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UNITED STATES AIR FORCE ARMSTRONG LABORATORY

ABOVE REAL-TIME TRAINING APPLIED TO AIR COMBAT SKILLS

Peter M. Crane

AIRCREW TRAINING RESEARCH DIVISION
6001 South Power Road, Building 561
Mesa AZ 85206-0904

Dutch Guckenberger

ECC International Corporation
2001 West Oakridge Road
Orlando FL 32809-3801

Brian T. Schreiber
Robert L. Robbins

Hughes Training, Inc., Training Operations
6001 South Power Road, Building 560
Mesa AZ 85206-0904

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AIR FORCE MATERIEL COMMAND
ARMSTRONG LABORATORY
HUMAN RESOURCES DIRECTORATE
7909 Lindbergh Drive
Brooks Air Force Base, TX 78235-5352

NOTICES

PETER M. CRANE
Project Scientist

DEE H. ANDREWS
Technical Director

LYNN A. CARROLL, Colonel, USAF
Chief, Aircrew Training Research Division

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6. AUTHOR(S)

Peter M. Crane
Dutch Guckenberger
Brian T. Schreiber
Robert L. Robbins

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Armstrong Laboratory
Human Resources Directorate
Aircrew Training Research Div
6001 S. Power Road, Bldg 558
Mesa AZ 85206-0904

ECC International Corp
2001 W Oakridge Rd
Orlando FL 32809-3801

Hughes Training Inc
Training Operations
6001 S Power Road
Mesa AZ 85206-0904

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Armstrong Laboratory
Human Resources Directorate
Aircrew Training Research Division
6001 S. Power Road, Bldg 558
Mesa AZ 85206-0904

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Above real-time training (ARTT) is an instructional strategy in which events in a training simulator occur faster than normal. Three experiments were conducted to evaluate applications of ARTT for training air combat skills and emergency procedures. Two of these experiments were conducted with experienced Air Force F-16 pilots who practiced air-to-air radar skills, air intercepts, and emergency procedures using conventional, real-time simulation or ARTT at 1.5 times real time. The pilots trained using ARTT received the same number of training trials but less clock time in the simulator as pilots trained in real time. All pilots were then tested in real time. Pilots trained using ARTT performed radar-skills tasks as well as pilots trained in real time. Pilots trained using ARTT performed emergency procedures tasks more quickly than pilots trained in real time. In a third experiment, student F-16 pilots practiced using air-to-air radar in real time or ARTT. Students trained using ARTT received more training trials in approximately the same amount of clock time as the students trained in real time. ARTT students performed better on a real-time test than students trained in real time. It is concluded that for selected tasks ARTT is more time efficient than conventional, real-time simulation because it allows more events to be experienced within a given period of training time. ARTT also supported better real-time test performance under some conditions.

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PREFACE

This research effort was conducted under Work Units 1123-B3-03, Above Real-Time Training, and 1123-B2-06, Aircrew Training Research Support. The effort was sponsored by the Air Force Material Command, Human Systems Center's Training Technology Planning Integrated Planning Team (Training TPIPT) directed by Lt Col Peter Demitry and Capt Christine Poprik. The effort was supported by Hughes Training, Inc. (HTI), under Contract F41624-95-C-5011. Principal Investigator for Armstrong Laboratory's Aircrew Training Research Division (AL/HRA) was Dr Peter M. Crane; Laboratory Contract Monitor was Mr Daniel H. Mudd. Portions of this research were conducted in cooperation with the National Aeronautics and Space Administration's Dryden Flight Research Center (NASA DRFC) and the University of Central Florida. We would like to thank Rogers Smith and Larry Schilling from NASA DFRC; Vern Carter from Northrop-Grumman Corp.; Matt Schifter, Pedro Claudio, Dale Jewell, Chuck Lutz, Matt Archer, Laura Miller, Soni Basi, and Bud Conyers of ECC. Our special thanks to Jack Kolf from NASA DFRC who originated the concept of above real-time training (i.e., "fast-time simulation") while working on the NASA X-15 and Lifting Body research programs during the 1960s and 70s.

Special thanks go to the pilots of the USAF 68th Fighter Squadron (FS), 69th FS, and the 347th Operations Support Squadron from the 347th Fighter Wing at Moody Air Force Base, Georgia; and the 61st FS, 63rd FS, 308th FS, and 309th FS from the 58th Fighter Wing, Luke Air Force Base, Arizona.

ABOVE REAL-TIME TRAINING APPLIED TO AIR COMBAT SKILLS

1. INTRODUCTION

Design of flight training simulators is often based on the concept that, "transfer of training is highest when similarity of the training and transfer situations is the highest fidelity . . . this is the governing principle for most simulators that are built," (Adams, 1979, p. 717). Although there have been many efforts directed toward discovering when high fidelity simulation is not required for effective training (see Adams 1989, ch 18), there have been almost no attempts to deliberately reduce simulator fidelity in order to increase training effectiveness. In the early 1970s, however, engineers and test pilots at the National Aeronautics and Space Administration's (NASA) Dryden Flight Research Center apparently increased the effectiveness of flight training simulators by deliberately distorting simulated time.

1.1 NASA's "Fast-Time" Simulations

Kolf (1973, Appendix A) and Hoey (1976, Appendix B) briefly document simulator training interventions which were aimed at improving test pilots' ability to keep up with the pace of events in flight. Kolf notes that, "regardless of the type or amount of pre-flight simulator training accomplished by the pilot, the actual flight seems to take place in a much faster time frame than real time," (Appendix A, p. 1). Hoey (1976) reports that in the X-15 program, pilots typically spent ten hours in the simulator for each ten minutes of flight. Even with this preparation, pilots reported that, "It sure seems to happen faster in the real airplane," or, "I had the feeling that I was 'behind the airplane' ", (Appendix B, pp. 2 - 3).

As an experiment, Kolf increased the rate of simulated time in the M2-F3 Lifting Body simulator. The effect of this "fast-time" modification was to increase the pace of events by changing the simulator's time integration factor. In the modified simulator, a mission profile which normally required 10 minutes to complete took place in only 6 minutes, 40 seconds. Unfortunately, the Lifting Body test program was canceled and there were no opportunities for a pilot to fly a mission profile in fast-time before flying the actual mission. However, three experienced M2-F3 pilots flew a familiar mission at 1.5 times real time and all agreed with "enthusiastic responses," (Appendix A, p. 2) that the modified simulator felt exactly like the aircraft.

Hoey (1976) describes further applications of fast-time simulation at NASA. The response of the technical community to Kolf's M2-F3 experiment had been that the physical environment of flight is so different from simulation that it was impossible to draw inferences about training and fast-time. The next application of fast-time, however, was to a flight test program for remotely piloted vehicles (RPV). In this case, the training environment was exactly the same as the actual flight environment. Nevertheless, RPV pilots who used simulation at 1.4 times real time as final preparation before a flight (Appendix B, pp. 5 and 18) reported being, "Less rushed and more confident," (p.18) than when using real-time training exclusively. A typical practice was to conduct 70% of training at real time with the last 30% at 1.4 times real time. Hoey reports, however, that information about these experiments with fast-time simulation was not widely disseminated and no further research was conducted.

1.2 Temporal Plasticity

While there has been little research directly relating apparent time to training, it is well documented that human perception of time is highly adaptable depending on circumstances. Anticipating a pleasant experience (Edmonds, Cahoon, & Bridges, 1981), boredom (DeWolfe & Duncan, 1959), or literally waiting for a pot to boil (Cahoon & Edmonds, 1980) can increase the perceived duration of time. Similarly, adaptation to rapidly paced events seems to decrease the perceived duration of time. Mathews (1978) reports that drivers adapted to freeway speeds travel on city streets 7% faster than non-adapted drivers. Casey & Lund (1987) report that this effect occurs even if freeway drivers are required to stop before entering city streets.

1.3 Applications of Temporal Plasticity

The research on temporal plasticity cited above has concerned the effects of different factors on time perception as a dependent variable. Other researchers have used apparent time as an independent variable. LaBarbera & MacLachan (1979) used a compressor-expander to increase the presentation rate for tape recorded speech without distorting pitch. Subjects listened to radio commercials presented in normal or fast mode and reported greater interest and higher brand name recall for fast mode messages. McLachan & LaBarbera (1978) found increased ratings of reported interest and increased brand-name recall for time-compressed television advertisements.

1.4 Time and Performance in Training

The NASA efforts reported by Kolf (1973) and by Hoey (1976) used time as an independent variable. More typically, research on training uses the time required to complete a task as a dependent measure of skill acquisition. Fitts & Posner's (1967) model of skill acquisition uses time and errors to define three stages in learning a skill. In the first or cognitive stage, the trainee is given instruction in facts and procedures. Performance is slow and errors are frequent. The trainee must rely on declarative knowledge to perform the task. In the second or associative stage, declarative knowledge is transformed into procedural knowledge and errors in understanding are eliminated. Time required for performance is reduced but performance can be disrupted by unexpected events. In the third or autonomous stage, performance is most rapid and error-free. In this stage, performance is entirely based on procedural knowledge and the performer may not be able to verbalize the declarative knowledge used to solve a problem.

The associative and autonomous phases in Fitts and Posner's model correspond well with the phenomenon of controlled vs. automatic processing (see James 1890, Schneider 1985).

> "Automatic processing is a fast, parallel, fairly effortless process that is not limited by short-term memory capacity, is not under direct subject control, and performs well-developed, skilled behaviors. Automatic processing typically develops when subjects deal with the stimulus consistently over many trials.

> Controlled processing is characterized as a slow, generally serial, effortful, capacity-limited, subject-controlled processing mode that must be used to deal with novel or inconsistent information." (Schneider, 1985, pp. 296-297)

Controlled processing is characteristic of a trainee in the associative stage while the autonomous stage demonstrates automatic processing. Klein's (1989) model of recognition-primed decisions and Ericsson & Polsson's (1988) analysis of skilled-memory illustrate the differences in performance between controlled and automatic processing.

Hoey (1976) conducted interviews with test pilots who had experienced above real-time training (ARTT) when participating in the RPV program. These individuals were highly experienced pilots with several thousand flight hours. Automatic processing for flight skills was not an issue. However, to maximize data return from a given test flight, mission profiles were designed to be demanding and to increase pilot workload on successive flights. The pilots reported that using ARTT as the final step in mission preparation helped them feel more confident, less rushed, and better able to handle the workload. They also thought that ARTT should be applied to training high workload tasks such as instrument approaches or emergency procedures and that it could be used to evaluate task planning effectiveness and pilot readiness. Overall, the NASA experience suggests that ARTT as a training strategy provides benefits that result from automatic processing: reduced workload and less time required to complete tasks.

1.5 Recent Research on ARTT

The NASA application of ARTT was limited to experts preparing for specific missions. Manipulating apparent time has been evaluated more recently as an instructional tool using both novices and experienced individuals as trainees.

1.5.1 ARTT applied to training novices. Schneider, Vidulich, & Yeh (1982) and, Vidulich, Yeh, & Schneider (1983) used time-compression to help train air traffic controllers. The task was for the controller to monitor an aircraft's flight path on a radar display and issue turning instructions so that the aircraft would fly through a specific vector. Actual aircraft would traverse 20 nautical miles and require approximately five minutes at 260 knots to complete the turn. These researchers increased the apparent rate of time in the simulator to 20 times real time so that a turn would be complete in approximately 15 seconds. The primary effect of this high level of time compression was to make it easier for the novice controller to see the aircraft's turn. Secondary effects were that the rapid pace of events focused the trainee controller's attention to the immediate task and to allow more training trials per hour than real-time simulation. Vidulich, Yeh, & Schneider (1983) trained university students over four hours to perform a turn point task. A group of students who performed the task in real time using a high-fidelity simulation of an aircraft traveling at 260 knots experienced approximately 32 trials in four hours of training. A group performing the same task using ARTT at 20 times real-time received approximately 260 time-compressed trials followed by only 3 or 4 real-time trials in four hours of training. All trainees were tested at real time for two hours. ARTT subjects showed significantly better performance at initiating turns properly. These authors assert that the ARTT training procedure encourages automatic processing by allowing many trials and training under a mild speed stress.

Guckenberger, Uliano, & Lane (1992) trained novices, university students, in tank gunnery using several ARTT conditions. In this experiment, students were trained in gunnery tasks which required them to detect, identify, and shoot a moving target using an M1 tank part-task trainer. Students received five familiarization trials in real time followed by 15 training trials in real time or in one of four ARTT conditions. Students were then tested in real time. Subjects in all four ARTT groups showed better performance on test trials than the students trained in real time.

Schneider (1989) proposes that the primary effect of time compression is to allow more training trials within a given period of clock time. In the air traffic control studies, subjects were given the same amount of training time in the simulator so that the ARTT subjects received more training trials. In contrast, Guckenberger et al. gave all subjects the same number of training trials so that the ARTT subjects received less training time than the students trained in real time. Since the students trained using ARTT performed better on real-time test trials than students trained in real time, Guckenberger et al.'s results indicate that ARTT has a beneficial effect beyond simply increasing the number of training events. It should be noted, however, that the Guckenberger et al. findings are based on a task familiar to anyone who has played video games, i.e., locate the target, put the cross-hairs on the target, and shoot. In a different study, Guckenberger, Guckenberger, Stanney, & Mapes (1993) used a very unfamiliar task to compare the effects of normal time vs. fast-time training. In this experiment, university students wore a virtual-reality, helmet-mounted display and a gesture recognition glove. Subjects used the helmet-mounted display to watch cubes moving in three-dimensional space. They would also see a representation of their hand which was wearing the glove. Subjects were instructed to touch the hand icon to the cube as quickly as possible. Subjects were trained at either a standard rate of motion or at 1.7 times the standard rate. All subjects then tested at the standard rate. Guckenberger et al. found no evidence for improved performance for the ARTT compared to standard time subjects, however, the perceived workload of the ARTT group was significantly less than that of the standard time group during the testing phase.

1.5.2 ARTT applied to training for experienced individuals. Guckenberger, Uliano, Lane, & Stanney (1992) conducted an experiment using 24 experienced F-16C pilots. The pilots used a low-cost, F-16A trainer to fly several different missions. Pilots trained at real-time, 1.5 times real time, 2.0 times real-time, or with a random mix of apparent times. Pilots then tested at real time. The results for 1 vs. 2 air combat maneuvering and a stern conversion task were inconclusive due to difficulties in scoring the data. A third task required the pilot to engage a bandit and, to perform a complex albeit contrived threat response when a warning was detected. For this third, dual-threat task, the 2.0 times real-time and mixed ARTT groups showed faster threat response than the group trained in real-time and, all ARTT groups achieved significantly more bandit kills during real-time, test trials.

1.6 Summary of Research on ARTT

The reported literature on ARTT is promising but not conclusive. The NASA experience with ARTT strongly suggests that time-compressed simulation can be used to augment conventional simulator training in order to encourage automaticity and reduce pilot workload. Following Fitts & Posner's (1977) three stage model of skill acquisition, NASA's application of ARTT suggests that ARTT should be more useful for the second or associative stage of training rather than for the first or cognitive stage. There is limited experimental evidence to support this position. Schneider, Vidulich & Yeh (1982) and, Vidulich, Yeh, & Schneider (1983) used ARTT with great success with novices as trainees. These studies used an extreme level of ARTT, 20 times real time, in order to time compress events that take too long to see in real-time. The novice subjects in these studies received extensive training on the task suggesting that for much of their training they were in the associative rather than the cognitive stage. Guckenberger, Uliano, & Lane (1992) also trained novices using ARTT. In a tank gunnery task, Guckenberger et al. found that ARTT increased performance on a real-time transfer task. Guckenberger, Guckenberger, Stanney, & Mapes (1993) found that ARTT provided decreased perceived workload but no significant training benefits for novice subjects learning an unfamiliar task. Finally, Guckenberger, Uliano, Lane, & Stanney (1992) found ARTT to be beneficial for a group of experienced pilots in a dual-threat task. A shortcoming of the Guckenberger et al. (1992) study was that the simulator was of such limited capability that threat response training tasks were overly contrived.

Overall, previous research suggests that ARTT should be an effective training strategy for:

a) Tasks which require significant effort at time and workload management, and

b) Trainees who have completed the cognitive portions of skill acquisition.

For this combination of task and trainee, ARTT represents an instructional tool consistent with Schneider's (1985) guidelines for training complex skills, i.e.:

- Design training to allow many trials of critical skills.
- Maintain active participation by minimizing passive observation of the task.
- Train under mild speed stress.
- Train strategies that minimize operator workload.
- Train time-sharing skills for dealing with high-workload environments. (pp. 297-298)

If used inappropriately, ARTT may also violate Schneider's rule that training not overload temporary (i.e., working) memory. Limiting ARTT to trainees who have completed the cognitive stage of skill acquisition should minimize this problem. It is also possible that a time-compressed simulation will be noticeably different from the real world and lead to negative transfer of training.

1.7 Potential Application of ARTT in Air Force Training

The Air Force Material Command's Human Systems Center (HSC) has established a Technical Planning Integrated Product Team (TPIPT) for training to investigate technologies such as ARTT. The TPIPT has proposed that ARTT may benefit Air Force training by:

1. Increasing task performance.
2. Increasing trainee retention of skills.
3. Increased situation awareness.
4. Decreasing real-time workload.
5. Decreasing real-time stress.
6. Increasing the rate of skill acquisition (faster and steeper learning curves).
7. Reduced simulator and aircraft training time.

Research has been conducted to assess whether ARTT can produce the benefits proposed by HSC's Training TPIPT. The present research effort focused on air radar interpretation/air intercept and emergency procedures. Previous research on ARTT has used university students as trainees and/or low fidelity simulators. The research described in this report has employed Air Force F-16 pilots and student pilots, high-fidelity simulators, and training problems which emphasize skills required for air combat.

1.8 Report Organization

Following this introduction, the report contains four major sections:

- Engineering modifications required for changing apparent time in a real-time simulator,
- Experiment 1: ARTT for air combat skills with experienced pilots,
- Experiment 2: ARTT for emergency procedures training with experienced pilots, and
- Experiment 3: ARTT for radar-skills training with student pilots.

The report concludes with a summary and discussion plus recommendations for further research.

2. ENGINEERING FOR ARTT

Modifying real-time simulators for above real-time operations has not proven to be difficult or costly. The major problem has been to overcome misunderstandings regarding the concept of ARTT.

2.1 Definitions

- *Clock time* and *Real time* refer to the unalterable real-world passage of time.

- *Simulator time* is the apparent rate of time in a simulated environment. Most often, simulator time equals real time.

- *Time integration factor or delta_t* refers to the amount of simulator time the simulator assigns to have passed between hardware ticks. This assignment is usually a hard-coded value that the simulation uses for all timing functions. For example, in a real-time simulator operating at 60 Hz, the time integration factor [delta_t] assigned between two hardware ticks would be 1/60th of a second or 16.6 milliseconds.

- *Less than real time* refers to simulator time passing slower than real time. A slow motion movie demonstrates less than real time in that movie presentation time is slower than real time.

- *Above real time, fast-time, or time compression* refers to simulator time passing faster than real time. Time-lapse photography showing a flower's growth for a month in one minute demonstrates above real time.

- *Hyper-time algorithm* is a procedure for alteration of time in a real-time simulator. The hyper-time algorithm provides an interface which allows dynamic manipulation of the time integration factor so that a simulator can be made to operate at less than real-time or above real-time. The *hyper-time factor* is a scalar value which describes the relationship between real time and simulated time. A hyper-time factor less than one results in less than real-time training while a factor greater than one produces above real-time simulation.

2.2 Effects of changing simulator time.

When describing their air traffic control task, Vidulich, Yeh, and Schneider (1983) characterize simulation at 20 times real time as, "simulating an aircraft flying at 5200 knots," (p. 162). While this characterization is easy to understand, it leads to misunderstanding. A fighter aircraft simulator operating at 1.5 times real time might be described as having the aircraft fly at 450 knots rather than at 300 knots. This description is incorrect. An aircraft flying at 450 knots has different handling characteristics such as turn radius than the same aircraft at 300 knots. Also, other systems on-board the aircraft such as radar and other entities in the simulation have not changed their simulated time. More correctly, in a simulation operating at 1.5 times real time, everything happens 1.5 times faster. Ownship moves over the earth faster, the radar antenna sweeps faster, enemy aircraft move faster, and missiles fly faster.

While time compression seems to benefit training, it will lead to simulator effects being physically incorrect. If a simulated aircraft flies at 300 knots and a bank angle of 30°, its turn rate is approximately 126° per minute. When increasing simulated time to 2.0 times real time, indicated speed and turn rate are unaffected while in the physical world; doubling air speed should decrease turn rate by half for a given bank angle. In ARTT at 2.0 times real time, the out-the-window appearance will be that of flying at 600 knots but with a turn rate of 252° per minute of clock time. Such anomalies have the potential for negative transfer of training from ARTT to real-time flight.

2.3 Inappropriate implementation of ARTT

A technique often suggested for implementing ARTT is to instruct the pilot to fly faster. While this will decrease the amount of time available to perform a task, it will also change the task. As described above, aircraft behave differently at different speeds and having a pilot fly a mission segment at 600 knots rather than at a normal 400 knots changes the task leading to the potential for negative transfer of training. Further, the timing events other than ownship position such as radar antenna sweep rate and missile fly-outs will be unaffected.

2.4 Time-Warping algorithms.

Two basic types of algorithms changes have been utilized to implement ARTT. The first method is to change the basic update rate of the system. If a simulator system normally operates at 60 Hz, increasing its update rate to 90 Hz produces ARTT at 1.5 times real time. Modifying a simulator system to change its update rate is a viable technique. Update rate alteration is the technique preferred at NASA Dryden Flight Research. Conversion of the time base by alteration of the update rate requires no alteration to simulation model software and can be implemented without costly changes. As a simple illustration, consider the case where a simulator responds to hardware interrupts 30 milliseconds apart. By altering the hardware interrupts to occur every 22.5 milliseconds, we have produced 1.5X simulation time. Modification using this technique usually requires providing a change to the hardware clock and analysis to confirm sufficient spare processing time to satisfy the predicted update rate. This method is frequently cost effective and requires little change to the software.

The second method is referred to as the Hyper-Time Algorithm, and has been primarily utilized in converting existing simulation systems. These systems are modified by altering the software encoded time integration factor. Specifically, the hyper-time algorithm is a technique for implementing ARTT by altering the amount of assigned simulated time between frame updates. The key to understanding how the hyper-time algorithm functions is understanding that the assigned, simulated time is an alterable value which the simulation model uses for its ownship calculations. When the hyper-time algorithm is operating, the simulation model produces the same number of frame updates as during real-time operation but more or less simulated time has passed between updates. In a system operating at real time, the time integration factor, delta_t, equals the time between hardware updates. As an example, assume that a system operates at 100Hz with delta_t equal to 10 msec (.01 s). By multiplying delta_t by 2, the simulation will calculate the next update as if twice (20 ms) as much time has passed as the real-time simulation (2X above real time). If delta_t is multiplied by 0.25, the simulation will calculate the next update as if one fourth (2.5 ms) as much time has passed as the original (0.25X less than real time). Update rate or frame time is unaffected. A 30 Hz simulator still computes 30 updates per second. When operating in real time, each of the 30 frames are computed as if 33 ms has passed. In 3 times above real time, each frame is computed as if 99 ms have passed. From the pilots' view, aircraft behavior, out-the-window imagery and, instruments are all synchronized to the simulated time. For simulations running at a non-deterministic frame rate, the time constant, delta_t, is calculated between frames by calling an operating system time function each interation and computing the difference between successive times to determine the current frame time (Guckenberger et al., 1995).

2.4.1 Sample implementation of the hyper-time algorithm. The following example describes a procedure for modifying the Silicon Graphics, Inc. (SGI) Flight software for above or less than real time operation. (Flight is a free demonstration included with all SGI products.)

Step 1. Identify the frame rate control function(s). Identify the Executive or portion of code that controls simulated timing of the application. In the case of SGI's Flight, search the source code for "CLOCK."

Step 2. Define a variable called HTA_FACTOR in the declaration portion of the program. Ensure that the HTA_FACTOR is of the same type as the time integration factor to avoid round-off or truncation errors.

Step 3. Modify the simulated time number, "CLOCK", by multiplying by the HTA_FACTOR. SGI's Flight example:
Existing CLOCK_RATE is altered by multiplying by HTA, that is,

```
original    CLOCK_RATE = 40;
modified    CLOCK_RATE = 40 *  HTA_FACTOR
```

(Note: Remove CONSTANT from the header definition of CLOCK_RATE to allow dynamic reassignment of the variable value)

Step 4. Alter user interface to allow the user to input desired HTA_FACTOR. Example:

```
printf("\n  Enter the desired HTA_FACTOR ( float format) \n");
scanf("%f", HTA_FACTOR);
printf("\n  You Entered HTA_FACTOR = ", HTA_FACTOR );
```

Step 5. (Optional) Put error checking code to prevent inadvertent boundary user errors
Example:

```
    if ((HTA_FACTOR > 10) || (HTA_FACTOR < 0.001))
      {confirm_with_user();}
```

A quick test can be conducted to verify implementation of the hyper-time algorithm. In real-time simulation (hyper-time factor equals one), a pilot flies from a known initial position at a constant heading and airspeed and notes the aircraft's location after one minute of clock time. This flight is repeated after implementing a hyper-time factor of 2.0. The pilot should reach the same location after 30 s of clock time.

2.4.2 Potential problems in implementing the hyper-time algorithm.

- Multiple locations or forms for delta_t. Often, the value for the time integration factor is assigned as a variable such as delta_t and all calculations which use time refer to the variable rather than to a specific value. However, it is also possible that there is no single location for the time integration and that the source code must be scrubbed for all instances of time. The time integration factor may also be found in multiple forms. Delta_t may be a constant in a first-order equation but also buried as a coefficient to be used in a difference equation. This is a particular problem for legacy systems which may contain several generations of code.

- Multiple processors. If a simulation system incorporates multiple processors, and the designer did not utilize a master clock, the hyper-time algorithm must be implemented for each. It may be possible, however, to implement above or less than real-time training in such a system by limiting the scope of operations for ARTT. For example, if flight operations are incorporated into one processor and ground operations onto another, it should be possible to implement ARTT limited to flight operations only so that ARTT is stable only while the aircraft is in flight. The separate processes and time constants used for simulating the landing gear would produce catastrophic instabilities if the pilot attempted to taxi, take off, or land. This limitation may or may not be a problem depending on training objectives.

Networked simulators. ARTT within a network of simulators operating under Distributed Interactive Simulation (DIS) protocols, has been accomplished by implementing the hyper-time algorithm on each simulator (Guckenberger et al, 1995). This demonstration was conducted at the 1994 Industry/Interservice Training Systems and Education Conference (I/ITSEC). Four flight simulators, a computer-generated fighter aircraft, and a DIS stealth platform were modified using the hyper-time algorithm to operate at three times real time. The different simulators used different host computers and operating systems and required unique adaptations of the hyper-time algorithm. However, in all cases, the modifications required less than one hour. Additional modifications were required to insure that the DIS dead reckoning algorithms correctly incorporated changes to simulated time. No difficulties with cross-platform compatibility, network stability, or interactions among players such as missile fly-outs were observed. More extensive research is required to determine whether above real-time modifications could be successfully implemented on a more complex network. Also, procedures must be established to assign a hyper-time factor as a component of exercise setup or debrief.

3. EXPERIMENT 1: ARTT FOR AIR COMBAT SKILLS TRAINING WITH EXPERIENCED PILOTS

Previous research suggests that ARTT should be an effective training strategy for: (a) tasks which require significant effort at time and workload management and, (b) trainees who have completed the cognitive portions of skill acquisition. In Experiment 1, the tasks selected required the pilot to employ the F-16's air-to-air radar for beyond-visual-range air combat and to conduct air intercepts. The trainees were active-duty F-16 pilots who are trained in air combat but had few recent opportunities to practice using these skills. The questions evaluated in this experiment were:

1. Is above real-time training as effective as real-time training?

2. Will above real-time training produce better transition to more difficult tasks than normal time training?

3. How will fewer clock hours of above real-time training compare to conventional, real-time training?

3.1 Research methods

3.1.1 Overview. Volunteer F-16 pilots participated in a simulated training session with two tasks: radar skills and air intercepts. In the first task, pilots practiced using air-to-air radar to search and sort radar contacts and to build a picture of bandit aircraft positions and actions. Pilots were instructed to fly their F-16 straight and level, directly into a bandit formation. Pilots were to use their radar to identify the altitude, airspeed, position, and actions of two to six aircraft. The second task required the pilot to fly intercepts using the air-to-air radar. The pilot was instructed to search and sort the bandit formations, select the trailing threat as his target, offset appropriately, and perform a stern conversion. An intercept was scored as successful if the pilot was able to roll out inside a 60° cone of the bandit's tail, within two nautical miles, and with a positive rate of closure. For both the radar skills and intercept tasks, training scenarios were presented in building block format with two simple scenarios followed by two scenarios of medium difficulty and finally three difficult scenarios. Task difficulty was increased by increasing the number of bandits from two to six and increasing the complexity of bandit actions. The experimental sessions were conducted by a former F-16 instructor pilot and squadron commander who acted in the role of evaluator during training. After the participating pilot completed each scenario, the pilot debriefed the evaluator regarding scenario content, actions, positions, and final parameters. The pilot was then informed if any responses were incorrect. The evaluator scored the pilot's performance during run time and a second time during debriefing. After each pilot completed the training trials, he flew five test scenarios for both the radar skills and intercept tasks. The test scenarios were designed to be more difficult in terms of complexity and workload than any of the training scenarios. The evaluator scored each test scenario during run-time and during the pilot's debrief. The evaluator did not provide any feedback to the pilot during test trials. Half of the subjects trained at real time and half trained at 1.5 times real time. All pilots were tested at real time. Pilots were informed that the experiment was an evaluation of ARTT but they were not informed whether they were to receive real-time training (RTT) or ARTT.

3.1.2 Participants. The participants in this effort were 14 active duty, Air Force F-16C pilots from the 347th Fighter Wing at Moody AFB, GA. F-16 experience ranged from 150 h to 1600 h with a mean of 939. Pilots who volunteered for this experiment received temporary duty expenses from Armstrong Laboratory.

3.1.3 Apparatus. An F-16 trainer developed by the ECC International Corporation, Orlando FL, was selected for this experiment. The ECC F-16 simulator was developed for the Air Force Unit Training Device program and later modified for ARTT research. The ECC simulator incorporates F-16 aerodynamics and avionics capabilities with a three-screen, out-the-window, visual display system. The system has the capability to present scenarios in which other aircraft fly in pre-recorded flight paths.

3.1.4 Procedure. Pilots were randomly assigned to the RTT or ARTT group. On arrival at ECC, pilots were briefed on the nature of the evaluation and completed a consent form. All pilots performed the radar skills task first followed by the intercept task.

3.1.4.1 Radar Skills. The objective of radar skills training was to increase pilot proficiency in using air radar to search and sort multiple, maneuvering targets. For the radar skills task, pilots received the following instructions:

> During training and testing of the radar skills task, fly your F-16 on a straight and level course. All bandits in the scenario will fly preplanned routes. Your task is to use the radar as effectively and efficiently as possible to provide you with all of the critical information concerning the inbound bandits. When performing the radar skills tasks, your performance and the evaluator's grading will depend on your ability to:
>
> Search all airspace (surface to 50 k) before the closest bandit is within 40nm
>
> Know the initial picture (number of bandits, formation, aspect, altitude, airspeed).
>
> Determine bandit actions.
>
> Monitor actions.
>
> Know the picture at 20 nm.
>
> Know which bandit is the highest threat.

Pilots were further briefed that the bandits were MiG-23s in air-to-ground roles as bombers. The pilot's F-16 was initialized at 15,000 ft, 450 knots airspeed, and heading 360°. Other initial conditions are specified in Appendix C.

The radar skills portion of the evaluation began with a relatively simple scenario (see Fig. 1). The pilot was to call out radar contacts and bandit actions as they occurred. The evaluator stood just behind the cockpit and could view the radar screen on a video monitor. The run-time scores were recorded on the data sheet in Appendix D.

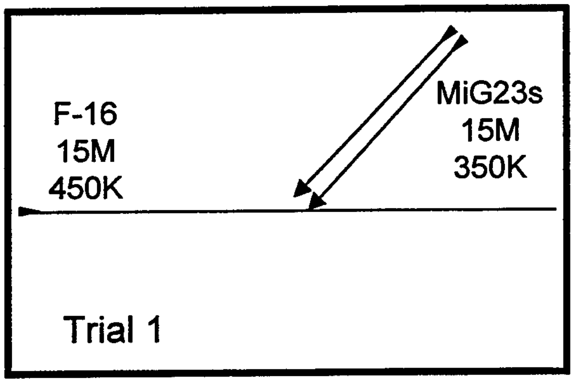

Figure 1. Simple scenario from the radar skills task.

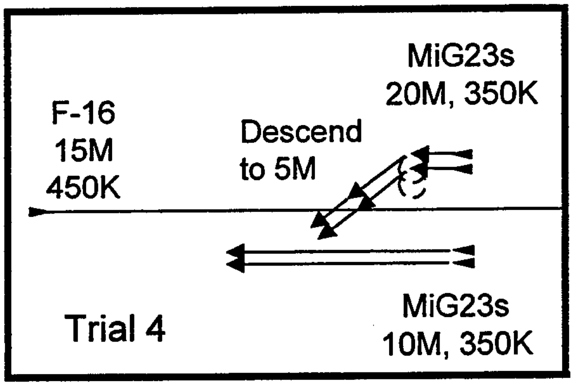

Figure 2. Moderately complex scenario from the radar skills task.

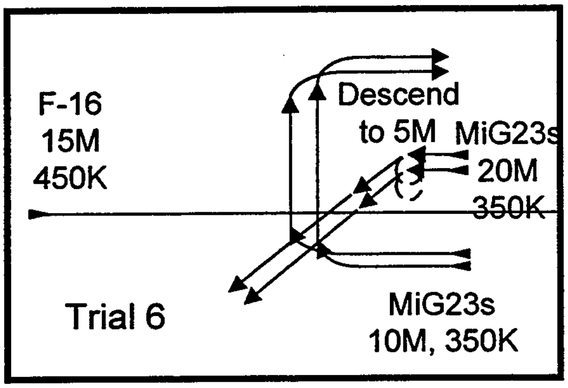

Figure 3. Difficult scenario from the radar skills task.

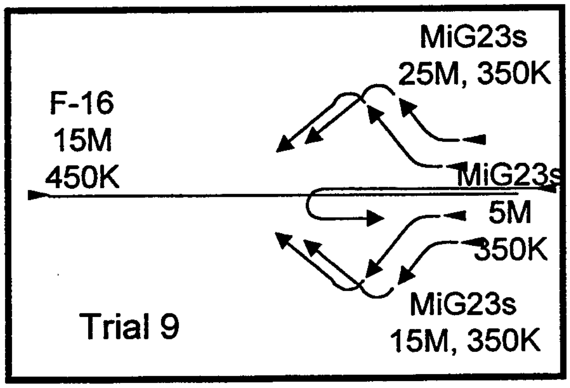

Figure 4. Test scenario (most difficult) from the radar skills task.

The pilot's radar skills performance was scored on a scale of 0 - 3 for each of four sub-tasks: search the airspace and sample the contacts; sort the formations and monitor actions; describe picture at 20 nm; and, target the highest priority threat before coming within 10 nm. Grading criteria were:

3: Performance is correct
2: Performance is essentially correct but late
1: Performance is only partially correct
0: Totally incorrect.

The pilot's scores, 0 - 3, for each of the four sub-tasks were summed for a run-time score of 0 - 12.

After passing the bandit formation, the simulation stopped and the evaluator asked the pilot to debrief the scenario. Debrief consisted of four sub-tasks: describe the initial picture, bandit actions, the picture at 20 nm, and the factors used to determine the highest threat. Debrief performance was scored using the same scale as for the run-time scores. The pilot's scores, 0 - 3, for each of the four sub-tasks were summed for a debrief score of 0 - 12. After the pilot had completed his debrief, the evaluator provided feedback on the scenario.

After completing two relatively simple scenarios, the pilot flew two moderately complex scenarios followed by three more complex scenarios (see Fig. 2 and 3). At the completion of training, the pilot completed a NASA TLX questionnaire which measures subjective workload (Appendix E). After completing the TLX, the pilot was informed that the next five scenarios would constitute the test phase. These scenarios were designed to be more difficult than any of the training scenarios (see Fig. 4). No feedback was offered after the test scenarios. All pilots were tested in real time, however, the ARTT pilots were not informed that simulated time had changed. Test scenarios were scored as during training. After completing radar skills test, the pilot completed a second TLX and then took a break.

3.1.4.2 Intercept Task. The intercept task was similar to the radar skills task except that the pilot was instructed to target the trailing threat, select an offset, and perform a stern conversion in order to visually identify the bandit. Run-time scores were recorded for seven sub-tasks: search airspace, sample contacts, sort formation and monitor action, target the trailing threat, obtain proper offset, convert to stern (within 30° and 6000 ft) and, shoot within parameters (see Appendix D). The evaluator used the same grading criteria as for the radar skills task. The pilot's scores (0 - 3) for each sub-task were summed for a run-time score of 0 - 21. After completing each intercept, the pilot debriefed the evaluator. Debrief consisted of four sub-tasks: describe the initial picture, bandit actions, the picture at 20 nm, and the factors used to determine the highest threat. Debrief performance was scored using the same criteria as for the run-time scores. The pilot's scores, 0 - 3, for each of the four sub-tasks were summed for a debrief score of 0 - 12. After the pilot had completed his debrief, the evaluator provided feedback on the scenario. Pilots flew intercept scenarios which were arranged in building block format as with the radar skills task; i. e., two simple trials, two moderately complex trials, followed by three difficult trials. After completing intercept training, pilots completed a third TLX workload questionnaire and then began the test phase. The test phase consisted of five intercepts presented at real time for all pilots without feedback from the evaluator. Immediately following the last intercept test scenario, a final TLX questionnaire was administered.

Following completion of the intercept phase, the experiment concluded with a final debriefing to the pilot explaining the specifics of the evaluation. Total time for this experiment was approximately three hours providing all systems remained operational.

3.2 Results

3.2.1 Radar Skills Task Performance. Run-time and debrief scores for the radar skills task were transformed to percent of maximum possible score. Scores for training and test trials were pooled into three blocks of scenario difficulty: training trials 1-4 which were scenarios of simple to moderate complexity, training trials 5-7 which were difficult scenarios, and test trials. Mean percent run-time scores and debrief scores for these three blocks of trials (levels of scenario difficulty) are plotted on Figures 5 and 6.

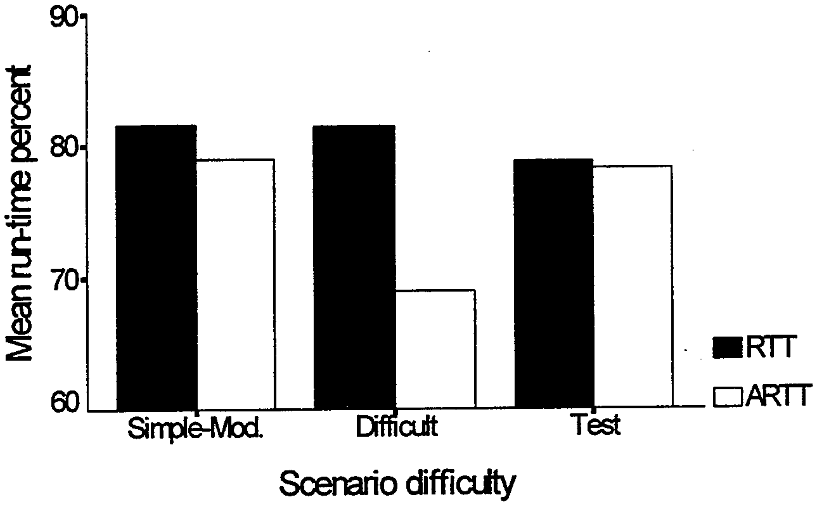

Figure 5. Mean run-time percent scores for radar skills task.

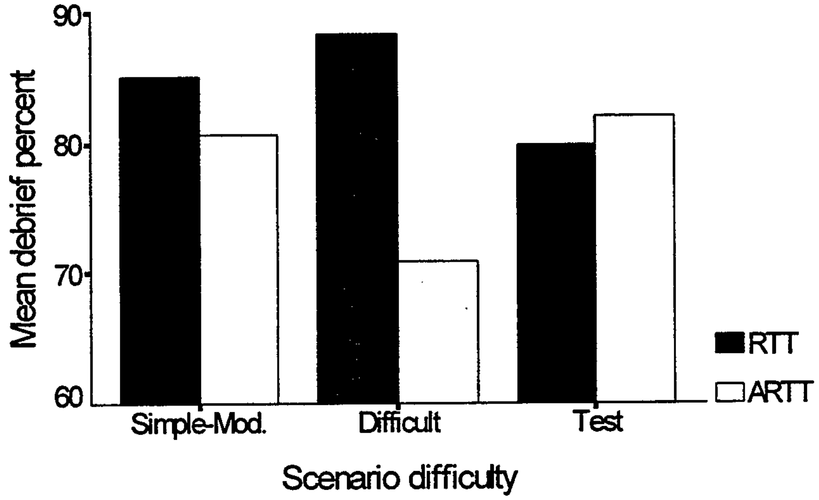

Figure 6. Mean debrief percent scores for radar skills task.

Test performance between the RTT and ARTT groups was not significantly different for either the run-time scores, $\overline{X}_{RTT} = 79\%$, $\overline{X}_{ARTT} = 78\%$, *ns*, or for debrief scores, $\overline{X}_{RTT} = 80\%$, $\overline{X}_{ARTT} = 82\%$, *ns*. There is a significant interaction between training group and scenario complexity for both run-time scores, $F(2,24) = 6.39, p = .006$, and for debrief scores, $F(2,24) = 11.24, p < .001$.

For run-time scores (Fig. 5), radar skills performance for pilots trained in real time did not change significantly as scenario complexity increased, $F < 1$. However, run-time scores for pilots trained using ARTT changed significantly across trials, $F(2,24) = 11.29, p < .001$. Least significant difference (LSD) tests show that run-time scores for difficult trials were significantly lower than scores for simple and moderate trials, $t(24) = 3.75, p = .001$, and for test trials, $t(24)$

$= 3.70, p < .001$. Scores for simple and moderately complex trials were not significantly different from scores for test trials, $t(24) = 0.07$.

Debrief scores (Fig. 6) show significant change across levels of scenario difficulty for both pilots trained in real time, $F(2,24) = 3.60, p = .043$, and ARTT, $F(2,24) = 31.08, p < .001$. For pilots trained in real time, LSD tests show that there is a significant decrease in debrief scores between the difficult training trials and the test trials, $t(24) = 2.87, p = .008$. The differences in debrief scores for pilots trained in real time between the simple–moderately complex trials and the difficult trials, $t(24) = -1.12, p = .28$, or between simple–moderate and test trials $t(24) = 1.0, p = .33$) are not significant. For pilots trained using ARTT, there is a significant decrease in debrief scores between simple–moderately complex trials and difficult trials, $t(24) = 3.32, p = .003$, and a significant increase in scores between the difficult training trials and test trials, $t(24) = -3.78, p = .001$. The difference between debrief scores on the simple–moderate training trials and test trials, $t(24) = 0.45$ is not significant.

3.2.2 Intercept Task Performance. One pilot was unable to complete the intercept task due to equipment failure. Run-time and debrief scores for the intercept task were transformed to percent of maximum possible score. Scores for training and test trials were pooled into three blocks of scenario difficulty: training trials 1-4which were scenarios of simple to moderate complexity, training trials 5-7 which were difficult scenarios, and test trials. Mean percent run-time scores and debrief scores for these three blocks of trials (levels of scenario difficulty) are plotted on Figures 7 and 8.

Test performance between the RTT and ARTT groups was not significantly different for either run-time scores, $\overline{X}_{RTT} = 74\%$, $\overline{X}_{ARTT} = 73\%$, *ns*, or debrief scores, $\overline{X}_{RTT} = 71\%$, $\overline{X}_{ARTT} = 85\%$, *ns*. There were no significant differences among the intercept run-time scores (Fig. 7) due to training group, $F < 1$, level of scenario difficulty, $F < 1$, or the group by difficulty interaction, $F(2, 22) = 1.21$, *ns*. There were no significant differences among the intercept

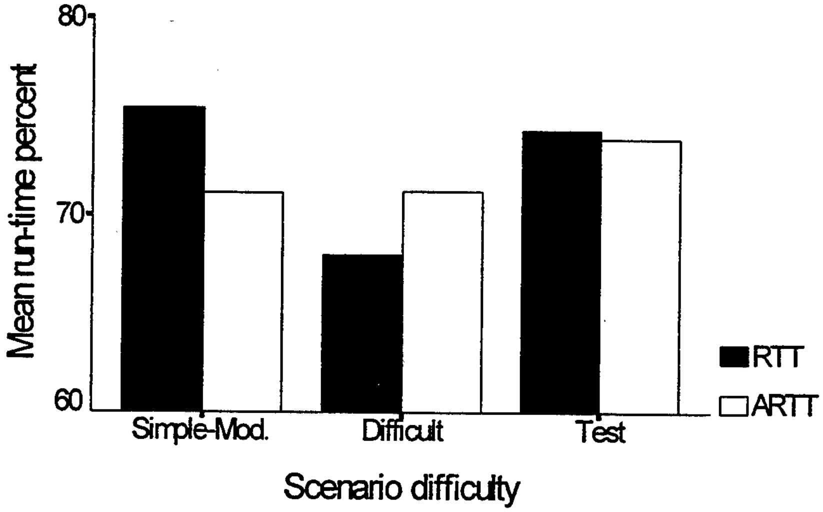

Figure 7. Mean run-time percent scores for intercept task.

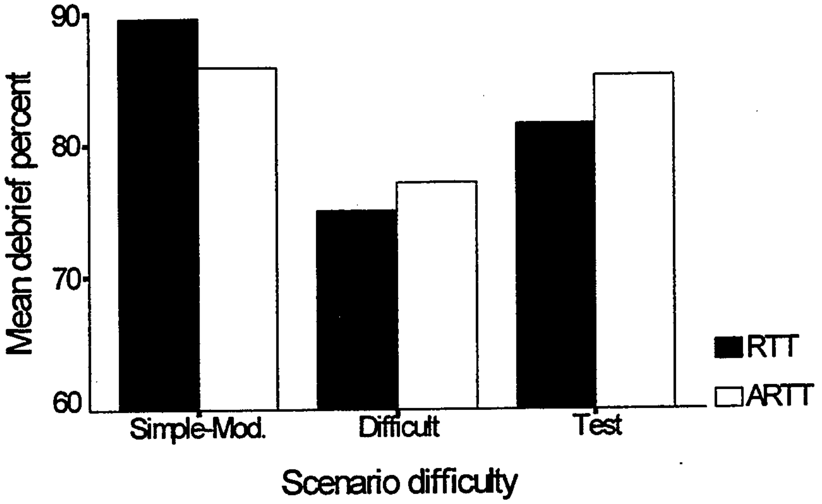

Figure 8. Mean debrief percent scores for intercept task.

debrief scores (Fig. 8) due to training group, $F < 1$, or the training group by level of difficulty interaction, $F = 1$. There were significant differences in debrief scores among the levels of scenario difficulty, $F(2,22) = 10.45, p = .001$. LSD tests show that debrief scores significantly decreased between the simple–moderately complex trials and the difficult trials, $t(22) = 4.46, p < .001$, and significantly increased between the difficult training trials and test trials, $t(22) = -2.86, p < .001$. The difference between debrief scores for the simple–moderate trials and test trials was not significant, $t(22) = 1.59$, *ns*.

3.2.3 TLX ratings. Pilots completed a TLX workload rating form (Appendix E) after radar skills training, radar skills testing, intercept training, and intercept testing. This form asked pilots to rate the perceived effect of six different demands (workload categories) on their performance: physical demands, time pressure, interpreting radar, switchology, flying the aircraft, and frustration. TLX ratings were compared by training group (RTT vs. ARTT), TLX workload category, and time of rating. Training group did not significantly affect overall workload ratings, $F(1, 11) = 1.21$, *ns*. Workload ratings were also not significantly affected by the interactions of training group with workload category, $F(5, 55) = 1.05$, *ns*; training group with time of rating, $F < 1$; or training group by workload category by time of rating, $F(15, 165) = 1.71$, *ns*. Workload ratings were significantly influenced by the interaction of workload category and time of rating, $F(15, 165) = 3.93, p < .001$. Mean TLX ratings for the different workload categories and rating times are presented on Figure 9. Of the six workload categories, only flying the aircraft, $F(3, 36) = 9.96, p < .001$, and frustration level, $F(3,36) = 5.89, p = .002$, were significantly affected by time of rating. For both of these demands, there was a significant increase in rated workload between the radar skills task and the intercept task: flying the aircraft, $F(1,12) = 11.99, p = .005$, frustration level, $F(1,12) = 8.39, p = .013$.

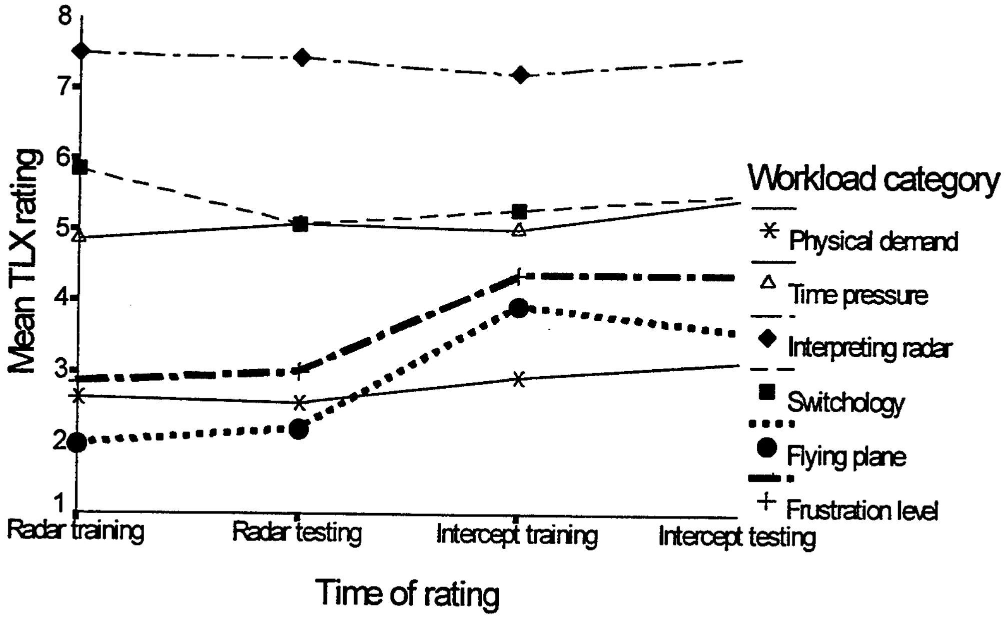

Figure 9. Mean TLX ratings for each workload category and time of testing.

3.3 Discussion

The questions which were evaluated in this research were:

1. Is above real-time training as effective as real-time training?
2. Will above real-time training produce better transition to more difficult tasks than normal time training?
3. How will fewer clock hours of above real-time training compare to conventional, real-time training?

3.3.1 Training effectiveness of ARTT. RTT and ARTT resulted in equal performance on the real-time test trials for both the radar skills and intercept tasks, however, performance on training trials for the radar skills task was degraded by ARTT. For the simple and moderate scenarios, the ARTT pilots were able to maintain their performance while coping with the increased time pressure. When the task became more difficult, their performance scores decreased. Viewed from this perspective, ARTT may save training time but at the cost of poorer performance in the training simulator for the most demanding tasks.

3.3.2 Transition to more demanding, real-time tasks. The rationale for ARTT, however, is more than reducing training time. The experience of NASA test pilots who first used ARTT was that the demands of ARTT in the simulator provided better training for flying the actual aircraft than normal simulator training. One hypothesis is that simulator training is inherently less demanding than actual flight and that ARTT replaces some of the demands of flight with additional time pressure. This evaluation mimics the transition from simulator to aircraft by a within-simulator transfer of training design in which task demands increase from training to test conditions (see Fig. 1 - 4). Test scenarios were more complex than any of the training scenarios and testing was conducted in normal time. Pilots who trained in real time showed no significant change in performance from training to test trials for radar skills run-time scores (Fig. 5) and showed a significant decrease in performance for debrief scores (Fig. 6). ARTT pilots improved performance on the radar skills task when transitioning from above real time to normal time even though the test scenarios were more complex than the scenarios used in training (Fig. 5 and 6). However, test trial performance of pilots trained using ARTT was not significantly better than performance of pilots trained in real-time. While ARTT trained pilots performed the test trials as well as the real-time-trained pilots, there is no support for the hypothesis that ARTT provided better training than conventional, real-time simulator training.

This conclusion is further supported by the TLX workload rating data. Based on the NASA experience with ARTT, it would be predicted that ARTT pilots would report lower levels of workload, particularly time pressure, when transitioned from above real-time training trials to real-time test trials. The interaction effects of training group with time of rating or of training group by time of rating by workload category were not significant. The only factor which significantly affected workload ratings was the transition from the radar skills task in which pilots were instructed to fly straight and level to the intercept task in which pilots performed an offset and stern conversion. For the intercept task, all pilots reported significant increases in effort for flying the aircraft and in frustration level. Using the present experimental protocol in which pilots immediately transitioned from ARTT to real-time test, there were no reported decreases in workload.

The results from the intercept task show that ARTT may not be beneficial for all training problems. Unlike the radar-skills task, there is no training-group by scenario difficulty interaction for the intercept task (Fig. 7 and 8) even though the intercept scenarios progressed from simple to difficult in the same manner as the radar skills scenarios. Further, debrief scores for intercept training show a significant decrease for both RTT and ARTT pilots as the scenarios become more demanding. Test performance was not significantly different for either run-time or debrief scores between the RTT and ARTT groups nor was there a significant change in performance scores from training to test. For the intercept task, pilot performance seems to be insensitive to the demands of above real-time training. For all pilots, performance was highly sensitive to increasing task complexity. Review of the exact procedures used in the experiment is required to understand the discrepancy between the results of the two tasks. All pilots participated in the radar-skills task before the intercept task. Therefore, pilots had over an hour's practice at using their air-to-air radar before beginning to fly intercepts. All pilots were therefore able to use their radar effectively to build the picture of bandit actions. The evaluator who observed and scored pilot performance in this research noted that the variability in intercept scores did not result from differences in time management or radar employment but from differences in selecting an offset. Pilots who selected an offset which provided a tactical advantage nearly always received high scores while pilots who selected a less advantageous offset or who offset at the wrong time received poorer scores.

The radar skills data show that ARTT can be as effective as real-time training for tasks which emphasize time and workload management. The intercept data show that ARTT is probably much less effective for tasks which emphasize other skills, in this case, tactical decision making. While ARTT may be effective for training a pilot to quickly gather and integrate information, other instructional strategies such as case study, video debrief, or freeze and reset may be more effective for teaching decision making skills.

3.3.3 Effect of ARTT on time required for training. The final issue is whether ARTT saves training time, i.e., clock hours in the simulator. Given that the simulator was operating at normal time or 1.5 times normal time, the ARTT group received only two thirds the time in the simulator of the RT group. Since test trial performance was not significantly affected by training group, the hypothesis that ARTT can provide effective training with fewer clock hours of simulator time is supported.

3.4 Experiment 1: Conclusions

1. ARTT was more difficult than conventional, real-time simulator training. The effect of increasing time pressure was poorer task performance in the simulator particularly for demanding tasks.

2. Pilots trained using ARTT were able to perform a very demanding task as well as pilots trained in normal time even though they received only two thirds of the simulator time.

3. The effect of ARTT was dependent on the skills required to perform a task. In this experiment, ARTT had greater effect on a task which required information gathering, switchology, radar interpretation, and time and workload management. A task that required tactical decision making was unaffected by ARTT.

4. EXPERIMENT 2: ARTT FOR EMERGENCY PROCEDURES TRAINING WITH EXPERIENCED PILOTS

Experiment 1 demonstrated that ARTT at 1.5 times real time supported training some of the skills necessary for effective air combat as well as real-time training with fewer clock-hours of simulator time. A second interest of the Human Systems Center's TPIPT is the potential application of ARTT to emergency procedures (EP) training. Simulator-based training for emergency procedures allows the pilot to practice performing tasks which may never be performed in the aircraft but if required, must be performed correctly and promptly. ARTT may enhance simulator training for emergencies by increasing automaticity and decreasing workload. The result should be faster responses to emergencies and better performance on a secondary task.

4.1 Research methods

4.1.1 Overview. For this experiment, pilots conducted single-ship, defensive counter-air missions over a ground target using two scenarios. In one scenario, single emergency, the pilot's aircraft suffered engine failure. The pilot's task was to restart the engine and then to engage an incoming bandit. In the other scenario, multiple emergencies, the pilot has to clear an indication that equipment was overheating, restart a failed engine, respond to a warning light, and engage two bandits in succession. Pilots received initial training in real time followed by additional practice in real time or at 1.5 times real time. All pilots were then tested in real time. The dependent measures were time required to correct emergencies and time required to kill the bandits.

4.1.2 Participants. The participants in Experiment 2 were 12 of the 14 pilots who participated in Experiment 1. Two pilots were unable to complete Experiment 2 due to equipment failure.

4.1.3 Apparatus. The F-16 simulator used in Experiment 1 was also used in Experiment 2. The bandit aircraft were flown by an automated threat system integral to the ECC F-16 trainer.

4.1.4. Procedure. Pilots were randomly assigned to either the RTT or ARTT condition. All pilots received familiarization training in the ECC F-16 simulator in real time. Familiarization consisted of flying vertical-S maneuvers, 90° turns, and loops. After familiarization, pilots were trained and tested in one of the two emergency conditions (single or multiple) selected at random. After a break, the pilot was trained and tested in the other condition. For both conditions, pilots received initial training in real time until they could complete the task without failures or re-starts. Typically, initial training required three or four trials. Data from these trials were not analyzed. Six additional practice trials were then conducted in real time or above real time. Finally, all pilots received four real-time, test trials using the same scenarios as used in training.

4.1.4.1 Single emergency. Pilots were initialized at 2000ft above ground level (AGL) and 480 knots inbound toward a power plant which they were tasked to defend against air assault. Shortly after the trial started, the F-16's engine failed and the pilot had to restart using established procedures. Immediately after restart, the pilot engaged a MiG-29. The trial ended when the F-16 pilot or the bandit was killed. Dependent variables were time to restart engine and time to kill the bandit.

4.1.4.2 Multiple emergency. The multiple emergency task was similar to the single emergency except the pilot first had to check an equipment hot indicator light, restart a failed engine, acknowledge another indicator light (hydraulic failure), and then engage a MiG-29 followed by a second MiG-29. Dependent variables were time to respond to the equipment hot light, time to restart the engine, time to respond to the hydraulic failure indicator light, and time to kill both bandits.

4.2 Results

4.2.1 Single emergency. Mean time to restart the engine and time required to kill the bandit on test trials are plotted on Figure 10.

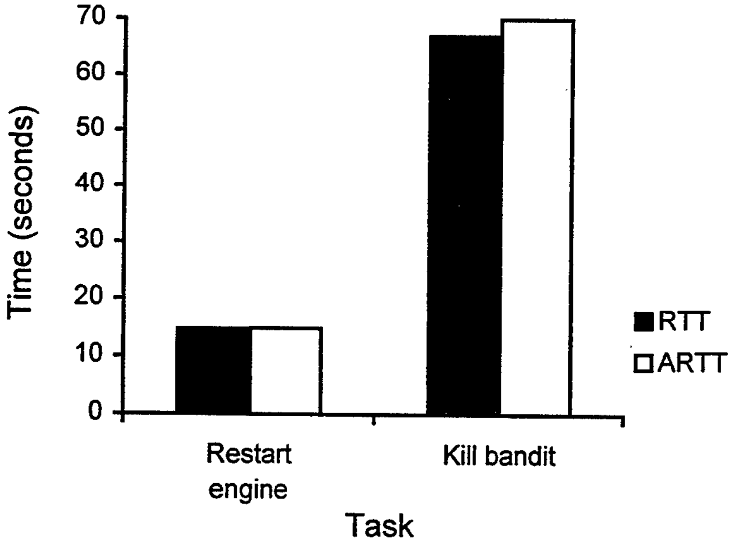

Figure 10. Mean time to restart engine kill bandit for test trials.

Test performance on both variables was not affected by training condition. Time required to restart the failed engine, *t(11) = 0.08, ns*, and time required to kill the bandit, *t(11) = 0.4, ns*, were not significantly different between the RTT and ARTT pilots.

4.2.2 Multiple emergency. Mean time on test trials to respond to the equipment hot light, time to restart the failed engine, time to respond to the hydraulic failure light, and time to kill both bandits are plotted on Figure 11. For performance on test trials, time to clear the equipment hot light was not significantly affected by training condition, *t(11) = 1.65, ns*. However, times required to restart the failed engine, *t(11) = -4.54, p < .001*, respond to hydraulic failure, *t(11) = -4.93, p < .001,* and kill both bandits, *t(11) = -2.76, p = .018*, were all significantly less for pilots trained using ARTT than for pilots trained using RTT.

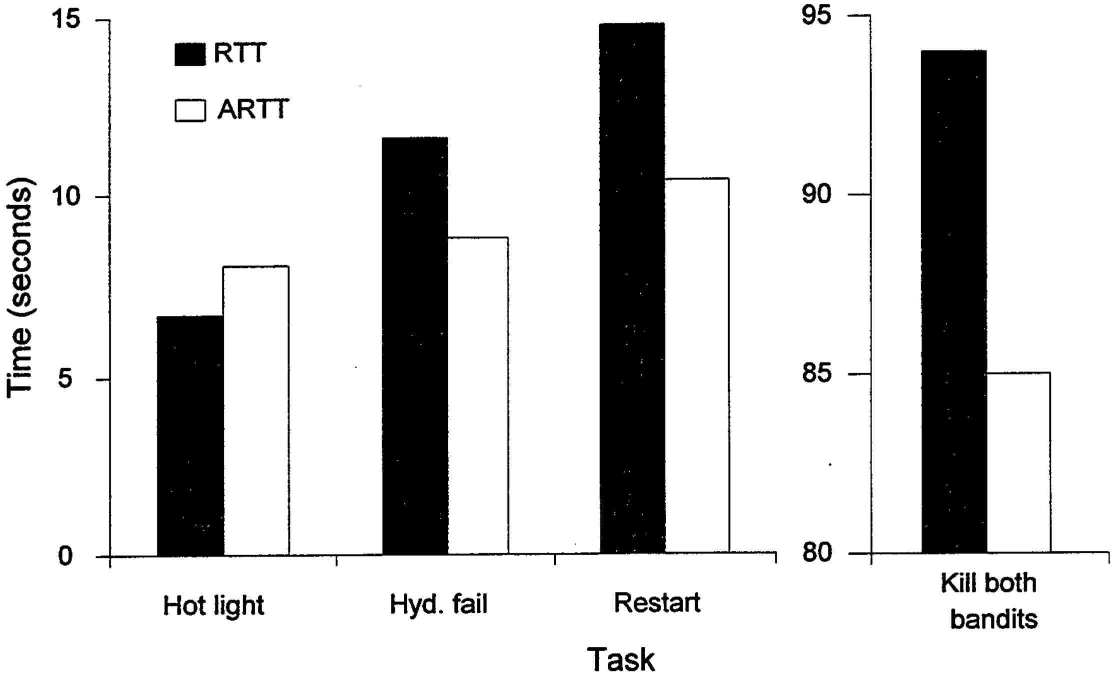

Figure 11. Mean time to respond to multiple emergencies on test trials.

4.3 Discussion

The ARTT pilots in Experiment 2 replicated the training procedures used by NASA in that the pilots first experienced initial training in real-time followed by additional trials at 1.5 times real-time. The RTT pilots in experiment 2 received all training trials in real-time. The experience of NASA pilots in the F-15 RPV program was that ARTT provided better preparation for highly demanding missions than real-time simulation. In Experiment 2, ARTT was more time efficient than RTT for the single emergency task but provided no other training benefit. Pilots in the single emergency task performed engine restarts and defeated a bandit aircraft as quickly as pilots trained in real-time but no faster. However, in the more complex multiple emergency task, pilots who practiced using ARTT were able to perform two of the three required emergency procedures and, killed both bandit aircraft significantly faster than pilots who trained in real time. For the experienced F-16 pilots in experiment 2, the single emergency task which consisted of restarting the engine and engaging a single bandit was not especially demanding. ARTT provided no training advantage for this task other than reducing the amount of clock-time required to complete a given number of practice scenarios. The multiple emergency task was more demanding of the pilot's time and workload management skills. For this task, practice using ARTT after initial training in real time helped the pilot to perform the emergency procedures and to successfully engage both bandits significantly faster than pilots who received all of their training in real time.

4.4 Experiment 2: Conclusions

The results of the Experiment 2 support the hypothesis that ARTT provides improved training for some emergency procedures compared to conventional, real-time training. Pilots trained using ARTT performed responses in the single emergency task as well as pilots trained in real-time. ARTT was more efficient than real-time training in that pilots trained using ARTT were able to perform on test trials as well as pilots trained in real time but with less training time. For the more demanding multiple emergency task, pilots trained using ARTT performed emergency responses faster than pilots trained using RTT for three of the four dependent variables. ARTT provided better training than real-time training provided that: a) the tasks being trained are highly demanding of a pilot's time and workload management skills, and b) the pilot has received initial training in real-time.

5. EXPERIMENT 3: ARTT FOR RADAR SKILLS TRAINING WITH STUDENT PILOTS

In Experiments 1 and 2, the trainees were mission-ready fighter pilots who were well trained in the tasks that were simulated but lacked recent experience. For these trainees, ARTT produced equal or better test performance with less training time than real-time simulation. The results of Experiments 1 and 2 suggest that ARTT could increase time efficiency within a squadron continuation training program designed to maintain or improve proficiency for seldom practiced skills. In Experiment 3, the training benefits of ARTT were assessed with student pilots in a Formal Training Unit (FTU). In this experiment, the radar-skills task from Experiment 1 was used as a supplement to an existing training syllabus. Students practiced radar skills within a mission context after they had successfully completed the air-to-air portion of the F-16 FTU syllabus. Further, in Experiments 1 and 2, all pilots received the same number of training trials with the ARTT pilots receiving less time (clock hours) in the simulator than the pilots trained in real time. In Experiment 3, ARTT pilots received more training trials using approximately the same amount of clock-time in the simulator than the pilots trained in real time. In this respect, Experiment 3 replicated the procedure used by Vidulich, Yeh, and Schneider (1983) who used ARTT to provide more training in a given time period than could be provided using real-time simulation.

5.1 Research methods

5.1.1 Overview. The radar-skills task from Experiment 1 was modified for use with student pilots. The major changes were increasing the number of training scenarios from 7 to 15 and eliminating the TLX workload ratings. Also, pilots assigned to the RTT condition received 10 training trials while pilots assigned to the ARTT condition received 15 training trials. Both conditions required approximately 30 minutes of simulator time. Experiment 3 was designed to assess whether ARTT is an effective training strategy for use with advanced student pilots and, whether using ARTT to increase the number of training trials will increase the effectiveness of training.

5.1.2 Participants. The participants in this experiment were 24 students in the F-16C training course at Luke AFB, AZ. All participants were new to the F-16 with between 40 and 130 F-16 hours. Of the 24 pilots, 19 had no previous Air Force flying experience other than Undergraduate Pilot Training and Lead-in Fighter Training for a total of 260 to 615 flight hours. The remaining pilots had previous assignments in other aircraft which were not equipped with air-to-air radar. These pilots had 1500 to 2100 hours in other aircraft but only 50 to 100 F-16 hours. All pilots had completed the air-to-air portion of training and had successfully completed simulator and aircraft sorties requiring use of the air-to-air radar.

5.1.3 Apparatus. The Armstrong Laboratory Air Intercept Trainer-Plus (AIT+) was selected for Experiment 3. The AIT+ is an Armstrong Laboratory F-16 Air Intercept Trainer which has been modified by replacing the computing hardware and software with components from the Armstrong Laboratory Multi-Task Trainer (Boyle & Edwards, 1992). The AIT+ is a high-fidelity, F-16C simulator limited to air-to-air operations. The AIT+ incorporates flight, engine, and radar simulations, with hands-on-throttle-and-stick (HOTAS) controls, a radar display, radar control panel, and a color monitor which includes a heads-up display (HUD) and a limited out-the-window display. For this experiment, the AIT+ operated in autopilot mode in that the aircraft's altitude, airspeed, and heading were fixed. The pilot's only task was to use the radar.

5.1.4 Procedure. Pilots were randomly assigned to the RTT or the ARTT group. Pilots were given instructions on the radar skills task as described in section 3.1.4.1 above except that the aircraft was flying on autopilot. Also, the scoring procedure was modified slightly. Rather than asking the pilot to describe the picture at 20 nm, pilots in Experiment 3 were asked to describe the picture after bandit maneuvers (actions). See Appendix D for sample score sheet. As in Experiment 1, all pilots were scored on two dependent measures for each scenario: scores recorded by the evaluator during run-time and, scores recorded by the evaluator while the pilot debriefed the scenario. Unlike Experiment 1, pilots received 10 or 15 training scenarios. Pilots in the RTT condition received two relatively simple scenarios, three moderately complex scenarios, and five complex scenarios. Pilots in the ARTT condition received the same simple, moderate, and complex scenarios plus five additional complex scenarios for a total of 15 training trials. All pilots were tested in real time on five scenarios which were more complex than any of the training scenarios. After completion of the test scenarios, pilots 12 through 24 were asked to estimate whether the training trials were presented in real time or above real time and, whether the test trials were presented in real or above real time. Total time for the experiment was approximately two hours.

5.2 Results

Scores for training and test trials were grouped into blocks depending on scenario difficulty. Trials 1 - 5 were grouped as simple-moderate complexity scenarios, trials 6 - 10 as difficult, and trials 11 - 15 also as difficult but for the ARTT group only. Trials 16 - 20 were test trials and were designed to be more difficult than any of the training trials. Mean percent scores grouped into blocks are plotted for run-time scores on Figure 12 and for debrief scores on Figure 13. Test performance was not significantly different between the RTT and ARTT groups for run-time scores ($\overline{X}_{RTT} = 77.5,\ \overline{X}_{ARTT} = 81.7,\ t(22) = 1.97, p = .062$). For debrief scores, test performance for the ARTT group was significantly higher than for the RTT group ($\overline{X}_{RTT} = 75.8,\ \overline{X}_{ARTT} = 82.5,\ t(22) = 2.38, p = .026$).

Comparing scores on training trials and test trials, run-time scores for the ARTT group show significant increase from training to test ($F(1, 11) = 19.64, p = .001$) while for the RTT group there is no significant change in run-time scores from training to test ($F(1, 11) = 1.44, p = .256$) see Figure 12. For debrief scores, the ARTT group shows a significant increase from training to test ($F(1, 11) = 10.76, p = .007$) while the RTT group shows a significant decrease ($F(1, 11) = 38.71, p < .000$), see Figure 13.

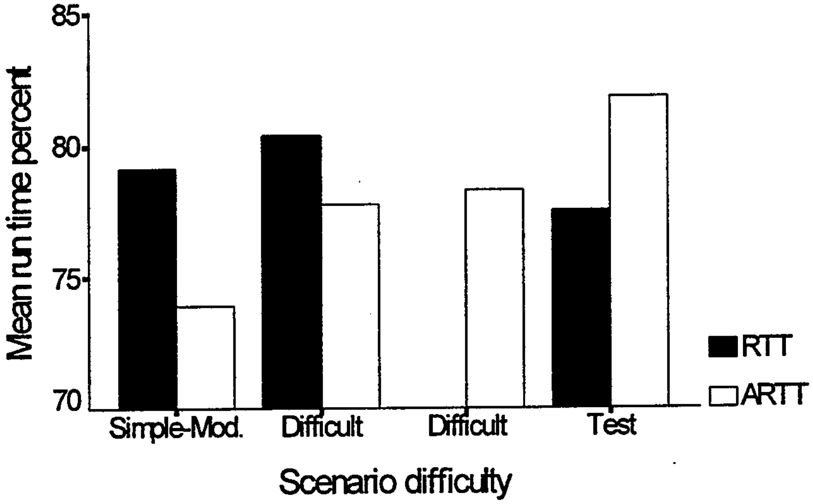

Figure 12. Run-time scores grouped by scenario difficulty.

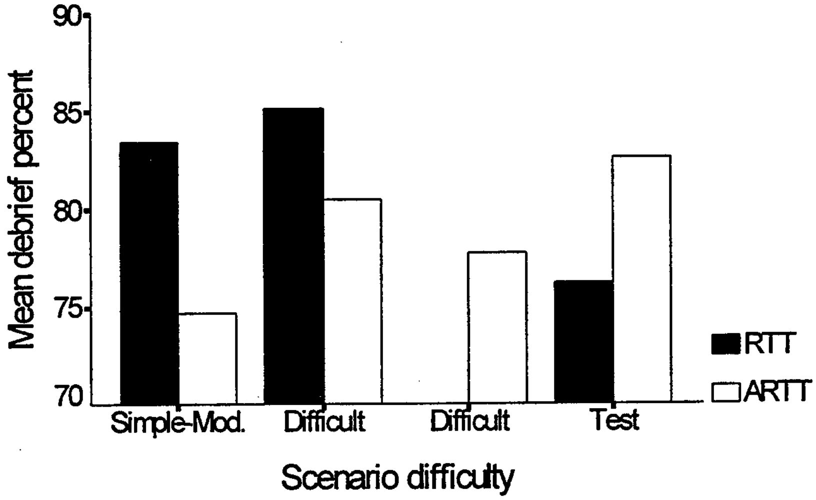

Figure 13. Debrief scores grouped by scenario difficulty.

Thirteen student pilots were asked to estimate whether training or test trials were presented in real-time or above real time. Of the pilots trained in real-time, 5 out of 7 correctly judged that the training trials were presented in real-time; one judged that training was faster than real-time and one could not tell. In addition, two of these pilots believed that the test trials were faster than real-time. Of the pilots trained using ARTT, 2 out of 6 correctly judged that training was faster than real time, 3 believed that training trials were in real-time and one could not tell. Two of the pilots trained using ARTT incorrectly judged that the test trials were presented faster than real-time.

5.3 Discussion

The questions which were evaluated in this experiment were:

1. Will ARTT provide effective training for advanced student pilots?

2. Will additional training trials using ARTT provide a better transition to a more complex task than the same amount of time spent in the simulator using real-time training?

5.3.1 ARTT for student pilots. ARTT will interfere with effective training if the pace of events is so rapid that students cannot keep up. In more formal terms, the training would overload temporary (working) memory thus violating one of Schneider's (1985) rules for training complex skills. Evidence for this effect would be that students using ARTT would produce lower performance scores than students using RTT and that the ARTT student performance scores would not improve. In this experiment, performance scores of students using ARTT were indeed initially lower than scores of students using RTT (run time percent scores for trials 1-5: $\overline{X}_{RTT} = 79.2$, $\overline{X}_{ARTT} = 73.83$, $t(22) = 2.32$. $p = .03$, Figure 12; debrief percent scores for trials 1-5 $\overline{X}_{RTT} = 83.4$, $\overline{X}_{ARTT} = 74.7$, $t(22) = 3.53$, $p = .002$, Figure 13). However, ARTT student performance significantly improved from trials 1-5 (simple-moderate scenarios) to trials 6-10 (difficult scenarios) for run-time ($F(1, 11) = 12.41$, $p = .005$, Fig. 12), but not for debrief scores ($F(1, 11) = 3.81$, $p = .07$, Fig. 13). Performance scores for students trained in real time did not change significantly from the simple-moderate scenarios to the difficult scenarios for either run-time ($F < 1$, Figure 12), or for debrief scores ($F < 1$, Figure 13). At first, the student pilots appear to have had more difficulty with ARTT than the experienced pilots. However, the students overcame this deficit within five trials. In addition, pilots were unable to reliably distinguish real-time form above real-time simulation when they were asked whether they thought that the simulation had been presented faster than real-time. Overall, ARTT at 1.5 times real-time was not a problem for advanced student pilots although there was an initial performance deficit.

5.3.2 Using ARTT to provide additional training trials. In Experiment 3, debrief scores on the test trials were significantly higher for the ARTT group than for the RTT group. Further, the ARTT group showed a significant increase in run-time and debrief scores from the difficult training trials to the more complex test trials which were presented in real time. The RTT group showed no change in performance between training and test trials for run-time scores (Fig. 12) and a significant decrease for debrief scores (Fig. 13). Pilots trained using ARTT showed increased scores when transitioned from a difficult task presented faster than real time to one that is even more demanding but presented in real time.

In Experiment 1, ARTT provided equal training using less time spent in the simulator. In Experiment 3, ARTT pilots received more training trials than the RTT pilots while time spent in the simulator was approximately equal for both groups. The RTT group required an average of 26.5 minutes in the simulator to complete 10 scenarios; the ARTT group required an average of 30.2 minutes to complete 15 scenarios. The slightly longer time for the ARTT group was required because the additional scenarios were more complex than the first five scenarios and more time was required for bandit actions. Overall, the idea of using ARTT to provide additional training trials within the same amount of clock time as real time training as suggested by Vidulich et al (1983) was supported. However, due to the specific training task used in this experiment, the total training time for the two groups was different. After each scenario, the pilot would debrief the evaluator describing the number, altitude, airspeeds, and actions of bandit aircraft. As scenarios increased in complexity, see Figures 1 - 3, the amount of time required for debrief increased. As a result, pilots in the ARTT group spent longer in debrief than the RTT pilots leading to more total training time for ARTT pilots than for RTT pilots ($\overline{X}_{RTT} = 47$ *minutes*, $\overline{X}_{ARTT} = 60$ *minutes*). Total training time did not correlate with test scores ($r = +0.11$, *ns*).

5.4 Experiment 3: Conclusions

1. With advanced student pilots as trainees, ARTT at 1.5 times normal time initially produced lower performance scores than real time training even for relatively simple scenarios. This problem was not observed with more experienced pilots. Otherwise, ARTT provided acceptable training for student pilots.

2. As with the more experienced pilots, ARTT was more difficult than real-time training. Performance scores during training were lower for students trained using ARTT than for students trained in real time. However, performance scores on test trials were higher for students trained using ARTT.

3. Students trained using ARTT showed a significant increase in performance scores when transitioned from a difficult ARTT task to a more complex real-time task. Students trained in real-time showed a significant decrease in performance when transitioned to a more complex task.

4. ARTT provided the opportunity for more training events without increasing the amount of clock time spent in the simulator. ARTT and the additional training trials resulted in higher real-time test scores than fewer training trials presented in real time.

6. SUMMARY AND DISCUSSION

The concept of above real-time training was developed by engineers and pilots as a practical solution to an immediate problem. While early implementations of ARTT were promising, there was no follow-up research by either flight-test engineers or cognitive scientists. Training research that is relevant to ARTT suggests that time-compressed simulation should be most effective for training tasks which require significant time and workload management and, for trainees who have completed the cognitive portions of skill acquisition. There is no evidence that ARTT should disrupt or interfere with training unless: (a) the pace of events overloads the trainee's working memory or, (b) above real-time simulation introduces artificialities to the simulation sufficient to produce negative transfer of training. There are two proposed advantages to ARTT. The first is simple efficiency. Using time-compressed simulation, a pilot using ARTT can experience a given number of training events in fewer clock-hours of simulator time than a pilot using conventional, real-time simulation. Alternatively, the pilot using ARTT could experience more training events in a fixed amount of simulator time. The second proposed advantage to ARTT is that ARTT should provide for easier transition to the more demanding environment of actual flight than normal-time simulation. The experience of NASA test pilots was that actual flight was more demanding than simulation; ARTT felt more like the airplane than a high-fidelity, real-time simulation. Recent training research (see Guckenberger et al, 1992, and Guckenberger et al, 1993) has supported both of these hypothesized advantages to ARTT for some combinations of tasks and trainees.

In the first of three experiments, experienced F-16 pilots used either real time or above real-time training to practice air combat tasks. In one task, the pilot used the F-16's air-to-air radar to locate and track multiple, maneuvering bandit aircraft. For this task, training performance was unaffected by ARTT for simple and moderately complex training scenarios. Pilot performance was degraded by ARTT during training for difficult scenarios. Pilots trained in real time or using ARTT performed equally well on test trials which were presented in real time for all pilots and were more complex than the training trials. There was no evidence that ARTT provided for improved transition to the more demanding test trials. While performance of the pilots trained using ARTT was degraded for some of the training trials, there was no evidence that ARTT at 1.5-times real time had a detrimental effect on test performance. Pilot performance on an intercept task decreased with increasing scenario complexity but was unaffected by ARTT. Overall, the hypotheses that ARTT represents an efficient training strategy was supported. Pilots trained using ARTT were able to perform air-combat tasks as well as pilots trained in normal time even though they received only two thirds of the simulator time.

In a second experiment, experienced F-16 pilots performed air-combat tasks while responding to in-flight emergencies. As in the first experiment, pilots trained using ARTT performed a single emergency procedure and engaged a single bandit as well as pilots trained in real-time but no better. ARTT was more efficient than real-time training in that pilots trained using ARTT were able to perform on test trials as well as pilots trained in real time but with fewer clock-hours of simulator time. However, in a more demanding multiple emergency task, pilots who received initial training in real time followed by additional practice using ARTT performed emergency procedures and engaged two bandits faster than pilots who received all training in real time. This experiment supports the hypothesis that ARTT may provide better transition to a more demanding task environment than real-time training. The ARTT pilots in experiment 2 were able to complete emergency procedures more rapidly than pilots trained in real-time. Completing a given procedure more quickly will allow the pilot more time for other tasks and should increase a pilot's effectiveness in highly demanding conditions.

In the third experiment, student F-16 pilots performed the radar skills task used in the first experiment. Unlike the more experienced pilots in experiment 1, performance of student pilots on this task was degraded by ARTT for simple and moderately complex training scenarios. ARTT pilot performance increased with additional training trials but was still reduced compared to pilots using real-time training. In this experiment, ARTT was used to increase the number of training trials presented within approximately 30 minutes of simulator time. Student pilots trained in real time received 10 training trials while pilots trained using ARTT received 15 trials. Pilots trained using ARTT performed better on real-time, test trials than pilots trained in real time. The combination of ARTT plus additional training trials led to improved performance on the test trials without increasing clock-hours in the simulator.

Overall, the hypothesis that ARTT is more efficient than real-time simulation was supported. These results concur with the findings of Schneider et al. (1982) and Vidulich et al. (1983). Compared to real-time simulator training, time-compressed training that does not overload the trainee's working memory can support equivalent levels of test performance with fewer hours of clock-time in a simulator or improved test performance with equal amounts of clock-time in a simulator. The hypothesis that transfer of training to a more demanding task will be increased by ARTT without additional training trials was also supported for some tasks. Pilots who received initial training in real time followed by additional practice using ARTT performed faster than pilots trained in real time for highly demanding tasks.

7. CONCLUSIONS AND RECOMMENDATIONS

1. The Air Force Human Systems Center's Technical Planning Integrated Product Team (HSC TPIPT) has proposed that ARTT may benefit Air Force training by:

(a) Increasing task performance,

(b) Increasing trainee retention of skills,

(c) Increased situation awareness,

(d) Decreasing real-time workload,

(e) Decreasing real-time stress,

(f) Increasing the rate of skill acquisition (faster and steeper learning curves),

(f) Reduced simulator and aircraft training time, and

(g) More effective emergency procedures training.

The scope of the present effort limited research efforts to focus on items 1 (task performance), 6 (skill acquisition), 7 (training time), and 8 (emergency procedures). Results from the present study support the following conclusions:

- Task performance under Above Real-Time Training is degraded compared to real-time training. However, real-time test performance was as good or better for pilots trained using ARTT than for pilots trained using real-time simulation.

- There is a trade-off between skill acquisition and training time. ARTT which does not overload the trainee's working memory can provide equivalent training with fewer clock-hours in a simulator or better training with equal time in a simulator compared to real-time training.

- The results of this study support hypothesis that ARTT benefits training emergency procedures under some conditions. Practice using ARTT after initial training increased pilots' response speed when performing emergency procedures.

2. As an instructional strategy, ARTT is inexpensive to implement and can increase time efficiency for many training tasks. The major difficulty introduced by ARTT is that training performance is degraded compared to real-time simulation. If pilots are required to meet a minimum standard of task proficiency before progressing to the aircraft or to another task, ARTT will increase training systems management complexity. Training managers must establish alternative proficiency criteria for ARTT or allow for additional training trials to overcome the greater difficulty of ARTT. Since ARTT is more time efficient, these additional trials may not require increased clock-time in the simulator.

3. ARTT combined with real-time training decreased pilot's emergency response time. Further research is recommended to determine what combinations of tasks, trainees, and training procedures will most benefit from ARTT. Further research is also recommended regarding skill retention and the duration of ARTT effects.

4. The use of individual, low-cost training devices is becoming more common within the Air Force particularly for continuation training. The F-15 weapons and tactics trainer (WTT), F-16 unit training device (UTD), and F-16 multi-task trainer (MTT) are examples of this family of training systems. ARTT combined with concentrated practice on specific tasks such as the radar skills task in the present study may be a useful training strategy to maintain proficiency or prepare for an exercise. Further research on training strategies which will maximize training benefits of individual, low-cost training devices is recommended.

5. ARTT is only one application of variable time training. The hyper-time algorithm described in section 2.4 above allows for rapid adjustment of simulator time. While simulator time would normally be set equal to clock-time for most training, it could also be set to less than real time for novices and to greater than real-time as a final step in training. Further research on the use of variable time training is recommended.

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Appendix A

NASA/DFRC memo, 12 Apr 73, Documentation of a Simulator Study of an Altered Time Base, which describes fast-time training concept.

Appendix A is a transcription of Jack L. Kolf's memo describing the application of ARTT to the M2-F3 lifting body program.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
FLIGHT RESEARCH CENTER
EDWARDS, CALIFORNIA 95523

April 12, 1973

MEMORANDUM

TO: Director of Research

FROM: X-25B Project Manager

SUBJECT: Documentation of a Simulator Study of an Altered Time Base

For at least the last ten years a study of pilot comments following rocket aircraft research flights has shown one recurring problem. That is, regardless of type or amount of pre-flight simulator training accomplished by the pilot, the actual flight appears to take place in a much faster time frame than real time. This problem is much more apparent in a pilot's first few flights in any given aircraft and seems to lessen almost linearly with experience. At any rate, no pilot has ever obtained the necessary experience in any particular rocket research aircraft to completely slow the actual flight reference down to a real time environment.

It is apparent, and intuitive, that this problem has to compromise both the quantity and quality of research data gathered on a particular flight as well as increasing the pilot's workload and response effectiveness in the event of an emergency situation.

Therefore, it was decided to attempt an experiment during the M2-F3 flight program designed to at least minimize the effects of this speeded up time reference. The intent was to train an experienced M2 pilot in the simulator using a speeded up time reference and carry the training right up to an actual flight. This would allow a comparison of perceived workload on a flight trained for in this manner and a similar one conducted in the usual method. Unfortunately the compressed schedule necessitated by the premature demise of the M2-F3 did not allow any simulator time for program changes. As a second choice, we decided to accomplish the simulator study using a flight that had already been flown. Although comments based on a flight flown months in the past are not extremely reliable, some rather significant and enthusiastic response and results were obtained.

The actual changes made to the simulator turned out to be much less extensive than anticipated. It was determined that only the scale had to be changed on the analog integrators and the integration rate on the digital computer. This amounted to: 1) 4 cards or steps were added to the XDS-9300 digital program, 2) 19 pot setting changes were needed on the EAI-231R main analog computer, 3) 13 pot setting changes on the EAI-TR48 OAS control system analog computer, and 4) 1 pot setting change on the EAI-TR5 pitch stick trim rate analog computer. After having made this switch a few times, it was found that the entire change from real time to the speeded up time or vice versa could be accomplished in less t6han fifteen minutes.

The only other change required was more complex but only had to be made once. One of the prime instruments used by a pilot during boost is the engine timer. He uses this for both profile control and data maneuvers as well as an energy management tool. This timer, then, had to be altered to reflect the same time base as the basic simulation. For the optimum results, a new watch should have been modified to complete one sweep (100 sec on the dial) in the same ratio as the speeded up time base. In order to save time it was decided to just have a new face made that showed one sweep to be 150 seconds. This established the time base for the rest of the simulation as 1.5 times real time. Pilot comments indicated that the difference between this timer and the 100 second one in the airplane did not compromise the study results. Also, the 1.5 time factor appeared to be near optimum for the M2-F3.

All three of the current M2-F3 pilots were asked to fly the flight M-42-57 profile until they regained enough proficiency to retain the validity of the study. They were then asked to fly the same profile with the speeded up time base. Less than 30 seconds were required to evoke comments on the realistic appearance of this simulation to an actual flight. In no case was more than one run necessary to establish the fact that we had "stumbled" on an effective research and/or pilot training tool. The study, although shorter and less detailed than desired, was conclusive enough to convince us to make use of the technique in the X-24B program if a similar change is feasible on the air force simulation computers.

The following conclusions and/or observations are offered for information:

1) This technique could find application wherever procedural trainers are used. Possibilities range from airline operations to highly complex research air/space craft.

2) Further study would be required to optimize the time base factor. It would appear to be a function of aircraft,

individual, task, and experience. A precise factor in each case may or may not even be necessary.

3) In a program such as the lifting body program, probably only the last hour or two of training would be in the fast time base. Preliminary training would be accomplished as it is now.

4) Overall program results would most likely be improved if second level positions such as "NASA-1" flight controller and the flight planner trained in the same speeded up time base along with the pilot.

5) An electric engine timer (or clock in other applications) would allow the time base to be varied at will without the necessity of a time consuming gear change in the timing mechanism.

6) Emergency or non-standard procedural techniques could benefit highly from this system of training as timing is usually most critical in such cases.

Finally, we feel this technique could and should be evaluated in any program using a simulator. As mentioned, the X-24B project office already is planning to if time and equipment allow.

(signed)

Jack L. Kolf

Appendix B

Hoey, R.G. (1976). “Time compression as a means for improving value of training simulators”. Unpublished paper on time-compressed training for Dr Van Slyke, Course SSM 517.

Robert G. Hoey, a test engineer at NASA’s Dryden Flight Research Center, documented the experiences of flight test pilots using Above Real-Time Training (ARTT). This paper was written while Mr. Hoey was pursuing graduate studies. The following is a transcription of Mr. Hoey’s typewritten manuscript.

TIME COMPRESSION AS A MEANS
FOR IMPROVING VALUE OF
TRAINING SIMULATORS

BY

ROBERT G. HOEY

JULY 1976

FOR DR. VAN SLYKE

COURSE SSM 517

INTRODUCTION

In a paper discussing discrepancies between flight simulators and the actual flight experience, Milton O. Thompson, X-15 rocket airplane pilot, concluded that "The actual flight of environment must still be investigated, since the effects of apprehension and anxiety on the pilot cannot yet be simulated".[1] Recent experiments performed at the National Aeronautics and Space Administration Dryden Flight Research Canter (NASA DFRC) indicate that a psychological effect similar to that produced by anxiety and stress may be produced by operating the pilot training simulators raster than real time (time-compression). Although the experimental work leading to the idea of time compression training was not conducted under controlled, laboratory-type conditions, the concept has been applied quite successfully to a recent fight test program. This paper discusses the background of the time-compression concept, some aspects Of the psychological basis for its application, an evaluation of the experimental results and some ideas on potential application.

BACKGROUND

Research Airplane Piloting Task

The piloting task associated with the flight testing of

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[1] Thompson, Milton O., "General Review of Piloting Problems Encountered During Simulation and Flights of the X-15", 9th Annual Report to the Aerospace Profession, Society Of Experimental Test Pilots Annual Symposium, 1965

research aircraft has typically been highly specialized and demanding. As a result of the relatively unknown environment of these aircraft and the high cost and safety implications of each flight, it was probably natural that sophisticated, real time flight simulators would find their first practical application in this field. Flight simulators were first used in support of the X-2 rocket powered research airplane in approximately 1955, gaining acceptance rapidly thereafter. A highly sophisticated simulation of the famous X-15 research aircraft was used successfully throughout its test program.[2] It is estimated that each X-15 pilot averaged more than <u>10 hours</u> in the X-15 simulator <u>for every 10 minutes</u> that he spent in actual flight.

For research aircraft test programs the simulator is used first to plan each flight in minute detail. Typical air-launched, rocket-powered fights are between 7 and 11 minutes in total duration. The short duration of each flight dictates that the pilot commit to memory all of the necessary flight plan details, test maneuvers, and emergency procedures. The simulator is then used to train the pilot to fly the normal mission, and to recognize, and respond properly, to all conceivable emergencies or unexpected flight occurrences.

Although the flight simulator has proven to be an extremely valuable contribution to the successful and safe flight testing of research aircraft, the pilots have continually expressed opinions such as; "It sure seems to happen faster in the real

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[2] Hoey, R.G., Day, R.E., "Mission Planning and Operational Procedures for the X-15 Airplane", <u>NASA TN D-1159</u>, March 1962

airplane", or "I had the feeling that I was 'behind the airplane'" or "I felt rushed trying to get everything done compared to the simulator". These comments were generally felt to be related to the differences in the physiological environment. Certainly the visual cues, motion cues (including relatively large "g" values), pressure suits, and other obvious physical environmental differences between the simulator and actual flight, could not be discounted. (All simulators referred to in this paper were fixed base simulators).

Early Simulator Time-Compression Experiments

The similarity of each pilots subjective evaluation of the simulator/flight comparison led to a brief and informal experiment in 1971. After completion of the M2-F3 Lifting Body flight test program, but before dismantling the simulator, the engineers modified the computers in the simulator so that they could be operated at a selectable time rate which was faster than real time. (This was quite easily accomplished by applying the same speed-up factor to the integration rate of all integrators in the computer). Pilots who had previously flown the actual M2-F3 evaluated the simulator with various time-compression factors. The pilots selected a factor of about 1½ times faster than real time as the factor which most represented the way it felt in flight. They were unanimous and highly enthusiastic about the realism provided by the 1½ time-compression simulation. Again the validity of the concept was largely discounted by the technical community due to the known large environmental differences between the fixed base simulator and fight.

Application To Remotely Piloted Research Vehicles (RPRV's)

In 1972 engineers at NASA DFRC conceived of the idea of expanding upon the radio-control-model-airplane technology in order to conduct hazardous flight tests without exposing the pilot to the associated dangers. The concept was to place the pilot in a simulator-like cockpit on the ground with typical aircraft-type controls and displays. These controls and displays were linked to the actual, unmanned, flight vehicle through radio signals. An "uplink" transmitted pilot commands to the individual control surfaces on the flight vehicle. Instrumentation on the vehicle measured the aircraft responses and appropriate data were transmitted to the ground via a "downlink". Vehicle response was presented to the pilot on his ground cockpit displays in real time. This permitted the pilot to close the loop in exactly the same fashion as he would have, had he been flying on instruments in the flight vehicle, thus the name, Remotely Piloted Research Vehicle (RPRV). The effort culminated in the flight testing Of a subscale glider version Of the F-15 air superiority fighter.[3]

A flight simulator was again a key factor in the successful accomplishment of this program, and, although the pilot remained on the ground, the piloting task, procedures and training requirements were identical to those discussed earlier for piloted research aircraft.

Early in the F-15 RPRV program the simulator was programmed

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[3] Holzeman, Euclid C. (Ed) "Initial Results From Flight Testing a Large, Remotely Piloted Airplane Model", NASA TM X-56024, March 1974

to operate in either real time or 1.4 times real time.[4] Throughout the program the 1.4 time-compression simulation was used for final pilot training before a fight.

Implications Of RPRV Application

As in the M2-F3 simulator experiment, the F-15 RPRV pilots felt that the 1.4 time-compression was a realistic simulation of the way it felt during the actual flight. There is an important difference, however, between the M2-F3 application and the F-15 RPRV application of time-compression. For an RPRV the pilot's physical environment while flying the simulator is essentially identical to his environment while flying the actual vehicle! He is in no immediate danger, has no motion or additional visual cues present, and is in a comfortable, shirtsleeve environment. Any differences in the perception of time passage must therefore be related primarily to psychological effects.

Physiological Data Base

Man's first real exposure to the zero-g environment occurred during the X-15 program. This prompted the development of a sophisticated biomedical monitoring package for measuring the physiological status of the pilot during flight. The most useful measurement was found to be an EKG. The medical monitoring program continued throughout the X-15 program and persisted

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[4] The 1.4 time-compression factor was not related to the scaling effects between the subscale F-15 model and the full size F-15. The 1.4 time-compression factor was applied over and above the other mathematically-correct scaling factors which correct for differences in size and inertia.

through the entire lifting body flight test program. During this program the data base was expanded to include EKG monitoring of ground control personnel as well as the pilots in flight. (Test pilots served as ground controllers in the control room, thus control room data was seen as part of the data base for each individual test pilot).

Over the years a considerable volume of data has been accumulated with some surprising results. A repeatable pattern of pilot's heart rate variation during a fight was found which correlated with key flight events.[5] Three peaks were evident in the pilot's heart rate. The first peak occurred at launch, which was the beginning of his term of responsibility. The second peak occurred at rocket engine burnout where the pilot's task changed from trajectory control to the performing of test maneuvers. The third and usually highest peak occurred at landing which marked the end of the experience.

The only significant variation on this pattern was the expected increase in heart rate associated with sustained, high g maneuvers such as during reentry. Although the maximum values of heart rate varied considerably between pilots, the pattern relating peak values with the same key fight events was consistent for all pilots.

Heart rate data on ground controllers also provided some surprises. Peak values were nearly as high when a pilot was

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[5] Bratt, Harry R., Lt. Col. USAF, "Biomedical Aspects Of the X-15 Program, 1959-1964", AFMC-TR-65-24, August 1965

serving as a ground controller as they were then he was actually flying the aircraft. The highest rate usually occurred at launch which corresponded with the end of the ground controllers term of primary responsibility. (He transmitted the final decision to launch).

Heart rates measured during simulator training runs were quite low and exhibited no particular patterns since the pilots were not experiencing any stress.

The biomedical monitoring program was extended to gather data on the pilots and ground controllers in the F-15 RPRV program even though both individuals remained in a ground environment. In general, the same patterns and same peak values of heart rate were observed for the RPRV pilots while remotely flying the flight vehicles, as had occurred when these same pilots were actually flying in the test aircraft.

The observed physiological and postulated psychological stress on test pilots is summarized in Table I for the research airplane test programs discussed earlier.

(Note: Comments in this section represent rather gross generalizations of a great volume of EKG data, much of which is unpublished at this time. The general trends reported herein were obtained by interviews with the pilots and biomedical personnel at NASA DFRC who are actively engaged in the data gathering process).

PSYCHOLOGICAL BASIS

Perception of Time

We are all aware of an "internal sense of time" which is often different from that recorded by clocks and calendars. Hoaglund performed experiments which related the subjective sense of time to body temperature. (According to Hoaglund's results a time-compression factor of 1.4 would be produced by a 4.5 degree F increase in body temperature). As related by Cohen[6] "Hoaglund thereafter explored the subject extensively and concluded that there are chemical pacemakers in the brain that govern the speed of its metabolism and thereby affect the rhythm of subjective time". Certainly this statement is consistent with recent findings in the rapidly expanding field of biochemistry. The question relative to this topic is; what are the physiological and psychological factors which trigger these chemical pacemakers, how are they related, and how can we measure their effects?

Cohen discusses evidence of "an interrelation of inner clocks and sensory-motor activity. Each can influence the other". The pilot training functions described earlier involve both sensory-motor training (operation of controls) and mental training (memory and decision criteria). A change to the inner clock produced by one or more psychological factors could very well introduce an imbalance or difference between the mental

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[6] Cohen, John, "Psychological Time", <u>Scientific American</u>, Nov. 1964, pp. 116-124

processes and the sensory motor processes. This might be manifest to the pilot as a feeling of being "rushed" mentally.

Measurement of Stress

Stress is defined by James G. Miller as a "force that pushes the functioning of important (body) subsystems beyond their ability to restore equilibrium through ordinary, non-emergency, adjustment processes".[7] It has long been recognized that stress can be produced by both physiological and psychological stressors; however, the only known yardsticks for measuring stress are physiological responses. There has been little solid laboratory or experimental work on the isolation of psychological stress from physiological stress.[8] It appears that our present knowledge is such that there are recognized physiological measures of stress which do, in fact, measure stress regardless of the type of stressor present. In his discussion of psychological time Cohen relates; "Ones orientation toward future events is often characterized by a 'gradient of tension'. The heart beats faster as the clock emphasizes that a fateful moment draws near."[9] Clearly this common phenomenon, with which we can

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[7] Miller, James G., "A Theoretical Review Of Individual and Group Psychological Reactions to Stress", In Grosser, Wechsler, Greenblatt (Ed) <u>The Threat of Impending Disaster</u>, M.I.T. Press, 1964, p.13

[8] Lazarus, Richard S., "A Laboratory Approach to the Dynamics of Psychological Stress", <u>American Psychologist</u>, 1964, 19, pp. 400 - 411

[9] Cohen, John, "Psychological Time:, <u>Scientific American</u>, Nov. 1964, pp. 116 - 124

all identity, is a form of psychological stress characterized by a physiological change, namely, increased heart rate.

Heart rate has often been used as an indicator of stress level and for the remainder of this paper it will be assumed that it is a valid measure. This measuring device is of particular interest in this case since a considerable volume of EKG data has been accumulated during past research airplane test programs.

Fear, Anxiety, Responsibility

If we assume for a moment that the physiological environment of the RPRV pilot is constant, regardless of whether he is flying the actual flight vehicle or a computer simulation, we must conclude that any difference in measured heart rate between the two is attributable to psychological stress. (Table I) But what kind of psychological stress?

Fischer [10] differentiates between anxiety and fear as follows:

"Being Anxious - uncertain actualization of a lived for-and-toward world and to-be-realized identity.

Being Fearful - uncertain defense of, and holding onto, that which I already am and have.

Being anxious implies some task-related impotence and apprehending of fulfillment. Being fearful implies defense mechanisms and not impotence."

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[10] Fischer, William, Theories of Anxiety, Harper and Row, 1970, p. 166

A further differentiation between fear and anxiety relates to the time element. Anxiety is based on the subjects projection of future events which have not yet occurred, whereas fear is based on recognition of some event which has immediate connotations of danger.

A test pilot actually flying in a research aircraft might reasonably be expected to experience some elements of both anxiety and fear depending on how he views his assigned tasks and his relative safety. Notice that he is also experiencing physiological stressors due to the visual and motion stimuli.

The RPRV pilot, in addition to not experiencing any physiological stressors, is in absolutely no danger and should therefore not experience any significant element of personal fear. High pilot heart rates (and therefore assumed stress levels) were observed regardless of whether the pilot was actually <u>inside</u> a test aircraft or flying it from a ground cockpit. This evidence leads us to conclude that the primary stressor producing the high heart rate is anxiety, and that physiological stressors and psychological fear play a relatively small role. This is also consistent with the previously mentioned correlation of peak heart rates with responsibility-related flight events.

In assessing anxiety under various conditions, Fischer [11] found several "striking structural similarities";

"(1) In each---we discovered a situational event that

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[11] Ibid., pp. 129 - 130

constituted the focus of the individual's anxious orientation.

(2) In each---was also the question of the individual's identity---in some manner, an expression of the person's world.

(3) ---the network of relations and projects---of both his world and his identity, emerge as <u>demanding to be sustained</u>. This demanding---is experienced as a question of necessity, an absolute requirement of life. There are no conceivable alternatives---.

(4) ---the question of ability - specifically, the personal sense of uncertain ability or competence - is essential to the experience of anxiety."

These characteristics appear to fit quite well into the test pilots situation prior to and during a test flight <u>regardless</u> of whether he is inside the test vehicle or flying it from the ground. In either case he is <u>totally responsible</u> for the success or failure of the fight and all that it might portend for his personal future. The effect of this sense of piloting responsibilities was graphically demonstrated by Dr. Roman.[12] Two EKG-instrumented test pilots flew a very demanding, high speed, low altitude flying task in a two-place jet aircraft. On each run, one of the pilots was actually flying the aircraft as "pilot-in-command", and the other was a "passenger". Each pilot made several runs in each role. Although both pilots were experiencing the same physiological stressors, and psychological fears (if any) the "pilot-in-command" consistently registered much

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[12] Roman, James, M.D., "Risk and Responsibility as Factors Affecting Heart Rate in Test Pilots - The Flight Research Program II", <u>Aerospace Medicine</u>, Vol. 36 no. 6, June 1965

higher relative heart rates than his "passenger" (relative to each individual's base line heart rate).

Learning Methods

The applicability of a pilot-in-the-loop, real time simulator to the pilot training task has been widely accepted and need not be dealt with in any depth. It represents the epitome of reinforcement and rapid feedback learning methods. As indicated earlier pilot training in a simulator includes both perceptual motor skills and memory and decision-making skills. In a task analysis of perceptual motor skills Fitts[13] described three phases of the learning process;

(1) Cognitive Phase - Transfer of previous training is most important - getting the "feel" of some situation.

(2) Fixation Phase - Correct patterns of motor action are refined and fixated. Longest and most difficult phase.

(3) Automation phase - Rapid, automatic performance. Errors at a minimum. "Skill becomes not only well integrated, but resistant to the effects of stress and interference from other concurrent activities".

Simulator pilot training of the kind described earlier

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[13] Fitts, P.M.,(1962) "Factors in Complex Skill Training", In R. Gloser (Ed) Training. Research and Education, Pittsburgh, Pa., Univ. of Pittsburgh Press

and

Fitts, P.M.,(1964) "Perceptual-Motor Skill Learning", In A.W. Melton (Ed), Categories of Human Learning, New York: Academic probably achieves the "fixation phase" for all required motor skills with some skills attaining the "automation phase". Some of the learned motor skills obviously pass beyond the psychological refractory phase (wherein short term memory acts in a serial manner, processing one input at a time) and reach the automatic phase (wherein multi stimulus inputs can be handled).

During all of the research airplane test programs it can be generally stated that the pilots performed their tasks exceptionally well, in spite of the professed feeling of being "rushed" compared with the simulator. It would appear that the motor skills learned on the simulator became reflex actions for the most part; therefore, the proper pilot actions did occur at the proper times. The stress produced by anxiety resulted in an alteration to the pilot's internal sense of time which, in turn, produced an inconsistency between his physical and mental responses. Pilots described their awareness of this inconsistency as a "feeling of being rushed". The faster-than-real-time simulation artificially produced a mental situation similar to that produced by anxiety. The pilots have recognized and correlated this effect subjectively as a result of alternately flying the simulator (without anxiety but with 1.4 time-compression), then the actual flight vehicle (with anxiety but in real time).

EVALUATION AND POTENTIAL APPIICATION

Task Dependencies

The application of a time-compression factor of 1.4 has been shown to be beneficial (at least subjectively) for the particular task of training for F-15 RPRV flights. This task is typical of nearly all research aircraft flying tasks which are characterized by very high pilot work loads for relatively short time periods (7 - 11 minutes). Application to longer or shorter time periods and/or lower or higher work loads is unknown at this time. It is possible that the optimum time-compression factor is related in some manner to pilot work load.

It is most interesting to notice the implication in the previous discussion that a persons inner sense of time <u>might</u> be related <u>directly</u> to heart rate. If such a relationship could be established, observed pilot heart rate variations while accomplishing a particular real-world task (such as landing an airliner) could be used to program a variable time-compression factor for a training simulator. In-flight emergency situations might entail sudden changes in stress level (as might be associated with fear rather than anxiety) thus requiring some different logic for changing the time-compression factor of the simulator.

Physical Inconsistencies

Although the affect of anxiety on the mental processes may be approximately simulated by time-compression, the resulting speed-up of the physical task is probably incorrect. The muscular effort required to reach and activate a switch or move a cockpit control is not necessarily represented properly in the time-compression mode of simulation. This is especially true if the motor-skill learning (in real time) has progressed to the automatic phase. Thus, there is some concern about the physical de-training aspects of the time-compression simulator.

Pilot Interviews

In an attempt to explore, at least subjectively, some of the critical aspects of time-compressed simulation, four F-15 RPRV test pilots were interviewed as a group. Each of these pilots was a highly experienced test pilot with several thousand hours of flying time in a wide variety of test aircraft in addition to his "arm chair" flights of the F-15 RPRV. The questions asked, and a composite summary of their answers follows:

1. Q. Do you feel that the realism of the 1.4 time-compressed simulation is truly a psychological effect?

A. In general, yes. One pilot felt that it was mostly psychological but that there were still differences between simulation and flight due to flight discrepancies (i.e. flight events which are not exactly simulated).

2. Q. How critical is the time-compression factor of 1.4?

A. 1.4 was the only factor available to the F-15 RPRV simulation but all were satisfied that it was a good factor for this task.

3. Q. What were the environmental differences between simulator training and actual flights?

A. (1) The simulator had a map display which the pilot used directly to perform navigation. During actual flights navigation was done by the mission controller and directions were verbally passed to the pilot (such as "turn right 10°").

(2) The room and cockpit lighting were different during the actual flights.

(3) There was isolation from outside distractions on flight day.

(4) There was more copilot-type help during actual flights, such as altitude calls and other verbal reminders.

4. Q. Is there a learning curve associated with the 1.4 time-compression factor?

A. This was difficult to determine since the philosophy was to increase the pilot work load on successive flights in order to maximize data return. At least one pilot used the 1.4 time-compression runs as a means of establishing a balance between the magnitude and complexity of the requested maneuvers, and his training readiness to accomplish them.

With this philosophy in mind, the 1.4 factor appeared to be valid for all flights.

5. Q. How repeatable is the psychological effect of the 1.4 time-compression?

A. (See answer to 4).

6. Q. Are you bothered by incorrect physical response times when simulating in the time-compressed mode?

A. Physical differences, such as the time required to reach and actuate a switch, were apparent to the pilots, but all agreed that the effects were minor compared to the training benefit derived from the time-compressed mode.

7. Q. What was the ratio of real time training runs versus time-compressed training runs before a typical flight?

A. Approximately 70% of the training runs were in real time (early learning of the flight plan, primarily) and 30% were in 1.4 time-compression (the last day or s0 before flight) .

8. Q. Do you feel more relaxed and less rushed during flight if you have had the time-compression training?

A. More relaxed? --No.

Less rushed and more confident? -- Definitely Yes.

(Nearly all RPRV flights used the 1.4 time-compression training so the answer relates more to overall flying experience).

9. Q. What biomedical measurements were being taken during RPRV flights and what were the results?

A. EKG was being recorded on both the pilot and the mission controller. Work load, as evaluated qualitatively by pilots and quantitatively by heart rate measurement, were comparable to or higher than, the work load experienced by the same pilots when they were actually flying the rocket powered lifting bodies.

One highly experienced test pilot who has made many flights in four different rocket powered lifting bodies felt that the pilot work load during his first RPRV landing was the highest he had ever experienced and a maximum for him personally. EKG data confirmed that his heart rate was as high during the RPRV landing as during any of his actual landings in unpowered lifting bodies.

10. Q. What do you see as advantages of time-compression simulation?

A. All pilots felt that there was obvious application to any high work load piloting task such as emergency training, instrument landing approaches, and many others. All of the pilots were highly enthusiastic about its value, at least in this particular application. All felt that it forced the pilot to concentrate on the important aspects of the simulation.

11. Q. What do you see as disadvantages? .

A. There are minor effects due to physical differences (question 3) which could cause some training distortion. Pilots reiterated that time-compression should not be used for all training. Some balance of training for motor skills (real time) and mental skills (1.4 time-compression) is required.

12. Q. Comment on the following possible side benefits

(A) Evaluating trainee readiness (go-no-go)

(B) Evaluating task planning effectiveness

(C) Screening or selecting pilot candidates

A. All of the pilots felt that all three items were quite valid potential applications of time-compression simulation. One pilot had already been consciously applying (A) and (B) to his own training.

GAINING ACCEPTANCE

Documentation of the application of time-compressed simulator training to the F-15 RPRV program has not yet received wide dissemination. On at least one occasion the subject was mentioned to a simulator training expert employed by a major airline. When it was suggested that they might try speeding up their simulators his reaction was highly negative. "We're trying to teach the crews to slow down their responses in an emergency, not speed up. We have enough trouble with pilots reacting too fast and doing the wrong thing."

It is anticipated that this type of response may be typical for someone who has not totally analyzed the problem. If the motor skills for handling an emergency situation are learned only in a real time simulation, then the psychological effect of stress during a real occurrence will cause the pilot to feel behind mentally and therefore rushed in his activity (thus more likely to make errors). If, after learning the motor skills in real time, the pilot had been exposed to a time-compression simulation with instructions that "this is how it will feel", then the real occurrence would have presented him with a more familiar situation which he could handle more confidently (thus less likely to make errors).

Quantitative statistical confirmation of benefits of time-compression simulation may take many years to accrue. Selling the concept of time-compression simulation may, therefore, have some initial hurdles to overcome. A simple demonstration is probably the easiest and most convincing way of gaining acceptance. Generalized computer software modifications which would allow time-compression simulation to be done on almost any simulator should first be developed. A high work load task which can be quickly tried on a simulator and verified in the real world (rapid feedback) should then be demonstrated to a potential user (an airliner landing simulation for example). If time-compression simulation is truly applicable to the task, the trainee will recognize the benefits almost immediately and hopefully will be able to convince his own management of its value. Additional laboratory work to quantify time-compression factors for various different tasks or work loads is essential to any wider application of time-compression simulation to situations different from the one discussed in this paper. The concept could be improperly applied if rapid and effective trainee feedback were not heavily emphasized.

SUMMARY

Biomedical measurements of test pilots flying Remotely Piloted Vehicles (RPRV's), when correlated with past data taken in flight, has strongly indicated that the stress levels and physical and mental states of test pilots are primarily influenced by the strong sense of responsibility and resulting anxiety, rather than by fear of personal harm or direct physiological stress. It appears that this mental state can be approximately simulated under non-stressful conditions by increasing the simulated rate of time passage (time-compression simulation). A time-compression factor of 1.4, as used successfully on the NASA F-15 RPRV program, appears to be appropriate for relatively short, high work load, piloting tasks (Simulator operates 1.4 times faster than real time).

The concept of time-compression simulation appears to be applicable to a wide range of simulator training situations where stressful, operator-in-the-loop tasks are being simulated under non-stressful conditions.

Further testing under controlled conditions should be performed to establish a relationship between the time-compression factor and either work load, or a direct physiological measure, such as heart rate.

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TABLE I

GENERAL SUMMARY OF PILOT STRESS DURING RESEARCH AIRPLANE TESTS

Test Pilot Task	Test Pilot Environment	Heart Rate Results	Possible Stresors Present
X-15 Flights	Very high altitudes, 0 to 6 "g" (sustained)	High peaks at launch, engine burnout, landing, high "g"	Fear, anxiety, major physiological
Lifting Body Flights	Moderate attitudes, .5 to 3 "g" (transient)	High peaks at launch, landing	Fear, anxiety, minor physiological
F-15 RPRV Flights	Shirtsleeve ground cockpit	High peaks at launch, landing	Anxiety
Fixed Base Simulator Training (for all of above aircraft)	Shirtsleeve ground cockpit	Normal-No patterns	None

Appendix C

F-16 Initial Conditions Used In Experiments 1 and 3.

Bandits. The bandits are all MiG-23s assumed to be in air-to-ground roles as bombers. All contacts are considered hostile in the Radar Skills Phase. A visual identification is required (within 6,000 ft + 30° of stern aspect) for the Intercept Phase. Bandits simulate a limited forward looking radar capability and limited threat ground-controlled intercept coverage.

F-16 Configuration
AIM-9LIM on stations 1 and 9
AIM-120 on stations 2, 3, 7, and 8
Stations 4, 5, and 6 clean (no external tanks)

Avionics Setup
Master Arm - Master Arm position
Right MFD - SMS
- Inventory as described above
- AIM-120 in SLAVE
- AIM-9s cooled, SLAVE, BP, SPOT

Left MFD - Radar
- FCR Control Page (items of significance)
  - MTR LO
  - ALT TRK - OFF
  - TGT H1S - 3

Hands-on Controls - ANT ELEV Knob in detent
Dogfight Switch
- Center Position - A-A Master Mode selected:

	Radar	SMS
	TWS - MAN	AAM operating mode
	80 NM range	AIM-120 selected
	3 B	
	A6	
	Cursors centered on MFD	
	FOV - NORM	
MSL OVRD Position:	Radar	SMS
	RWS	MSL operating mode
	80 NM	AIM-120 selected
	4B	
	A6	
	Cursors centered on MFD	
DGFT Position:	Radar	SMS
	ACM	DGFT operating mode
	EEGS	
	AIM-9	

Appendix D

Experimenter's Rating Forms for Radar Skills and Intercept Training

Radar skills experiment 1.

RADAR SKILLS TRAINING

PILOT'S NAME	INSTRUCTOR

PILOT NUMBER	SCENARIO NUMBER	DATE

TRAINING START TIME:	TRAINING STOP TIME:

	GRADE			
MISSION TASKS:	0	1	2	3
SEARCH AIRSPACE				
SAMPLE CONTACTS				
SORT FORMATION AND MONITOR ACTION				
TARGET HIGHEST THREAT (SHOOT IN PARAMETERS)				
DEBRIEF:	XXXX	XXXX	XXXX	XX
DESCRIBE INITIAL PICTURE				
DESCRIBE ACTION				
DESCRIBE PICTURE AT 20 NM				
DESCRIBE FACTORS USED TO DETERMINE HIGHEST THREAT				
COLUMN TOTALS:	0			
TOTAL SCORE:				

A total score of 8 is required for proficiency. Base this score on debrief questions only!

GRADING CRITERIA:

Grade 3 - Performance is correct
Grade 2 - Performance is essentially correct, but late
Grade 1 - Performance only partially correct, errors of omission or commission
Grade 0 - Performance totally incorrect

Notes:

Radar skills experiment 3.

RADAR SKILLS TRAINING

PILOT'S NAME

INSTRUCTOR

PILOT NUMBER

SCENARIO NUMBER

DATE

TRAINING START TIME:

TRAINING STOP TIME:

MISSION TASKS:	GRADE			
	0	1	2	3
SEARCH AIRSPACE				
SAMPLE CONTACTS				
SORT FORMATION AND MONITOR ACTION				
TARGET HIGHEST THREAT (SHOOT IN PARAMETERS)				
DEBRIEF:	XXXX	XXXX	XXXX	XX
DESCRIBE INITIAL PICTURE				
DESCRIBE INITIAL ACTION				
DESCRIBE PICTURE AFTER ACTIONS				
DESCRIBE FACTORS USED TO DETERMINE HIGHEST THREAT				
COLUMN TOTALS:	0			
TOTAL SCORE:				

GRADING CRITERIA:

Grade 3 - Performance is correct

Grade 2 - Performance is essentially correct, but late

Grade 1 - Performance only partially correct, errors of omission or commission

Grade 0 - Performance totally incorrect

Notes:

Intercept task experiment 1.

INTERCEPT TRAINING

PILOT'S NAME	INSTRUCTOR	
PILOT NUMBER	SCENARIO NUMBER	DATE
TRAINING START TIME:	TRAINING STOP TIME:	

	GRADE			
MISSION TASKS:	0	1	2	3
SEARCH AIRSPACE				
SAMPLE CONTACTS				
SORT FORMATION AND MONITOR ACTION				
TARGET TRAILING THREAT(S)				
OBTAIN PROPER OFFSET				
CONVERT TO STERN (WITHIN 30 DEG. AND 6000 FT)				
SHOOT IN PARAMETERS				
DEBRIEF:	XXX	XXX	XXX	XXX
DESCRIBE INITIAL PICTURE				
DESCRIBE ACTION				
DESCRIBE PICTURE AT 20NM				
DESCRIBE FACTORS USED TO DETERMINE HIGHEST THREAT				
COLUMN TOTALS	0			
TOTAL SCORE				

A total score of 8 is required for proficiency. Base this score on debrief questions only!

GRADING CRITERIA:

Grade 3 - Performance is correct
Grade 2 - Performance is essentially correct, but late
Grade 1 - Performance only partially correct, errors of omission or commission
Grade 0 - Performance totally incorrect

Notes:

Appendix E.

TLX Rating Form

RADAR SKILLS TRAINING **TLX** Subject #________

Below is a list of descriptions concerning various aspects of the scenarios you just completed. You will be asked to make ratings and comparisons of each of these. Please review each of the descriptions and keep them in mind as you fill out this document.

PHYSICAL DEMAND (**PD**) Concerns the amount of physical activity that was required. For example, the amount of button pressing, reaching, control adjustments, etc. that was involved during the task.

TIME PRESSURE (**TP**) Concerns how much time pressure you felt due to the rate or pace at which the task elements occurred (for example, slow and easy or rapid and frantic).

INTERPRETING RADAR (**IR**) Concerns how much of your mental effort you delegated to interpreting elements of your radar, including items such as finding and sorting the bogies, determining the formation of the bogies, and tactical planning.

SWITCHOLOGY (**SW**) Concerns how much of your total effort (both mental and physical) was directly related to performing aspects of switchology for radar and weapons.

FLYING PLANE (**FP**) Concerns how much of your total effort (both mental and physical) was directly related to aspects of flying the aircraft (for example, stick and throttle controls).

FRUSTRATION LEVEL (**FL**) Concerns how discouraged, irritated, or stressed you were while performing the scenarios.

INSTRUCTIONS: Please select the member of each pair that contributed more heavily to your workload during the scenarios. That is, which member of each pair affected your performance more? Please base your responses on all of the radar skills training you just received, not just one particular scenario. It is important to complete each comparison, even if members of one pair seemed to have affected your performance equally.

PD / TP
PD / IR
PD / SW
PD / FP
PD / FL
TP / IR
TP / SW
TP / FP
TP / FL
IR / SW
IR / FP
IR / FL
SW / FP
SW / FL
FP / FL

Now please rate individually, on a scale from 1 to 10, the magnitude of the contribution of each factor on your performance during the scenarios you just completed.

EFFECT ON YOUR PERFORMANCE

TYPE	LOW									HIGH
Physical Demand	1	2	3	4	5	6	7	8	9	10
Time Pressure	1	2	3	4	5	6	7	8	9	10
Interpreting Radar	1	2	3	4	5	6	7	8	9	10
Switchology	1	2	3	4	5	6	7	8	9	10
Flying Plane	1	2	3	4	5	6	7	8	9	10
Frustration Level	1	2	3	4	5	6	7	8	9	10