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VISUALIZING SPATIAL RELATIONSHIPS: TRAINING FIGHTER PILOTS IN A VIRTUAL ENVIRONMENT DEBRIEF INTERFACE

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In flying air intercepts, a fighter pilot must plan most tactical maneuvers well before acquiring visual contact. Success may depend on the ability to create an accurate mental model of dynamic three-dimensional spatial relationships from two-dimensional information displays. This report describes an Air Force training program for visualizing large-scale dynamic spatial relationships. The Virtual Environment Debrief Interface (VirDI) was developed to study how virtual environment technologies can be applied to an aircrew training problem—specifically, the ability to visualize the geometry of an air intercept while the target is beyond visual range. The trainer employs a low-cost, portable system which accepts data from a F-16 part-task trainer. Within moments of completing a sortie on the simulator, the user may enter and walk through a virtual world containing the ownship, target, and their respective flight trajectories. The training capacity of the system is described along with recommendations for its future expansion.

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PREFACE

The research described in this report was conducted at the Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA), in Mesa, Arizona, by the University of Dayton Research Institute (UDRI).

AL/HRA conducts visual training effectiveness research in support of aircrew training technology. This research, performed by UDRI, describes a US Air Force training program for visualizing large-scale dynamic spatial displays. The Virtual Environment Debrief Interface (VirDI) shows how virtual environment technologies can be applied to an aircrew training problem.

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VISUALIZING SPATIAL RELATIONSHIPS:
TRAINING FIGHTER PILOTS IN A VIRTUAL ENVIRONMENT DEBRIEF INTERFACE

INTRODUCTION

Military and nonmilitary tasks alike often require the individual to acquire and maintain dynamic *spatial awareness*—that component of situational awareness which involves the ability to conceptualize the dynamic location of multiple objects in three-dimensional space. Under normal flying conditions, the out-the-window view usually provides sufficient visual information to maintain spatial awareness. However, there are many tasks which require the operator to attribute a logical set of spatial properties to unseen objects. For example, during an air intercept a fighter pilot plans most tactical maneuvers well before acquiring visual contact with the target. Success depends critically upon the ability to construct an internal representation, or *mental model*, of the problem space from which one can define or constrain the situation, and plan, test, and evaluate potential solutions. This would suggest that systems designed to train personnel for spatial awareness should address the perceptual and cognitive processes involved in the creation and use of mental models. One of the greatest challenges for developers of aircrew training systems, however, is to present information to the trainee in a manner that will engage these innate human capacities.

This report describes the goals, capabilities, and constraints of a virtual world visualization tool developed for the Air Force at the Armstrong Laboratory, Aircrew Training Research Division (AL/HRA), in Mesa, AZ. *The Virtual Environment Debrief Interface* (VirDI) is a portable post-mission feedback tool designed to allow pilots to study beyond-visual-range air intercept performance in a three-dimensional synthetic environment. There are alternative post-mission feedback systems currently available, but the graphics typically consist of two-dimensional representations of the airspace (e.g., the "god's-eye view"). Although two-dimensional images can enhance the training environment, subject matter experts continue to express the need for a three-dimensional visualization tool that would represent directly the intercept space. Recent developments in computer simulation and human/computer interface methods and technologies have provided the vehicle for the development of VirDI—a feedback system in which the trainee is immersed in an interactive three-dimensional virtual world of visual imagery.

Spatial Awareness Training in a Virtual World

Immersive virtual environments are defined as a coordinated set of computer, graphic, and synthetic sensory input/output technologies and techniques to create in the user an illusion of immersion in a computer-generated reality. "The user interacts with a world containing seemingly real, three-dimensional objects in three-dimensional space that respond interactively to each other and the user" (Bryson, 1992, p. 1.1). While computer-generated "realities" are synthetic, the psychological impact of the immersive experience may be very powerful. The user no longer feels that (s)he is interacting with a picture of a thing, as on a video monitor; rather, the experience is direct and intuitive—*as if* it were unfolding in the same world that envelops the user.

By providing an interactive synthetic world, virtual environments have considerable potential as training media for aiding fighter pilots in visualizing beyond-visual-range air intercepts (cf. Amburn & Stytz, 1992; Ellis, 1991a, b; Zeltzer & Drucker, 1992). The training medium provides a perceptual experience of data that otherwise could not be achieved in the real world. Moreover, the user can interact with the world in a natural and intuitive fashion as if interacting with objects in the real world. In a synthetic world, normal human capacities also can be augmented to endow the user with super-human control. Sensory-motor barriers can be breached, so the user also can walk through large expanses of airspace in a few steps, viewing the mission from multiple vantage points. It is anticipated that the virtual world experience also may serve to provoke or augment mental modeling in the student pilot. It is possible that such a system will facilitate the transition from the student's meager mental model of the air intercept problem to the well-articulated, efficient mental model characteristic of the expert fighter pilot.

THE VIRTUAL ENVIRONMENT DEBRIEF INTERFACE

The dual functions of the Virtual Environment Debrief Interface are: (a) to stimulate the senses with perceptual re-presentation of a data set containing the spatio-temporal parameters of an air intercept *and*, (b) to provide a template for the student to construct a mental image of air intercept space. In addition to these two functions, the requirements of this project focused on developing a visualization tool that, if successful, could be deployed with various training and operational flight squadrons. Thus, the VirDI system has been designed to be user-friendly, low cost and portable, with minimal installation or maintenance costs. It consists of an image generating system controlled by a 386 personal computer and commercially available helmet-mounted display and head tracking devices. The remaining sections describe the system in greater detail and provide an account of its training potential when deployed at the squadron level.

System Design

The VirDI system consists of a coordinated set of input/output devices controlled by an XTAR FALCON-PC™ 25 MHz 386 personal computer. The XTAR system contains:

1) 2 XTAR AP-2020 Array Processor™ boards, which perform the database transformations and deliver 45,000 50 x 50-pixel polygons per channel per second;
2) 2 XTAR PG-2000™ graphics boards, which project the images at a pixel fill rate of 160 million pixels per channel per second;
3) 2 XTAR GL-2000™ GenLOCK boards which generate the NTSC graphics signal to the helmet-mounted display.

A set of boards (1 AP-2020 board, 1 PG-2000 board and 1 GL-2000 board) is needed for each of two channels (left/right eye) to achieve a stereoscopic display. The pilot observes the intercept airspace using a Flight Helmet™, a stereoscopic helmet-mounted display. This display is composed of a pair of color LCD displays (360 x 240 resolution) viewed through LEEP™ wide-angle optics. The combined images seen through these optics produce a 90° (h) x 30° (v) (approx.) field of view. The pilot has unrestricted movement through the virtual environment using a head-tracking device provided by the extended range Flock of Birds™ (sensitive over an 8-foot radius). Alternatively, a seated user may maneuver through the virtual world using a 6-degree-of-freedom Spaceball™ (Fig. 1). A Cricket 3D™ input device allows the user to touch, select, and move objects about in the virtual world with tactile feedback. Finally, the helmet also is equipped with a stereophonic headset for inputting sound while the user experiences the virtual environment. At present, this capability is exploited with a simple audio cassette to provide prerecorded auditory feedback. Any user familiar with computers, simulators, or video arcade games can readily adapt to using the virtual environment interface.

Figure 1
Overview of the VirDI Post-Mission Feedback System.
Stereoscopic images are projected on a pair of helmet-mounted LCDs. The imagery is slaved to the pilot's head movements based on input from a head-tracking system. As shown here, the pilot also may move through the world using a 6-degree-of-freedom input device.

Hardware Interface

The VirDI system is designed to interface with the existing F-16 Air Intercept Trainer (AIT)[1] at Williams AFB. The AIT is a part-task training system designed to help fighter pilots define and implement air intercept strategies (Fig. 2). It offers concentrated practice on the symbology and switchology of the fighter aircraft under simulated air combat conditions. At present, 88 training scenarios are available, incorporating single and multiple-ship situations as well as maneuvering or nonmaneuvering targets. Throughout the simulated sortie, the AIT provides real-time simulation of the mission-critical displays found in the F-16 cockpit, including the radar electro-optical (REO) display, multi-function display (MFD), and head-up display (HUD). Training support for the AIT is provided by the Student Instruction Control Station (SICS) which augments the real-time spatial instrument displays by providing two-dimensional graphical presentations of the intercept as it unfolds in time, and a post-mission feedback system—AIT DEBRIEF.

The SICS graphical display consists of two orthographic projections[2] indicating the spatial relations of the aircraft (color coded as friendly or hostile) and the ownship's radar scan envelope. The orthographic projections depict the plan view of a 40 x 20 mile airspace, and an elevation view (35,000 ft) of the same airspace. Together, these displays indicate the absolute positions of all aircraft in three-dimensional space. Although each aircraft is identified only as a circle, a tick mark on the circle designates the plane's heading track vector.

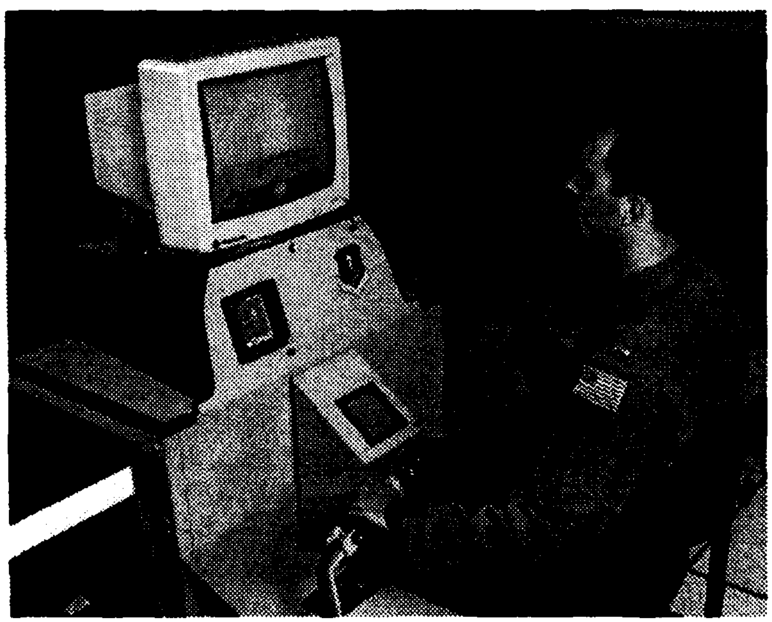

Figure 2
The Air Intercept Trainer.
The VirDI system interfaces with the AIT, a part-task trainer for concentrated practice on F-16 symbology and switchology.

[1] In principle, the device could interface with any training system capable of time sampling spatial information during real or simulated flight. The system can accept any data input in standard ASCII format.

[2] In orthographic projection the projection plane is positioned in front of the object or scene so that the line of sight is co-incident with a principal axis and orthogonal to the projection plane. All projectors from the object(s) are parallel to the line of sight and, therefore, perpendicular to the projection plane. The traditional top/front/side views of orthographic projection align two of the three principal axes with the projection plane and collapse the third axis (the line of sight axis) to expose two-dimensional profiles of the visible surfaces (top, bottom, front, back, left or right).

The post-mission feedback system, AIT DEBRIEF, has been operational since 1991 (Anselme, 1991). This feedback system contains two components, one for data capture and a second for performance analysis. The data capture component samples mission performance on the AIT throughout the simulated mission. The raw data set represents 53 variables, time sampled at a rate of 1 Hz. Among these data are the positions and orientations of all aircraft (up to 5 targets), as well as ownship radar information. The performance analysis component of the AIT DEBRIEF again displays a pair of orthographic projections indicating the flight trajectories of all aircraft involved in the intercept from the plan and right side profiles (Fig. 3). The timing and sequencing of critical mission events are depicted as they occur during the scenario with color codes and other symbology (e.g., path color is keyed to radar mode). Two additional windows display the corresponding information from the radar and HUD.

VirDI interfaces with the Air Intercept Trainer using the existing AIT DEBRIEF data capture component. Data collected during the simulated sortie is transported to a personal computer, converted to the ASCII format and prepared for graphic projection. Of the 53 variables collected by the AIT DEBRIEF system, 7 pertain to the spatial position of the ownship. Twenty additional variables describe the absolute position of the target and the position of the target relative to the ownship (6 additional bits of information are collected if the radar is locked onto a target). Finally, twenty variables describe the radar mode and scan pattern. This data set is truncated in VirDI to the 18 variables listed in Table 1. This subset of data describes the absolute location and orientation of the ownship and target, time-sampled at one-second intervals. In addition to this finely grained description of the flight trajectories, the VirDI data set also represents radar mode and scan pattern information. These data represent critical intercept information to be displayed as they occur along the flight trajectories.

Following the data processing stage, the time-sampled air intercept data set is projected onto the helmet-mounted stereoscopic displays at an average rate of 15 Hz. The total elapsed time between flying a sortie on the AIT to walkthrough in the virtual environment is 5-10 minutes, depending on the duration of the flight.

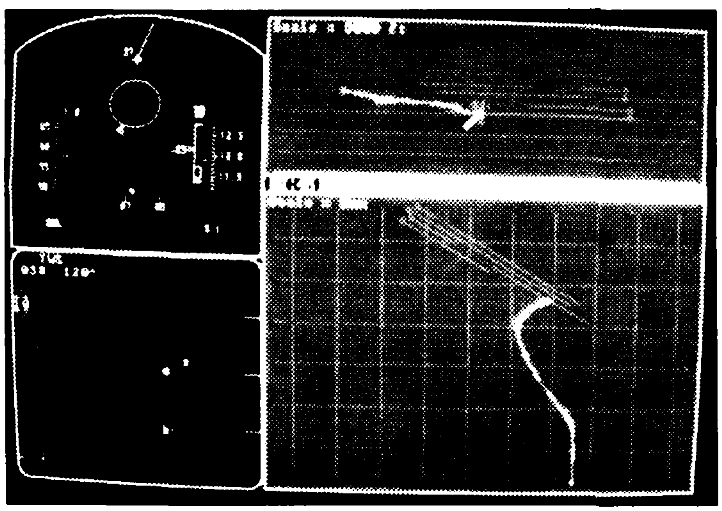

Figure 3
The AIT DEBRIEF Post-Mission Feedback System.
AIT DEBRIEF currently consists of a pair of two-dimensional orthographic projections indicating a top view and an elevation view.

Table 1. VirDI Post-Mission Feedback Variables Extracted from the AIT Data Capture Component.

Ownship Position/Attitude	Target Position/Attitude	Radar Variables
Latitudinal position (degrees)	(up to 5 targets)	Radar center of scan (azimuth)
Longitudinal position (degrees)	Flag: whether target is active	Radar center of scan (elevation)
Altitude (ft)	Latitudinal position (degrees)	RCP setting: radar range scale
Roll angle (degrees)	Longitudinal position (degrees)	RCP setting:radar elevation bars
Pitch Angle (degrees)	Altitude (ft)	Current selected radar mode
Yaw Angle (degrees)	Roll angle (degrees)	
	Pitch Angle (degrees)	
	Yaw Angle (degrees)	

TRAINING CAPABILITY OF VIRDI

By design, the VirDI system capitalizes on the principal properties of a virtual environment—immersion and interaction in a world of intangibles. There were two primary goals in developing this system as a spatial awareness training medium. First, it was intended to provide a tool for visualizing the pilot's performance in conducting an air intercept. Performance is defined here primarily in terms of the spatiotemporal properties of the intercept flight trajectory. Therefore, the VirDI system is designed to project the three-dimensional spatial coordinates of the flight trajectories (self and target(s), up to 5 targets) as they unfold during the intercept maneuver. Critical intercept events are displayed at the time and place of their occurrence. Second, the VirDI system was intended to provide the user with supervisory control of a three-dimensional visualization environment. Sheridan (1987) has defined supervisory control as an interactive human/computer system in which the human sets the initial state and intermittently adjusts the incoming information while the computer assumes a direct role in interacting with the task and the task environment. Thus, it represents a compromise between automatic and manual modification of the environment by the user. In the VirDI system, this is implemented so that the user controls only those aspects of the environment which will promote insight or understanding about the spatial problem and pilot's performance during the simulated mission. Direct control of extraneous degrees of freedom in the environment has been delegated to the computer.

Visualization Capacity

World Properties. A typical sortie in the AIT environment encompasses approximately 40 square miles of air space. In the VirDI system, the virtual world also extends 40 square miles, with 50,000 ft. vertical air space. This virtual world is scaled to the real-world coordinates of a room measuring 10' x 10' x 8'(H). The observer's natural eye height and interpupillary distance are not altered. Thus, the observer is effectively a giant in the Lilliputian world of the air intercept. This adjustment allows the user to view the entire air intercept from a single vantage point while maintaining sufficient proximity to capitalize on binocular disparity information for stereoscopic depth perception.

Figure 4
Close-Up View of the Debrief Aid.
Here two F-18s and their respective flight trajectories plotted as streamers in space. The pilot may view the trajectories from the vantage point of either cockpit or may assume any external viewpoint. When viewed stereoscopically, the trails' three-dimensional spatial relations are evident.

The virtual world of the air intercept space may be instantiated as a naturalistic flight environment, a room, or as an abstract data display. When the virtual world is presented as a naturalistic environment, it is furnished with a simulated terrain and various natural and man-made objects (e.g., mountains, airport, and buildings)[3] (Fig. 4). In early demonstrations of the naturalistic environment, we learned that users tend to believe that VirDI is presenting a real-time interactive event, rather than an historical record of a past event. As a result, they would attempt to participate directly in the sortie as if flying a plane (i.e., they did not just explore the environment to better visualize the data record). In order to dispel this

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[3] Because the commercially available components used in its development have achieved only moderate sophistication at providing visual realism in real-time graphics displays, the VirDI system cannot produce a high fidelity virtual environment in which the user will experience total immersion. Nevertheless, users have reported that the displays are sufficiently compelling to engage their imagination. Moreover, because the user can modify the viewpoint as well as affect the spatial relations among objects in the virtual world, it is not difficult to appreciate "presence" of the self in this computer-generated graphical world.

impression, we have instantiated the virtual world as the room in which the system is housed. The virtual room shows the floor, walls, and furnishings of the real room at their correct spatial locations. This allows the user to walk about the real room in safety while viewing the air intercept trajectories in the virtual room (cf. Figs. 5 & 7). Although the trajectories are scaled to the room, the user may step out of the virtual room and view the data record from a distance, not unlike viewing the traditional "sand table" used for strategic planning. Finally, the abstract virtual environment immerses the user in the world of a three-dimensional data display. The axes of Cartesian space are visible and are scaled to render more explicit the metrical relations among the ownship and target(s). This abstraction of the virtual world can be used to stress to the student that performance data may be subject to scientific analysis.

Air Intercept Trajectory Properties. As noted above, the primary purpose of this visualization tool is to enable the pilot to assess intercept performance, where performance is instantiated in the flight trajectory. The flight trajectories of the ownship and target are portrayed as "snail trails" or "streamers" projected into the three-dimensional space (Fig. 5). Each trail is attached to its respective aircraft and is color coded for ease of identification. Models of the pilot's ownship and target are projected at a scale far exceeding realistic size relationships in the virtual world. This exaggerated size is necessary to render the

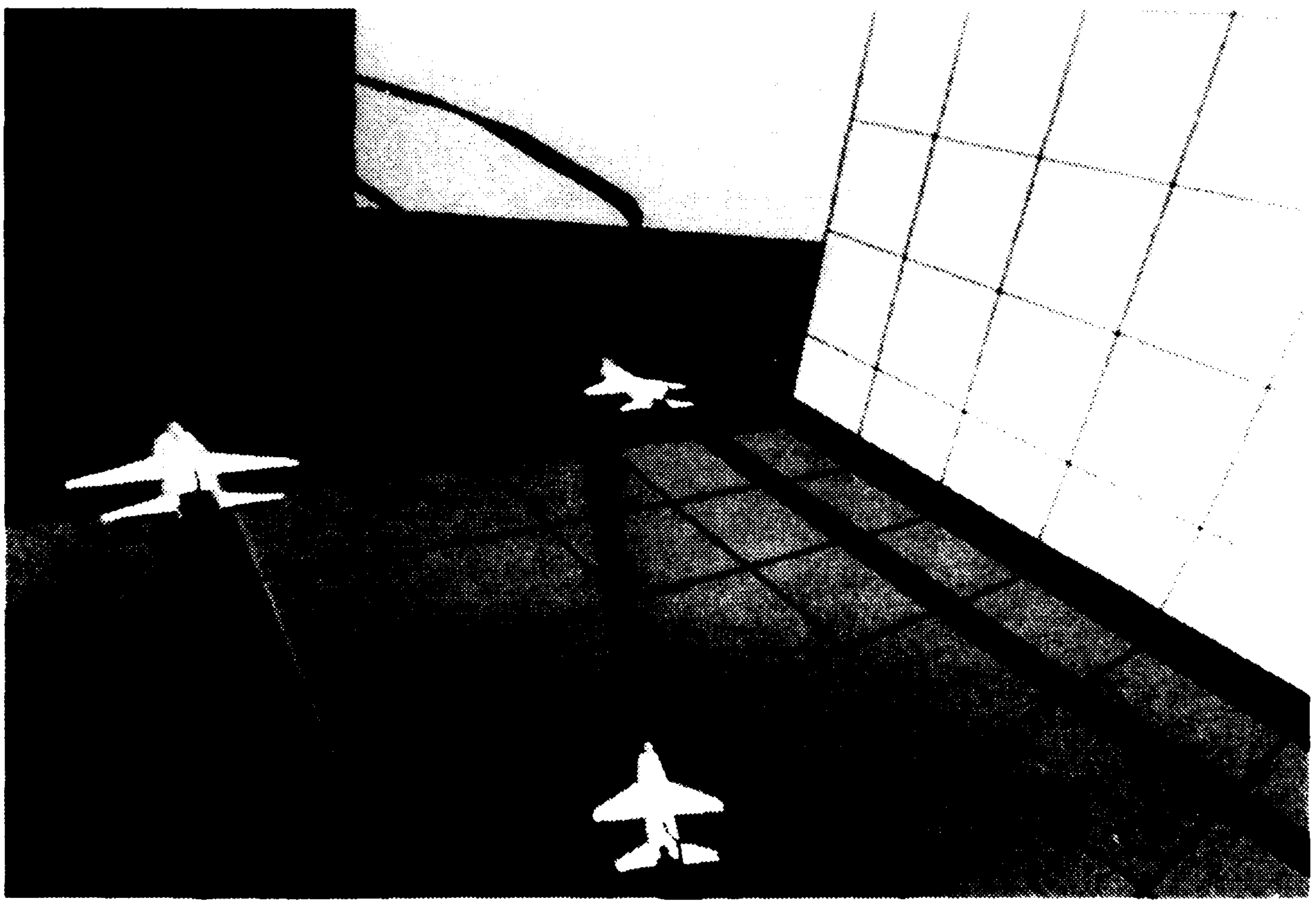

Figure 5
Close-Up View ofThree F-16s with Their Flight Trajectories Plotted as Streamers. This virtual world represents the room in which the system is housed.

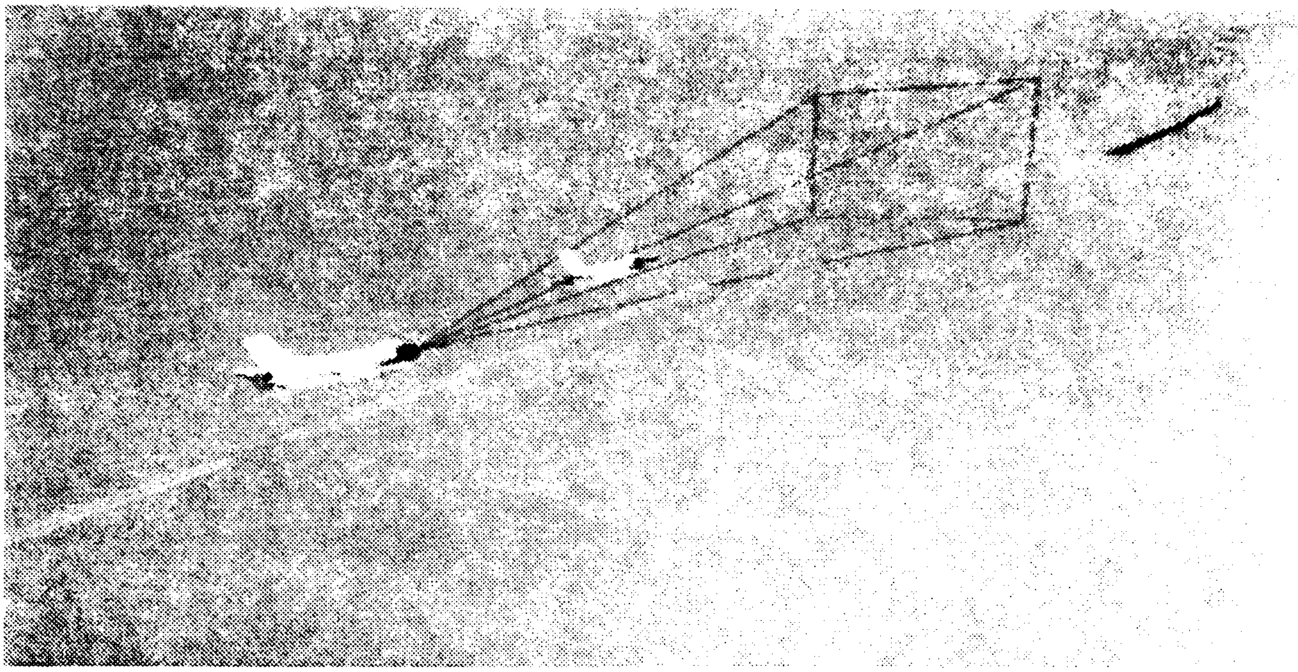

Figure 6
Two F-16s with Their FlightTrajectories Plotted in aThree-Dimensional Graphic World. The pilot may view mission-critical events, such as radar mode and scan pattern, in order to better understand the effect of certain strategic maneuvers.

relatively small aircraft visible in a full-scale environment of this size. The aircraft continuously travel their paths whose profiles remain stationary, suspended in time and space. Thus, the viewer can examine the spatial relations of the aircraft locally and globally at any given moment.

Critical Intercept Event Properties. During the course of an air intercept, the pilot performs certain mission-critical actions. Among these events are changes in the radar mode and radar scan envelope. At present the F-16C AIT allows five radar modes: RWS (range while scan), TWS (track while scan), ACM (air combat mode), ULS (uplook search) and STT (single target track). The pilot also controls the direction and size of the radar antenna's scan pattern. In VirDI an optional display mode permits presentation of the radar envelope as a visible wireframe projection attached to the aircraft. The wireframe envelope is color coded to represent the radar mode operational at any given time during the mission. Its size, shape and orientation specify the antenna elevation, range, and azimuth/ elevation scan pattern respectively. As the radar mode changes during the course of the intercept, the properties of the projected wireframe envelope change accordingly. Thus, the pilot or instructor may assess the strategic use of radar functions during the conduct of an air intercept (Fig. 6).

Supervisory Control in the Virtual Environment

The second goal in developing the VirDI system was to provide the user(s) with control in the virtual world. Unlike most visualization tools, the VirDI system allows the user to enter the computer-generated virtual world, to explore the environment through movement and to act on other objects.

Viewpoint Control. The VirDI system supplies the user with the means of visualizing the intangible—a set of flight trajectories. To increase opportunities for gaining insight from the virtualized spatial relationships, the user should be able to actively explore the data set—assuming a new viewing angle, zooming, panning, and so forth at will. Using either the head-tracking system or the Spaceball input device, the user may assume either of two viewpoints, an egocentric or an exocentric frame of reference. With the egocentric viewpoint, the pilot is positioned within the cockpit of the ownship, as when the original mission was flown in the AIT. Unlike the original simulated flight, however, the pilot can re-experience the flight with the target visible in the "out-the-window" view. Relinquishing the egocentric point of view allows the pilot to assume the exocentric frame of reference of an active outside observer. Once outside of the cockpit, the pilot may move anywhere within the three-dimensional world and assume any orientation relative to that world. This allows the pilot to examine in detail points along the trajectory at which critical changes in the spatial relationships of the ownship and target occurred. The real-time image generation system is designed to project imagery appropriate to the gaze direction as interpreted by the helmet-mounted head-tracking system or the Spaceball (Fig.7). In order to control for a user becoming 'lost' in the virtual world, a simple button press returns the user to home base in the coordinate system

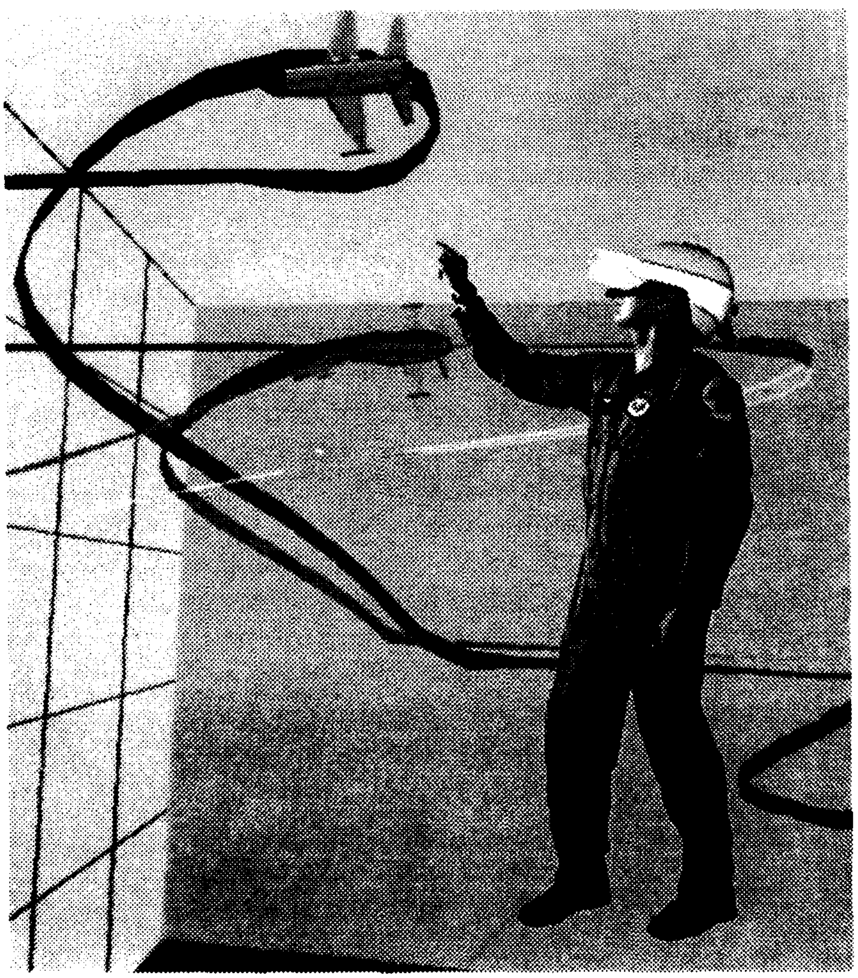

Figure 7
Expert Performance Models. Student pilot compares his flight performance with those of two expert fighter pilots by walking through the simulated airspace.

Instructor Feedback—Visual. A well known problem in pilot training is the fact that it is not possible to establish a "correct" intercept for the host of initial conditions and tactical considerations a pilot will encounter in an intercept. On the other hand, the student's performance on a given mission should be considered a tangible product that is open to review, discussion, critique or comparison with other air intercepts. One of the most exciting capabilities of the VirDI system is that it allows the student, instructor or supervisor to study the performance and provide visual and auditory feedback. Visual feedback can be provided in a variety of ways:

1. *Models of Expert Performances.* The Air Intercept Trainer allows the user to experience identical initial conditions for an air intercept. Under these conditions, the instructor or another expert pilot can fly a comparable mission. The expert's performance trajectory can be projected in the virtual environment simultaneously with that of the student. The student then has the opportunity to compare his/her air intercept performance directly with that of an expert pilot (cf. Fig. 7).
2. *Models of Personal Best Performances.* In training athletes, contemporary theory holds that rather than modeling the expert's performance, the novice may benefit most from modeling one's own personal best performances (Andersen, 1993). Because the AIT can provide identical initial conditions, the student can practice intercepts, varying and refining maneuvers within a specific performance arena. One or more of the performance trajectories can be projected simultaneously in the virtual airspace for comparison.
3. *Instructor Toolbox.* The pictorial format of the virtual environment platform also can be considered a virtual blackboard on which the instructor can interact directly with the portrayed trajectory. By marking the virtual blackboard, the instructor can 'post' editorial comments for the student to study. The VirDI system provides the user with a toolbox of icons which can be positioned in the virtual world using the Cricket 3D input device. These icons serve as editorial notation symbols that are keyed to verbal or written commentary. The icons and their positions in the virtual world may be saved as a part of the permanent data file for future access.

Instructor Feedback—Auditory. A critical component in any debriefing system is the direct communication between student and instructor. Therefore, much of the success of a virtual environment feedback system may depend on its ability to permit unimpeded discussion between the student and instructor. At present, the post-mission instructor/ student discussion occurs with one person viewing a standard computer monitor while the other experiences the virtual world within the helmet-mounted display. Both users can view the same imagery simultaneously with the viewpoint controlled by the head movements of the person wearing the helmet.

The helmet also is equipped with a stereophonic headset for inputting sound while the user experiences the virtual environment. At present, this capability is exploited with a simple audio cassette to provide recorded auditory feedback. This capability expands the system's versatility by allowing the instructor to tag commentary to the icons posted on the virtual blackboard. Thus, the student may take a self-guided tour through the virtual environment noting the instructor's iconic annotations on the projected flight path while listening to the recorded message. Because both the visual and auditory feedback may be saved or transmitted, it is feasible that instructors could provide feedback to students stationed at remote sites within minutes of receiving the original student performance data.

Summary

In summary, the first level of development for the Virtual Environment Debrief Interface—VirDI—provides the user with the ability to:

1. Walk through the virtual environment of the air intercept space while viewing a three-dimensional pictorial display of the flight trajectories.
2. Explore the flight performance from the egocentric cockpit view or from any exocentric point of view.
3. View multiple flight trajectories (produced by the student and/or experts) simultaneously.
4. Pick and place editorial icons within the virtual world that are keyed to auditory commentary.

In addition to the instructional benefits that are anticipated with the implementation of the VirDI system, this platform should provide low-cost, portable flexibility that presently is not available with existing debrief systems. These include:

1. *A permanent feedback record.* Typically, instructor feedback is provided verbally. With no tangible copy of the debrief, the student must rely on memory when attempting to correct errors and improve performance. With the VirDI system, visual and auditory feedback can be saved for review in standard formats of computer ASCII files or audio cassettes.
2. *A portable feedback record.* Because the feedback record is in standard format, it is available to anyone with the capability to download an ASCII file and has a tape recorder. Thus, it can be shipped to remote sites. This could allow a centralized system for evaluating intercepts practiced by remotely based personnel at minimal cost and without requiring personnel to travel to training centers.
3. *A training library.* The data storage and display capabilities of the VirDI system provide a readily accessible platform for developing a library of air intercept scenarios for future study. The library can contain exemplars of successful intercepts flown by established expert fighter pilots, as well as exemplars of unsuccessful missions. Because the playback allows alternate viewpoints, the user can experience the flight as the pilot did originally or view it exocentrically to study successful maneuvers or disasters.

FUTURE GROWTH OF THE VIRDI SYSTEM

In this rapidly evolving area of computer technology, we can presume that future hardware will soon exceed the processing capabilities of the present XTAR system. In anticipation of these developments (and success of the present system), it is not unreasonable to consider available technological enhancements to support the following second generation VirDI functions:

1. *Data display extensions.* The most important extension to the display capacity of the current system is the addition of simulated cockpit instruments. At present, the system provides only radar mode and scan envelope information. However, users consistently request the radar and HUD data that they were monitoring throughout the flight. Direct access to the radar and HUD data would be highly beneficial because it would allow the pilot to study the information that affected his decisions simultaneously with the outcome of those decisions. On the other hand, contrary to our expectations few users have indicated a need for greater realism in the virtual world. It appears that users are willing to accept a fairly "unrealistic" virtual world if it offers task-relevant information. This would suggest that increased processing capabilities should be devoted to display of cockpit information and to the display of mission-critical events, such as weapons control, G-load and energy state of the aircraft.
2. *Expanded interaction capability.* At present, the user can pick and place editorial icons in the virtual environment and key these symbols to written or auditory feedback. The next generation should include the ability to draw and write in the virtual world using a three-dimensional version of today's tele-lustrator[4]. Using a finger or pointer, the user could point to a maneuvering error or draw a suggested trajectory. Drawn trajectories then could be re-flown by the pilot to experience directly the correct path.
3. *Shared worlds.* At present, the VirDI system supports a single helmet-mounted display. Future developments should allow multiple users to experience the virtual air intercept space simultaneously. If supported by separate graphics display systems, each user could have autonomous control within the virtual world, as well as the ability to interact with other users of the world. For example, if an instructor and student are interacting in the virtual world, the instructor could point out an error and draw a corrected trajectory. The student could observe the instructor's changes from an exocentric viewpoint and then enter the cockpit and experience the correction first hand.
4. *A virtual world network.* The Aircrew Training Research Division of the Armstrong Laboratory at Williams AFB is a leader in the design and implementation of computer simulation networks for simulated air combat training. As networked communication systems continue to advance, it is desirable and feasible to link the VirDI system to a training network. This could offer several advantages in enhancing the training effectiveness of the network. First, remotely based personnel could be trained or evaluated by instructors located at a central location. Second, in multiship combat scenarios, instructors could assess individual or group effectiveness from a command and control center. Pilots also could review their performances, individually or in groups. This would allow friend and foe to describe their strategies and techniques or experience each other's point of view during the engagement.

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[4] The tele-lustrator is a digitized light pen used to draw/write on a computer or television screen. It is often used in television applications for direct, on-line input to the screen (e.g., weather reports or sports play-by-play illustrations).

RESEARCH OPPORTUNITIES WITH THE VIRDI SYSTEM

Virtual environment debrief systems are only in the initial stages of development. While there is considerable speculation that receiving post-mission feedback in a virtual environment could improve spatial understanding in novice pilots, this has not been established empirically. Indeed, there is considerable evidence to suggest that merely providing higher dimensional data in a three-dimensional display is no guarantee that the portrayed spatial relationships are comprehended accurately (cf. Ellis, McGreevy & Hitchcock, 1987; Smith, Ellis & Lee, 1984). Others have suggested (cf. Wickens and Todd, 1990) that if these displays do lead to enhanced performance, the "novelty factor" may increase the time needed for the student to process the information. Finally, the choice to implement a specific training environment must be based on the nature of the task to be learned. When the display format is not compatible with the task, it may cause interference and increase the cognitive-processing load on the user (cf. Liu & Wickens, 1992; Wickens & Andre, 1988).

Therefore, a significant component in the development of the VirDI system is the evaluation of its effectiveness as a visualization tool for training novice pilots to construct mental models of the air intercept space. At present, training evaluation studies that employ the VirDI system are being conducted at AL/HRA at Williams AFB, AZ. In one series of studies, the goal is to determine whether the VirDI system can lead to a demonstrable improvement in novices' performances at air intercept maneuvers on the AIT. Other research compares the effectiveness of two-dimensional orthographic displays, three-dimensional perspective displays, and the VirDI system by training novices to locate a target from HUD information alone. It is anticipated that the results of these studies will offer considerable insight into whether the virtual environment interface can advance the training of novice pilots to expertise in three-dimensional spatial problem solving.

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