REDFLAG SIMULATION: DEVELOPMENT OF AN INTERACTIVE, HIGH THREAT COMBAT ENVIRONMENT

Mr. Clarence W. Stephens, Computer Specialist
Mr. Thomas M. Dickens, Singer Company
Ms. Patricia A. Widder, Computer Specialist
Capt Raymond L. Sheen, Aerospace Engineer

Air Force Human Resources Laboratory
Williams Air Force Base, Arizona 85224

ABSTRACT

Flight simulators are being used to an ever greater degree to train combat related skills. The Air Force Human Resources Laboratory (AFHRL) has been tasked with determining the effectiveness of simulator training and providing guidance as to how to train for combat in a simulator. In order to provide these answers, high fidelity, realistic combat simulation must be accomplished. Using the Advanced Simulator for Pilot Training (ASPT), techniques have been developed for the generation of realistic combat environment scenarios. These techniques were used to develop an environment that closely models the Tonopah range at Nellis AFB, Nevada, a range that is often used for REDFLAG exercises. Advanced database modeling techniques were used to create the geographical features, cultural features, and provide low-level cues utilizing the maximum capability of the ASPT image generating system. The environment had numerous threats including surface-to-air missiles and anti-aircraft artillery. The pilot could interact with this environment in the same manner that he would interact with a real combat environment. Through the use of Radar Homing and Warning System (RHAWS) and the visual environment, the pilot could determine the location of potential threats and targets. The pilot could attack and destroy any target or threat within the environment and he could be "killed" by any threat. The environment simulation techniques that have been developed are very flexible and therefore the REDFLAG simulation can be quickly adapted to provide new scenarios.

INTRODUCTION

There is a critical need in the Air Force for realistic combat training. Studies have shown that if an aircrew member can survive his first 10 flights in the combat environment, his chances of survival are dramatically increased. These first 10 sorties represent the learning phase for the combat pilot. The Air Force currently trains pilots in combat skills through the various exercises that take place each year.

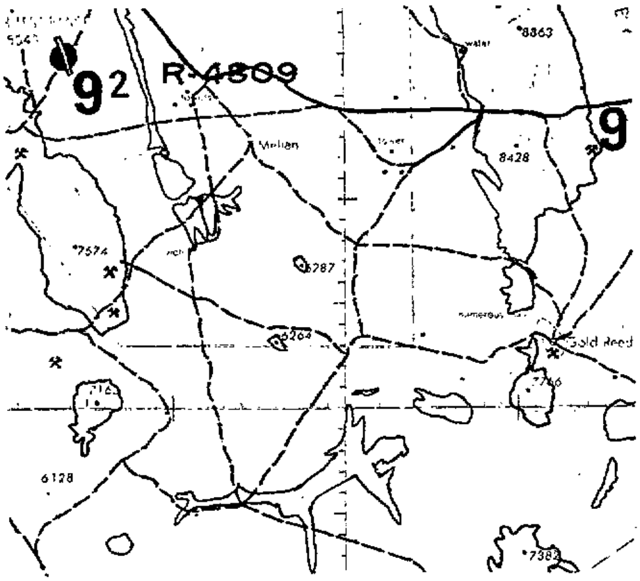
There are certain inherent disadvantages to these exercises. First, there is the loss of pilots and aircraft due to accidents. Second, there is a tremendous cost associated with conducting the exercises. Third, only a small percentage of the operational pilots get an opportunity to compete in an exercise at any one time. And last, the exercises do not constitute a continuous training but rather an occasional test of previously acquired skills. Flight simulators are not faced with these problems; however, the simulator has been faced with the problem of developing a realistic combat simulation.

Engineers and Behavioral Scientists with the Air Force Human Resources Laboratory at Williams AFB, Arizona, have been investigating the simulated combat environment. The primary tool used in this work has been the Advanced Simulator for Pilot Training (ASPT) located at Williams AFB. The ASPT has two cockpits, an A-10 and an F-16. The A-10 was used for this project. For details on the ASPT A-10 simulator, see Appendix A. As the focus of research being performed on the ASPT has shifted to the area of combat skills, techniques have been developed that allow for the simulation of realistic combat environments. The simulated REDFLAG described in this document was the first application of these techniques in direct support of simulator combat training research. The scenario chosen for the REDFLAG research study was comparable to a mission the subject pilots flew at an actual REDFLAG exercise. The intention of the study was to collect data that would provide a means of determining if there was a correspondence between the subjects' performance in a simulated REDFLAG mission profile and their performance in the actual REDFLAG exercise mission.

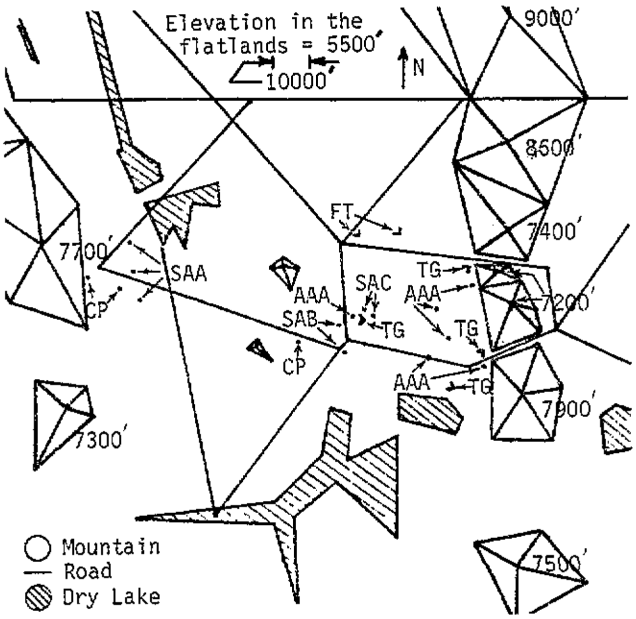
VISUAL ENVIRONMENT

Simulated environments are flat earth models of either real or imaginary places. Real terrain features such as mountains, dry lake beds, roads, and streams are depicted in abstract form in the simulated visual environment. Mountains are depicted by prisms shaped to correspond to the general contours of the real mountains they are intended to represent. Dry lake beds and fields are simulated by irregular areas of contrast on the ground's surface and are not associated with a change in elevation. Currently, roads are always composed of straight segments; curves are very expensive in terms of the image generation resources required to depict them.

The REDFLAG visual environment is a simulation of one of the Nellis Air Force Base ranges located southeast of Tonopah and northwest of Las Vegas (see Appendix B). Figure 1 is a partial Tactical Pilotage Chart of the area. Figure 2 is a map of the simulated visual environment with the locations of the targets indicated. The environment modelled includes command and control posts depicting real sized radar units, SAM and AAA sites, and tank



Tactical Pilotage Chart
Figure 1



AAA = Anti-Aircraft Artillery
CP = Command Post
FT = Friendly Tanks
SAA = SAM Type 1
SAB = SAM Type 2
SAC = SAM Type 3
TG = Tank Group

Map of the Visual Simulation
Figure 2

formations. Figure 3 is the visual simulation of a SAM. Figure 4 is the visual simulation of a Russian tank.

These vehicles are surrounded by a sea of random shaped rock-like objects, each 50 feet high. The REDFLAG scenario requires the pilot to fly a portion of his mission in the low altitude regime (see Appendix C). The vertical objects provide adequate visual altitude cues and do not exceed the displayable edge

SAM Threat
Figure 3

limitation. A continuing problem is getting the maximum number of cues using the least number of computer edges. Efficient 3-D cues, each having

Russian Tank
Figure 4

six edges, were used. The REDFLAG task required the pilot to maneuver his aircraft over a large area of ground. The vertical cues are placed in areas that would be used for ingress, egress, and threat evasion, and are placed 2000 feet apart, give or take 25%. Making the average spacing 2000 feet enabled the objects to cover a large area. The 25% variation is used to make the objects appear randomly positioned.

Finding a target using the 6 arc-minute ASPT visual system is a problem when the target is the size of a tank. The level of detail feature is used in an effort to correct this problem. When approximately 2-1/2 miles from a tank, the least detailed version becomes active. At about 1-1/2 miles, a more detailed version replaces the least detailed version. The most detailed tank becomes active at about one mile range. The least detailed version is made twice the size of a regular tank. The intermediately detailed version is 50% larger than an actual tank. The most detailed version is realistically sized. The other vehicles in the environment are handled the same way. The less detailed versions use fewer edges. This procedure made the targets large enough to be located from a somewhat realistic range.

Aerial View of Simulated Environment
Figure 5

The basic ground is a medium gray while mountains are shaded darker. Targets are generally medium dark. The vertical altitude cues and the roads are very dark. Dry lake beds are depicted using a gray shade that is lighter than the ground. Figures 5 and 6 are views of the simulated target area. At any given time, the environment will use approximately 150 edges for mountains, 50 for dry lake beds, 50 for roads, 500 for vehicles on the ground, 100 for a SAM inflight (there can be up to three visible at any time), and as many of the remaining edges as possible on the 3-D vertical visual cues.

The environment is modeled to depict accurately the actual REDFLAG area as nearly as a 2560 edge capacity permits. Every potential viewpoint was carefully considered to see that the maximum number of displayable edges were being used. The visual environment simulation operates synchronously with a set of threat simulation programs. The pilot is able to locate and kill a target while, at the same time, the target might kill him.

Aerial View of Simulated Environment
Figure 6

THREAT SIMULATION

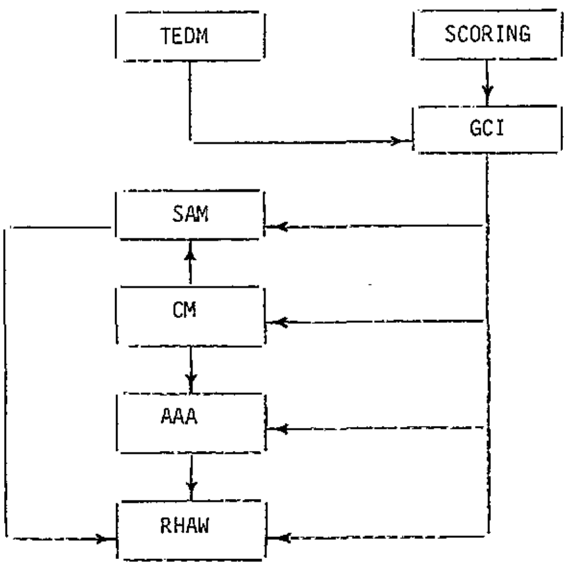
The programs which drive the threat simulation require information which describes the threats' environment in a fashion consistent with the manner in which they operate. Any specific threat site has its own perspective and experiences the environment only in terms of what it can "see" from its point of view and within its capabilities.

In the "real" world, threats "see" their environment through the information brought back via returning radar signals, infrared signals, or visual line of sight depending upon the system. In the simulator, this information must be provided in an entirely different way. Since the programmer knows where the threats are in the environment, the areas each threat will be able to "see" can be predetermined, given the known capabilities of the threat. In combat environment simulation, the limits of what each threat site is able to "see," i.e. its horizon, is defined in terms of two parameters called the maximum effective range and the minimum look angle. The meaning of maximum effective range is readily apparent, but what is meant by minimum look angle requires some explanation.

The minimum look angle is found by determining the angle of elevation (measured from the ground up) below which a threat would not receive meaningful information. Two types of factors influence the value of this minimum look angle: system induced limitations and terrain induced limitations. System limitations include the mechanical limits of the antenna scan and its susceptibility to ground return. Terrain limitations are imposed by the proximity of mountains to the threat site. The presence of a mountain within the line of sight increases the minimum look angle for all ranges beyond the mountain in that sector.

To define the horizon for each threat site, a polar coordinate "grid" is centered at each site. Each sector of the grid is bounded on the left and right by azimuth radials and the near and far side by concentric range rings. A single value for the site's minimum look angle is assigned to each sector of the grid. This requires that when a mountain contributes to only a part of the sector, its contribution is averaged on a proportional basis before determining what look angle value to assign to the entire sector.

The accuracy of the horizon defined in such a fashion depends on the interval between sample points along the horizon. Here a compromise must be reached between the simulation's realism and the available simulator resources. If a very small interval is chosen, the fidelity of the model is very good but the computer memory required is very large. Combat simulation requires that the correspondence between the visual environment and the threat's horizon defining data be close enough to allow the pilot to employ terrain masking in threat avoidance. Since the aircraft is in constant motion, it is possible for an approximation of the threat's horizon to suffice without losing realism.



Threat Simulation Module Structure
Figure 7

The threat simulation software is organized into a series of modules (see Figure 7) each of which performs a characteristic function. This structure allows easy modification of the method of implementing a particular function without necessitating that large portions of the supporting software be rewritten. What follows is a discussion of the basic functions and methodology of the major modules.

Since the threat horizon data are determined by location in a specific visual environment, it is convenient to place these data in a separate module. This is the sole function of the Threat Environment Data Module, TEDM. TEDM is an interchangeable module which contains all data that could be interpreted as scenario dependent. This includes the location data for each threat in the visual environment and some of the data determining the operational characteristics of the threat as well as the threat horizon defining data discussed above. This arrangement allows the threat simulation to be adapted to another combat scenario with minimum difficulty.

The logical heart of the threat simulation is the Ground Control Intercept (GCI) module. It uses data provided by TEDM and parameters defining the aircraft's location in space to determine which threats can "see" the aircraft. This is accomplished by calculating the bearing, range, and look angle from each site to the aircraft's current position and comparing them to the stored data that define the radar horizon for that site. As previously mentioned, the effect of local terrain is incorporated in the radar horizon data for each site. If the pilot approaches the threat using terrain masking, i.e., maintaining low altitude and/or keeping mountains between the aircraft and the threat, it is possible to get quite close to the threat without its becoming active. This capability is essential to realistic air-to-ground combat simulation.

Once the look angle test is satisfied, the threat site is activated. Threat activation consists of making an entry defining the nature of the site and its status in an array located in common memory. Data entered in the array tell all the user programs the status, location, and types of sites that are active. The nature of the data entered in the active threat array depends on the type of site. Basically each entry contains only data which are needed by user programs to drive the threat models. Site type and location are data that do not change within a given scenario; however, site status is highly time dependent.

A subsidiary function of GCI is the invocation of user programs in the proper sequence. Each user program may modify the data stored in the active threat array to further prepare it for use by other programs downstream. This is consistent with the modular concept by keeping all functions in the most appropriate module. For example, GCI will set the status of the Surface-to-Air-Missile site in either acquisition or track and will determine which of two otherwise equally active sites should be given priority for launch. It then lets the appropriate subroutine in the Surface-to-Air-Missile (SAM) module determine when to actually launch the missile from the site GCI has selected.

Once all sites have been checked, control passes to the countermeasures (CM) module. It checks for release of chaff and/or flares, then determines the effectiveness of the countermeasure selected. Effective countermeasures influence the operation of the SAM or Anti-Aircraft Artillery (AAA) modules by denying updated aircraft position and velocity vector data. Countermeasure effectiveness can be varied in many ways depending on the requirements of the research or training. In the REDFLAG simulation only chaff was available and each chaff release provided 3 seconds of effective chaff.

Upon completion of execution of the countermeasures (CM) module GCI calls the SAM module. Actually the SAM module consists of a series of subroutines each of which is responsible for driving a model of a particular type of surface-to-air missile. All surface-to-air missile systems are currently modeled in the same manner, i.e., the basic structure of the subroutine is the same for all models. However, each model uses different values for critical parameters such as maximum speed or turn rate so that the performance of the model reflects the capabilities of the system it represents.

Each SAM subroutine performs the same basic functions. First it searches the active threat array for threats of its type. Then it checks the status of each threat found. For threats in the aquisition mode no further action is necessary. For threats in the track mode the subroutine attempts to align the missile with the line of sight to the target aircraft. Once the missile is aligned it is launched and the subroutine guides it on a course intended to intercept the aircraft's flight path. While the missile is in flight, the subroutine continually checks the missile's proximity to the target to detect the moment of closest approach. It is assumed the warhead will detonate at closest approach. The distance separating the missile and the aircraft at closest approach, i.e., the miss distance, is compared to the kill radius of the missile warhead to determine if the aircraft has been destroyed.

Each subroutine in the SAM module is capable of handling several different threats of its type simultaneously. An exception is that only one missile of each type is allowed to be in flight at a time. This restriction is a result of the manner in which the REDFLAG threats were simulated. In the simulated REDFLAG three moving models were used to represent inflight SAM missiles; one dedicated to each type of missile modeled.

After the SAM module has executed GCI calls the AAA module. In the simulated REDFLAG, time elapsed since the aircraft came over the threat's horizon is the primary criterion governing operation of the AAA. A couple of seconds must pass before a site will recognize a target. Then a few more seconds will pass before the site will begin firing. A kill is determined by the amount of time the aircraft remains in the AAA firing envelope.

Both the AAA and SAM threat modules respond to evasive manuevers performed by the pilot. The SAM module subroutines react to aircraft manuevering when computing target intercept guidance and can be out-manuevered. The time required by AAA to kill the aircraft can be increased if the pilot executes a high-G turn while receiving fire.

The last module called by GCI controls the in-cockpit Radar Homing and Warning (RHAW) display. The RHAW informs the pilot of his exposure to threats using data supplied by the GCI, SAM and AAA modules via the active threat array. For the REDFLAG simulation a generic RHAW display was provided. Each active threat was shown on the face of the instrument at a clock position consistent with its bearing relative to the aircraft. The status (aquisition, track, etc.) and type (SAM or AAA) of each threat was indicated. However, no information indicating the highest priority threat or the specific kind of SAM was available to the pilot.

The results of the pilot's weapon attempts against targets are determined by the SCORING module. The SCORING module runs independently of GCI, but information identifying killed threats is communicated to GCI by scoring so that killed threats are deleted from the scenario. The REDFLAG visual environment contains numerous scorable targets. The scoring module must determine which of the possible targets the pilot is attempting to hit and report the results. To reduce the amount of processing required, a list of potential targets is formed from all those possible during the time between weapon releases. Potential targets satisfy three criteria:

1. They have not been killed previously.
2. They are in front of the aircraft.
3. They are relatively close to the aircraft.

When a weapon attempt occurs, SCORING selects the target closest to the weapon impact point from the list of potential targets as the target the pilot intended to hit. If the weapon attempt was a strafe pass, the miss distance relative to the target center and the clock position of each round is computed. The miss distance is used to determine if the round was a hit. At the completion of each strafe pass, the number of hits, total rounds fired and the distribution of rounds fired is provided on a CRT display located at the simulator operator's control console. For bomb releases miss distance and clock position are calculated and displayed.

The kill criterion in effect for the simulated REDFLAG was one strafe hit killed any target. A hit was defined as a round passing within 5 feet of target center. A bomb impacting within 150 feet of any target would also qualify as a kill.

CONCLUSION

Effective combat simulation could provide the pilot with the opportunity to learn, practice, and improve his combat skills in a safe and cost-effective manner. The methodology outlined in this paper significantly contributes to the capability to conduct research to determine what constitutes effective combat simulation and could provide the framework for operational simulator combat training.

APPENDIX A
ASPT/A-10 Description

The Advanced Simulator for Pilot Training (ASPT) is a research simulator originally designed with a full mission T-37 capability. A detailed description of the original device may be found in Gum, Albery, and Basinger, 1975 (AFHRL-TR-75-59). One cockpit has been modified to represent an A-10 configuration while the other cockpit has been configured as an F-16 aircraft. Neither of the modified configurations has full mission capabilities. Both systems were designed to have necessary cockpit and aerodynamic capabilities to support transition flight tasks such as takeoffs, approaches and landings, basic navigation tasks, and conventional air-to-ground weapons delivery tasks. Both cockpits are being continually modified to expand the capability for combat simulation and more closely simulate actual aircraft capabilities and characteristics.

The following is a description of the ASPT/A-10. The visual display is a monochromatic computer generated image displayed through seven CRTs with a 300° horizontal by +110° vertical field of view. The ASPT/A-10 also has a field of view of -20° over the nose, -40° over the left side, and -15° over the right side. There is a "G" seat/suit capability. The cockpit layout was designed to duplicate the aircraft in most major respects. Aircraft aerodynamics provide normal flight characteristics throughout the aircraft envelope and can provide characteristics for the Manual Reversion Flight Control System. The aerodynamic model does not account for weapon weight or station number but does account for weapon drag. All flight and engine instruments are operable, including the HSI. Communications panels are static mock-ups. The HUD provides displays for manual strafing and bombing. The weapons modeled on the A-10 are the BDU 33 and the 30mm cannon at the high rate of fire.

APPENDIX B
ASPT Visual System Description

The Advanced Simulator for Pilot Training (ASPT) Computer Image Generation (CIG) system stores the visual environment, defined in a three-dimensional reference system, in computer memory. The data are then retrieved and projected as a perspective image on a series of seven, 36-inch 1024 by 1024 CRTs.

Visual database modeling is the art of defining and storing the visual environment as numerical data in computer memory. Maps, photographs, and scale drawings are used as source data.

The CIG is composed of vertices defined mathematically in 3-D space. These vertices are connected by edges. The edges are used to make faces. The faces are assigned a gray shade and used to make 2-D or 3-D objects. The objects are used to construct models. The models are then put together to make the environment.

There are many limitations on the modeling of the visual environment. Faces must be convex with their vertices in the same plane. A face may have up to 16 vertices. An object may have at most 32 vertices and 16 faces. Models can have no more than 15 objects. In a visual environment there may be at most 300,000 edges, 40,000 objects, and 2000 models. The real-time visual system can display at most 2560 edges, 512 objects and 200 models in the frame time of 1/30 second.

The visible edges per system limitation are usually encountered first. Because of extra edges generated when edges cross window boundaries, the effective maximum edges used to make a visual scene should not exceed 2000. If the edge limit is exceeded, undesirable visual effects, such as priority problems and portions of the scene flashing in and out, occur.

The ASPT visual system allows three levels of detail per model. The switching distance from one level to the next is a function of the aircraft altitude above ground, the distance to the center of the model, and the size of the model.

ASPT uses shades of gray for painting the displayed faces. The scale goes from 0 (very black) to 63 (very white).

APPENDIX C
Low Level Modeling Considerations

Lack of adequate visual scene detail limits the usefulness of the Advanced Simulator for Pilot Training (ASPT) computer image generation (CIG) system for simulating low level flight. The visual environment modeler should optimize existing capabilities to compensate as much as possible for the lack of scene fidelity to better provide for the low level task.

Both ground texture patterns and vertical objects are used as primary visual cues by pilots in judging aircraft altitude above the ground. Ground texture patterns must be quite intricate in order to be effective. They therefore use a large number of computer graphic "edges." Ground texture can be used effectively without overloading the computers if a preset flight path is adhered to by the pilot. Vertical cues are more effective in a situation where the pilot is not required to fly a pre-defined flight path. These vertical objects provide a better altitude cue than a ground texture pattern composed of the same number of edges. A vertical cue can use as few as six edges. The cues are usually made much taller than they are wide to enhance their vertical appearance. These cues can be put throughout an environment up to the point of edge overload.

Environments can be set to work quite efficiently for a low level flight with models becoming active and inactive in a way that the system's edge limit is always being approached. The distance at which a model becomes active and then switches levels of detail is a function of the aircraft altitude and distance from the center of a model and the size of the model.

If the pilot must raise his altitude to turn or make a run on a target, the increased altitude can cause too many models to become active and thus overload the system. Under these circumstances, a trade-off must be found, usually by trial and error.

BIBLIOGRAPHY

1. Modern Soviet Armor: Combat Vehicles of the USSR and Warsaw Pact Today, Steven J. Zalaga, Prentice-Hall, 1979, p. 76-88.

2. Aviation Week & Space Technology, March 9, 1981, p. 34. (Aerospace Forecast & Inventory, Soviet missiles).

3. Tech Order 1A-10A-1 Flight Manual A-10A Aircraft, 1 July 1979.

4. Tech Manual 1A-10A-34-1-1, Non Nuclear Weapons Delivery Manual, A-10A Aircraft, 20 December 1976.

5. Monroe, E.G. Environmental data base development process for the ASUPT CIG system. AFHRL-TR-75-24, AD-A017845. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, August 1975.

ABOUT THE AUTHORS

Mr Clarence W. Stephens has been working as a Computer Specialist with the Air Force Human Resources Laboratory, Operations Training Division, at Williams AFB, Arizona since 1978. He is currently in charge of database modeling. He is currently completing a degree in Computer Systems Engineering.

Mr Thomas M. Dickens is an employee of the Singer Company and has worked at the Air Force Human Resources Laboratory, Williams AFB, Arizona since 1980. Since joining the Laboratory, he has been involved in programming work for several research studies in the area of combat environment simulation.

Ms Patricia A. Widder has been working as a Computer Specialist with the Air Force Human Resources Laboratory, Operations Training Division, at Williams AFB, Arizona since 1978. Her areas of expertise include the real-time visual software and the database modeling software. She is currently completing a Masters Degree in Electrical Engineering.

Captain Raymond L. Sheen received a B.S. degree from the United States Air Force Academy, majoring in both Aeronautical Engineering and Mechanical Engineering. He was a T-38 Instructor Pilot prior to his assignment as an Aerospace Engineer with the Air Force Human Resources Laboratory, Operations Training Division, at Williams AFB, Arizona.