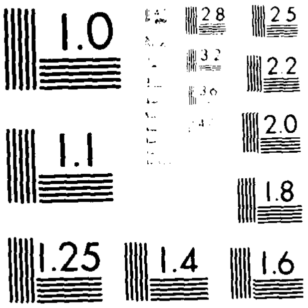
AD-A135 868 SURFACE-ATTACK MISSION SIMULATION: PRELIMINARY SCENARIO 1/1
EVALUATION(U) AIR FORCE HUMAN RESOURCES LAB BROOKS AFB
TX E L MARTIN ET AL. NOV 83 AFHRL-TR-83-21
UNCLASSIFIED F/G 5/9 NL

END
DATE
FILMED
1 84
DTIC



MICROCOPY RESOLUTION TEST CHART

[illegible]

(12)

AFHRL-TR-83-21

AIR FORCE HUMAN RESOURCES LABORATORY

AD-A135 868

SURFACE-ATTACK MISSION SIMULATION: PRELIMINARY SCENARIO EVALUATION

By

Elizabeth L. Martin
I. Gavin Lidderdale, RAF Exchange Scientist

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85224

November 1983
Interim Report for Period November 1980–October 1981

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

83 12 14 031

NOTICE

The Public Affairs Office has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

MILTON E. WOOD, Technical Director
Operations Training Division

ALFRED A. BOYD, JR., Colonel, USAF
Commander

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFHRL-TR-83-21	2. GOVT ACCESSION NO. A135 868	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* SURFACE-ATTACK MISSION SIMULATION: PRELIMINARY SCENARIO EVALUATION		5. TYPE OF REPORT & PERIOD COVERED Interim November 1980–October 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR*(s)* Elizabeth L. Martin I. Gavin Lidderdale		8. CONTRACT OR GRANT NUMBER*(s)*
9. PERFORMING ORGANIZATION NAME AND ADDRESS Operations Training Division Air Force Human Resources Laboratory Williams Air Force Base, Arizona 85224		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62205F 11230367
11. CONTROLLING OFFICE NAME AND ADDRESS HQ Air Force Human Resources Laboratory (AFSC) Brooks Air Force Base, Texas 78235		12. REPORT DATE November 1983
		13. NUMBER OF PAGES 30
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS *(of this report)* Unclassified
		15.a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of this abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Advanced Simulator for Pilot Training (ASPT)
air to surface
combat scenario
combat simulation
F-16
flight training
mission planning
simulation
tactical ground attack

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A part-task deep/strike interdiction scenario was developed for flight simulation application on the Advanced Simulator for Pilot Training (ASPT) configured as an F-16 aircraft. The scenario included visual target-area penetration, attack, and egress. The target was storage building located in a valley surrounded by mountainous terrain. The target area was defended by two threat sites containing surface-to-air missiles (SAMs) and quad-mounted anti-aircraft artillery (AAA) and one AAA site co-located with the target building.

DD Form 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 Jan 73

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

Item 20 *(Continued)*

Approximately 30 pilots participated in the development and refinement of the scenario. Sixteen pilots participated in the actual study. The subjects were experienced fighter pilots transitioning to the F-16 aircraft. The objective of the study was to investigate mission planning and mission effectiveness as a function of experience with the simulation scenario. The pilots prepared and documented two attack plans: the first based on intelligence briefing information and the second after four trails in the ASPT/F-16. Thus, each pilot flew eight trials in the simulated combat environment.

The results indicated improvement in weapons delivery and survivability skills. An analysis of mission planning revealed substantial variability amoung the pilots in their attack plans and little correspondence between each plan and the mission as flown. The tendency to execute the attack as planned improved somewhat on the second planned attack. Pilot opinion indicated a need to enhance the scenario by adding a formation attack capability, valid threat performance models, larger gaming area to include training in navigational systems operation, and additional detail in the visual scene in the areas of low-level flight. The addition of potential enemy aircraft threats, forward air controller in-flight briefing and simulation of a communications-jammed environment was also seen as valuable. The scenario as constructed was viewed as an acceptable first-step training aid. With the recommended improvements, most pilots felt that the training potential of a simulation approach to combat training was excellent, particularly in the areas of skill integration, mission planning, and threat evasion tactics with immediate feedback.

A-1

SUMMARY

Objective

The primary objective was a behavioral and engineering baseline for a simulated surface-attack mission adapted to the deep-strike/interdiction role of the F-16 weapons system.

Background/Rationale

Prior training research and development (R&D) efforts had demonstrated positive simulator-to-aircraft transfer of training for F-5 and A-10 air-to-surface weapons delivery tasks on a conventional range. Subsequently, a close-air-support simulation capability was developed on the Advanced Simulator for Pilot Training (ASPT) for application to the A-10 combat role, and a feasibility experiment was conducted in which mission-ready A-10 pilots flew the simulated combat scenario. The results demonstrated increased skill in both offensive and defensive categories (target kill and survivability). More recently, positive transfer of training from a simulated, high threat combat environment to the Red Flag exercise was demonstrated for the A-10. Based on these results, the scope of the R&D was extended to the skills and tasks of the F-16 weapons system.

Approach

The ASPT was used for the development of a generic deep-strike/interdiction simulation. A scenario was developed specifically for the F-16 weapons systems and included visual target penetration and attack in a target area defended by surface-to-air missiles and anti-aircraft artillery. Sixteen experienced fighter pilots flew the scenario according to attach plans of their own design. Primary data included mission outcome events, planned mission ground tracks, and pilot opinion.

Specifics

Method. After pre-mission planning, each of the F-16 pilots was given four trials in which to execute that plan in the ASPT. Following four repetitions of the initial plan (Plan A), each pilot left the simulator in order to prepare a second attack plan (Plan B). Each pilot then executed the second plan four times; thus, each of the 16 pilots flew a total of eight passes. The scenario included target area visual penetration and attack in an environment defended by two surface-to-air missiles and three anti-aircraft guns. The target was one of five buildings placed along a road located in a valley bounded on the east and west by mountainous terrain. Dependent measures included (a) automated objective data of each pass in terms of ingress, egress, weapons release status, bomb miss distances, number and type of threat activity, time within threat envelopes, chaff protection time and number of releases, and overall indications of altitude, g-levels, and airspeed, (b) video-tapes and experimenter-drawn records of aircraft ground track, and (c) pilot responses to pre- and post-mission questionnaires. Debriefings were also conducted.

Findings and Discussion. Analyses of mission outcome events showed that pilot performance improved in all categories. Terminal performance levels for Plan A and Plan B were approximately the same. No pilot executed the attack as planned on the first set of trials. No two pilots planned the same route. The majority of plans took advantage of direct terrain masking for ingress and egress. A small number of pilots chose to attack a threat site as well as the target. There was a greater tendency to execute the attack as planned on the second set of four passes.

Conclusions/Recommendations

The simulation of tactical scenarios provides an opportunity to integrate skills in mission planning, target acquisition, weapons delivery, and threat evasion under simulated combat conditions.

The existing simulation capabilities of the ASPT can be used to collect data that define requirements for generic scenario simulation. In the view of the authors, several enhancements would have beneficial impacts on a training scenario; specifically, (a) more low altitude cues in areas of likely ingress and egress, (b) a larger gaming area to provide a greater variety of attack routes and more systems-oriented navigation skills, (c) multi-ship capability for practice in planning and executing formation ingress, attack, and rejoin flight coordination, (d) high fidelity modeling of ground threats coupled with graphic and alphanumeric representations of threat versus aircraft engagements to enable instruction in defensive maneuvering, and (e) more complete avionics and navigation systems simulation. All of these enhancements are within existing simulation technology.

PREFACE

This effort represents a portion of the research and development (R&D) program of the Air Force Human Resources Laboratory for Technical Planning Objective 3, the thrust of which is Air Combat Tactics and Training. The general objective of this thrust is to identify and demonstrate cost-effective training strategies and training equipment capabilities for use in developing and maintaining the combat effectiveness of the Air Force aircrew members. More specifically, the effort was part of the R&D program conducted under the Air Combat Training Research subthrust, which has as its goal to provide a technology base for training high level and quickly perishable skills in simulated combat enviroments. Work Unit 11230367, F-16 Combat Scenario Development and Evaluation, addressed a portion of this subthrust, namely, the use of a simulated combat scenario for tactical mission planning and execution. Mr. James F. Smith was the project scientist and Mr. Robert Woodruff was the task scientist. Dr. Elizabeth L. Martin and Mr. I. Gavin Lidderdale were coprincipal investigators.

Mr. Lidderdale was at the Operations Training Division at Williams AFB from October 1979 to April 1982 as the Royal Air Force participant in the Exchange Scientist Program sponsored under the auspices of The Technical Cooperation Program (TTCP). Mr. Lidderdale has since returned to the United Kingdom as Head of the Human Factors Section, Operational Research Branch, Headquarters Royal Air Force Strike Command, High Wycombe, Bucks, England.

The authors wish to express their appreciation to Ms. Rebecca Brooks and Dr. Lowell Schipper whose assistance in data collection proved invaluable. We also appreciate the efforts of Maj Richard Engel in designing and modifying the simulation capability available on the ASPT and for providing inputs to the experimental protocol. Our special thanks go to the Air Force pilots who participated in the developmental phase and in the conduct of the actual study.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

PRECEDING PAGE BLANK-NOT FILMED

SURFACE-ATTACK MISSION SIMULATION: PRELIMINARY SCENARIO EVALUATION

I. INTRODUCTION

For a pilot to achieve combat readiness, several categories of flying skills must be mastered (Prophet & Monsees, 1980): (a) airmanship skills, (b) mission skills, and (c) combat skills. Basic airmanship skills are taught in undergraduate pilot training and continue to be reinforced through practice in all flights. Mission skills are introduced when transitioning into a new weapons system with instruction and practice continued throughout continuation training. Combat skills represent a higher task level that involves using the aircraft as a tactical weapon. As Prophet and Monsees (1980), pointed out the specific tasks and skills that underlie this higher level are not well understood. Therefore, designing a training environment to facilitate and maintain skill acquisition is a difficult task. It is a generally accepted notion that pilots need to train under the same conditions as those under which they will be expected to fight; therefore much effort is devoted to creating combat-like training conditions.

Readiness training for ground attack mission has emphasized the need for pilot participation in special tactical flight exercises. These special exercises are an attempt to augment the routine training regimen with more realistic exposure to combat-like conditions. Typically, these special exercises are held on a recurrent basis with each location having a designated name and purpose. Some of the better known ones are Red Flag, Maple Leaf, and Cope Thunder.

Although the special exercise form of combat simulation has many positive features, several restrictions limit the degree of "combat fidelity." For example, the minimum altitudes allowed in actual flight are somewhat higher than the altitudes projected for use in many modern tactical warfare scenarios. Further, due to the location of suitable ranges for staging the exercises, there are severe limitations with respect to exposure to various types of terrain, cultural features, and environment conditions. Due to financial, logistical, and safety limitations, any practice delivering live ordnance of some types is also limited or nonexistent.

All of the restrictions in the previous paragraph have the effect of reducing the maximum level of combat fidelity that can be attained. To the extent that these restrictive practice conditions limit the extent of the learning experience, it is reasonable to assume that some degree of potential training effectiveness (i.e., transfer of skills to actual combat) is lost. In addition, other restricitions limit the degree of training effectiveness that are specifically related to principles of learning and training. Perhaps the most significant limitation is the infrequency of the pilot's exposure to these programs. (Depending on a number of factors, a pilot may participate in a special combat exercise once in a 12- to 20-month period.) This is not often enough to maintain any high level of proficiency. The combat training syllabus does not always provide the immediate feedback needed to facilitate the learning process. Finding out during a debriefing that they were shot down 3 hours earlier is not likely to receive the same impact as being informed immediately and required to leave the exercise. It is difficult for the pilots to even remember what they were doing and thinking during the relevant time frame. Too often, the special exercise form of training is not readily adaptable to meeting the specific training needs of the individual pilot or in providing all participating pilots with an equal opportunity to practice the specific tasks.

Although flight programs of the Red Flag type are considered valuable, all of the previously mentioned restrictions limit the attainment of the long range goal of true combat readiness. Alternative training media must be developed and implemented to reach a combat-ready goal effectively. Recent developments in electronic and computer technology appear to provide a capability to create a ground attack combat training environment via ground-based flight simulation.

The concept of using synthetic flight devices to support training in air combat training is not new, however, because of limitations in visual system scene complexity levels, the primary operational application has been for the air-to-air mission. Even in this area, limitations in visual display technology have precluded a fully acceptable training capability. There are currently no operational flight simulators that can fully support training in tactical ground attack applications. The extent to which such a capability could provide an effective training adjunct to the special exercise flight programs is now being addressed with an exploratory research and development (R&D) program that seeks to determine the training potential and the simulation requirements. However, the real issue is not technology; it is training. Technology can only provide the medium. The issue is how best to train the skills and tasks required for mission and combat level effectiveness.

The purpose of the present study is to examine the potential of extending the scope of mission and combat readiness training through the flight simulation medium.

II. BACKGROUND

Several recent R&D efforts have demonstrated the effectiveness of simulator training in the area of conventional range weapons delivery tasks (Gray & Fuller, 1977; Gray, Chun, Warner, & Eubants, 1981). This training concept has also been extended on an experimental basis to the tactical ground attack domain. A feasibility study was conducted to demonstrate the potential of high threat tactical ground attack simulation scenarios for future training applications to a close air support (CAS) mission (Kellogg, Prather, & Castore, 1981). In this study, the Advanced Simulator for Pilot Training (ASPT), configured as an A-10 aircraft, was used as the test vehicle. The scenario was a part-task profile requiring a single ship target area penetration, attack, and egress under visual conditions. A tactical gaming area of about 10 square miles was modeled. The target was a stationary tank defended by anti-aircraft artillery (AAA) and surface-to-air missiles (SAMs). Bomb miss distances and ground threat activity were recorded in realtime. Thus, feedback to the pilot could be immediate as to a hit or miss on the attack and the success of threat evasion.

Seven mission-ready A-10 pilots each flew 20 attacks into the threat/target area. The following results were indicated:

1. The second 10 trails resulted in a significant increase in survival and offensive outcomes when compared to the first 10.

2. The first 10 trials showed marked improvement in offensive scores but not in defensive scores.

3. The last 10 trails showed an increase in defensive scores.

The subjective opinions of the pilots were favorable towards the simulation effort particularly because it provided immediate feedback in an interactive threat environment. Immediate and reliable information is typically not available during an in-flight combat exercise.

More recently, positive transfer of training from flight simulator to Red Flag performance has been reported (Hughes, Brooks, Graham, Sheen, & Dickens, 1982). This experiment used the ASPT/A-10 simulator with a new data base modeled after a real tactical engagement range. A-10 pilots received 2 hours of practice in simulated CAS and battlefield interdiction missions in a simulation of an electronic warfare environment. For the CAS mission, target arrays consisted of three groups of seven tanks each. Targets for the interdiction missions were two command posts, each of which consisted of a group of four vehicles. Threats were simulated AAA guns, and SAMs. All threats were modeled in an independent radar-controlled mode. The results showed that those pilots were trained in the simulator survived a significantly higher proportion of total Red Flag missions than did a control group of pilots who did not receive the simulator training.

The results of these initial experiments were encouraging in that learning effects were observed, pilot opinion was generally favorable, and positive transfer of training was demonstrated. Therefore, a deep-strike scenario tailored for F-16 operations was designed, using the original data base. The original T-37 configuration of a second ASPT cockpit was re-configured to an F-16 cockpit. The target was changed from a tank to a storage building, and the threat array and performance were enhanced. A subject protocol involving intelligence briefing and mission planning was developed.

Several preliminary data collection efforts were conducted in this environment using the ASPT/F-16 simulator and experienced fighter pilots undergoing F-16 training; approximately 30 pilots were used during this phase. As a result of their performance and comments, several changes were made to the simulation:

1. The visual scene models of the surface-to-air missiles were increased in size to compensate for a lack of contrail or smoke.

2. The maximum turning g capability was reduced from 24g to 15g to model missile performance capability more realistically.

3. The threat sites were programmed to deactivate if successfully attacked.

4. A previously used weather ceiling of 4500 feet above ground level (AGL) was removed because the ASPT/F-16 radar capability was not used in this study.

5. The range of exercise activation was increased to provide a sufficient gaming area for the F-16.

6. The initial position of the aircraft was changed in such a way as to provide a neutral starting point.

7. The pilot's choice of surface attack delivery mode and the type of ordnance selected were recorded and incorporated into the performance measurement print-out.

8. A subroutine was added to provide some defensive countermeasures capability by simulating the effects of chaff on the tracking ability of the missiles.

The phase of evolutionary development was stopped when no new significant suggestions arose that could be incorporated into the scenario without major engineering and hardware enhancements. At this point the configuration of the combat simulation environment was "frozen" (i.e., no hardware or software changes) for the purposes of collecting the data for the present study.

In the preliminary development of the combat scenario used in this study, it became apparent that those pilots who took the time to carefully study the intelligence briefing and the map of the environment were less likely to get lost and were more successful in finding the target and avoiding the threats than those who simply glanced at the materials and "climbed in." For the latter type of pilot, much time was spent in basic area orientation. It was of interest to examine this effect more systematically. One skill/task that directly contributes to effective missions in mission planning. A well-planned mission prepares the pilot for the unexpected. The pilot has already considered contingencies for poor weather, unbriefed threat activity, and communication jammed operations and has alternatives and estimates (even if subjective) of probability of success for these alternatives. Proficiency in mission planning should lead to skill in tactical decision making and situation awareness, two factors thought to be essential for an effective combat pilot (Prophet & Monsees, 1980). These terms are vaguely defined at best and most often recognizable by their absence. It seemed the even rudimentary preparation enhanced the benefits of the simulation experience and prevented many errors for the pilots who participated in the developmental stage.

The simulation scenario provided an efficient and accessible environment in which a pilot could "test" an idea or strategy. Repeated opportunities resulted in refinements and sometimes completely new approaches. It was of interest to study how pilots would change their strategy once they had acquired first-hand experience in the environment. Thorndyke (1980) postulated that the spatial knowledge derived from map study is quite different than the knowledge gained from actual navigational experience. He labels the type of knowledge gained from map study as survey knowledge characterized by knowledge of locations and Euclidean distances between objects. He argues that spatial reasoning tasks require a different type of knowledge which could come from a combination of survey and navigational knowledge. Presumably, effective mission planning involves a good deal of spatial reasoning. Therefore, a pilot would benefit from both kinds of experience. A protocol developed for this study would require plannng from map study and subsequent planning based upon navigation experience. Although it would be desirable to evaluate the goodness of the two types of plans, evaluation is not a simple matter. As Hayes-Roth (1980) pointed out, evaluation of a plan is difficult due to inherent ambiguity. The use of multiple criteria is possible, but the weighting of the criteria needs to be empirically determined. One approach is to evaluate the performance of the plan. That approach is implicitly consistent with the approach taken in the present study. However, it must be recognized that the soundness of the plan and the pilot's ability to execute the plan are two distinct entities. In the present study, there is no attempt to evaluate the plan independently from the execution of the plan.

The scenario was constructed to represent a single-ship daytime visual target area penetration to a storage building target. The target was located in a valley bounded on the east and west by mountainous terrain. The immediate target vicinity was defended by two SAMs and three AAA emplacements.

The general procedure for data collection involved each pilot's developing a plan for attack based on information made available in a written intelligence briefing. The pilot then proceeded to execute that plan in the ASPT scenario. Following the initial exposure to the environment, each pilot then formulated a second attack profile and was again given the opportunity to execute that plan in the ASPT.

To summarize, the study presented in this report represents an extension of the earlier work in a simulated hostile environment. The objective of this study was to establish a behavioral data base of pilot performance in a simulated deep-strike/interdiction surface attack scenario. The data base will be used to define the requirements of simulated environments in support of tactical surface attack training. The scenario incorporated elements of the following tasks and skills: (a) mission planning, (b) target area situation awareness, (c) target acquisition, (d) weapons delivery, and (e) ground defensive evasion. The research issues were to define tasks and skills that can be effectively practiced, performance measurement requirements, and simulation requirements to support the training objectives.

III. METHOD

Equipment

The ASPT used in the conduct of this study is a research simulator originally designed with a full mission T-37 capability. A detailed description of the original device may be found in Gum, Albery, and Basinger, 1975. One cockpit has been modified to an A-10 configuration, while the other cockpit has been configured as an F-16 aircraft. Both systems were designed to have necessary cockpit and aerodynamic capabilities to support transition flight tasks, such as takeoffs, approaches and landings, instrument flight, basic navigation tasks, and conventional air-to-ground weapon delivery. Neither of the modified configurations has full mission capabilities.

The following is a description of the ASPT/F-16 as it was configured during the conduct of the present study. The visual display was a monochromatic computer-generated image displayed through seven CRTs with a ±150° horizontal by +110° vertical field of view. (The aircraft field of view is 360° horizontal by +180° vertical −40° over the side and −15° over the nose.) The ASPT also has −15° over the nose, but −37° over the left side and −15° over the right side. The ASPT/F-16 does not have the capability to use the platform motion simulation system available on the original T-37 configuration. No kinesthetic device g-cueing was used in the present study. The cockpit layout was designed to duplicate the Block I aircraft in most major respects, except for the seat which was a modified T-37 seat titled back 27°.

Instrumentation. All flight and engine instruments were operable with the exception of the fuel flow gauge. The horizontal stability indicator was operable but not the inertial navigation system. Communications, chaff/flare, and electronic countermeasure panels were static mock-ups. The head-up display (HUD) was an operational model driven by a simulated flight control computer.

Aerodynamics Model. Aircraft aerodynamics were modeled from sea level to 40,000 feet from 0 to 0.9 mach, and to a maximum of 30° angle of attack. The simulation will allow higher and faster flight but without proper atmospheric modeling and drag coefficients. Engine performance was modeled from idle to after burner and from sea level to 55,000 feet.

Weapons Systems. The configuration included air-to-ground simulation of manual (bomb and strafe), continuously computed impact point (CCIP) (bomb and strafe), and dive toss deliveries. The potential ordnance included BDU 33, CBU 68, MK 61, MK 82 (high and low drag), and MK 106. For those modes and ordnance, the Stores Management System displayed proper indications for the bombing and strafe modes, as well as the current aircraft inventory. The simulation did not include air-to-ground missile deliveries or air-to-air capabilities. The aerodynamic model did not account for weapon weight.

In addition to the flight simulation, the ASPT/F-16 provided several advanced instructional features that were used in this study. A camera display of the HUD was projected at the advanced instructor console. Graphic displays of the terrain features and aircraft position were also available at the console; either of these could be videotaped with associated voice communications. The current status of the aircraft and ground defense was displayed on an alphanumeric CRT.

Environment Description

The general environment (Figure 1) consists of a broad, flat plain with mountains surrouding the target zone. Located on the eastern edge of the environment are two parallel mountain ridges separated by a valley which contains numerous high jutting pinnacles. Located on the western edge of the environment is a low mountain plain approximately 700 feet about the surface. Adjacent to this low mountain plain to the east is a series of three medium altitude mountains (no higher than 2100 feet). Located in the southern portion of the environment are two large mountains, 6500 feet at the highest point, with a saddleback between them. In the southeast corner of the environment are two moderate size mountains approximately 2250 feet high. In the immediate target vicinity (approximately 1.5 miles) there was a series of 35-foot-high, inverted tetrahedrons (cone-shaped). These objects have black sides with white triangular tops and are regularly spaced at 1000-foot intervals. The purpose of these cues was to provide depth and movement information to the pilots.

The target was a storage building located on the south side of a road that runs east-west between the small mountain ridge to the southeast and the two large mountains located in the southern portion of the environment. The target was the second building (of five) west of center. These buildings were located alongside a road and approximately halfway between the large mountain and the intermediate mountain range (Figure 2). The buildings were approximately 50 feet long, 25 feet wide, and 20 feet high. The buildings were shaded white.

Threat Simulation

SAMs. There were three predominant threat sources within the environment. Two of the sources consisted of a SAM and four quad-mounted 23mm AAA guns. A third gun site was located in the immediate vicinity of the target. The SAMs have a line-of-sight capability to approximately 40,000 feet with a 2-1/2° look angle and minimum altitude of 50 feet. The missiles operated as radar guided only (with a maximum 15g turning capability) and required 10 seconds from initial acquisition to launch. Direct terrain masking was effective against the missile radar. The operating logic was independent for the two SAMs but the first SAM to acquire the aircraft had priority for visual display. Only one of the two missiles could be launched and be in flight at one time (due to restriction in the number of moving models that can be visually displayed). After the missile in flight aborts, another missile from the same site or a missile from the other site could then proceed with the launch cycle. The missiles were visually modeled approximately 100 feet in length and shaded white. No smoke at launch or in-flight signatures were modeled. A SAM kill was defined by a miss distance from the aircraft of 200 feet or less.

AAA. The anti-aircraft guns were modeled to be visually controlled by proficient (nine-level) gunners. The range of the guns was approximately 3000 feet. The program controlling the guns recorded a kill if the aircraft was within their envelope for 4 consecutive seconds. Jinking at greater than 4g would defeat the AAA by resetting the 4-second counter (Figure 3). The gun sites were modeled as black tubes with strobe flashes (to simulate firing) at the base. The gun site defending the target was not visually modeled. Two visually modeled but inactive gun sites were located in the environment (one was located in a valley on the western portion between the plains and three peaked ridges; the other was located in the mid-valley north of the active northern threat site).

Rules of Engagement

The pilot's overall objective was to enter the target area from the start position indicated; acquire, engage, and destory the target; and egress the target area. The target area was defined as a 4-mile circle around the target. If the aircraft entered the target area and subsequently left the 4-mile area, the exercise automatically terminated and was scored as a safe exit. There were three means by which the aircraft could be destroyed: (a) SAM kill, (b) AAA kill, and (c) terrain crash. Each trial in the environment was independent of the previous trial. That is, all ordnance was restored and the threats reactivated for the next trial even if all bombs were used and all target or threats destroyed on the previous trial. The target and threat sites were considered destroyed if a bomb miss distance of less than 30 meters was obtained. The stores management set was programmed with six BDU-33 bombs dropped in pairs using the CCIP delivery mode. Three bomb drops were allowed (but not required) on any trial. Although the target was the primary objective, the threat

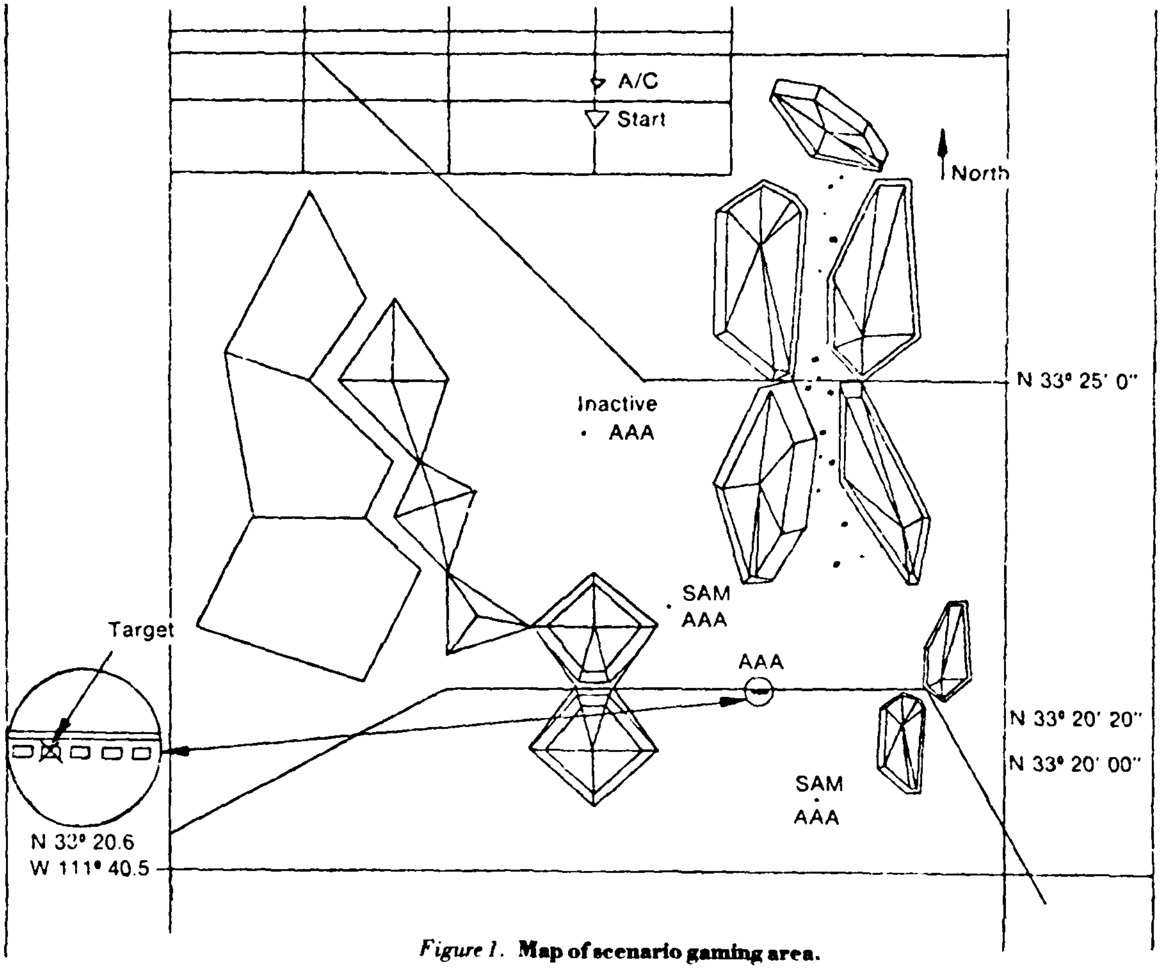


Figure 1. **Map of scenario gaming area.**

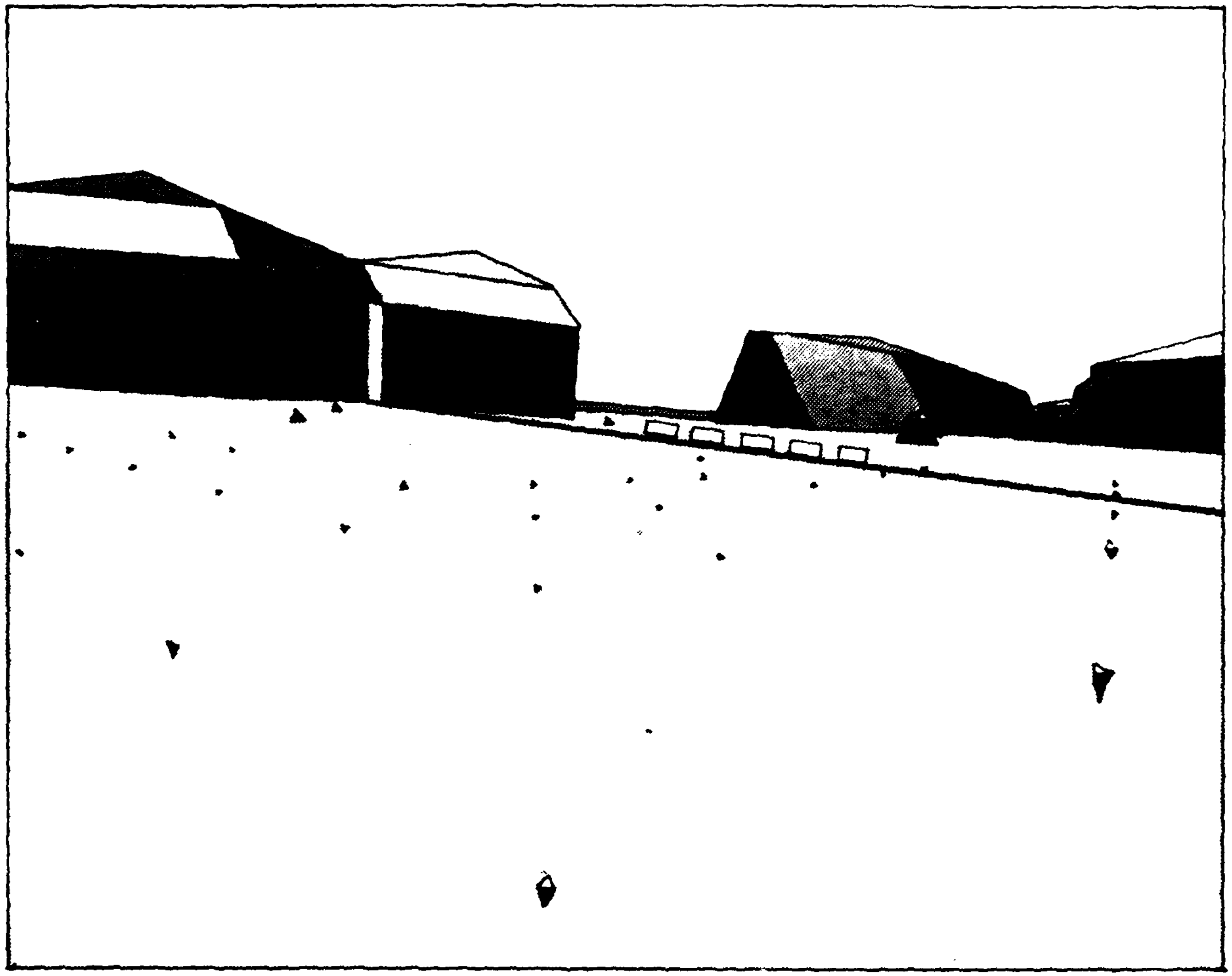


Figure 2. **View of target (target building second from left).**

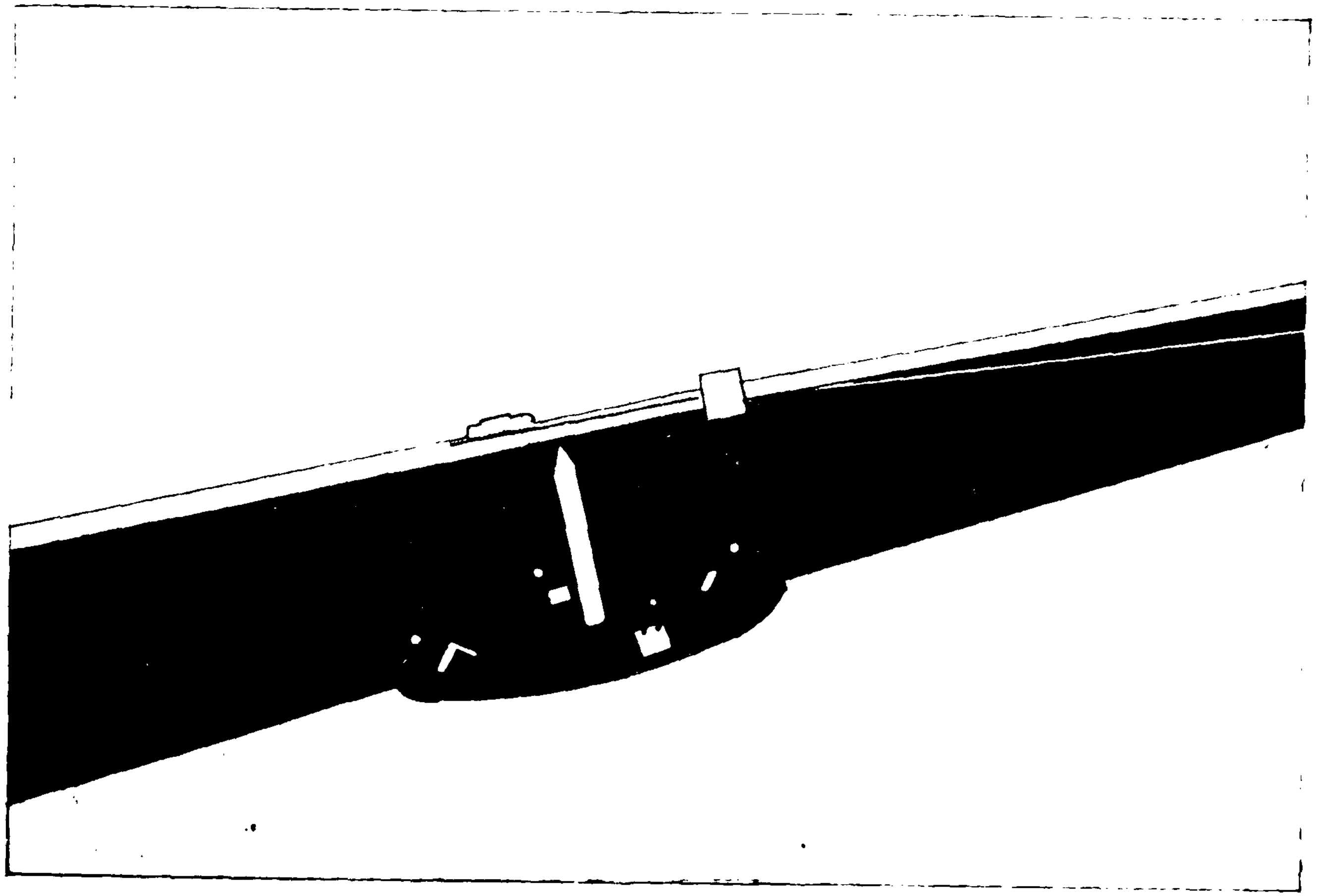


Figure 5 **Threat site (SAM and AAA)**

sites could be destroyed. If a threat was destroyed, both the AAA and SAM at that site were deactivated for the remainder of that trial only. When destroyed, the SAM missile disappeared from the launch pad. The strobe flashes from the AAA continued but no kills could be achieved.

Missile Warning. An auditory tone delivered through the headsets was provided as a cue when the SAM was tracking the aircraft. The frequency of beeps increased as the missile proceeded through the acquisition to launch phases. (There was no cockpit instrumentation for radar hazard warning.) Acquisition cues were provided for 7 seconds, track for 3 seconds, and throughout missile flight. There was no warning to the pilot who was being tracked by the AAAs.

Chaff. Chaff was simulated and had to be dispensed manually by the pilot (i.e., no programmed release patterns); 3 to 8 seconds of protection was afforded by each bundle (actual value is randomly selected). The chaff protection simulation logic denied the SAM missile updated aircraft position necessary for guidance for the time interval of protection. During this period of time, the SAM continues to project based on last know aircraft position.

Bomb Simulation. A bomb fragmentation envelope was simulated based on published Mark 82 data. When a weapon was released, a timer was started based on the time to impact. After 1, 3, 5, 7, and 9 seconds past bomb impact, aircraft position was compared to impact point. If the radial distance was less than that of the tabled data, a "frag" damage flag was set true to the advanced operator console. This did no affect the aircraft performance. The information was provided for pilot information only.

If, during the exercise, the aircraft was destroyed by either SAM or AAA, it was programmed to begin a slow spiral to the earth with all control inputs nonfunctional. Upon terrain crash, the visual display turned uniformly grey, and the aircraft was respositioned at the starting point for the next trial.

Protocol

The pilots received the equivalent of four missions of transition and weapons delivery instruction in the ASPT/F-16 prior to participation in this study. Two of the subjects in this study were F-16 qualified instructor pilots.

On completion of the ASPT traning syllabus, the pilots were given a written and verbal briefing detailing the scenario and purpose of the study. Written materials included an intelligence briefing, a small computer-drawn map of the environment, a Mark 82 frag envelope data graph, a large hand-drawn map of the environment. The verbal briefing explained the purpose of the study, summarized the contents of an intelligence brief, and outlined the protocol that the pilots would be expected to follow. It was emphasized that the data for each subject would be kept confidential and would be coded by an ID number only. It was also empahsized that there would be no attempt to evaluate the individual pilot on tactics or flying ability.

The pilots were asked to develop an attack plan based on the information available to them. They were told that they would subsequently be asked to execute their plan four times in the ASPT. The pilots were instructed to draw their planned ground track on the large map and to complete two questionnaires regarding various aspects of their plan. They were also asked to develop their plan individually and not to discuss it with other pilots. The pilots were provided with working space and the necessary materials (ruler, compass, protractor, etc.) for individual mission planning. When it was necessary to place more than one pilot in an office, every attempt was made to prevent collaborative planning by providing close supervision.

Following the completion of the planning effort, each pilot was asked to fly four repetitions of his plan in the ASPT. Pilots were not permitted to observe the performance of others. Following each pass, the pilot was given verbal feedback as to the outcome of the trial (bomb miss distance, threat activity, source of termination, frag damage, etc.).

Following the completion of the fourth pass, the pilot was given two postmission questionnaires, another set of maps, and computer printouts of each pass. (Format of the printouts is described in the performance measurement section.) The pilots were asked to formulate a second plan in the same manner as the first plan and told that they would be asked to execute four repetitions of the second plan. The same protocol (i.e., the planning exercise and experimental trials) was followed on the second plan as had been followed on the first plan.

Whenever possible, a group debriefing was held to provide an opportunity for discussion of problems and potential areas of improvement to the scenario and simulation capabilities. When it was not possible to meet as a group, an individual debriefing was conducted. The debriefings were not formal or structured in any systematic fashion, however, the comments were noted and are discussed briefly in the results section of this report.

Subjects

Sixteen Air Force pilots participated in this study. Two of these were F-16 instructor pilots. The remaining pilots were all previously experienced fighter pilots transitioning into the F-16. Their time in fighter aircraft is as follows: $\bar{x} = 1465$ hours (SD = 750), minimum = 500, maximum = 2850. Their time in other operational aircraft (not including UPT or non-military) is as follows: $\bar{x} = 907$ hours (SD = 773), minimum =0, maximum = 1725. Their ages ranged from 30 to 42 years with an average age of 36 (SD =3).

Performance Measurement

Pilot performance in the high threat scenario was monitored and recorded in three ways: (a) automated objective measures, (b) videotape recording of a graphic display depicting the environment and the movement of the aircraft in the environment with associated audio track, and (c) hand-drawn tracings made in real time of the aircraft in the environment with annotations of total time, significant mission events, and computer malfunctions.

The videotapes and hand-drawn tracings were used as complementary information to that obtained from the automated performance measures and were used to assess the correspondence between the pilot's planned mission and the actual performance.

The development of the automated measurement capability used in this study took place over a period of 3 months prior to data collection and represents a significant enhancement to the research and training tools available in the initial A-10 feasibility study. The data were collected using the ASPT data record capability with start/stop and computation logics controlled through preprogrammed algorithms; the sampling rate was 30 Hz. Performance measures were available shortly after the termination of the trial on a line-printer hard copy only (no data storge or retrieval system). The printout is arranged according to pilot and trial identification information, aircraft position captures, target data, threat data, and termination data.

The following data were available from the automated measurement routine: (a) subject identification number, (b) pass number, (c) weapon type, (d) weapon mode, (e) aircraft parameter capture values at the points of ingress, weapons release, and egress (altitude, airspeed, bank angle, heading, distance, and azimuth to target and probable target), (f) time elapsed between ingress, weapons release, and termination, (g) average heading and altitude between those events, (h) maximum and minimum altitude between those events, (i) total time, (j) bomb miss distances in feet, (k) overall maximum, minimum, and average altitude, (l) maximum g-force, (m) source of termination, (n) number of rounds fired by each threat, (o) percentage of time aircraft was within SAM and AAA tracking envelopes, (p) whether a threat site was destroyed, (q) number of chaff release, (r) time protected by chaff, (s) SAM and AAA site active at termination, (t) SAM kill occurred, time of missile flight and miss distance of missile, (u) tabular and numeric representation of bomb distance relative to target and clock position, (v) if aircraft entered its own frag envelope, the envelope time and distance, and (w) maximum angle of attack.

IV. RESULTS

The results of the study are discussed under the headings of mission planning, mission outcomes, and pilot opinion. It should be emphasized that the pilots who participated in this study were not yet F-16 qualified (with the exception of the two instructor pilots), had not yet received ground training in F-16 tactical surface attack operations and tactics, and did not receive any instruction during the conduct of the study. In addition, limitations in the simulation capability and rules of engagement precluded exploiting the F-16 to its maximum potential. Therefore, the data presented in this section should not be considered representative of operational mission-ready capability.

Mission Planning

The problem offered to the pilots was to plan a flight path that minimized exposure to threats and maximized the opportunity to bomb the target. For their planning activities, the pilots were given an intelligence briefing, a simplified map of the target gaming area, rulers, protractors, and as much time as they needed. The time required to plan the initial mission was approximately 1 to 1.5 hours. The planning activity for the second phase required slightly less time (.75 to 1.0 hour).

The analysis of the mission plans shows at least three items of interest:

1. The degree of agreement between the pilots' plans.

2. The changes in the content of the plans as a function of familiarity and experience in the environment.

3. The extent to which the planned missions corresponded to those actually flown.

The data sources available to address these three items included the flight plans as depicted by the pilots on their maps, the flight path tracings made during the experimental trials, the automated performance measures, and the pilot's responses to the premission and postmission planning questionnaries. The primary data, though, were the ground tracks as depicted in the pilot-drawn plans and experimenter-drawn tracings. Each of these was coded by reference to geographical position relative to the major terrain features (i.e., mountains, roads, hills, etc.). In order to compare they *planned route* with the routes actually flown, the sequences (planned vs. flown) of terrain features were compared. A deviation from the plan was scored for each discrepancy between the sequence of terrain features as coded for the plan versus the sequence coded for the pass as flown. If a pass was terminated due to a threat kill or terrain crash, only the sequence flown to that point was considered. Therefore, if a pilot was shot down by a missile but had flown the ground track to that point as planned, no deviations were scored.

Several shortcomings of this analysis are apparent. The analysis was confined to ground track and did not include airspeed or altitide data. Thus, for example, it was possible for a pilot to make large deviations in altitude from that indicated in the plan without their being scored as deviations. In addition, this analysis does not take into account the tactical signficance of the observed deviations. It is quite possible that some deviations had major tactical implications (e.g., earlier exposure to a threat) while others did not. Based on this analysis procedure, the following questions were addressed.

1. What degree of similiarity occurred in the plans? The answer to this question is simple. No two pilots planned the same attack route. This diversity is surprising in lights of the relative simplicity of the environment and scenario.

2. How did the plans change as a function of familiarity and experience in the environment? Four pilots repeated the same plan (i.e., no change) from the first four trials to the second four. Six pilots simply reversed the sequence of their route. The remaining six pilots made changes that could be characterized as "new." One of these pilots constructed four individual plans (one for each pass). It is, thus, difficult to summarize the influence of familiarity and experience. Many factors (other than success or failure) could act as an impetus for making (or not making) significant alterations in the plans. Considering responses made on the questionnaires and during debriefings, it is clear that no simple performance rules (e.g., win, stay-lose, shift) will account for choices and decisions made on the plans. For example,

of the four pilots who chose to repeat their initial plan, (a) *two indicated that they did so because they had not achieved* the success they felt they should have (one in fact had been shot down on three of the four passes), (b) one had been successful in the first plan and saw no reason to change, and (c) one thought it was the most tactically reasonable alternative. Several pilots indicated their plan B was an option that they had originally considered but disregarded, and they wanted to try it. Several pilots felt their original plan was inadequate because some aspects of the environment were significantly different from what they expected (e.g., spatial-distance relationship, difficulties in low-level flight).

3. Were the missions flown as planned? *If the ground tracks as flown contained any deviations from the ground* tracks depicted on the planning maps, the mission was considered to be different from the plan. The results of this analysis indicated that *no pilot flew all four passes of Plan A as planned.* Of the total 68 Plan A passes, only three (two by the same pilot) were flown as planned. During the second set of missions, there was a greater tendency for the pilots to fly their missions as planned. Three pilots flew each of the four passes without deviation. Of the entire set of Plan B passes, 20 were flown as planned. Thus, it appears that, while it is unlikely a mission will be flown as the pilot planned it, there is a greater correspondence between the plan and the actual flight as a function of experience and familiarity with the environment.

Tactical Consideration

No formal attempt was made to assess the effects of different tactics in this scenario; however several descriptive statements can be made about the way the pilots chose to accomplish the mission. In general, the passes were characterized by high speed (450 to 540 knots), terrain masked, low to medium altitude (less than 500 feet AGL) ingress and egress with a single pass on the target.

Ingress. All subjects except one took advantage of terrain masking. (One pilot planned two of his Plan B passes using a head-on ingress route, which could be accomplished without detection by maintaining an altitude profile below the 2.5 degree look-angle of the missile.) There was some measure of agreement for those who chose an easterly ingress. These were generally planned and flown at a low to medium altitude (100-500 feet AGL), which was lower than required by the masking terrain's elevation. Westerly ingresses were generally flown over the top of the far western flat plateu (elevation 700 feet) but below the ridge lines of the inner three mountains of the valley. Although peak elevations ranged from 1450 to 2100 feet, the ridge lines were of graduated elevations; therefore, this route also required a medium AGL flight path in order to avoid detection.

Attack. An easterly ingress was generally associated with a pop-up attack pattern. Planned pop-ups were often replaced on later repetitions by low angle "non-standard deliveries." A westerly ingress over the saddle-back resulted in a 30 to 40 degree dive bomb delivery. If a pilot chose to attack more than one of the targets (e.g., the target building followed by a threat site), low-level deliveries or shallow pop-ups were used. Several pilots executed multiple releases (accomplished manually) on the target. Subsequent attacks on the same target were not planned, but several were attempted.

Egress. Most pilots planned a low-level high-speed recovery accompanied by horizontal jinking toward the nearest positions with terrain masking potential. Afterbunner was frequently used during egress. Evasive manuevering from SAMs in flight occasionally forced the pilot into a position unmasked by terrain. In the latter cases, the trial would result in a safe egress if the pilot arrived at the preprogrammed automatic termination position even if a SAM with a lethal flight path was in flight. This situation occurred on several trials and safe egresses were recorded when in fact given a little more flight time, a SAM kill would have occurred.

Mission Effectiveness

In the ideal case, a totally successful mission would be in the natural product of a carefully constructed and well executed mission plan. However, as noted in the mission planning analysis section, there was considerable variety in the plans and little correspondence between the plans and the observed performance, thus making it impossible to analyze effectiveness from the perspective. For the purpose of this study, mission effectiveness is defined in terms of outcome events, considered independently from a pilot's plan or correspondence of flight to mission plan. There are at least three outcome categories to be considered under the rubric of effectiveness: (a) mission success, (b) partial mission success, and (c) mission failure. Target kill and aircrew/aircraft survival define the successful mission. Failure to accomplish either one of these objectives defines failure. Accomplishment of either target kill or survival define the partial success category.

It is of interest from both a research and operational viewpoint to examine the inital performance levels, the amount of improvement that occurs with limited practice, and the overall differences in effectiveness between sets of plans. The outcome event data, arranged according to first and last pass and overall plan effectiveness levels, are presented in Table 1.

Table 1. **Mission Outcome Events**

	Mission, Percent			
Event/ Trial	**Target Destroyed**	**Safe Egress**	**Target Destroyed and Safe Egress On Same Pass**	**No Target Kill and AC Lost**
A1	31	56	25	38
A4	56	88	56	13
A1-4	47	80	38	16
B1	44	69	31	19
B4	56	88	44	0
B1-4	55	83	41	5

It is evident from examination of these data that (a) performance improved in all categories, (b) a greater amount of improvement took place during the first four passes, (c) the probability of survival is far higher than that of destorying the target, and (d) terminal performance levels were similar for both plans even though initial performance levels were better on Plan B.

Offensive Effectiveness

There were five successful target attacks on the first pass and an equal number of dry passes. Based on experimenter observation and pilot report, four of the dry passes were due to failure to detect the target. One pilot unsuccessfully attacked a threat site and was forced out of the environment by missile-evading manuevering. The remaining six pilots delivered ordnance beyond the 30-meter kill criterion distance. The average miss-distance for these passes was 129 meters (SD = 116 meters). Pilots attributed the misses to late target detection and/or defensive maneuvering. The number of dry passes dropped to four on A-2, two on A-3, and one on A-4. By the fourth pass, there were nine target kills, an improvement of 25% from the first pass. The average miss-distance for the no-kill releases was reduced to 99 meters (SD = 88 meters), an improvement of 17 meters with less variability.

By comparison, the first pass of Plan B was characterized by only two dry passes. The average miss-distance for the six non-kill releases was 74 meters (SD = 43 meters). By the fourth pass, there were no dry passes, an increase of 12% in the number of kills, and reduction in the average non-kill miss distance to 65 meters (SD = 36 meters). Thus, as the amount of experience in the scenario increased, the offensive effectiveness increased as indexed, *not only* by the probability of a kill, but by a reduction in the number of dry passes, the distance, and variability of the misses.

Table 2 presents the average bomb distances with associated standard deviations for all weapons releases on each pass. It is evident that Plan B releases were more accurate and less variable than those of Plan A.

Table 2. **Average Bomb Scores (Meters)**

Parameter	A-1	A-2	A-3	A-4
$\overline{X}$	74	35	82	50
SD	99	22	136	76
N	10	11	14	15
	B-1	**B-2**	**B-3**	**B-4**
$\overline{X}$	43	26	28	38
SD	41	26	16	34
N	13	13	15	16

Survivability

Mission survival depended on the pilot's ability to avoid anti-aircraft artillery fire, surface-to-air missiles, and the ground. Probable "frag" damage and airframe damage due to excess g-forces were also recorded. However, the latter two events were not programmed to have any consequences for the pilot or aircraft and are not discussed in detail. There were no frag envelope violations, and almost all passes exceeded 9g with ordnance loaded.

As can be seen from Table 1, the survival rates were relatively high. Of the total 128 trails, there were only 20 (84% survival) in which the pilot failed to egress safely. Of these 20 trials, 12 (60%) losses occured during the first pass of each plan. On the first pass of Plan A, there were five SAM kills and two terrain crashes. On the first pass of Plan B, there were two SAM kills and three terrain crashes. Scattered among the remaining six trials were three more terrain crashes and nine SAM kills. Altogether, there were no AAA kills, 16 SAM kills, and eight terrain crashes.

AAA. The fact that there were no AAA kills may be an artifact of the computer modeling of the guns rather than the result of piloting skill. The program required 4 seconds of continuous firing before an AAA kill would be allowed. Aircraft jinking above +4g broke the firing. A momentary excursion beyond the 4g point would break firing. However, a momentary excursion beyond 4g could be made (and frequently was) without significantly altering the aircraft flight path (which would be required to defeat an actual threat). A more acceptable alternative would be to use a model of gun's performance capabilities with bullet ballistics modeled directly. However, the data for deriving a completely satisfactory model were not available for use in this study.

SAM. Unlike the simulation of the AAA, the SAM performance was modeled directly in order to retain the system as a "generic" performance model. The missile was modeled to approximate the performance capabilities of a modern, mobile SAM, except that it remained a radar-controlled missile rather than being converted to other sensors. The only tools the pilot had to defeat the missile were terrain masking, low-level flight, and judicious use of chaff. A main limitation of the threat modeling in this scenario was that only one missile could be in flight at any given time. (This restriction was due to a limitation in the number of moving models available on the ASPT). It was possible, however, for another missile site to be progressing through the acquisition to launch sequence while a missile was in flight. The next missile could be fired as soon as the previous one aborted.

An average of 1.4 SAMs were launched per pass (range 0 to 5 SAMs). There was a total of 16 SAM kills with an average 92% SAM miss rate (or pilot evasion rate). Of the SAM launches which resulted in a kill, the average time of flight was 9.9 seconds. The only measured pilot behavior taken to defeat the SAMs was the use of chaff. (The measurement system was not equipped to correlate evasive maneuvers with SAM flight.) There was a tendency for the use of chaff to increase as a function of trials (1.25 bundles per pass in Plan A compared with 3.6 bundles per pass of Plan B). Experimenter observation and pilot reports suggested that task loading or lack thereof (situational awareness) was a mediating factor influencing the pilot's use of chaff, such that initial passes were associated with heavier workloads and a decreased likelihood of chaff dispense.

Terrain Avoidance

There were eight terrain crashes, comprising 6% of the total number of trials and 33% of the nonsurvived trials. It is believed that the lack of adequate depth cues in the computer image generated visual display was a primary contributing factor to the incidence of terrain crashes. However, an analysis of when and where the crashes took place suggests that workload and motivational factors, as well as perceptual factors, were involved.

Of the eight crashes, four (50%) occurred in the vicinity of the target, an area containing artificial vertical visual cues at 1000-foot intervals. These cues, inverted tetrahedrons with black sides and white tops, have been shown to be effective height cues for low-level flight in noncombat-like flight tasks (Martin & Rinalducci, 1983). Only one crash occurred on ingress (in an area without the additional cues). Seven of the eight crashes occurred following weapons release. Four of these crashes occurred in the immediate target vicinity (area with additional cues) during hard evasive manuevering. Two occurred after pilots had successfully maneuvered to a terrain-masked, threat-free position; they simply flew into the ground. The remaining crash occurred as the pilot was attempting to break missile lock by flying below 50 feet (in an area with no additional cues). Thus, it would appear that the terrain crashes were the result of an interaction between the inadequate depth cueing and the nature of the task requirements.

Pilot Opinion

Pilot responses to questionnaires and points of discussion during debriefings serve a valuable function in identifying strengths and weaknesses in the basic simulation and the scenario. They also helped in elucidating behavioral sequences that were not captured by the automated performance measurement profiles. The major topics covered included scenario construction, visual display characteristics and scene content, performance feedback and measurement, and training applications.

1. *Scenario Construction.* The most frequent criticism of the scenario was the limitation of a single-ship attack. It was felt that for realism and effective training applications, at least a two-ship attack was required. Another area of concern was the relatively small gaming area. This problem was compounded by the use of mission planning maps that were of a larger scale than normally used, leading some pilots to expect a larger working environment. A larger gaming area would also permit the use of navigation procedures and instrumentation.

2. *Visual Display and Scene Content.* The most frequently mentioned limitation of the visual display was the lack of low altitude depth perception. In fact, the most frequent response to a question concerning the biggest challenge of the scenario was the absence of low altitude cues. Difficulty in target acquisition and the small gaming area were mentioned more frequently than were AAA and SAM threats. Most pilots felt that additional vertical cues would be more beneficially placed in areas of ingress and egress rather than in the immediate target vicinity. The rationale for this preference was that they felt they had to fly an ingress and egress that were higher than planned due to the absence of cues, and the attack phase was generally at a higher altitude where cues were not needed as much. However, some pilots reported never seeing the vertical cues. Without the cues, pilots reported that they could fly in the 100 to 500 foot AGL zone but that with the cues they could fly in the 50 to 200 foot AGL zone.

The visual modeling of the gun installations was less than satisfactory because the strobe flash feature (used to simulate gun firing) continued to flash even when the gun was not firing. Thus, some pilots were jinking to evade a gun that was not active. In addition, the visibility range of the strobe was slightly greater than the 300 foot range modeled for the gun.

Developmental efforts with this scenario had identified the difficulty in sighting the missiles in flight as an item of concern to many of the combat experienced pilots. For this study, the length of the missile was increased to 100 feet. This intentional oversizing was necessary to overcome the resolution and luminance levels of the ASPT visual system. Pilot opinion regarding the visibility of the missile was solicited. There was considerable disagreement as to the requirement to have such a missile visible in flight. Most pilots felt that some visual indication of launch, such as the spot of light used to indicate bomb impact point, would be helpful. They also felt that a visual representation of the missile signature would be at least as valuable as the visual acquisition of the missile itself. The fact that the missile was modeled considerably larger than reality was not seen as a limitation. In fact, of the pilots who observed the missiles in flight at close range, few were aware that the size of the missile was so exaggerated.

The abstract nature of the terrain and target display, the low resolution (approximately 6 arc minutes and brightness approximately 2 foot-lamberts), and the monochromatic display were not reported as major limitations. There was a general consensus that more detail and realism would be required for adequate operational training application. Difficulties in target acquisition were generally attributed to spatial/distance judgment problems stemming from the planning maps rather than from the characteristics of the visual display. Additional moving models for the display of multiple aircraft, missiles, and ground vehicles were viewed as a necessary enhancement for visual displays.

3. *Performance Feedback and Measurement.* Performance feedback was provided to the pilot during flight for a SAM or AAA kill by a loss of aircraft control and a slow spiral to the ground. A terrain crash was accompanied by a "grey-out" of the visual display. Bomb impact points were indicated by a white spot on the ground. If a threat site was destroyed, the visual models of the missile were removed. Following each trial, the pilot was verbally informed of the bomb distance from the target (when appropriate) and of the source of a fatal missile and was also given a summary of the threat activity during the pass. Following completion of all eight trials, each pilot was given a copy of the automated performance measurement printout and the hand-drawn ground tracks. This type of information was viewed as essential for potential operational types of debriefings. The consensus was that the most desirable format would be a graphic printout indicating flight path, altitude, airspeed, g-levels, the flight path of launched missiles, and the occurrence of significant events such as weapons release, guns fired, chaff dispensed, and terrain masking. The remaining numerical information could be displayed at the bottom of the page. A graphics display available in the cockpit with the same capabilities was also frequently mentioned as highly desirable. The main pilot concern was having all of the information necessary to reconstruct the pass for review and critique.

4. *Training Applications.* The pilots generally agreed that the training potential of this type of simulation exercise was high. The greatest benefits were seen as the opportunity to fly against active defenses with immediate feedback and the opportunity to test various strategies. Given a full mission simulation capability, the value for integrating systems management and procedures within a dynamic tactical environment was viewed as excellent. The potential for tactics training was viewed as high, given high fidelity models of the defensive weapons. The requirement for high fidelity modeling of threat performance was considered to be the most important requirement for operational application. It was generally agreed that as the training objectives move towards a specific real-world mission rehearsal, the need for full aircraft systems and better visual display would increase.

V. DISCUSSION

The purpose of a combat-like scenario, such as the one investigated in this study, is to provide the pilot an opportunity to practice tasks and to integrate skills that would be required in an actual mission with emphasis on those aspects which are not readily practiced in actual flight. In this study, the pilot was given the opportunity to integrate (a) target area mission segment planning with mission execution, (b) target area navigation with target acquisition and attack, (c) weapons delivery skills that threat avoidance and evasion, and (d) defensive maneuvering with low-level flight and terrain avoidance.

Mission planning is often mentioned in fighter-oriented publications, such as *Fighter Weapons* and *Fighter Attack*, as one of the most important, if not the most important, factor contributing to the ultimate success or failure of a mission. As in most learning situations, higher skill levels are achieved only with frequent practice. The principles, concepts, and procedures involved in tactical planning are generally taught to pilots in a classroom lecture format supplemented with paper-and-pencil planning problems. The opportunity to plan and execute a mission is relatively limited in frequency and type and is further limited to a subset of the pilot population (e.g., flight leaders). The flight simulation environment could provide the medium to plan and execute a limitless set of plans at a high frequency to all pilots at a fraction of the cost of comparable flight experience. Data from the present study can be interpreted as both supporting the need for such training and as demonstrating the potential of the flight simulation medium to support the training.

The fact that in the study no two pilots (from a group of experienced fighter pilots) prepared the same plan of attack on a common target complex attests to the existing variability between pilots. This variability also indicates that even a simple scenario has some characteristics of a good problem in that there was no one obvious solution and that a number of alternatives proved successful. For an instructional courseware designer, this is encouraging since it illustrates the potential of using one problem for a variety of instructional purposes without redundancy. The advantages, disadvantages, and tradeoffs among alternative strategies can be explored. The use of one data base for multiple purposes is also a significant economy factor in terms of computer software development costs associated with constructing the scenario data base. A small number of environments could be designed and used to instruct most of the general principles and to permit practice of tactical mission planning.

A requirement of an effective data base and scenario is that a tactically valid problem be presented and that tactically appropriate pilot behavior be facilitated. Although the data base and scenario used in this study had several significant shortcomings, they did provide a planning problem in which the plans made by majority of pilots reflected generally accepted tactical considerations: (a) the need for careful and accurate mission planning, (b) heavy reliance on direct terrain masking, (c) minimized exposure to ground defense, (d) routes that minimized the difficulty in target acquisition, (e) defensive maneuvering airspace, and (f) the use of chaff to break missile lock. The structure of the environment made it possible to apply these principles to a variety of routes including both medium-level and low-level attack profiles.

Comparison of planned versus actual ground tracks indicated that it is extremely unlikely that a pilot will follow this aspect of his plan. Deviations varied in magnitude and in mission segment (i.e., ingress, attack, egress). Although these changes may be indicative of inadequate preparation, it seems more likely that a number of factors contributed. One which was clearly operating was the difficulty of translating the spatial-distance relationship as depicted on the planning maps to those aspects of the environment itself. The skill of cognitive mapping has been demonstrated to be an important factor affecting mission effectiveness, particularly for unfamiliar locations. In recognition of the overall importance of mission planning and the difficulty involved for pilot's conceptualize the impact of their planning options in three-dimensional space, the Air Force is currently evaluating a mission planning aid: the Computer Aided Mission Planning System (CAMPS). This system displays the planned ground track, amount of fuel used, altitude, and other information. CAMPS has knowledge of terrain threat location and capabilities and will display when the pilot's plan route is vulnerable and to what degree. The system also analyzes the attack plan for probability of successful attack (see Sipe, 1981 for more details on CAMPS). Although CAMPS is still in a developmental phase, some automated mission planning aid would clearly benefit pilot training.

In fact, the characteristics of the map have been shown to be more important than the difference between day and night for nap-of-the-earth helicopter flight (Bynum & Holman, 1979). The use of operational-type maps (maps used in this study were not of the type or scale used in normal operations) may enhance the realism of the scenario. However, it is doubtful that such maps would solve the underlying problems that the pilot has in effectively translating an abstract two-dimensional representation of the world into three-dimensional reality, whether it be simulated or actual flight. The Office of Naval Research has sponsored research in this area. Thorndyke and Hayes-Roth (1980) have studied how people learn from maps versus actual navigation and have discussed a number of factors that need to be considered. Stasz and Thorndyke (1980) have studied the relationship between visual-spatial ability and study procedures on map learning skill. Stasz (1980) has studied the relationship between visual-spatial abilities and strategies that successful and unsuccessful individuals exhibit. A simulated scenario such as the one used in this study could be used to extend this line of research into the dynamic situation and to study the relationship between tactical planning skills and visual-spatial abilities.

The success of the first mission into an unfamiliar area is critical to combat readiness. Application of flight simulator combat scenarios to a training program will not eliminate the loss in effectiveness due to cognitive mapping problems. A training research program addressing this specific problem needs to be undertaken, the results of which can be incorporated into both flight and simulated flight combat scenarios.

Target acquisition was not a major problem for the pilots in this study. The use of a single white building complex, located along a black road, surrounded by a gray background made the target complex visible and minimized target acquisition problems. Problems experienced by some pilots were due to primarily to misjudgments regarding their position relative to the expected position of the target. These problems were most common to plans that called for a low altitude ingress and pop-up attack. This problem also occurs in flight. Specific training in target acquisition skills could be accomplished by presenting an array of alternative targets that vary in discriminability and location.

Although the ASPT/F-16 does not have a fully operational navigation system, it does have the capability of inputting destination points for steerage information. The pilots wanted to practice using this system; therefore, most pilots programmed the location of the target in the Fire Control Navigation Panel with the intent of using the command steering display to locate the target. However, the small size of the valley containing the target made it an extremely difficult sequence to switch from the navigation display to the air-to-ground display in time to set up for weapons delivery. In a few instances it was clear that attention paid to the navigation display reduced out-of-the-cockpit visual scanning sufficiently to make target acquisition far more difficult than it would have been strictly a visual search. Thus, even though the target location was stored for use, this feature was rarely used after the initial pass, if then. As a guideline for data base construction for an advanced fighter, a larger gaming area should be planned so that the navigation systems can be used effectively.

The rules of engagement for this scenario limited pilots to the use of the Continuously Computed Impact Point (CCIP) bomb release mode. During their ASPT syllabus training prior to participating in this study, all pilots received at least 2 hours of instruction and practice on all standard CCIP delivery applications. All pilots had achieved at least the qualification standards for computed deliveries, and most pilots could consistently deliver a bomb at an acceptable distance using a pop-up delivery pattern. Thus, as far as the weapons delivery in the simulator is concerned, the scenario provided a transfer situation from the conventional range to a novel environment where a kill would be achieved by dropping within 30 meters of the target (considerably larger than their terminal syllabus training performance). The low kill rate on the initial passes may have been due to lack of familiarization with the environment. If this were the case, the effect should dissipate within the first few passes, with later passes resulting in a very high kill rate. However, 56% was the highest target kill rate achieved.

Clearly, other factors are operating to degrade weapons delivery accuracy, even after eight passes. It seems reasonable to assume that the threat posed by the ground defenses was a large factor interfering with weapons delivery. The capabilities of the ground of defense were described in the intelligence brief, and the mission planning activities forced the pilots to deal with the vulnerability of their plan to the various ground defenses. The functional lethality of the threat was obviously affected by the attack profile flown, and any deviations from their plans introduced uncertanity for the pilots to their a priori analysis of vulnerability.

Although improvement in the probability of target destruction across eight trials was observed (23% to 56%), terminal levels in the 50 percent region indicate the need for instruction and further practice. This environment was not particularly lethal (no AAA kills, 92 percent overall missile miss rate, and 88 percent survivability at terminal performance); the levels of total mission effectiveness (target destruction and survival on the same pass) were just slightly lower than target kill levels. The fact that these performance levels did not increase in the second planning set indicates that the low target kill levels are not simply due to a poor choice in the initial attack plan. The decisions regarding alternative attack profiles did not result in appreciably higher effectiveness levels. Presumably instruction and guided practice would elevate performance levels considerably.

Two aspects of this simulation most frequently criticized by the pilots were the lack of low-level visual cues and the inability to visually detect a missile early in flight. Although the performance characteristics of the missile were more like those of the smaller missiles, which would be difficult to detect visually in any case, the fact that they were modeled to be 100 feet long, white in shade, and still were not easily detected clearly points to an area of inadequate visual display quality. Another visual system inadequacy is reflected in the difficulties encountered in low-level flight. Four of the eight terrain crashes occured in an area devoid of any ground reference vertical cues. These crashes were simply level flight into the ground. The other four crashes occurred in the target area supplemented with artificial vertical cues. These crashes occurred during controlled descent (recovery from weapons delivery) and hard maneuvering flight (evasive jinking). Although these cues had been shown to enable level flight at slower airspeeds, they evidently do not provide sufficient depth and surface cues for more extensive maneuvering at high speed.

The data obtained from this study indicated that that the logic for the AAA and chaff features needs to be improved for further scenarios. The logic for the AAA was such that a kill would be recorded if the aircraft was within the envelope for 4 consecutive seconds at less than 4g. If the aircraft exceeded 4g, the clock would be reset. The intent was to force the pilot to execute evasive maneuvers that would result in rapid and significant changes in the aircraft flight path, making it difficult for a human to successfully track the aircraft. However, the logic which reset the clock for any excursion above 4g (at 30 Hz sampling rate) did not actually require significant changes in flight path in order to defeat the threat. Thus, although the pilots spend an average of almost 19% of the pass within the AAA envelopes, no AAA kills were recorded. Future logics need to require sustained maneuvering sufficient to assure tracking difficulties.

The chaff logic denied updated aircraft position data to the missile program for a time period ranging from 3 to 8 seconds (actual value randomly determined) per chaff release. During this time, the missile travelled ballistically based on last aircraft position information. Thus, if the pilot used chaff without making significant changes to the flight path, the chaff would be ineffective. However, judicious use of chaff could render the missile totally ineffective. It is unlikely that chaff would cause such a strong picture for such a long period of time. Future logic needs to take into account the time it takes a bundle to separate from the aircraft and the time course of the dispersal pattern.

Debriefings held with the pilots, using the performance measurement printouts, made it clear that some form of graphic representation of each pass is a minimum requirement for effective feedback, instruction, and analysis. A graphic display with associated numerical information of the type collected in this study should be made available on a monitor located in the cockpit (as well as at an instructor console) so that the pilot could review each pass prior to initiating the next. The graphic display should include the flight path of each missile and some indication of AAA activity. The performance measurement system should be capable of storing, recalling, replaying, and printing a hard copy version of the numeric and graphic displays.

According to pilot opinion, the greatest limitation was the single ship scenario. Most pilots felt that at least a two-ship would be required. Although most pilots indicated that the scenario and supporting simulation and high training potential in its present form, the overwhelming consensus was that more tactical training objectives could be met with a multi-ship capability. This capability would increase the complexity and content validity of the mission for the pilots. A multi-ship scenario would also add significantly to the simulation requirements. It could be accomplished with a multiple cockpit (and pilot) facility or with some form of computer controlled profile for the other members of the flight. In order for a pilot to plan a multi-ship mission and have the other members of the flight displayed and performing their functions, novel types of software support would be required. An alternative would be to have a menu of preprogrammed (i.e., "canned") routines for the flight members from which the pilot could choose. This approach would necessarily restrict the available options in the mission planning phase.

VI. CONCLUSIONS AND RECOMMENDATIONS

The following training and simulation conclusions emerged from this study:

1. The simulation of tactical scenarios provides an opportunity for the pilot to integrate skills in mission planning, target acquisition, weapons delivery, and threat evasion through frequent and safe rehearsal.

2. Performance improvements in all major mission effectiveness categories occur even without explicit instruction.

3. The state of the art in flight simulation is adequate to develop a tactical ground attack simulation training program.

Based on the objective performance data and the consensus of pilot opinion, the following recommendations are proposed for improvements to the training potential of tactical simulation scenarios:

1. A multi-ship attack capability should be provided.

2. The gaming area should be enlarged to provide a greater alternative set of routes and more systems oriented skills.

3. More low altitude cues are needed in areas of likely ingress, egress, and low atitude threat evasion.

4. Enhanced modeling of ordnance and enemy threat characteristics is required.

5. Graphic representation of attacks and threat evasion tactics for debriefing would be helpful.

Future research and development in this area should explore the following: (a) the instructional requirements for simulated tactical training in terms of both hardware and software, (b) the proper sequencing of tasks, (c) the level of instruction/practice necessary for initial skill acquisition and medium term (e.g., 6 months) skill retention, (d) the effects that known stressors such as workload, fatigue, and uncertainty have on mission performance, and (e) the relationship between visual-spatial abilities and mission planning and execution skills. Accumulation of knowledge in these areas would provide the necessary training technology base for implementation of an effective operational training program.

References

Bynum, J.A., & Holman, G.L. *Tactical Night Terrain Flight Navigation.* ARI Research Report 1226. Fort Rucker, AL: Army Research Institute Field Unit, September 1979.

Gray, T.H., & Fuller, R.R. *Effects of simulator training and platform motion on air-to-surface weapons delivery training.* AFHRL-TR-77-29, AD-A043 649. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, July 1977.

Gray, T.H., Chun, E.K., Warner, H.D., & Eubanks, J.L. *Advanced Flight Simulator: Utilization in A-10 conversion and air-to-surface attack training.* AFHRL-TR-80-20, AD-A094 608. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory, January 1981.

Gum, D.R., Albery, W.R., & Basinger, J.D. *Advanced simulation in undergraduate pilot training: An overview.* AFHRL-TR-75-59(I), AD-A030 224. Wright-Patterson AFB, OH: Advanced Systems Division, Air Force Human Resources Laboratory, December 1975.

Hayes-Roth, B. *Human planning processes.* N-1532-ONR, Santa Monica, CA: The Rand Corporation, December 1980.

Hughes, R.G., Brooks, R., Graham, D., Sheen, R., & Dickens, T. Tactical ground attack: On the transfer of training from flight simulator to operational red flag range exercise, 1982, in *Proceedings of the Fourth Interservice/Industry Training Equipment Conference and Exhibition*, Orlando, Florida.

Kellogg, R.S., Prather, D.C., & Castore, C.H. Simulated A-10 combat environment, in *Proceedings of the 1981 Image Generation/Display Conference II.* June 1981, 36-44. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Martin, E.L., & Rinalducci, E.J. *Low-Level flight simulation: Vertical cues.* AFHRL-TR-83-17. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory, September 1983.

Prophet, W.W., & Monsees, I.H. *An Examination of combat skills training needs.* Seville Technical Report 80-4. Pensacola, FL: Seville Research Corporation, August 1980.

Sipe, R. *Air Force mission planning by computer.* Computer Gaming World, November-December 1981, 1(1), 20.

Stasz, C. *Planning during map learning: The global strategies of high and low visual-spatial individuals* N-1594-ONR. Santa Monica, CA: The Rand Corporation, December 1980.

Stasz, C. & Thorndyke, P.W. *The influence of visual-spatial ability and study procedures on map learning skill.* N-1501-ONR. Santa Monica, CA: The Rand Corporation, December 1980.

Thorndyke, P.W. Spatial Cognition and Reasoning. N-1333-ONR. Santa Monica, CA: The Rand Corporation, April 1980.

Thorndyke, P.W., & Hayes-Roth, B. *Difference in spacial knowledge acquired from maps and navigation.* N-1595-ONR. Santa Monica, CA: The Rand Corporation, November 1980.

IR.

N-

pril

95-

END

DATE
FILMED

1-84

DTIC