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Teaching High-Performance Skills Using Above-Real-Time Training

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ABSTRACT

The above real-time training (ARTT[®]) concept is an approach to teaching high-performance skills. ARTT refers to a training paradigm that places the operator in a simulated environment that functions at faster than normal time. It represents a departure from the intuitive, but not often supported, feeling that the best practice is determined by the training environment with the highest fidelity. This approach is hypothesized to provide greater "transfer value" per simulation trial, by incorporating novel training techniques and instructional features into the simulator. This report discusses two related experiments. In the first, 25 naive male subjects performed three tank gunnery tasks on a simulator under varying levels of time acceleration (i.e., 1.0x, 1.6x, 2.0x, sequential, and mixed). They were then transferred to a standard (1.0x) condition for testing. Every accelerated condition or combination of conditions produced better training and transfer than the standard condition. Most effective was the presentation of trials at 1.0x, 1.6x and 2.0x in a random order during training. Overall, the best ARTT group scored about 50 percent higher and trained in 25 percent less time compared to the real-time control group. In the second experiment, 24 mission-capable F-16 pilots performed three tasks on a part-task F-16A flight simulator under varying levels of time compression (i.e., 1.0x, 1.5x, 2.0x, and random). All subjects were then tested in a real-time environment. The emergency procedure (EP) task results showed increased accuracy for the ARTT groups. In testing (transfer), the ARTT groups not only performed the EP more accurately, but dealt with a simultaneous enemy significantly better than a real-time control group. Although the findings on an air combat maneuvering task and stern conversion task were mixed, most measures indicated that the ARTT groups performed better and faster than a real-time control group. Other implications for ARTT are discussed along with future research directions.

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ACKNOWLEDGEMENTS

This research effort was made possible by a grant from the NASA Dryden Flight Research Facility (DFRF). Special thanks to Vern Carter of Northrop for his kind assistance in tracing the history of "fast time" simulation back to Jack Kolf at NASA DFRF. Mr. Kolf was the contract monitor for this effort, and he was the first to originate the concept of "fast time" simulation in 1973 while working on the NASA X-15 project. His encouragement and support of our research effort began long before the actual contract. His prior experience and suggestions were invaluable.

This research was a collaborative effort between the University of Central Florida, Institute for Simulation and Training (IST) and ECC International, Inc. Frank Luongo and Jim Rawlins from ECC and Raouf Benhaji and Yosef Ma from IST provided expert software design and development in spite of some cumbersome third party software that they were required to use. Jada Kearns and Carol Hilton from IST helped with scheduling and running subjects, data analysis, and report organization. We would also like to thank Rogers Smith from NASA DFRF who took time out of his test pilot schedule to assist with task selection and validation. Bud Conyers of ECC also lent his prior Navy attack pilot experience in helping us select tasks. Bud was also the first to coin the term "above real-time training", replacing a much wordier term that had been used since 1989.

We would like to extend our gratitude to the National Security Industrial Association for recognizing the ARTT research as "Best Paper" at the 1992 Interservice/Industry Training Systems and Education Conference.

Finally, the authors would like to express their deep appreciation to the pilots of the 56th Tactical Training Squadron, MacDill Air Force Base, Tampa, Florida.

INTRODUCTION

Training is big business. The armed forces alone spend in excess of $20 billion annually. Most of the emphasis is on training high performance critical skills which allow the individual to perform complex real world tasks requiring smooth integration of numerous subtasks and subskills. Computer-based simulators and trainers are progressively serving as the mechanism for imparting these skills. Simulators are also expensive, with high fidelity flight simulators costing about $30 million each. The problem centers around ways to reduce training time and thus costs, or to obtain greater "transfer value" per simulation trial, by incorporating novel training techniques and instructional features into the simulator. These techniques should allow individuals to acquire these critical skills faster and with greater retention.

Much of the literature dealing with skill learning/skill acquisition relates to learning relatively simple and self-contained skills (e.g., target tracking). Other than continued and extended practice, we know very little about how to foster or accelerate the acquisition of high performance skills. Schneider (1985) defines a high performance skill as one for which (1) more than 100 hours of training are required to develop proficiency; (2) a substantial number of individuals fail to develop proficiency; and (3) there is a qualitative yet distinct difference in novice and expert performances.

The Above-Real-Time Training (ARTT) concept is a novel approach to training high performance skills. ARTT refers to a training paradigm that places the operator in a simulated environment that functions at faster than normal time. In the case of air combat maneuvering, a successful tactical air intercept which might normally take five minutes, would be compressed into two or three minutes. All operations of the intercept would correspondingly be accelerated such as airspeed, turn and bank velocities, weapons flyout, and performance of the adversary. In the presence of these time constraints, the pilot would be required to perform the same mission tasks to the same performance criteria - as he would in a real time environment. Such a training paradigm represents a departure from the intuitive, but not often supported, feeling that the best practice is determined by the training environment with the highest fidelity. ARTT can be implemented economically on existing simulators. It is important to realize that ARTT applications require the simulated velocity of the targets and other entities to increase, *not* the update rate. Over 25 years ago, flight test engineers recognized that if one could program a simulator to operate in "fast time", one could give test pilots a more accurate experience or "feel" of real-word stresses that would be present in the aircraft (Kolf, 1973).

Researchers in the advertising industry have long since recognized the economic benefit of accelerating television commercials, for example. Riter, Balducci, and McCollum (1982) demonstrated that when subjects were allowed to control the speed of an original 30 second television commercial, they preferred a rate that was 25 percent higher than real-time. Moreover, the subjects' recall (both aided and unaided) was 36 percent higher compared to a control group. Similarly, MacLachlan and Siegal (1980) showed that subjects preferred and remembered television commercials that were accelerated from 25 - 30 percent. The MacLachlan and Siegal paper also presented three explanations for their findings. First, the

novelty hypothesis posits that commercials that are different or unique in some way lead to greater recall. The second, the **viewer effort hypothesis**, posits that viewers have to expend greater effort and attention to understand the message of an accelerated commercial. This, the authors stated, leads to greater retention and recognition performance. Finally, the **viewer preference hypothesis**, simply states that viewers pay closer attention and retain a commercial's message better and longer if they "prefer" the commercial. The evidence is clear that viewers preferred the accelerated commercials.

Sports trainers and their athletes have long since recognized the performance benefits of training in an environment that is slightly faster or more difficult than the competition environment. The professional water skier, when practicing for the slalom event, will have the boat driver exceed the required course speed, thereby decreasing the skiers time to run the course and making the practice runs more difficult. During competition, the course is then run at a perceived slower (and easier) speed. Analogously, a field goal kicker with a National Football League (NFL) team practices kicking field goals through goal posts that are 50 percent narrower than those used in regulation play. This NFL kicker currently has the highest accuracy rate in NFL history. Similar positive results were witnessed for basketball players who practiced shooting through a hoop that is smaller in diameter than a regulation hoop (Ecklund, 1975).

Consider two existing examples of ARTT, and a relatively new application to videogames. In World War II, observers would be trained to recognize enemy planes based on their shape. These shapes or silhouettes would be presented to the observers on cards or slides at faster and faster rates during training. Elementary school students would be quizzed with math flash cards much in the same way. And recently, the Nintendo® and Sega® videogames that kids seem to be playing incessantly have an ARTT-like option. For these kids, playing the games at faster speeds and at higher difficulty levels makes the perceived lower, slower levels easier to play.

One of the few published studies in the mainstream skill acquisition/performance literature that investigated the ARTT concept was conducted by Vidulich, Yeh, and Schneider (1983). The researchers in that study examined the utility of time compression as a training aid for training a basic air traffic control skill (a high performance skill). The task required the subjects to direct an aircraft through a single turn in order to have the aircraft pass through a specific point at a specific heading. The researchers trained two groups, each for three hours. One group practiced the intercept with the target plane travelling at 260 knots. The subjects in this group received between seven and nine trials per hour during training. The second group practiced the intercept at 5200 knots - 20 times real time! The subjects in this group received between 72-80 trials per hour during training. Both groups were then tested in real time. The time compressed group was significantly better at identifying the turn point; there was no difference between groups on estimating rollout heading for the intercept. The authors stated that these results clearly supported the utility of time compressed training. They were also convinced that many other components of air intercept control skill could benefit from such training.

In another study, Matin and Boff (1988) presented results on a series of experiments that used a visual display technology characterized by the serial (versus simultaneous) transmission of independent frames of information via a single display window. The authors call this technique RAPid COMmunication display (RAP-COM). In one experiment, subjects were presented with a digit reading and recall task. The information was presented in either a conventional display with three spatially separated windows or in a serial display in which data frames were presented sequentially in one window. Their results showed that human subjects are time adaptive and can accept, process, and retain information that is presented rapidly.

The concept of difficult-easy performance contrasts has been studied before. Holding (1962), for example, showed that transfer on a pursuit tracking task was clearly better in the difficult-easy direction. Bliss, Lampton, and Boldovici (1992) used an arcade-type tank gunnery training device called TOPGUN to train naive subjects. Three practice strategies were used: (1) easy-to-intermediate-to-difficult progression; (2) all difficult; and (3) random mix of easy, intermediate, and difficult. Their results showed that the easy-to-intermediate-to-difficult group achieved a greater hit percentage than the other two groups when later tested with either easy or difficult target. They defined difficulty in the context of the simulator as a function of target speed and range. Earlier, Lincoln and Smith (1950) studied the transfer of training of visual tracking performance. They trained subjects at target speeds of 23, 30, and 37 revolutions per minute (RPM). They then tested the subjects at speeds that differed from those on which they were initially trained. Their findings indicated that those subjects trained at a medium target speed scored higher than those training at either low or high speeds. These authors, over 40 years ago, recognized an important aspect of skill acquisition that has been largely ignored since. Namely, that "... training at certain target speeds leads to superior performance when particular target speeds are introduced at a later time." (Lincoln & Smith, 1950, p. 361).

The bulk of support for ARTT, and the impetus for this research study, comes from anecdotal reports from NASA and Northrop. Researchers at the NASA Dryden Flight Research Facility (DFRF) during the X-15 program in the late 1960's needed a mechanism to address the X-15 test pilots' post flight comments of being "always behind the airplane..." and "... could never catch up" (Thompson, 1965). Clearly, there were some differences between the perceived time in the well-practiced simulator flights and perceived time in the experimental aircraft. What was needed, the researchers thought, was a way to provide a fast time simulation. Unfortunately, the analog computers at the time were only simulating some instruments. The first time NASA used fast time simulation was toward the end of the M2-F3 lifting body program. Pilots compared practice runs at various time constants with flights they had already flown. A fast time constant of 1.5x felt closest to their flight experience and was planned on being implemented, but the program was canceled before the capability was fully developed. Regardless, NASA's test pilots at DFRF have endorsed the use of "fast time" simulation as part of the training process.

Other anecdotal evidence for ARTT can be found in the defense simulation industry. In 1967, the Advanced Manned Strategic Aircraft (AMSA) Ride Qualities Simulation Study was testing the impact of a less gust-sensitive B-1 prototype wing on pilot and system operator performance. Crews of B-52 pilots and one crew of B-58 pilots served as test pilots in the simulator and performed a subsonic egress to the target followed by a supersonic "dash" to the target. During the supersonic part of the mission, the B-52 crews were missing their checkpoints as well as the targets because of the speed they were flying, which was much faster than they were used to in the B-52. The last crew to fly was a B-58 (a supersonic bomber) crew. The instructor/operators noted that this crew was whistling and joking all though the supersonic part of the mission. The marked difference in performance was attributed to the fact that the B-58 crew was accustomed to finding waypoints and targets at an airspeed much closer to the airspeed of the B-1 prototype that was being simulated (V. Carter, personal communication, 1991).

Finally, Hoey (1976) poses some interesting effects of what he also called fast time simulation on both psychological and physiological indices of stress. Specifically, he asserts that fast time simulation can elicit stress-related responses that are primarily a function of *task responsibilities* and its associated anxiety. These responses are not usually present in simulations. Roman (1965), using heart rate as a physiological stress index, showed that pilots in command of an aircraft had higher heart rates during flight than another test pilot who was just a passenger. When the roles were reversed, however, the former passenger (now the pilot) experienced much higher heart rate levels, while the former pilots (now passengers) experienced significantly lower heart rates.

THEORETICAL UNDERPINNINGS

Humans can judge time extremely well. There is nearly a perfect relationship (i.e., a 1:1 power function based on a log scale) between actual versus perceived time judgements (Stevens, 1975, Fraisse, 1984). Most of the psychophysical research into time perception, however, has been performed in laboratory settings with nearly static and controlled environments. Time perception can be altered if a particularly boring or interesting task is introduced, or if the arousal state of the subject is changed through external environmental cues (Parasuraman, 1986). The more general statement of the relationship between perceived time and actual time is that humans perceive time differently depending upon the individual's "stimulation state." This stimulation state is based, in part, on the sensory cues in the environment and the interactivity level between the individual and his/her environment. Perceived time, therefore, is tied to the particular individual at his/her particular stimulation state to form a "time frame of reference" for that individual. It is interesting to speculate that the large time distortions (i.e., "minutes seem like hours...") reported by those exposed to sensory deprivation environments may be due to the lack of timing input from the environment. The subject's time norm, lacking timing input, begins to "race", much like a computer "races" when its CPU chips loses its timing mechanism. Some of the initial work in sensory isolation in the latter 1940s at McGill University supports this contention. Researchers there (e.g., Bexton, Heron, & Scott, 1954) linked some of the bizarre changes in subjects' behavior to a decreased activity in the reticular activating system (RAS) which is thought to influence the "timing" of the central nervous system. Finally, Cohen (1964) discusses evidence for an interrelationship between one's "inner clock" and sensory/motor functioning where each can influence each other to alter the perception of time. Most high performance tasks involve both sensory/motor and cognitive skills.

The ARTT principle is based in part on *accelerated* time frames of reference. ARTT seeks to exploit human perception of time, and is analogous to Einstein's space-time frame of reference.

To restate, each person has a norm of time frame reference. This norm is relative and is set by the speed of events around that individual. The norm can be moved up or down by changing the speed of sensory cues. Time norm changes are everyday occurrences. For example, when you first reach 100 miles per hour (mph) in a car, it seems fast, but after a few minutes your norm resets to the new time frame of reference and 100 mph now seems normal. When you slow down to 55 mph it seems slow, and you seem to have long subjective times between events. The large subjective time remains until the norm resets.

When this subjective time reference is perceived as long, it may offer a unique advantage for providing training on critical high performance skills. This artificially accelerated frame of reference may give the operator more "time" in which to actually perform key elements of the mission. It is important to note that when using ARTT more compressed training trials can be performed in the same amount of time. The very realization that the operator has more time may lead to better decision making and situational awareness. It may give the operator the edge that makes the difference in today's modern battlefield. More training trials per unit time is reason enough to implement ARTT. As long as no negative training is introduced, more economic training can occur on existing simulators. The simplest case for ARTT is improved simulator usage either by more trials per unit time per trainee, or higher trainee throughput.

There is some well-rooted research in skill acquisition and, specifically, the phenomena of automaticity and contextual interference which provide indirect theoretical support for the benefits of ARTT. The research literature dealing with very high skill training suggests that such skills may be a separate and distinct class of skills. In fact, Lane (1987) reports that much of the mainstream research on learning and training does not generalize well to the unique environments of military training. Shiffrin and Schneider (1977) have provided us with the "automaticity" of behavior in which the execution of a task has evolved over extended practice or performance to a stage of highly integrated semi-voluntary control of task activities. Schneider (1985) states that the acquisition of high performance skills is very similar to the formation of automatic behaviors. Critical high performance skills that are practiced at least in part in an ARTT environment could lead to a faster acquisition of automaticity patterns of performance, less opportunity for memory decay, and a sustained level of motivation during training. Analogously, ARTT can be considered as over-training in the time dimension.

Performing a new task that is inherently difficult will probably lead to poor task performance initially; however, the transfer or retention of that skill may be superior to learning the same skill under real time conditions. This phenomenon is generally referred to as "contextual interference" (Shea & Morgan, 1979) and is well supported in the literature (see Lane, 1987 for an overview). With respect to ARTT, a new task that is practiced and learned in accelerated time (i.e., a difficult task) would require the learner to expend more than normal attention and effort, and hence accelerate the development of automaticity patterns. When the learner then performs the task in the real time environment, less effort and attention would be expended during a perceived "longer" than normal time to perform the task; superior performance would likely result. It could also be advantageous to provide varying levels of acceleration during training. Lee and Magill (1983), among others, have suggested that a broader range of task conditions can enhance both transfer and retention.

Finally, there is strong anecdotal evidence from NASA's DFRF between 1960-1980 in which ARTT was implemented on a few occasions with astounding success. Fast time simulation applications for the X-15, M2-F3 lifting body, and F-15 remotely piloted vehicle (RPV) produced unanimous and highly enthusiastic pilot comments (Hoey, 1976, Kolf, 1973). Jack Kolf and his engineers at NASA's DFRF were the pioneers of "fast time" simulation, having used the technique to give pilots the "feel" of real aircraft performance capabilities. Unfortunately, the research was not formally documented.

PRESENT RESEARCH DESIGN CONSIDERATIONS

This research effort into ARTT attempts to empirically investigate the effect of time acceleration in training on the performance of real-time transfer tasks. Two existing simulator platforms were chosen. The Videodisk Interactive Gunnery Simulator (VIGS), a part-task M1A1 tank gunnery simulator, involves training psychomotor gunnery skills. The Avionics Situational Awareness Trainer (ASAT), a part task F-16 trainer, involves training primarily air combat and engagement skills that have both psychomotor and cognitive planning components. These two specific simulators were used because they were available to the experimenters, and the software that controlled them was accessible and modifiable within the budget and time constraints of this project. Results of the experiment with each simulator platform are discussed below.

RESEARCH OBJECTIVES AND HYPOTHESES

The objectives of this task were to conduct research regarding: (1) the relative effectiveness of ARTT versus conventional training on different simulator platforms; (2) the relative effectiveness of alternative implementations of ARTT; and (3) the impact of ARTT versus conventional training on total time. A fourth objective, the need to examine the effects of variation in task content, became apparent in Experiment 1 (VIGS) and was an important focus of the Experiment 2 (ASAT) design. Generalizations from previous work suggested that tasks with higher psychomotor content or straightforward procedures would show greater benefit from ARTT than those with extensive cognitive requirements and the presence of a variety of alternate strategies for task performance. Prior research in the area of contextual interference suggests that training in a time accelerated environment should lead to poor performance versus a control group, but should lead to greater performance on a real-time transfer task. Second, it is expected that there will be group differences in training as a function of the time acceleration constant that is used. Third, it is obvious that training time will be reduced in direct proportion to the time acceleration constant used. Finally, it is not expected that training under various time manipulations will lead to negative transfer of training to a real-time task.

EXPERIMENT 1 - VIGS STUDY

METHOD

Subjects

Twenty-five male undergraduate students from the University of Central Florida served as subjects for this experiment. The median age of the participants was 23 years. All subjects were recruited on a voluntary basis in accordance with American Psychological Association (APA) Principles for Research with Human Subjects. Prior to testing, subjects were given written instructions informing them as to the general nature of the experiment (see Appendix A). Subjects were also required to read and sign an informed consent form (see Appendix B). Subjects reported themselves to be in good overall health prior to testing. After the experiment, subjects were fully debriefed (see Appendix C for a copy of the debriefing form).

Equipment and Materials

The M1 Videodisk Interactive Gunnery Simulator (VIGS) was used for this experiment. The VIGS is manufactured by ECC International Corporation, and is designed as a table-top part-task gunnery trainer for M1 or M1A1 tank gunners (see Figure 1).

The VIGS utilizes computer generated imagery to present engagement scenes to the user. These scenes, along with target identification slides, are presented, modified, and stored via laser videodisc. For the purpose of this study, four "missions" or tasks were selected (for a more detailed explanation of the tasks performed, see the "Tasks" section below). These lessons had previously been stored on the videodisc by ECC. Through the use of synthesized speech, the subject is presented information regarding the target type, required ammunition, and fire instructions.

Procedure

Subjects were randomly assigned to one of five time acceleration groups (i.e., 1.0, 1.6, 2.0, mixed, or sequential). Prior to participating in this study, each subject read and signed an informed consent form. This form explained the nature of the experiment and the tasks that were to be performed, as well as basic operating instructions of the VIGS. The experimenter then demonstrated the function of the gunner's control handles, and asked the subject if he had any questions. The final part of familiarization involved the subject performing five practice trials at real-time (i.e., 1.0) In the familiarization task, the subject was provided with daytime color images depicting a desert-type terrain with two tanks moving essentially from right to left. The terrain had gentle hills, but was otherwise without any features. The range of the two tanks was approximately 2000m. The purpose of this familiarization phase was to allow the subject to become acquainted with the operation of the VIGS.

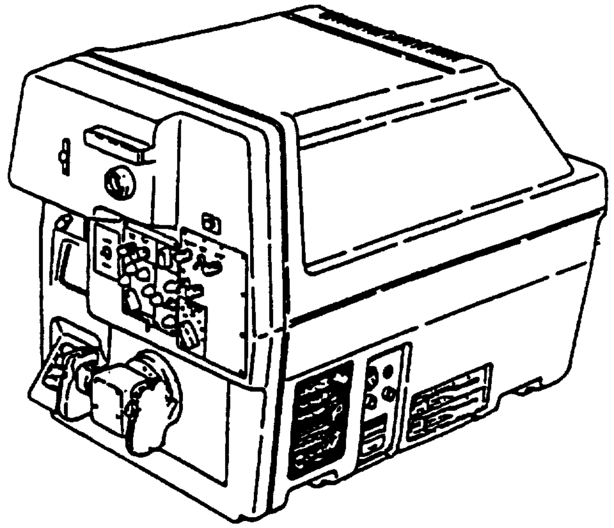

Figure 1. Videodisk interactive gunnery simulator (VIGS)

Next, the training phase was presented. In this phase, the subject performed fifteen randomly presented trials, with each of the three training tasks being performed five times under an assigned time acceleration. After the training phase, the subjects were presented with six random transfer trials at real time, with each of the training tasks being presented twice. Finally, each subject was debriefed regarding the precise purpose of the experiment.

Experimental Design. This study used a transfer of training experimental paradigm. Data were analyzed within a three-way mixed Analysis of Variance (ANOVA) framework . The between-groups factor was time acceleration group. This factor had five levels: 1.0x (real-time), 1.6x, 2.0x, random, and sequential. In the random group, subjects were presented with a random presentation of the first three time constants. In the sequential group, subjects were exposed to progressively higher time constants (i.e., 1.0x, then 1.6x, then 2.0x). The two within-group factors were segment (either training or transfer), and task (either training task 1, 2, or 3). For the training segment, each subject received 20 trials, the first five of which were considered familiarization, and were not subjected to further analysis. The transfer segment consisted of six trials. Dependent variables included a gunnery index that was calculated using the opening time (i.e. time to fire), time to kill, azimuth and elevation errors, and hit/miss percentages (Hoffman and Morrison, 1987) . Also calculated were minutes of practice, mean time to kill, and hit/miss percentage. All dependent variables were collected after every trial for every subject.

The power of this experimental design expressed as 1-β for a given effect was calculated at .86. This value exceeds the recommended power guideline of .80 suggested by Cohen (1988).

Training Tasks. The three tasks that were used for this study are listed and explained below. A task ended when the subject "killed" the target(s) or when the task timed-out. Each task was normally about 45 seconds in duration when performed at real-time. The VIGS required about 25 seconds to load a new task regardless of the assigned time acceleration.

Task 1 - Daytime Helicopter. In this task, the subject was provided with daytime color images depicting a helicopter moving essentially from left to right over trees and grassy terrain at a range of approximately 2000m, and an altitude of 300 ft.

Task 2 - IR Helicopter. In this task, the subject was provided with night infrared images depicting a helicopter resting on the ground amid some trees. When the task begins, the helicopter takes-off, climbs to about 200 ft and begins to move essentially from right to left at a range of 2000m.

Task 3 - IR Tank. In this task, the subject was provided with night infrared images depicting a tank moving essentially from left to right just beyond some buildings and structures representing a town. The view the subject sees is down a road and just beyond and between two buildings. The range of the tank is 1600m.

RESULTS

Data were analyzed using the GB-STAT statistical package (version 3.0) for the personal computer (Friedman, 1991). The design structure for analysis is outlined in the Experimental Design section. Four separate ANOVAs were conducted using this design - one for each dependent variable. In the presence of significant main effects or interactions, *post hoc* pairwise comparisons among means were performed using the least significant difference (LSD) method.

Separate analyses were first conducted using two measures of tank gunnery proficiency -- the gunnery index and the hit/miss percentage. Analysis of the these two dependent variables showed a significant group x testing phase interaction for the gunnery index ($F_{2,149} = 2.8$, $p < .05$) and the hit/miss percentage ($F_{4,149} = 3.70$, $p < .02$), respectively . In both analyses, the group trained under random time accelerations performed significantly better in transfer than either of the other four groups, while the standard 1.0x group performed worse in transfer than in training. Table 1 provides means on the gunnery index and hit/miss percentage variables for training and for transfer phases across all groups. These data are also graphically portrayed in Figures 2 and 3. The training segment represents the average of the 20 training trials performed at that assigned ARTT condition (i.e., 1.0x, 1.6x, 2.0x, sequential, and mixed). The transfer segment represents the average of six trials conducted at real-time immediately after training.

Table 1. Means by group and testing phase for gunnery index and hit/miss percentage

	Training		Transfer	
Group	Gunnery Index	Hit/Miss%	Gunnery Index	Hit/Miss%
1.0x	56.9	.45	44.8	.35
1.6x	52.2	.47	56.5	.55
2.0x	55.3	.57	60.2	.56
Sequential	55.5	.51	58.2	.62
Random	62.8	.56	66.5	.80

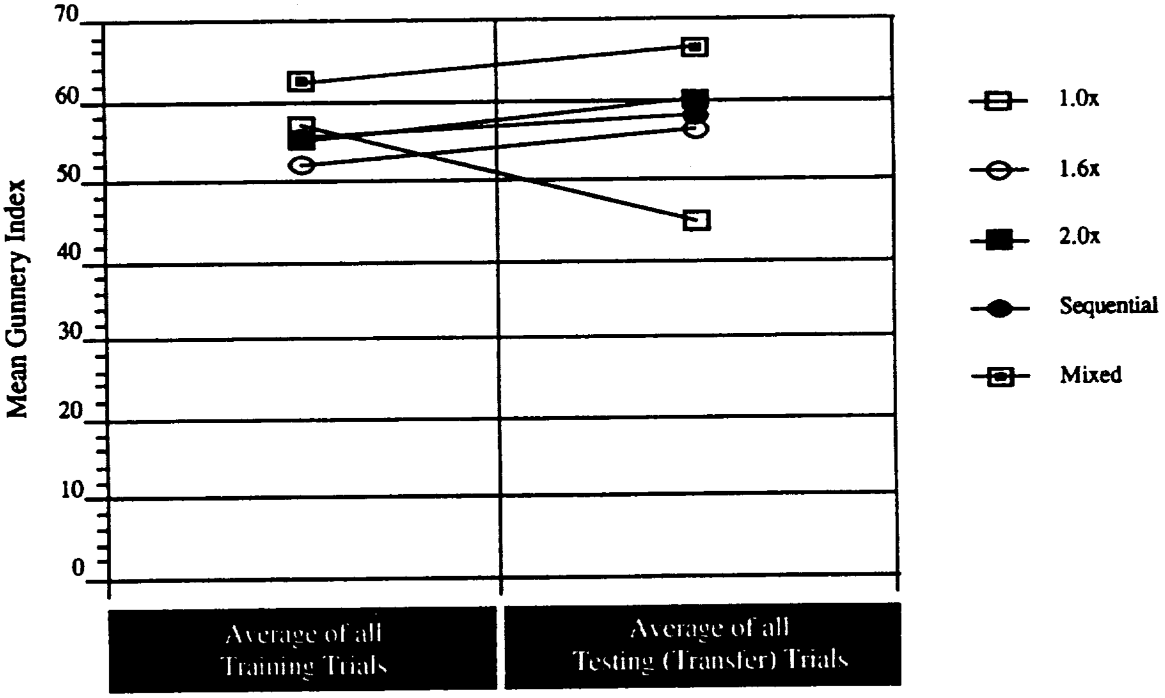

Figure 2. Mean gunnery index by group and testing phase

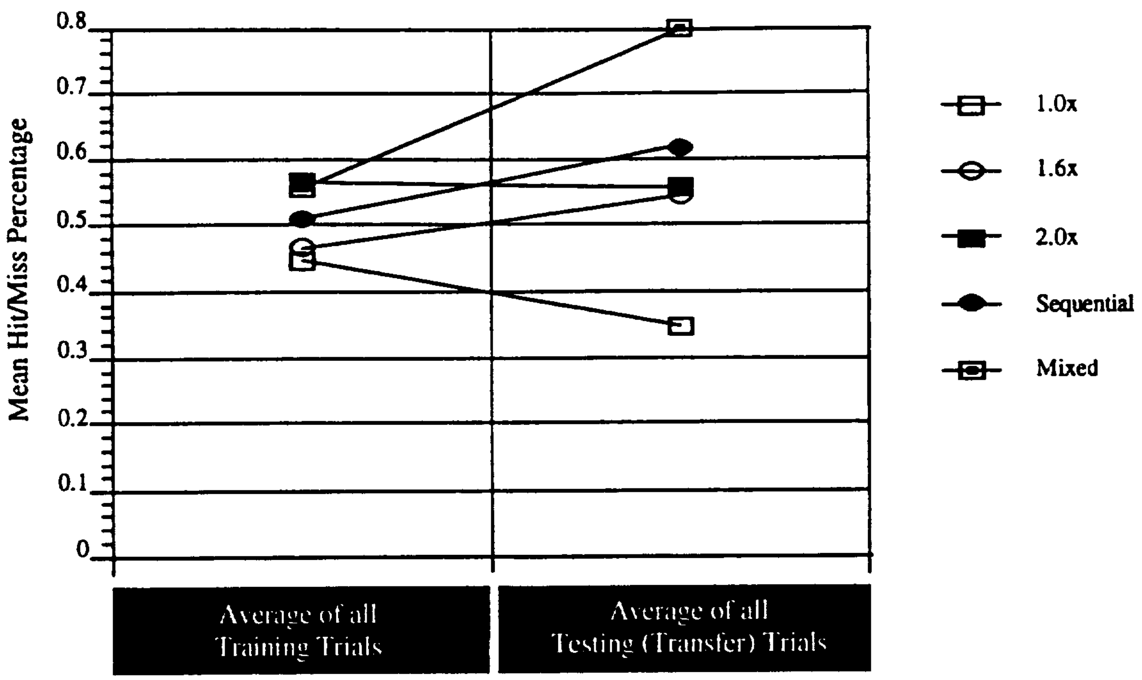

Figure 3. Mean hit/miss percentage by group and testing phase

There was also a significant main effect for task type using two separate measures as indicators of task difficulty. First, using the gunnery index, Task 1 was the easiest, while Tasks 2 and 3 were more difficult ($F_{2,149}$ = 12.8, $p < .0001$). Second, using the mean time to kill measure, the objective of the task was met quicker in Task 1 while Task 2 and 3 took significantly longer ($F_{2,149}$ = 36.16, $p < .0001$). For this latter measure, there was also a significant task x testing phase interaction ($F_{2,149}$ = 9.06, $p < .0008$). Specifically, for the easier task (i.e., Task 1) there was essentially no improvement from training to transfer; however for the other more difficult tasks, there was a significant decrease in the mean time-to-kill from training to transfer (see Figure 4). This finding may indicate that the effectiveness of ARTT is linked to task difficulty. It is also obvious that very simple tasks are quickly learned and would not be expected to show much improvement as a result of training manipulations. This point seems to be in line with what we know about high performance tasks.

Finally, as expected, those trained in the four time accelerated groups received significantly less practice time than the real-time or control group ($F_{4,149}$ = 9577862, $p < .0001$). Figure 5 shows actual training time as a function of group assignment. The 2.0x group, for example, received 50% less practice time than the 1.0x group. The sequential and random presentation groups received roughly 25% less practice time than the 1.0x group. This observation, taken with the results of the other analyses, shows that a significant reduction in training time can be achieved with performance staying equal to or surpassing a real-time control group.

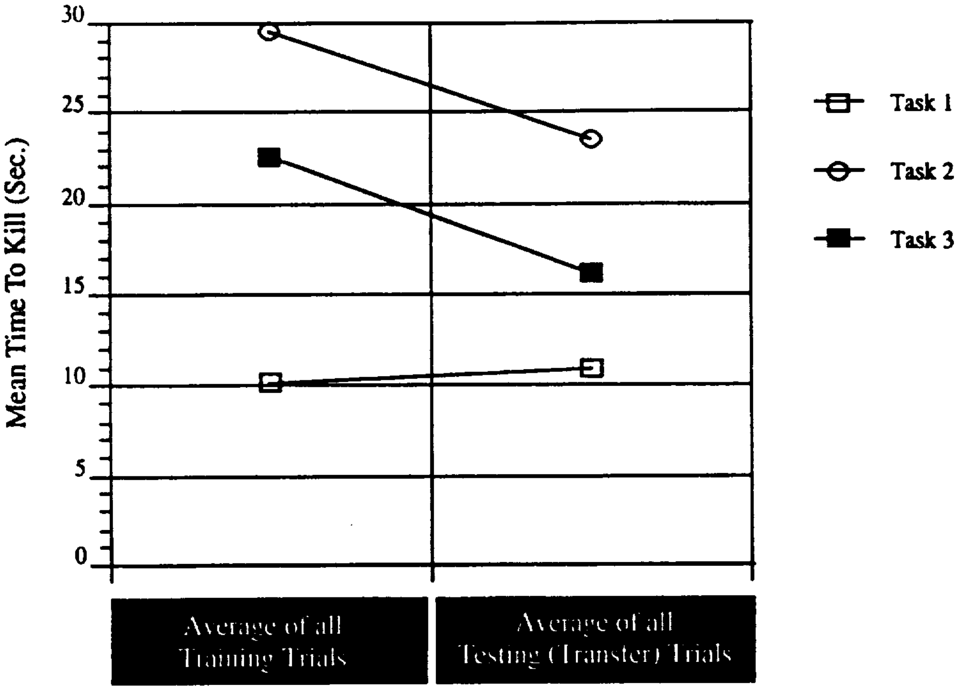

Figure 4. Mean time-to-kill by task and testing phase

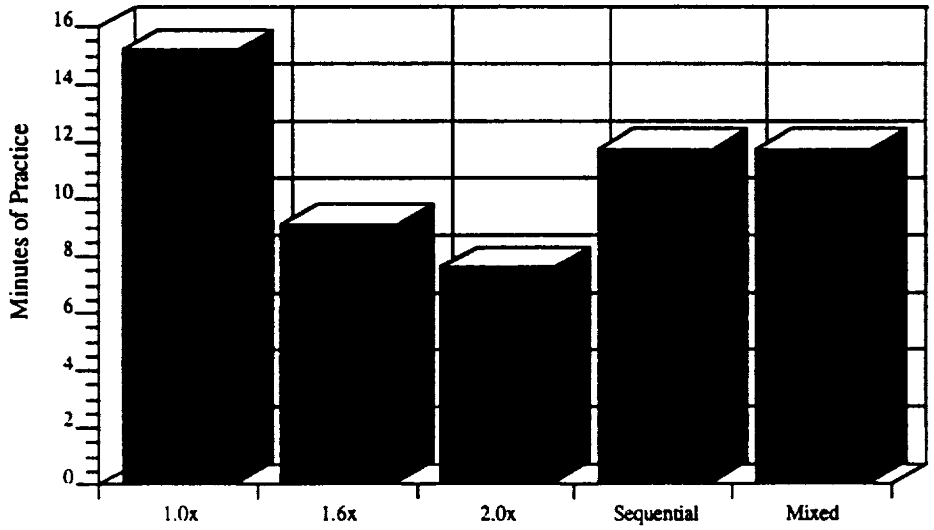

Figure 5. Training time by group

DISCUSSION

For the VIGS experiment, a random assignment or order among the three time accelerations (i.e., 1.0x, 1.6x, and 2.0x) appears to be the most effective condition for achieving the highest performance, both during training and transfer for this task. ARTT also saved simulator time. It represents about a 25% reduction in training time compared to the nominal or standard 1.0x condition. This is consistent with suggestions from Lee and Magill (1983), among other, that increasing the variability of task conditions during training might produce greater transfer. However, these findings show that improved performance for accelerated conditions is not consistent with the majority of literature in contextual interference. This literature base predicts degraded performance in training that is then associated with greater transfer performance. Such discrepancy may be due to a relatively extended training period (five familiarization plus 15 training trials) during which the benefits of accelerated practice were sufficiently realized to enhance performance during the late trials of practice. This discrepancy could also be due to the fact that the accelerations used were not large enough to cause the training/transfer contrast. This is an expected area of future research.

Findings on the hit/miss percentage generally concur with those from the gunnery index analysis. There is a steady trend of increasing performance between the standard 1.0x condition and the random condition, with both 1.6x and 2.0x also superior to 1.0x, while 1.0x shows a performance decrease from training to transfer. Restated, all the experimental conditions involving accelerated trials generally produced improved performance in both training and transfer. Results from the gunnery index analysis showed less differentiation of conditions, both in training and in transfer, than results using the hit/miss percentage. The gunnery index is an extremely complex index involving calculations of ratios and ratio products, and may be differentially sensitive to the accuracy effects reflected in the hit/miss ratio. Part of our further research in the area of ARTT will focus on the development of consistent and appropriate metrics.

While these findings are strongly supportive of enhanced transfer from ARTT, it should be noted that the tank gunnery tasks in this experiment involved largely psychomotor coordination and some procedural content. There was minimum demand for planning or for higher-order cognitive functioning. These results, while highly encouraging, are not necessarily generalizable to all other tasks regardless of content.

Experiment 2 investigated the application of ARTT to an F-16 part-task flight simulator.

EXPERIMENT 2 - ASAT STUDY

METHOD

Subjects

Twenty-four mission-capable F-16 Air Force pilots from the 56th Tactical Training Wing, MacDill Air Force Base, Tampa served as subjects for this experiment. Pilots in this sample fell into three classes. First, there were those pilots who recently graduated from undergraduate pilot training (UPT), and were receiving advanced fighter training in the F-16. Second, there were those pilots who had relatively high flight time, and were transitioning from another aircraft (e.g., A-10, KC-10) to the F-16. Finally, there were those pilots with relatively high flight time who serve as instructor pilots at MacDill. Unfortunately, it was not possible to get a sufficiently large sample of pilots with approximately the same flying experience(s) and level and training. This subject pool had 743 mean flight hours (range of 300-3400), and 134 mean simulator hours (range of 30-500). No formal power tests were conducted to determine the required sample size. The sample size used in this study was restricted due to subject availability and budget constraints. Previous research, however, has indicated this sample size to be adequate given the experimental design.

All subjects were recruited on a voluntary basis in accordance with American Psychological Association (APA) Principles for Research with Human Subjects. Prior to testing, subjects were given written instructions informing them as to the general nature of the experiment (see Appendix D). Subjects were also required to read and sign an informed consent form (see Appendix B). Subjects reported themselves to be in good overall health prior to testing. After the experiment, subjects were fully debriefed (see Appendix C' for a copy of the debriefing form).

Equipment and Materials

Two Avionics Situational Awareness Trainers (ASAT) were used as the testbed for this study. The ASATs were located in the Aviation Technology Laboratory at IST. This lab is approximately 20 ft x 20 ft., and the ASATs were independently enclosed by ceiling to floor curtain enclosures. The ASAT is a low-cost F-16A cockpit trainer designed primarily to train in the beyond visual range (BVR) environment (see Figure 6). The ASATs can be configured to operate in single ship or team mode. When working in the team mode, the pilots can fly against one another or as a team against computer generated threats.

The hardware components that make up the ASAT consist of three personal computers (PCs). The host computer is a PC-AT with an i386 CPU and a i387-20 co-processor, which drive the head-up (out-the-window) and radar electro-optic (REO) displays and collect the data coming from the stick and throttle. Another PC-AT computer (i286), drives the radar warning receiver display. Sound and vibrational cues are provided through the third PC (Commodore Amiga ™)

which drives a Sony ® amplifier, seat and back cushion-mounted speakers, and Cerwin-Vega ® subwoofers. Aural cues available in the ASAT include radar sensor tones, engine and air noise, missile launch, and gunfire, radar warning receiver (RWR) tones, and missile seeker head tones.

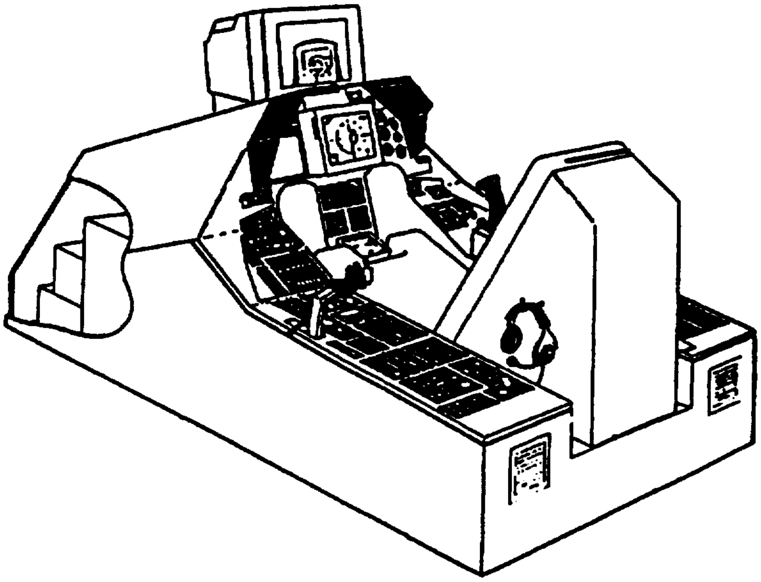

Figure 6. Avionics situational awareness trainer (ASAT)

Graphics for the head-up display are high resolution, 1024 x 1024 RGB, with a 63.36 kHz horizontal scanning frequency. The monitor for the head-up and visual display is a 19-inch JVC ® color CRT monitor which is mounted in front of the pilot on top of the cockpit enclosure, and gives the pilot a 23° X 23° field-of-view. The REO display simulates that of the F-16A Block 15S AN/APG 66 radar, and is presented on a 5" monochrome monitor. It is driven by the i386 and is controlled through switch activation on the throttle and by a radar control panel located on the left side of the simulator. The panel contains active switches to control antenna azimuth, antenna elevation and target history selection. The radar warning receiver (RWR) simulates the ALR-69 RWR, and the display consists of a 9" EGA resolution color monitor. All symbology is generic and unclassified.

The side-stick controller and throttle are high fidelity copies of the controls used in the actual F-16A. The stick can experience a maximum deflection of 0.25" in each of the four axis (forward, backward, right, left), and is equipped with buttons that allow the performance of different functions which include four way trim, missile release, gun triggering, missile select button (AIM 9-J/L), and a return to search switch.

The throttle controls thrust from idle to full military power and beyond through five stages of afterburner. (It should be noted that no change in thrust results in the ASAT from afterburner stage 2 through stage 5; the afterburner has only two states: on and off.) Other throttle functions include: four way radar cursor, UHF/VHF transmit switch, missile uncage button, speed brake switch, antenna elevation knob, chaff/flare release button, and dog fight switch.

Experimental Network Design: Hardware/Software

The ASATs communicate via a PC-based ethernet network at the asynchronous rate of approximately 10-14 packets per second. For the purpose of this experiment, the network was modified so that each ASAT communicated through a i386, 33 mHz PC which served as the experimental interface. This PC controlled task selection, trial start and stop times, duration, data storage, and other experimental information. In this design, the PC would also send messages to either ASAT instructing the simulator to activate or deactivate certain functions (e.g., sound) that were required for a subject to perform a given task. Special purpose *C* and assembly software was written to handle these special requirements (see Appendix E). During testing of the network a Hewlett-Packard 4972A LAN Protocol Analyzer was used to verify that no data packets were lost. Figure 7 shows a functional diagram of the ASAT network.

Procedure

The subjects' first mission was to familiarize themselves with the simulator, including its displays, controls, and handling qualities. These aspects of the simulator are probably different than what the subjects are normally accustomed to. Since the F-16A model is no longer in service with the U.S. Air Force, only some of our subjects had ever flown it. Based on inputs from test subjects, we do not believe this to be a problem since the F-16A and F-16C models have sufficiently similar aerodynamic and avionics characteristics.

The subjects were given approximately forty-five minutes for familiarization across a wide variety of scenarios. During this time, the subjects were encouraged to test and experiment with the control and displays, and the flying characteristics of the simulator.

After the familiarization period there was about a fifteen minute break. The subjects then flew an assigned order of three tasks at an assigned ARTT value. These assignments were made beforehand and represent a complete counterbalancing of the four ARTT conditions, three tasks, and 24 subjects. For each task, the subject flew 10 trials at the assigned ARTT value and four test or transfer trials at real-time (i.e., 1.0x). A five minute break was given between tasks. The dependent variables outlined in the Experimental Design section were collected after every trial, including familiarization.

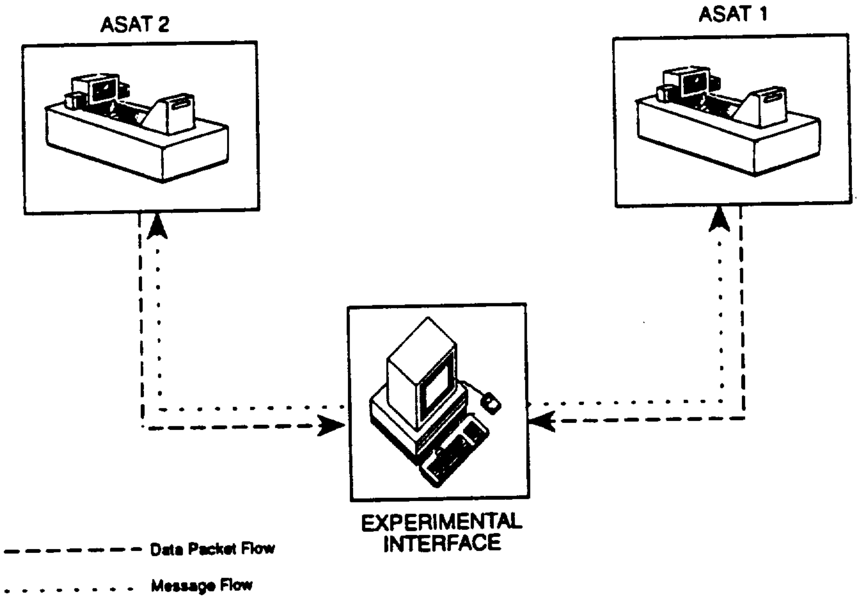

Figure 7. Experimental network: Functional diagram

Experimental Design. This study utilized a three factor design, analyzed within an Analysis of Variance (ANOVA) framework . The between-groups factor was time acceleration. This factor had four levels: 1.0 (real-time), 1.5, 2.0, and mixed. In the mixed group, subjects were presented with a random presentation of the first three time constants. Six subjects were assigned to each of the four groups, with the flight experience of each group being equated to the extent possible. The within-group factor tested a trial effect with each subject receiving 10 training and 4 test or transfer trials. Dependent variables included varied flight performance data such as time-to-lock, time-to-kill, hit/miss percentage, mission performance times, and emergency procedure checklist performance. Specific data collected were a function of the task being performed (see Table 2).

Training Tasks and Initial Conditions. The three tasks selected for this study were chosen to provide the broadest possible range of task content. These tasks are listed and explained below. A task ended when the subject "killed" the target(s) or when the task timed-out. We limited any given task to five minutes to optimize data storage. For each hop for each task, the subject had unlimited fuel. The subject did not have access to any ground control intercept (GCI) or airborne AWACS information. The following task briefings were the only information available.

Task 1 - One versus Two Air Combat Maneuvering. Two bogeys on the nose at 25,000 ft. Goal was two valid face shots on the initial merge. The subject continued to engage the bogeys until both were killed, or until the experimenter terminated the hop.

Task 2 - Stern Conversion (Air Intercept). Bogey was 40 miles on the nose at 20,000 ft. Goal was to perform stern conversion and position for a possible AIM 9J missile or gun shot as quickly as possible. Maximum distance for weapons employment was 1500 ft. The subject was required to maintain a 30 degree aspect cone at no more than 1500 feet before permission to fire was given. This allows for adequate data collection. This hop ended when the bogey was killed, or when the experimenter terminated the hop.

Task 3 - Emergency Procedure. In this task, the subject was flying over enemy area suspected of having energy pulse weapons (better known as "power sucker"). The subject was exposed to two external threats. Namely, the "power sucker" and an enemy bogey. When the subject was painted by the "power sucker", he heard a constant low rumbling noise through his headset indicating an imminent and catastrophic power loss. If this happened, the emergency procedure (EP) to defeat this weapon was as follows:

- fire energy decoy (missile)
- change heading left 10 degrees
- hit energizer (flare)
- change heading right 10 degrees
- fire energy decoy (missile)
- hit energizer (flare)

If the subject performed the procedure above exactly, and in the correct order, the "power sucker" would be defeated and aircraft power would be restored. If not, the subject would crash. The goal of this task was to perform the EP above as quickly as possible while at the same time successfully engaging a hostile bogey.

Table 2. Dependent Variables (DV) by Task

TASK	DV	DESCRIPTION
Stern		
	time to reach criterion (min.sec).	This is the time it took to achieve ≤ 30 degree aspect angle and ≤ 1500 ft range. If the intercept was missed a value of 5.0 was used.
	distance from target at first lock	This provided a measure of target acquisition performance.
	stern score (points)	This is a measure of overall task performance. It looked at the range and closure speed when the 30 degree aspect cone was first established. Scoring profiles were derived from instructor pilots at MacDill AFB.
ACM		
	time to first lock (min.sec)	This variable provided a measure of target acquisition performance.
	hit/miss percentage	This is the number of missile hits divided by the total number of missiles fired. For the ASAT weapon logic, one missile hit "killed" the enemy.
	time to reach criteria (min.sec).	This is the time to kill both MiGs.
EP		
	time to complete EP (min.sec)	This is the time from the cue onset to the completion of the last step in the checklist. If the checklist was performed out-of-sequence, then a value at 5.0 was used.
	percent of procedure correct (%)	This is the percentage of the checklist items performed correctly.
	number of MiG kills	This is the total number of MiG kills by trial.

RESULTS

Raw flight performance data originally collected at a 10-14 Hz iteration rate were reduced into trial summaries by a *C* program designed and written expressly for this research effort. This program summarized the experimental files by subject, task, and group for each dependent variable of interest (see Table 2). Summary data were then analyzed using the Statistical Package for the Social Sciences (SPSS) (SPSS, 1992). The multivariate analysis of variance (MANOVA) syntax for SPSS was used as the overall design structure for the analysis; however, univariate *F* tests were calculated for specific planned comparisons of interest. These planned comparisons focused on identifying statically-reliable differences between the performance of the four time acceleration groups in training, and performance comparing the average of the three training blocks (for a given task/dependent variable combinations) with the two transfer trial blocks.

The first training trial was considered a practice trial and was not analyzed. Trials 2-4 composed trial block 1; trials 5-7 composed trial block 2; and trials 8-10 composed trial block 3. These three trial blocks represent *training* performance at an assigned ARTT condition (i.e., 1.0x, 1.5x, 2.0x, or mixed). Trials 11-12 composed trial block 4; and trials 13-14 composed trial block 5. These last two trial blocks represent *transfer* performance and were conducted at real-time immediately after training.

For the emergency procedure (EP) task, number of MiGs killed, time to complete EP, and percent of EP performed correctly were analyzed by group. Table 3 shows the means and standard deviations averaged across both training and transfer blocks by group for the EP. Figures 8 through 10 portray the dependent variable of interest on the ordinate plotted against the trial block on the abscissa for each group. Analysis of the EP flight data demonstrated a significant increase in MiG kills from training to transfer for all accelerated conditions ($F_{3,20} = 10.87, p < .01$) with the 1.5x and 2.0x conditions slightly outperforming the mixed group. The three accelerated groups, at the conclusion of the last transfer block, had a better than sixfold advantage in the number of MiG kills compared to those trained at real-time (see Figure 8).

When comparing performance in training on the number of MiG kills, there is also a significant difference among the groups ($F_{3,20} = 3.95, p < .05$). Both the 1.5x and 2.0x groups performed better in training when compared to the 1.0x and mixed groups. This finding was not expected, and is not consistent with what is known about the contextual interference phenomenon.

Table 3. Summary data matrix: Emergency procedure task

Dependent Variable	Group	Training		Transfer	
		Mean	*S.D.*	*Mean*	*S.D.*
time to complete EP (sec.)	1.0	10.21	2.20	8.70	1.63
	1.5	11.50	2.38	8.12	.39
	2.0	11.48	2.38	9.08	3.02
	Mixed	9.86	2.72	8.41	1.26
% of EP performed correctly	1.0	81.94	20.49	71.88	34.82
	1.5	94.14	6.42	88.90	12.17
	2.0	86.88	13.77	96.57	4.56
	Mixed	90.74	7.75	100.00	0.00
Number of MiG Kills	1.0	.34	.21	.34	.43
	1.5	1.99	.71	3.36	.82
	2.0	.67	.53	2.86	.79
	Mixed	.76	.56	2.57	.73

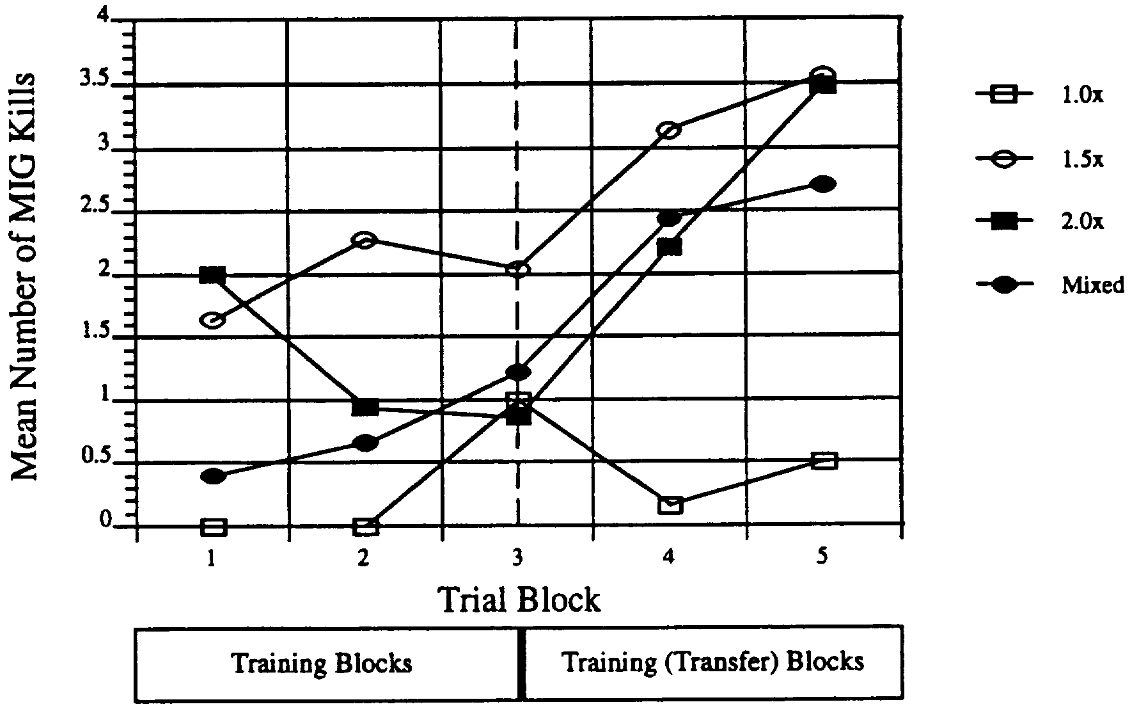

Figure 8. Mean number of MiG kills by trial block

Next, the time to complete the EP procedure, and percent of EP procedure performed correctly were analyzed. As time went on, all the groups completed the EP checklist items quicker, although that difference was not statistically reliable (see Figure 9). When comparing the accuracy performance, however, both the 2.0x and mixed conditions performed the checklist task significantly better than either the 1.0x or 1.5x groups, when later tested at real-time ($F_{3,20} = 7.45, p < .002$). In fact, subjects in the mixed group scored perfectly in the transfer condition. The 1.0x and 1.5x groups actually saw a slight decrease in accuracy performance from training to transfer. There were no important differences among the groups in training (see Figure 10).

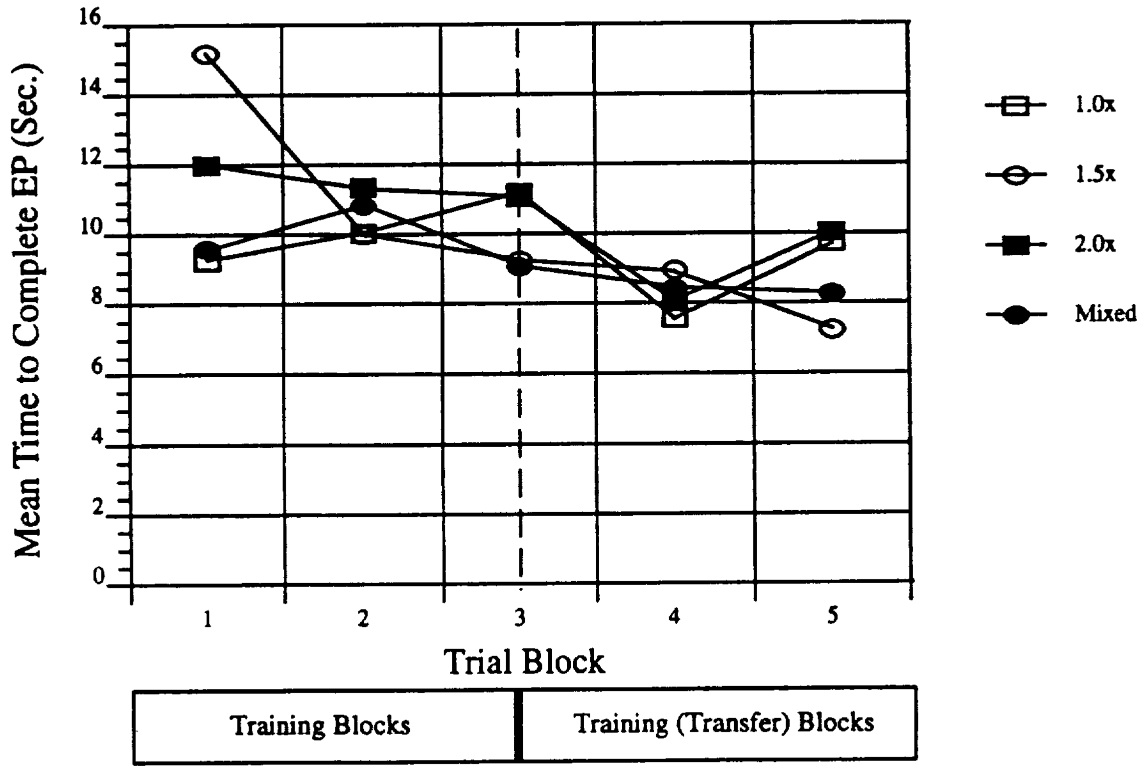

Figure 9. Mean time to complete EP by trial block

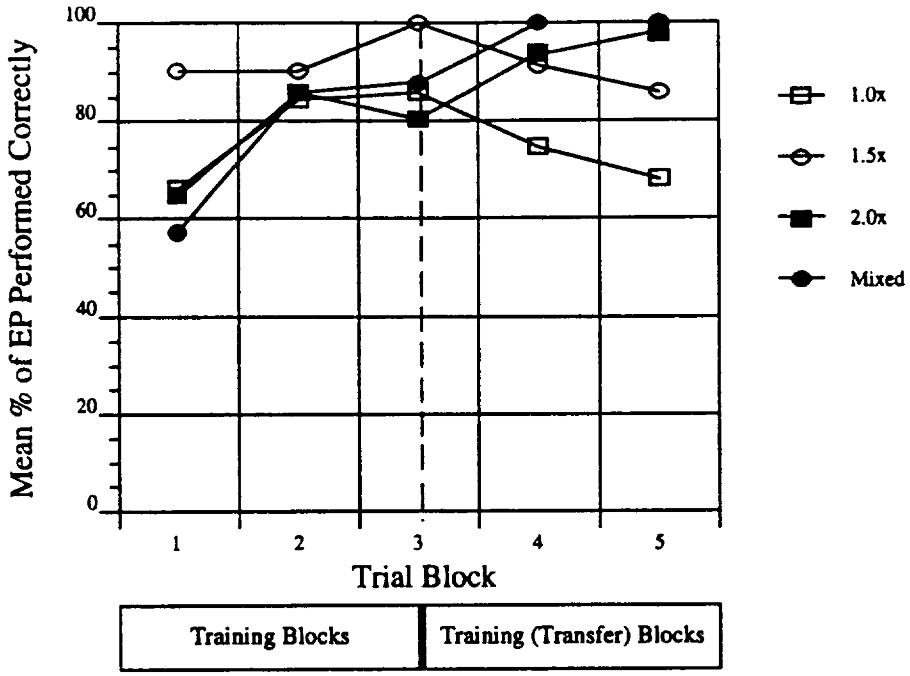

Figure 10. Mean percentage of EP performed correctly by trial block

For the stern conversion task, time to reach criterion, stern score, and distance at lock were analyzed by group. Table 4 shows the means and standard deviations averaged across training and transfer blocks by group for the stern task. Figures 11 through 13 portray the dependent variable of interest on the ordinate plotted against the trial block on the abscissa for each group. Analysis of the stern conversion task showed that the 1.5x group performed only slightly better than the other groups in the time to reach a preset position criterion. The 1.5x group performed the task faster in training *and* in transfer (see Figure 11), but the reader will note that these findings are not statistically significant.

For the distance at lock variable, which represents a measure of radar target acquisition performance, the 2.0x and 1.5x groups performed slightly worse in training, indicating that subjects in those two groups took somewhat longer to locate and lock the bogey. With this variable, the greater the range at which the bogey is identified and locked, the better opportunity a pilot has to make decisions. In transfer, the 1.0x and 1.5x groups continued to improve, however, the mixed group showed a significant decrease in the first transfer trial block ($F_{3,30}$ = 37.64, p < .001)(see Figure 12). This latter finding could be due to the relative uncertainty of the initial closure speeds and range-to-target caused by mixing the accelerated conditions.

Table 4. Summary matrix: Stern conversion task

Dependent Variable	Group	Training		Transfer	
		Mean	*S.D.*	*Mean*	*S.D.*
Time to reach criterion (sec.)	1.0	149.42	14.01	215.06	29.63
	1.5	153.76	19.63	189.34	7.26
	2.0	196.94	48.41	214.34	29.84
	Mixed	210.37	23.02	230.67	22.34
stern score	1.0	1.58	1.23	1.46	1.30
	1.5	1.51	1.19	.63	.83
	2.0	2.66	1.89	1.11	1.87
	Mixed	2.22	1.34	1.25	1.43
distance at lock (miles)	1.0	33.32	3.72	34.48	2.87
	1.5	29.47	4.92	37.11	2.75
	2.0	32.73	6.38	35.59	4.76
	Mixed	31.16	8.88	18.70	2.98

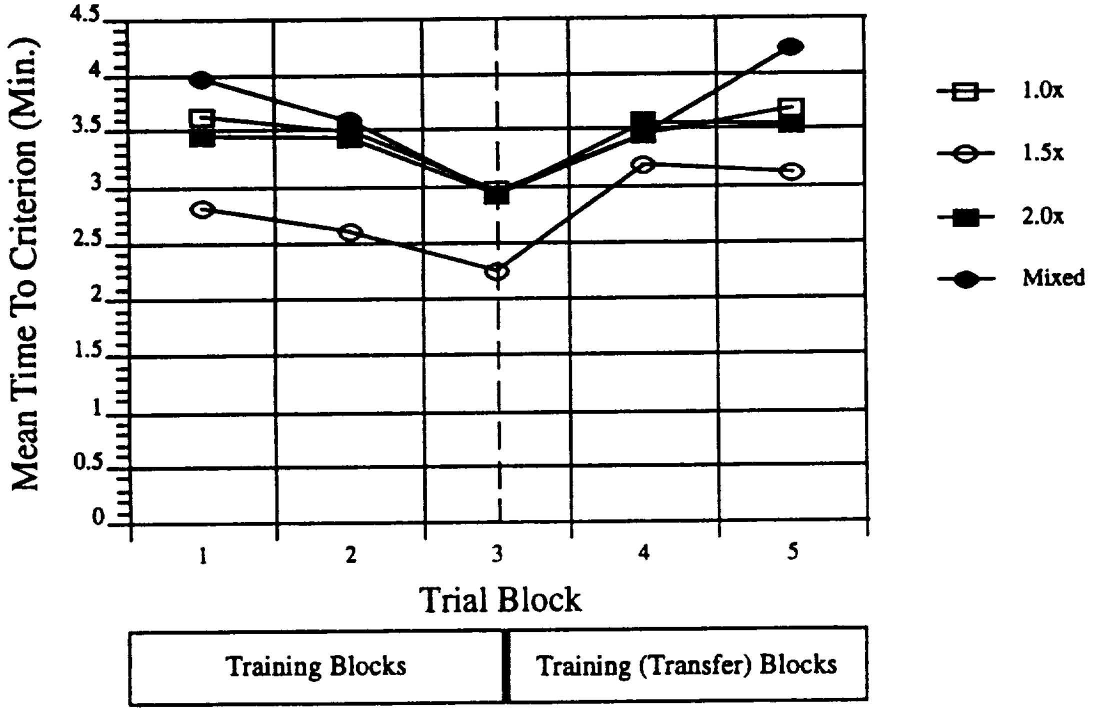

Figure 11. Mean time to reach criterion by trial block (Stern)

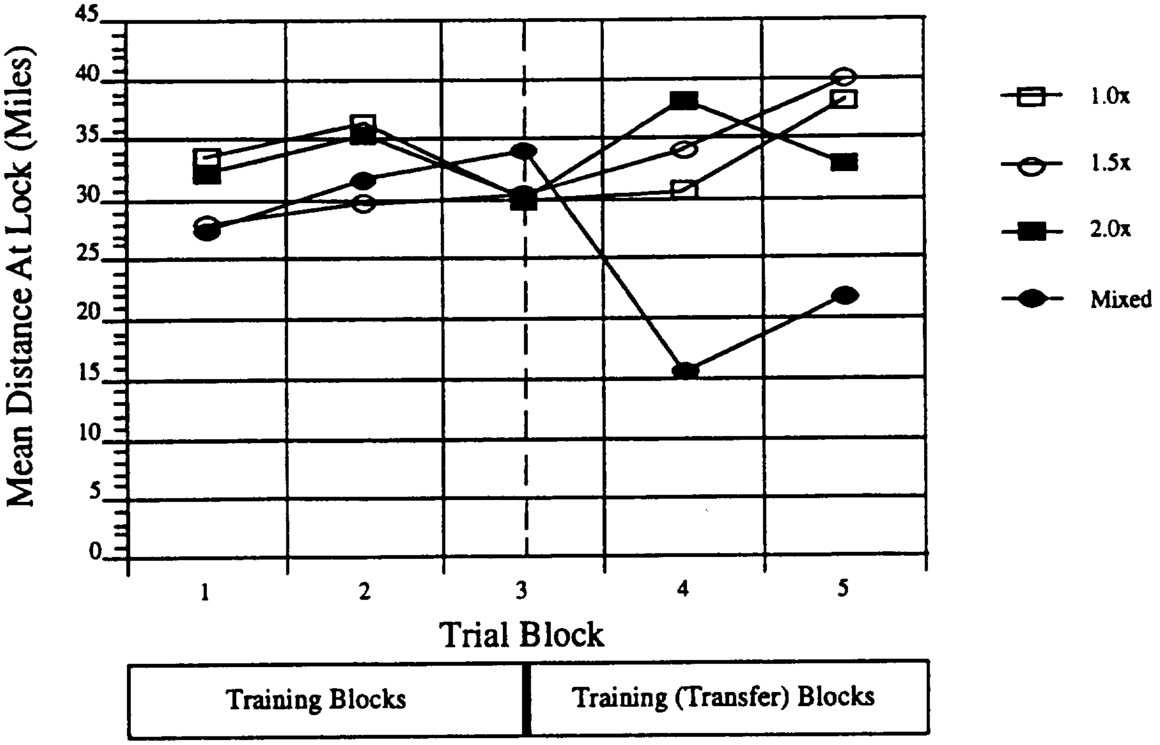

Figure 12. Mean distance at lock by trial block

For the stem conversion score, there are no significant differences among groups in training or between training and transfer performance among the four groups. These data are presented graphically in Figure 13. The scoring procedure used for the stem task is based on a subjective rating that is often given by instructor pilots (IPs) to students. The score is based on assessing both the closure speed and aspect angle during the conversion. The rationale is that when the pilot rolls-out behind the bogey (low aspect angle), the pilot should not be more than three miles or less than one mile behind the bogey. As a rule-of-thumb, the closure speed should also be in proportion to the distance (e.g., at 2 miles, 200 knots closure speed). From Figure 13, the reader will note a repeating pattern of performance. Although not statistically different, there is an actual decrease in performance from the last training block to the first transfer block followed by a slight increase in performance at the last transfer block. In the end, performance for the 1.0x group is higher than the other groups.

The results of the stem conversion are difficult to interpret. Taken together, they tend to suggest that piloting tasks that involve well-learned (at real-time) and continuous responses to both internal and external positioning cues might not benefit from above-real-time simulation. This is consistent with the notion that task content and task requirements may mediate ARTT effectiveness. At the same time, the lack of differences among groups and the absence of any learning patterns with practice also suggest that the subjective stem conversion score may not be an appropriate metric for that task under accelerated conditions.

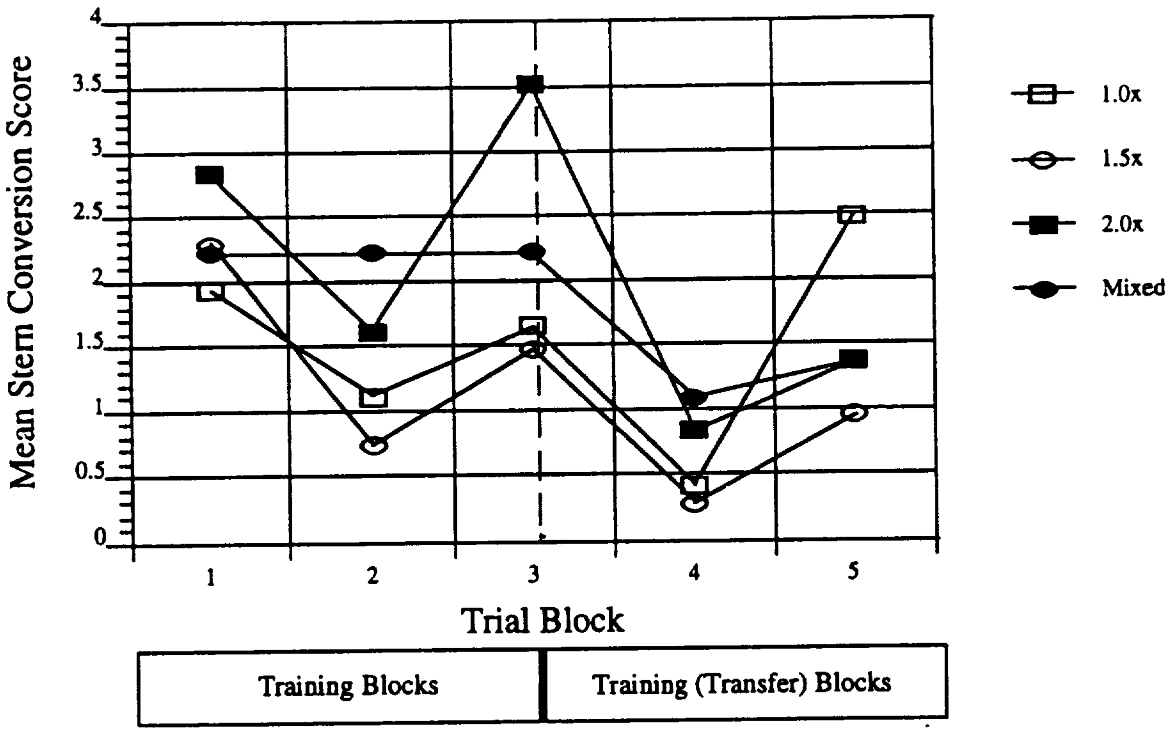

Figure 13. Mean stern conversion score by trial block

For the air combat maneuvering (ACM) task, time to first lock, time to reach criterion, and number of valid missile shots were analyzed by group. Table 5 shows the means and standard deviations averaged across training and transfer blocks by group for the ACM task. Figures 14 through 16 portray the dependent variable of interest on the ordinate plotted against the trial block on the abscissa for each group.

For time to first lock, which is a measure of the speed at which a pilot acquires his adversary on radar, all groups except the 1.0x group saw a significant increase in lock time from the last training block to the first transfer block ($F_{3,20} = 2.92$, $p < .05$). In comparing the groups at the final transfer block, both the mixed and 1.0x groups performed significantly better than either the 1.5x or 2.0x group. The 2.0x group also outperformed the 1.5x group in transfer (see Figure 14).

For the time to reach criterion, there was no significant difference between groups from training to transfer. In comparing the last transfer block, however, the mixed group performed significantly better than either of the other groups ($F_{3,20} = 4.55$, $p < .014$) (See Figure 15).

Table 5. Summary matrix: Air combat maneuvering task

Dependent Variable	Group	Training		Transfer	
		Mean	*S.D.*	*Mean*	*S.D.*
Time to first lock (sec.)	1.0	15.88	4.21	12.47	2.05
	1.5	24.76	17.16	32.50	16.09
	2.0	19.88	16.60	23.27	20.72
	Mixed	25.78	8.46	11.82	3.28
Time to reach criterion (sec.)	1.0	238.34	42.47	188.90	65.23
	1.5	253.35	35.24	211.05	59.18
	2.0	209.60	72.39	222.78	66.07
	Mixed	210.04	27.56	172.75	33.14
Hit/Miss percentage					
	1.0	.258	.077	.392	.162
	1.5	.525	.134	.435	.198
	2.0	.420	.196	.421	.146
	Mixed	.364	.127	.283	.044

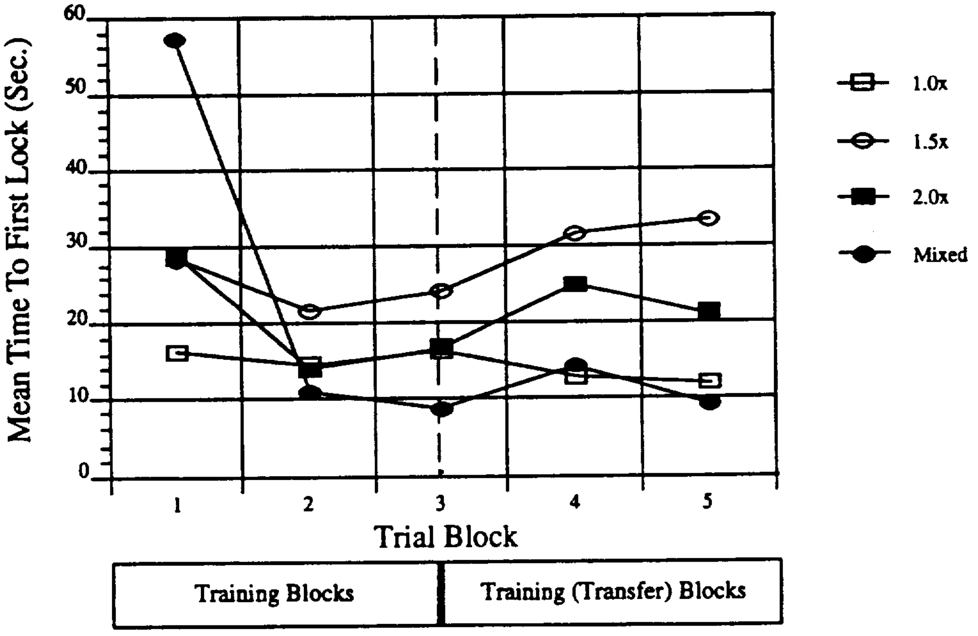

Figure 14. Mean time to first lock by trial block (ACM)

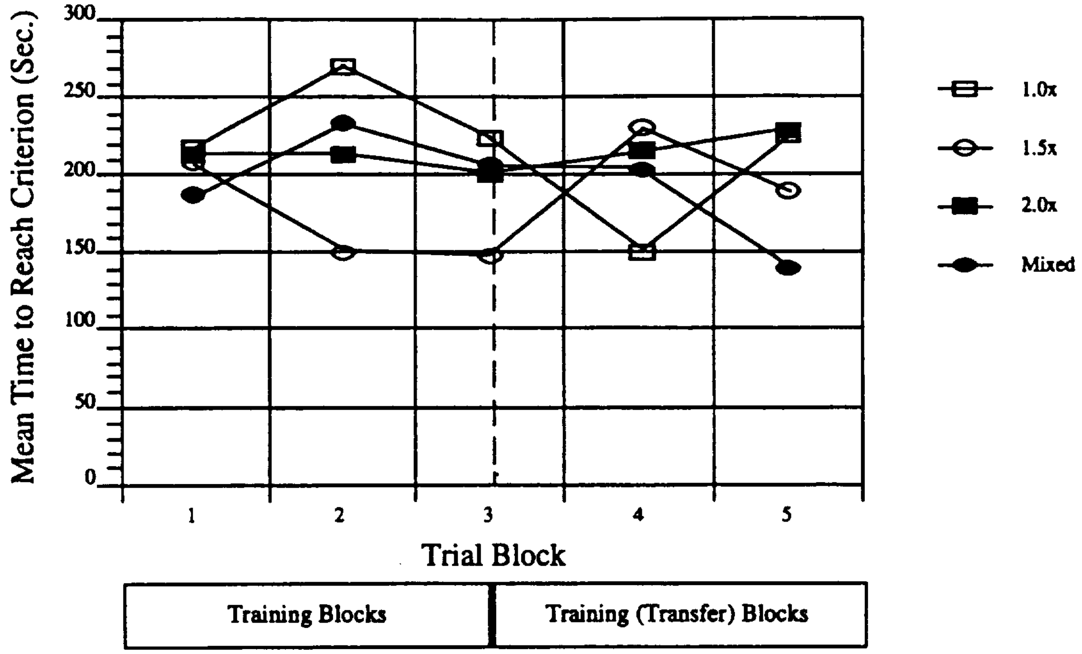

Figure 15. Mean time to reach criterion by trial block (ACM)

Finally, the mean hit/miss percentages were analyzed and revealed no significant differences between groups in either training or transfer (see Figure 16). Upon further inspection, it was apparent that this metric was somewhat biased due to the performance of the missiles. This point is expanded in the discussion section below.

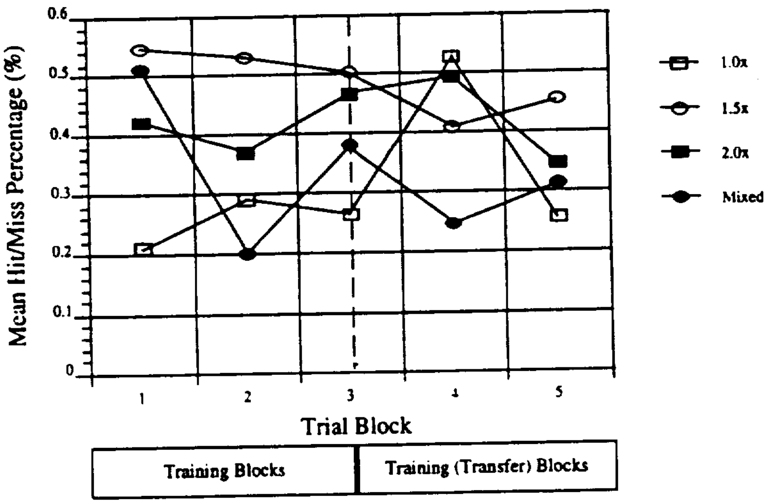

Figure 16. Mean hit/miss percentage by trial block (ACM)

DISCUSSION

The results of the ASAT study reveal some similarities and differences when compared to the results of the VIGS study. The results of the ASAT study will be discussed below by task. First, the EP results demonstrated that all the groups trained under accelerated time conditions produced significantly higher accuracy in performing an emergency procedure in the transfer condition than did a real-time control group. The mixed and the 2.0x groups performed the EP near perfectly (100% and 96.6%, respectively). The 1.5x group's accuracy was almost 90%, while the control group scored the lowest at about 72%. This finding in particular demonstrates that ARTT may have potential to train procedural tasks with greater accuracy and in less time. In the EP task, the difficulty of the task was increased by placing all groups under the additional (simulated) stress of having to perform the EP during a secondary air combat task. For the ARTT group taken as a whole, the number of enemy MiGs killed was six times higher than the 1.0x groups when compared in the real-time transfer blocks. There was also no significant difference between the groups when analyzing the time to complete the EP variable. The subjects, after a few trials, mastered the procedure and their performance stabilized. This seems to indicate that ARTT does not necessarily effect the speed with which pure motor tasks are performed.

Results of the stern conversion tasks are less clear, and neither support or refute the ARTT concept. For this task we attempted to implement ARTT by increasing the velocities of the ASAT and the bogey. In retrospect, due to the physics and geometry of the stern task, we failed to create a savings or reduction in training time which is a central tenet in ARTT. The task forced the ARTT groups to take essentially the same time in training as the real-time control group. In other experiments we have been successful by speeding up targets, ownship, or both. This was not the case for the stern task. Moreover, pilots differ greatly in their approach to performing the task. Some would perform a low/high or high/low vertical conversion while some would initially offset left or right and perform a "standard" conversion. This made it difficult to establish useful measures of performance. Tasks such as the stern conversion that could be performed successfully using one or more alternate strategies, may not benefit from time compression. It may be that tasks that have clearly identified performance components (such as the EP) benefit the most from ARTT.

The air combat maneuvering (ACM) task also produced mixed results. Again, the fact that pilots have different flying styles leads to difficult performance assessment. The pilots were instructed to take two valid face shots - one at each bogey. A "valid" shot was one in which the range from the bogey was less than or equal to six miles **and** the aspect angle was between 135 and 180 degrees. The ASAT software modeled only the older AIM-9J and AIM-9L missiles. Unfortunately, when the raw data were inspected, it became clear that the pilots had great difficulty achieving "valid" missile shots, as they were defined, regardless of the group they were assigned. The explanation for this phenomenon lies in the performance of the missiles and the attack profiles preferred by the pilots. Specifically, the AIM-9L is capable of high aspect kills, but its performance is significantly worse than the newer AIM-9M which the pilots are familiar with. The hit/miss percentage metric, therefore, cannot be considered a true reflection of pilot/weapon performance. In addition, most pilots chose to "offset" or break right or left to create more of an advantageous aspect angle. With a less than optimal high aspect kill performance of the AIM-9L missiles, the fight usually degenerated into a tail chase with any time savings disappearing since both the ASAT and the MiGs were both accelerated.

There were some trends in the ACM task that, although not statistically significant, are indicative. The mixed group were 11% faster in disposing of the two MiGs. The mixed group also showed the fastest reduction in time to first lock from training to transfer. Finally, the hit/miss percentage score was highest in the 1.5x and 2.0x groups.

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

Based on the results of this research, tasks that contain simple psychomotor or procedural components such as the VIGS tank gunnery tasks and the emergency procedure (EP) task performed on the F-16 ASAT clearly benefit from ARTT. Moreover, this research demonstrated that tasks which vary in type and content are differentially affected by ARTT. The ARTT groups showed higher performance scores when compared to a real-time control group in transfer for the VIGS and EP tasks. Further, it was abundantly clear in the VIGS tasks that we could not only achieve higher performance scores in transfer for the ARTT groups, but we could do so with less training time. For tasks with more complex cognitive components such as the ACM and stern conversion, there was no clear advantage in the ARTT groups compared to a real-time control group. The stern and ACM tasks allowed for alternative performance strategies that pose particular measurement and interpretation problems, and the inconsistent outcomes of these tasks may be attributable to measurement problems and strategy differences.

We discovered through debriefing that the VIGS subjects in the mixed and sequential groups did not notice any difference between the 1.0x and 1.5x or between the 1.5x and 2.0x conditions. Our F-16 pilots in our second experiment were aware of differences between conditions, but only because external cues from the head up display (HUD) were available.

The increased accuracy of EP performance bears further study because of the obvious implications for safety training. Many real-world emergencies require accurate performance of checklist procedures under extremely stressful circumstances. In this study, those trained under an accelerated conditions not only performed the EP task more accurately (nearly at 100% in transfer), they also were able achieve a significantly greater number of MiG kills on a concurrent task.

With respect to the initial research objectives:

1. ARTT was more effective than conventional real-time training in the case of all three of the tasks examined for the VIGS and the ASAT EP task. The stern conversion and ACM task results were mixed, due probably to inappropriate and insensitive metrics.

2. For those significant effects, the group that provided the greatest performance improvements was the one that mixed the presentation at different speeds. This supports the contention that task variety in training leads to higher performance.

3. ARTT's impact on training time for the VIGS experiment was highly favorable. Time savings in that study ranged from 25% to 50%. The impact of the ASAT study on training time is inconclusive due to methodological considerations.

Finally, as expected none of the ARTT groups in either study experienced any negative transfer of training to real-time transfer tasks.

Future work in this area will continue with a replication of the ASAT study - this time with a different time compression technique. Specifically, we plan to alter only the update rate so that we do not affect the flight qualities of the simulator. The only reasonable way to implement ARTT on the ASATs involved changes to the flight equations and consequently the handling qualities of the simulator. For the replication study, we will use a different simulator platform that will allow modification of the frame rate. The frame rate modification technique was used for the VIGS study. Other near-term work will focus on expanding the application of ARTT for emergency procedure training. We are also beginning to explore techniques to test the effectiveness of ARTT on subsequent performance in the actual aircraft.

The overall aim of the ARTT concept is to exploit the time adaptability of humans and foster a new way of thinking about time manipulation in the man-machine interface. Future research directions might include safety, education, medical, and entertainment applications. For example, it would be possible to increase the voice and data communication rate over a network to allow crews or teams to train at faster than real-time. Also, as scientists explore the concept of virtual reality, the real world bond we have with perceived time will weaken. Time flow could be controlled for the benefit of the trainee. New training methods that are *time flexible* will change form, fit and function of the man-machine interface.

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APPENDIX A

INSTRUCTIONS TO SUBJECTS - VIGS STUDY

Please have a seat in front of the trainer. VIGS, which stands for Videodisk Interactive Gunnery Simulator, is a trainer which uses videodisk technology to present 30-35 second engagements to the trainee. You will see many switches and knobs on the VIGS. You WILL NOT have to set or move any of these switches or knobs to perform the tasks.

In front of you, you will see two connected handles (called "cadillacs"). These cadillacs move the gun tube up, down, and side-to-side. To move the crosshairs (called the "reticle") you see in the display, turn the cadillacs like a steering wheel. To move the reticle up or down, twist the cadillacs accordingly.

You will also notice two sets of buttons on the cadillacs. The first set of buttons, located near the top and inner portions of the cadillacs, controls the laser rangefinder mechanism. This gives you a "lock" on the target, as well as computing the target's range which is shown on the screen. The second set of buttons, located near the index fingers' position are the fire buttons. Finally, in order for any buttons or movements to work, **THE PALM LEVERS ON THE FRONT OF THE CADILLACS MUST BE PRESSED.**

Therefore, when engaging a target, the sequence of activities is as follows:

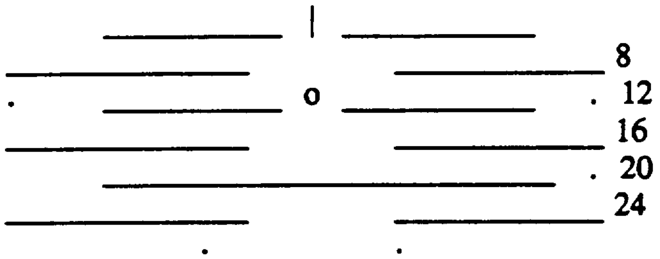
1. Squeeze the palm levers and hold them down.
2. Manipulate the cadillacs to bring the reticle on target. You must wait for the tank commander to say "Fire" before firing the first round. On subsequent rounds, you must wait for the command "Up" (meaning that a round has been loaded) prior to firing.

   When manipulating the cadillacs, be sure that the last movement of the reticle onto the target is in an UPWARD direction. Also, when reengaging the target, be sure to "dump lead" by releasing and then reengaging the palm levers.
3. Activate the Laser Rangefinder.
4. While still tracking the target, press the fire button.
5. Assess results and reengage if necessary.
6. Disengage palm levers.

Before each trial begins, you will hear a tone that indicates that the computer is initiating a mission. An automated tank commander will slew you to the target, After you hear the tank commander's instructions to fire, you should place the reticle on the target, press the laser rangefinder button, and fire.

There will be a brief pause between missions where you can rest your eyes and hands.

On some trials the reticle will appear as shown below. This reticle gives you an indication of the distance of your target. The numbers shown on the right are the number of meters (in hundreds) that you are from your target. When the tank commander gives you the distance of your target, select the proper line and center the target on that line or between the lines as indicated.



If you have any questions regarding these instructions, please ask the experimenter now. The experimenter will not be able to answer any questions after the experiment has begun.

APPENDIX B

Consent Form

I understand all procedures that will be used in the present study. I further understand that all results will be held in strict confidentiality in accordance with the guidelines set by the American Psychological Association. Participation in this study is strictly voluntary and I may discontinue participation at any time without penalty. The data will be coded such that my responses will be held in complete anonymity. I hereby give my consent to participate in this study.

____

Participant's Signature

____

Participant's Printed Name

____

Date

APPENDIX C

Debriefing Form

The experiment in which you have participated is designed to study the application of above-real time training for simulators. Depending upon the condition to which you were randomly assigned, some of your trials may have happened in "compressed time." That is, they may have appeared to proceed faster than they otherwise would if they had occurred in a normal "real-time" environment. Up to five conditions were used for this experiment. They are as follows: (1) training trials at real-time; (2) training trials at 1.5x faster than real-time; (3) training trials at 1.6x faster than real-time; (4) training trials at 2.0x faster that real-time; (5) training trials sequentially ordered from the above four conditions; and (6) training trials presented in a random or mixed order.

The final trials to which you were exposed proceeded in real-time. Your performance on all trials will be analyzed to see how the speed at which you were trained impacts the transfer of skills to the actual real-time trials. The hypothesis is that learning in compressed time will facilitate the transfer of learning to real-time conditions. Even if the transfer of skills is equivalent to that of real-time training, the time and cost savings of learning in compressed time may be substantial.

Because other students may be participating in this study after you, it would be most appreciated if the experiment were not discussed with anyone until all subjects have had an opportunity to participate. If you have any questions about the manner in which this research was conducted, or if you desire further information, please contact
________________________ at ______________________ or
__________________________ at ______________________.

Thank you for your participation in this study.

APPENDIX D

INSTRUCTIONS TO SUBJECTS - ASAT STUDY

Thank you for helping us with our research. The project you are helping us with is being sponsored by NASA Dryden Research Flight Center. The objective of this research is to test the effects of different flight models and configurations. Today you will be flying three "missions":

- stern conversion
- 1 v 2 ACM
- emergency procedure

While you are flying, we will be recording flight performance data from the simulator. All data that are collected will be recorded by subject number. Your specific data will be kept strictly confidential, and only UCF/IST researchers will have access to the data.

Your initial task will be to familiarize yourself with the simulator, including its displays, controls, and handling qualities. These aspects of the simulator are probably different than what you are normally accustomed to. You will be given approximately forty-five (45) minutes for familiarization. We will set you up on a variety of scenarios. During this time, please feel free to test and experiment with the control and displays, and the flying characteristics of the simulator.

After the familiarization period there will be about a fifteen (15) minute break. You will then fly the three missions above (in no particular order). For each mission, you will fly between eight (8) and fifteen (15) trials. A ten (10) minute break will be given between missions.

ABOUT THE SIMULATOR

The Avionics Situational Awareness Trainer (ASAT) you see is an F-16A part-task trainer. You will notice obvious differences between the displays and controls in the ASAT and the simulator/aircraft with which you are most familiar. In the ASAT, the REO display replicates that of the F-16A, Block 15S AN/APG 66 radar, and the RWR display replicates the ALR-69 RWR indicator. All RWR symbology is generic and unclassified.

The following information in this packet involves a technical description of the ASATs controls, displays and other specific functions. Please take a minute to carefully review the material. We will be happy to answer any questions you may have.

F-16 ASAT TECHNICAL DESCRIPTION

Perceptronics' F-16 Avionics Situational Awareness Trainer (ASAT) is designed to capture the best mix of proven hardware and software components and desirable applications of existing technology. No new research and development is necessary to support training needs. Perceptronics has selected trainer components from commercial off-the-shelf and/or existing in-house designs. The result is an integrated design based on a majority of familiar, proven components which exhibit superior reliability and maintainability.

Perceptronics' F-16 ASAT, as depicted in figure 3-1, replicates the flight, avionics, weapons system and primary controls of the F-16A, the current front line tactical fighter aircraft of the United States Air Force and many other countries around the world. The F-16 ASAT features high fidelity hands-on throttle and stick (HOTAS) controls from which the pilot controls nearly all avionics and weapons system functions. Cockpit radar and radar warning displays are replicated on two monitors and heads-up-displays with out-the-window visual imagery are depicted on a single 20" high resolution monitor. All controls and displays are accurately placed in the cockpit enclosure which provides the required "feel" of the F-16. All components except for the Aural Cue system are housed within the cockpit unit.

The following major components comprise the ASAT trainer:

- Computer and network systems
- Heads-Up Display (HUD)/external view monitor
- Radar Scope and Radar Control Panel
- Multi-function Display
- Fully functional stick and throttle controls
- Cockpit enclosure with inclined seat
- Aural Cue system
- Communications system

Flight Functionality

The F-16 ASAT features a high fidelity five degree freedom aerodynamic model which closely replicates the aircraft. Forces from the side-stick controller and control response are also accurately simulated. Since the F-16's computer "fly-by-wire" flight control system automatically interconnects and coordinates the rudder, rudder pedals are not required. Throttle response is from idle thrust through five stages of afterburner.

ASAT was developed to assist the pilot in task management by providing an affordable training device available at the squadron level. ASAT places emphasis on those switches, sensors and displays that are necessary for pilot tactical execution of a mission. The force ratios, mission scenarios, type threat, and quality values (aircraft, avionics and weapons) are derived from unclassified sources and are representative of actual capabilities.

Within Visual Range (WVR)

The high resolution 20" Monitor provides an effective viewing area of 22° * 22° through which the pilot views terrain database features, Mig targets and the full HUD symbology of the F-16A. In addition, to compensate for the limited view of the monitor, the multi-function, situational awareness display graphically presents target relative location if it would be in view from the aircraft cockpit.

Beyond Visual Range (BVR)

The ASAT cockpit radar monitor replicates the F-16A, Block 15S Radar Electro Optical (REO) Display. Antenna azimuth, elevation and range scan are controlled by HOTAS controls and the radar control panel as are target acquisition functions. The ASAT software reproduces radar displays and modes as in the actual aircraft. The situation awareness display also depicts the aircraft radar warning receiver (RWR), azimuth indicator which provides a relative bearing to target search or track radars detected by the aircraft sensors.

Flight Capabilities

The F-16 ASAT simulated flight model is a cross-coupled, linearized aerodynamic model of the controlled airframe. That is, an effects model of the combined airframe and flight control system which offers the optimum in fidelity and execution performance. The pilot inputs are throttle and stick force components in pitch and roll. Again, because of the characteristics of the aircraft computer-coordinated ailerons and rudders, sideslip and rudder simulation is not required for the normal operating envelope. The model uses four coordinate systems as follows

- Aircraft body coordinates
- X coordinates
- Velocity coordinates
- Fixed coordinates

Performance detection

Outside Performance envelope

The flight model will respond with appropriate HUD warning indications and control difficulties when the combinations of velocity and angle of attack result in stall onset. Over-G maneuvers are also detected and displayed with "red-out" and "black-out" of the HUD monitor. In addition, simulation of the F-16 voice warning system provides "warning" calls at parameter limits and a "pull up" low attitude warning through the cockpit audio system.

Collision Detection

The ASAT software accurately calculates aircraft and target locations along with size parameters which compute airborne object collision detection resulting in an audible explosion and termination of mission. Impact with terrain is detected in the same manner.

Weapons Impact detection

The ASAT target software library contains pre-programmed scenarios which are drawn from ten basic categories. Random lookup features within all but the basic selections keep the targets from being predictable. Where the target pursues, geometry calculations determine radar and missile envelopes which, when properly resolved, result in a missile launch from the target. Missile fly-out, burn time and maneuvering ability are modelled, in addition, the ASAT pilot's chaff and flare countermeasures are simulated which, if employed within the proper envelope will distract the missile. If the target missile satisfies the conditions for a hit on the aircraft, an explosion will sound in the audio system, monitor screens will go black then return to the set-up menus. The same is true for cockpit missile launch on the target. AIM-9J and AIM-9L, heat seeking missiles are simulated. The missile launch and flight are displayed on the HUD monitor and target impact is graphically depicted. The targets have the capability to drop flares as a countermeasure, these are also graphically displayed on the HUD monitor. The F-16 20mm gun is simulated with tracer bullets shown visually.

Weapons and Communications Systems

Electronic Communication

Electronic air and ground communications like computer data link and tactical information systems data are not features of the F-16A aircraft and therefore, are not part of the F-16 ASAT. The F-16 radar warning receiver (RWR), which gives the pilot relative location and type of search and track radars contacting the aircraft, is simulated. The RWR azimuth indicator is depicted on the multi-function display graphics. All RWR indications are generic and unclassified.

Radar Modes and capabilities

The combination of HOTAS controls, radar control panel and REO monitor simulation render a fully functional, unclassified replication of the F-16A Block 15S AN/APG-66 radar. System performance characteristics are derived from commercially available aircraft data. The following air-to-air radar modes are simulated:

- Search (AIR) mode - 10, 20, 40 & 80 nm search
- Spotlight mode
- Single Target Track

- Air Combat Maneuvering (ACM) mode including dogfight and missile override
- Situation Awareness (SAM) mode

The following radar controls are full functional

- Antenna elevation scan - 1 bar, 2 bar & 4 bar
- Antenna azimuth scan - ±10°, ±20° & ±60°
- Antenna elevation control
- Target history selector - present plus three additional frames
- Dogfight, missile override select
- Radar cursor control and range selector - 10, 20, 40, & 80 nm
- Target designator/de-selector

Heads-Up Display (HUD)

The HUD is mounted directly in front of the pilot, atop the cockpit enclosure. The unit consists of a 20" color monitor with 1024 * 1024 lines of resolution. The HUD display is a high-fidelity replication of the actual HUD imagery found in the representative aircraft. In addition, a "through-the-windscreen" visual provides terrain and detailed target, weapons and countermeasures graphics to enhance the realism of the simulation.

Multi-function Display

The multi-function display consists of a 9" EGA resolution color monitor which supports several paged display functions including:

- Situation Awareness Display (SAD)
- RWR indicator
- scenario replay

The Situation Awareness Display (SAD) is ASAT-unique and serves to provide those visual cues that help increase a pilot's situational awareness when he looks outside the cockpit during the pre-merge phase. It is therefore provides a smooth transition from the Beyond Visual Range (BVR) to the Within Visual Range (WVR) arena and compensates for the limited field of view in the trainer. The SAD screen area represents a 5 * 7 mile area around the aircraft. Targets entering this range which would normally be visible to the pilot will be displayed with a "V" symbol pointing in the direction of target heading. A target within range but below the aircraft and out of view will not be displayed. The targets also appear in three colors. Red represents a target below the aircraft altitude, blue above, and yellow at the same altitude.

Overlaid on the SAD is a generic version of the ALR-69 RWR indicator. A symbol appearing on this display indicates the relative azimuth to a radar detection from a target. A diamond symbol with a "1" indicates Mig-21 radar has locked on, a "2" indicates Mig 29 radar lock. A corresponding tone will sound in the headset which will change to a louder warning tone if missile tracking radar is detected, indicating a launch.

Perceptronics high fidelity digital aural cue system provides all cockpit sounds and vibration through seat vibration plates. The system is capable of reproducing eight independent sounds simultaneously. The following audio reproduction is included in the ASAT

- radar sensor tones
- missile seeker head search and lock tones
- RWR tones
- engine and air noise and vibration
- missile launch and gun fire
- miscellaneous background radio chatter
- aircraft and target explosions

Each cockpit has a sound computer, mixer, high fidelity two-channel amplifier, two speakers, one sub-woofer and two seat vibration units. Sounds are also selectable to the cockpit headsets.

TASKS

Today you will fly three tasks. For each hop you will have unlimited fuel. You will not have access to any CGI or AWACS information. Your weaponry includes AIM 9J and AIM 9L missiles and a 20mm cannon. The cannon has unlimited rounds; however only four (4) missiles will be allowed in the air at any one time. After that, it takes approximately 30-45 seconds for missile resupply. Remember that the smaller (1 inch) reticle indicates an AIM 9J is selected, while the larger (2 inch) reticle indicates an AIM 9L is selected. The following task briefings will be the only information available to you:

1 v 2 ACM ------> **MISSION 30**

Two bogeys on the nose at 25,000 ft. Goal is two valid face shots on the initial merge. Continue to engage the bogeys until you have killed them, or until the experimenter terminates the hop.

STERN CONVERSION ------> **MISSION 40**

Bogey is 40 miles on the nose at 20,000 ft. Goal is to perform stern conversion and position for a possible AIM 9J missile or gun shot as quickly as possible. Maximum distance for weapons employment is 1500 ft with 15° R to 15° L aspect). NOTE: DO NOT FIRE UNTIL THE EXPERIMENTER ISSUES CLEARANCE. This hop will end when you have killed the bogey or when the experimenter terminates the hop.

EMERGENCY PROCEDURE ("Power Sucker") ------> **MISSION 50**

In this task, you are flying over enemy area suspected of having energy pulse weapons (better know as "power suckers"). If you have been painted by one of these weapons, you will hear (and feel) a constant low rumbling noise indicating that you are about to lose all power. If this happens, the emergency procedure to defeat this weapon is as follows:

- fire energy decoy (missile)
- change heading left 10 degrees
- hit energizer (flare)
- change heading right 10 degrees
- fire energy decoy (missile)
- hit energizer (flare)

If the following procedure is performed exactly, and in the correct order, you will defeat the weapon and your power will be restored. If not, you will crash. Perform the emergency procedure above as quickly as possible. **Remember that you are in enemy airspace and you could encounter hostile bogeys at any time during the mission.**

APPENDIX E

EXPERIMENTAL INTERFACE SOFTWARE

PURPOSE

In order to collect real-time flight performance data from the ASAT, software was developed to allow for data collection and storage within an ethernet network. The EtherLinkII ™ adapters manufactured by 3Com, Inc. were used to create a local-area network (LAN). The software developed for this effort was resident in a i386 PC that was connected to the ASAT LAN. A total of eleven software modules were developed. All software was written in either Microsoft ® *C* (version 7.1) or Miscrosoft ® Assembler (version 5.1). The module names a brief description of their functions are explained below.

1. STAMP.ASM

This file contains subroutines which provides a *C* program with an interface to 3Com's 3L 1.0 routines.

2. NETTO3L.ASM

This file contains subroutines which provide a C program with an interface to the 3L 1.0 routines.

3. MENU.C

This file draws the main menu on the screen. It allows the experimenter to enter items such as subject number, task number, ASAT number.

4. STERN.C

This file draws the menu for the stern conversion task. It allows the experimenter to enter items such as subject number, task number, ASAT number. It also provides organization for the real-time presentation of the task variables being stored.

5. ACM.C

This file draws the menu for the ACM task. It allows the experimenter to enter items such as subject number, task number, ASAT number. It also provides organization for the real-time presentation of the task variables being stored.

6. EP.C

This file draws the menu for the EP task. It allows the experimenter to enter items such as subject number, task number, ASAT number. It also provides organization for the real-time presentation of the task variables being stored.

7. PCCOM.C

This file contains the code which calls the functions provided by the 503.lib to transmit packets to command one ASAT's actions through 3COM EtherLinkii board.

8. POWER.C

This program will control and monitor the performance of the EP sequence. The results of are saved into a data file.

9. S3COM.C

This file augments the access functions for the 3COM ETHERNET board.

10. GETDATA1.C

This file contains the code which calls the functions provide by the 3Com libraries to receive/transmit packets through 3Com EtherLinkii board. ASAT data packets will be read and transformed.

11. GETNAME.C

This file gives allows the experimenter to enter and edit data. It has similar capabilities of a screen editor.

APPENDIX F

ASAT SOFTWARE CONVERSION

1.0 PURPOSE

The ASAT flight simulator was developed as a low fidelity procedural flight trainer. The purpose of this report is to define the methods used to implement the ARTT concept into performance aspects of the F-16, enemy Migs, and all weaponry, thereby making the ASAT time adaptable.

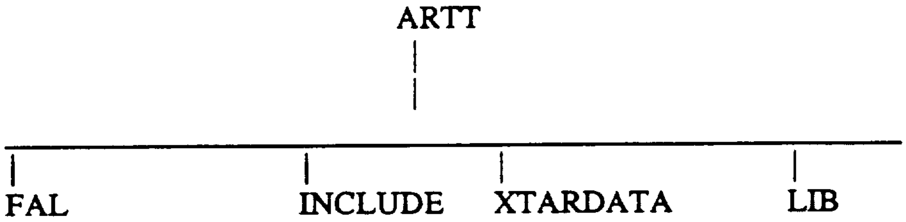
2.0 APPROACH

The variables *F16_ARTT* and *MIG_ARTT*, entered on the command line, are used as multiplication constants in routines which reside in **ASAT.C**. The increased performance of the aircraft and weaponry was accomplished by increasing the initial velocity, speed, and thrust parameters. In addition, several speed and g-force limitations were increased in order to maintain subsonic flight characteristics. The surface deflection equations were also normalized to remain in the subsonic range.

In addition to the actual flight parameters, some additions and modifications were necessary to the display routines, and sort lists used by the XTAR graphics board.

2.1 Building the executable

The file **ART.BAT** resides on the Bernoulli drive in the ARTT/FAL directory. This file contains the **ASAT.MAK** file and the source files necessary to build the executable. One may build the **FAL.EXE** (providing the directory structure shown in the diagram below is maintained) by running the **ART.BAT** file. The **ART.BAT** file requires that the Microsoft "C" compiler, Microsoft macro assembler and Borland Turbo macro assembler are all present and visible from the Bernoulli directory ARTT\FAL. **ART.BAT** will issue the command 'make ASAT.MAK'. This will begin the compilation and produce the **ASAT.EXE** file. **ART.BAT** then renames the executable to **FAL.EXE**.



2.2 Modified Modules

2.2.1 ASAT.C This is the top level "C" program . It initializes all cards and devices and calls **MAIN.ASM**. The need to perform floating point calculations made it desirable to use high level multiplication and divide routines. Therefore, *f16_mult, f16_mult2, mig_mult, mig_mult2, mig_div, and f16_div* were created and placed in this top level "C" module. *F16_mult, mig_mult, mig_div, and f16_div* all accept and return 16 bit unsigned integers. *F16_mult2* and *mig_mult2* accept and return 32 bit unsigned long integers.

2.2.2 F16C.C This module contains all of the routines which control the displays. It contains the XTAR initializing routines to create objects and sort lists necessary for all visuals. Due to the increased speeds and g-forces, all the defines following *gforcehud* were increased by two, also the text speed pointer initialization was modified to accommodate speed displays up to 300, the *apdata* array was increased from 200 long integers to 202 long integers and the procedure *displaygforce* was modified from converting a 2 digit real number into a text display to converting a three digit real number to a text display. This two to three digit display modification necessitated reserving space in the XTAR sort list.

2.2.3 FMODEL.C This module contains all flight equations necessary for the simulation of the F-16. All tables were extrapolated out to 2.0 mach. The procedure *Initmodule* was modified by multiplying the variable *V* (velocity) by *F16_ARTT*. This had the effect of increasing the initial velocity of the aircraft by *F16_ARTT*. The procedure *Module* was modified by limiting the *TEMPB* variable to 2000. This variable was used in the surface deflection equations which began to lose their validity at speeds greater than mach 2. The variable *thrust* is multiplied by *F16_ARTT* and the angle of attack variables *ALPMAX* and *ALPMIN* are calculated using the *F16_ARTT* multiplied g limits *GLIMUP* and *GLIMDN*.

2.2.4 WEAPON.ASM This module contains procedures which pertain to F-16 and Mig weaponry. This includes target locks, flares and chaff, missiles, and bullets. This module also contains the routines to draw tracers and missiles and determine whether or not the target is hit. The missile capabilities are tied to the capabilities of the F-16. The procedure *Mov_missile* was modified by multiplying the *missile_turn* and *missile_accel* variables by *F16_ARTT*, thus eliminating the possibility of the aircraft unrealistically outperforming the missile. The procedure *Move_one_missile* was modified by multiplying the existing limit on *mspeed* (4720*256) by *F16_ARTT*. The procedure *Init_bullets* which is used to initialize the bullet variables, was modified by amending the variable *bspeedX256* to depend upon the *F16_ARTT* multiplied *f16_speedftsecx256* + 1500*256**F16_ARTT*. The procedure *Move_bullet* which updates the bullet variable for display is modified by amending the variable *bspeedX256* to depend upon the *F16_ARTT* multiplied *f16_speedftsecx256* + 1500*256**F16_ARTT*.

2.2.5 F16ASM.ASM This module puts the global variables *ARTT_TEMP* and *ARTT_TEMP2* into the global symbol table. These two variables are used as temporary passing parameters between the assembly and "C" code segments. This is the module which contains the main simulation loop. The procedure *Init_enemy* initializes many of the flight parameters for the

F-16. These include, *f16speed, f16speedx256*, and *f16_thrust* - all of which are multiplied by the *F16_ARTT* constant. The procedure *Redout* checks the F16 *gforce*F16_ARTT* to determine whether the pilot is entering greyout, blackout or redout g_force limitations. Due to the increased speed attainable, the pilot will endure a higher g-force than normal. The procedure *Mig_starter* initializes the flight parameters for the Migs much as the procedure *Init_enemy* did for the F-16. The variables *Mig_thrust, Mig_rpm, Mig_speed*, and *Mig_speedx256* are all multiplied by the *MIG_ARTT* constant. The *Mig_thrust* variable is used to determine whether or not the Mig is employing it's afterburners. The procedure *Get_Mig_data* retrieves the specific Mig data from the general data storage area. The variables in the general storage area are kept in normalized form, therefore the *Mig_speed* and *Mig_speedx256* variable are multiplied by *Mig_ARTT*. The procedure *Get_lock_val* uses the current position, heading, and *thrust*MIG_ARTT* (for acceleration) to determine whether or not a radar lock is obtainable. The procedure *Test_missile_track* uses the *Mig_thrust*Mig_ARTT* variable to seed a random generator which in turn determines whether of not a missile tracking is obtainable.

2.2.6 FLIGHT.ASM This module contains various flight routines for both the F-16 and Migs. It sets up and maintains the plane and general data areas. It also calculates some 2d distances and mig speeds. This module also decreases performance for engine damage and determines plane status. The procedure *Get_factor* uses *mig_speed* (normalized by a call to *mig_divide*) as an index into a gfactor/turnrate table. The procedure *Calculate_Mig_Speed* updates the acceleration vector, and updates *mig_speed* accordingly. The *mig_speed* and *mig_speedx256* variables are multiplied by *MIG_ARTT*. The *Mig_thrust* limits for full throttle are multiplied by *MIG_ARTT*. The procedure *Mig_power* adjusts *mig_thrust*, *mig_rpm*, and the brake factor. The full speed variable is multiplied by *MIG_ARTT* to update the full power variable. Brake factor is 40% of updated speed. The procedure *Move_F16* updates the F-16 position/orientation. The *Max_turnrate* variable is multiplied by *F16_ARTT*. The procedure *Mig_envelope* sets a performance factor based on skill level. *Max_mig_factor* is multiplied by *Mig_ARTT* to increase the skill factor in accordance with increased capabilities.

2.2.7 MANEUVER.ASM This module is the Mig maneuver manager. When a maneuver is either randomly selected or part of a "canned" scenario this module contains the detailed script for each maneuver. The procedure *Climbup* determines the Migs' climb angle. The *mig_speed* limit is multiplied by *MIG_ARTT* before determining the climb angle. The procedure *Divedown* is similar to *climbup*. The *mig_speed* limit is multiplied by *MIG_ARTT*. The procedure *Limitspeed* limits the Migs speed to between 20 and 900 knots. Both the upper and lower limits are multiplied by the *MIG_ARTT* constant.

2.2.8 MATH.ASM This module does most of the trigonometry and g-force calculations. The procedure *Max_g_force* uses the normalized speed (*mig_speed/MIG_ARTT*) as an index into a lookup table. The indexed value is then multiplied by *MIG_ARTT* and returned. The procedure *Calc_F16_gforce* uses the gforce to calculate the required g's for a particular maneuver. The constants used as benchmarks are multiplied by *F16_ARTT*. The procedure *Cat3* calculates the max g's pulled by the F-16. The benchmark constants are multiplied by *F16_ARTT*.

2.2.9 SCENARIO.ASM This module initializes the Migs for each formation (or scenario). The *mig_speed* and *mig_speedx256* variables in each procedure are multiplied by *MIG_ARTT*.

2.2.10 DLSUBS.DLO This module sets the XTAR board sort list size for the various aspects of the head-up display (HUD). The *hudsize* variable was increased by reserving enough space for the tens' place on the *gforcehud* part of the list.

3.0 TESTING

A very simple series of tests were made to determine if the ARTT modifications were effective. In the case of enemy Migs, the F-16 radar screen displays the speed of the target once a radar lock has been established. A "canned" scenario with known speeds was selected and a lock was obtained. Checking the obtained speed with the anticipated speed (using **MIG_ARTT** from the command line), a confirmation was made.

The F-16 effectiveness was made by a quick check of the initial velocity (real time initial velocity was 300 knots) to confirm that the initial velocity was real_time_velocity X F16_ARTT (from the command line). The other variables were confirmed by the "feel" of the aircraft at various values of F16_ARTT as compared to real time. The XTAR and other display modifications were checked by visually inspecting the ASAT HUD display under varying conditions during a scenario.

The missile velocities and turn rates were confirmed by visually inspecting their behavior in comparison with their real time counterparts.

Two mission-qualified F-16 instructor pilots flew the ASAT prior to experimentation. Although these pilots never flew an aircraft (or simulator, for that matter) with the enhanced capabilities provided by the ARTT software, their input concerning general handling characteristics was used in the alterations of the software modules, variables, and procedures described in Section 2.2.

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13. ABSTRACT (Maximum 200 words)

The above real-time training (ARTT®) concept is an approach to teaching high-performance skills. ARTT refers to a training paradigm that places the operator in a simulated environment that functions at faster than normal time. It represents a departure from the intuitive, but not often supported, feeling that the best practice is determined by the training environment with the highest fidelity. This approach is hypothesized to provide greater "transfer value" per simulation trial, by incorporating novel training techniques and instructional features into the simulator. This report discusses two related experiments. In the first, 25 naive male subjects performed three tank gunnery tasks on a simulator under varying levels of time acceleration (i.e., 1.0x, 1.6x, 2.0x, sequential, and mixed). They were then transferred to a standard (1.0x) condition for testing. Every accelerated condition or combination of conditions produced better training and transfer than the standard condition. Most effective was the presentation of trials at 1.0x, 1.6x and 2.0x in a random order during training. Overall, the best ARTT group scored about 50 percent higher and trained in 25 percent less time compared to the real-time control group. In the second experiment, 24 mission-capable F-16 pilots performed three tasks on a part-task F-16A flight simulator under varying levels of time compression (i.e., 1.0x, 1.5x, 2.0x, and random). All subjects were then tested in a real-time environment. The emergency procedure (EP) task results showed increased accuracy for the ARTT groups. In testing (transfer), the ARTT groups not only performed the EP more accurately, but dealt with a simultaneous enemy significantly better than a real-time control group. Although the findings on an air combat maneuvering task and stern conversion task were mixed, most measures indicated that the ARTT groups performed better and faster than a real-time control group. Other implications for ARTT are discussed along with future research directions.

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