-to-Air (last 6 mos__, 1 year__, more __)
b. Air-to-Ground (last 6__, 1 year__, more__)
c. Air Defense (last 6 mos__, 1 year__, more__)
d. Other. Explain

PART II: Airborne Target Cues:

Some airborne target cues that you normally experience may provide vital information in making decisions about your handling of the air attack.

1. What is the primary, real-world condition/indicator that you depend on in a live engagement?

a. Answer:

2. What other indicators do you use (separate the cues into the three groups shown below)?

a. Vital:

(1)
(2)
(3)
(4)

b. Important:

(1)
(2)
(3)
(4)

c. Desirable:

(1)
(2)
(3)
(4)

PART III: Aircraft Image Generator (AIG) Cues:

Recognizing that a projected image cannot depict all of the visual characteristics of an airborne aircraft, provide your answers and comments to the following questions about the visual cues available from the AIG.

1. Have you been able to readily accept the projected target image as an opposing aircraft for air combat training?

a. Yes
b. Generally
c. No

Comment:

2. Do the front-quarter approach, closure, and passing provide a realistic indication of what happens for a pass against an airborne aircraft?

a. Yes
b. Generally
c. Cannot compare. Why?
d. No. Why?

Comment:

3. Does a stern overtake and pass maneuver provide a realistic image?

a. Yes
b. Generally
c. Cannot compare. Why?
d. No. Why?

Comment:

4. Does the target appear realistic in other attitudes (above, below, on either side, etc.)?

a. Yes
b. Generally
c. Cannot compare. Why?
d. No. Why?

Comment:

5. Does the target appear to maneuver realistically?

a. Yes
b. Generally
c. Cannot compare. Why?
d. No. Why?

6. Overall, does the SAAC fulfill your expectaions of what a real air-to-air combat encounter would look like?

a. Yes
b. No

Comment:

7. Circle the number of the items below that are *essential* to improving the conditions discussed in 1 to 6 above. Add any more you believe are *essential.*

a. Improved aircraft features (operational flight controls, detailed cockpit, emblems, etc.).
b. Contrails and/or exhaust smoke
c. Sun glint, shadows, and clouds
d. Improved sun image
e. More ground images
f. Shading

Additional Items:

Comment:

8. Considering a live engagement, list the visual cues now available in the SAAC that are not needed or that confuse you as different from the real world:

a. Not needed:

(1)
(2)
(3)
(4)

b. Confusing cues:

(1)
(2)
(3)
(4)

PART IV: SAAC Update:

Modifications of the SAAC take engineering and parts acquisition lead time. Several programs are in the developmental stage to enhance the existing target display.

1. If you were due to return to the SAAC soon as an Instructor Pilot, what improvements in the target projection would you like to see available when you returned (list in priority order)?

a.
b.
c.
d.

2. Considering your list of needed improvements (See III, No 7), which missing cue do you feel is most important to add (or to be improved) immediately?

a. Answer:

Please provide the following information.

Name Date

Unit

AV No.

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