Training Fidelity of a Unmanned Aerial Systems Complementary Family of Trainers

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ABSTRACT

The use of Unmanned Aerial Systems (UAS) in the National Airspace System (NAS) is of concern by a number of entities. The public is concerned about safety and privacy issues. The private sector is interested in how to exploit the technology to drive down operational costs and create profit. Finally, the public sector is concerned about air safety, privacy, and policy issues, as well as, making use of the technology to drive down operational costs for numerous oversight activities from traffic monitoring to fighting forest fires. Private and public sector implementation pioneers will be faced with unique challenges. Despite the name unmanned, there is a plethora of people in the UAS operational loop from air support crews to pilots to air traffic controllers which creates an extraordinarily complex training requirement. Adding to complexity is the size and mission of the UAS as each size dictates airspace considerations, location of Ground Control Stations (GCS) and operational environments. While the US military has invested in UAS training and research, it is a new area constrained by limited resources. Thus it is incumbent on early UAS adopters to address their complex training challenges and leverage the training resources and research done by the US military. One critical NAS integration issue is training pilots to safely operate UAS, particularly medium altitude, long range UAS which will share airspace with private aircraft and amateur pilots. This paper discusses the need for and creation of a complementary family of UAS trainers. The authors draw on the training research, and training simulators and technologies developed and used at the Air Force Research Laboratory, and the commercial simulators used at University of North Dakota, and Sinclair Community College. The findings from the training fidelity assessment are presented and conclusions are drawn.

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INTRODUCTION

Throughout engineering history there have been firsts, the first locomotive, the first automobile, the first airplane, the first space rocket, the first space station. Today, we think of those achievements as pedestrian, but to the people of the times, they were a marvel. With each subsequent achievement, mankind adapted the environment to exploit the capability. Today, we again stand at a seminal moment in engineering history. It may not seem like it as we are busy adapting our current environment to exploit unmanned aircraft capability in civil aviation, but we are, no less, marking a point in history, one day our grandchildren will board a commercial unmanned aircraft and think of it as pedestrian. However, before that can happen, there is much work to be done.

There is a great deal of adaption required within the current aviation environment to exploit all of the capabilities that unmanned flight offers. The promise of the future depends on successfully addressing the issues apparent today. It means building training, certification standards, and regulations that are appropriate to the system, not simply adapting manned aircraft standards to unmanned systems. The current view is predicated on the unmanned system as the novelty in a manned aviation environment. But, how would the system be built if unmanned aircraft were common and manned aircraft were the novelty? In this view of the environment, it would be the manned system that would be the hazard to the unmanned system. With this kind of future in mind, how should systems evolve and in particular, how should training systems evolve?

Live, virtual and constructive (LVC) training systems have long been a part of military aviation training. There is much that the civil and public aviation communities can glean from the military to develop training systems to rival military counterparts. Research conducted at the Air Force Research Laboratory (AFRL), supports the use of a family of complementary trainers in a multi-echelon training approach. The goal is to have an embedded individual and collective training capability that supports adaptive, live, virtual and constructive training in the operational environment. This would mean that Air Traffic Controllers, maintainers, logisticians, manned system pilots, and the unmanned system crew could be training with any other member anytime, anywhere in any kind of dynamic state, at the level needed by the trainee. For example: a live unmanned system pilot could be training with a constructive air traffic controller and interacting with a virtual sensor operator, while trying to troubleshoot a malfunction with a live maintenance operator. Furthermore, the live maintenance operator may be interacting with a constructive replica of the unmanned system.

The ability to host an embedded, LVC, training capability needs to be part of the materiel acquisition process for new operational systems so that with the flip of a switch the operational system is an LVC-capable training system. At the time of new system acquisition, the training function is defined such that the hardware and/or software configuration supports training, assessment and control of exercise scenarios on the operational equipment, and when activated, starts a training session overlaid on the system's normal operational capability. Having embedded, LVC training in operational platforms enables operators to meet training requirements by providing the necessary flexibility and technology to train anytime, anywhere (United States Army Training and Doctrine Command (TRADOC), 2003). This capability taken to a system-of-systems level would mean that on the same operational platform, training is embedded not only for the system operators but for the maintainer, the logistician, and anyone else who must routinely interact with the platform. Taken to the multi-echelon environment, the embedded training system interacts with other embedded training systems in the same manner that the systems would interact in the operational environment. Rounding out the ensemble is scaffolded training systems, part-task trainers, and classroom instruction that provide foundational level knowledge, skills, and experiences.

AFRL, in conjunction with its partners at the University of North Dakota (UND) and Sinclair Community College (SCC), are working toward this embedded, LVC training vision. AFRL has developed the Predator Research Integrated Networked Combat Environment (PRINCE). The purpose of the system is to provide a high fidelity environment to support ongoing training effectiveness research for standalone Remotely Piloted Aircraft (RPA) crews (see Schill, Rowe, Gyorai, Joralmon, Schneck, & Woudstra, 2014). PRINCE is a game-based trainer that unites commercial off-the-shelf (COTS) technology to enhance simulation fidelity and backbone architecture. Gaming software is capable of rendering extremely realistic environments, high fidelity entities with articulated parts, material-specific infrared radiance data, and highly detailed urban environments equivalent to commercial video games. Based extensively on work done by AFRL's Gaming Research Integration for Learning Lab, PRINCE uses X-Plane 9 for the flight models, and renders terrain and ground features using Cry Engine 3. PRINCE is Distributed Integrated Simulation (DIS) capable, and connects to other AFRL DIS systems for distributed training. In addition, AFRL has complementary simulators built by SDS International, for Predator and Reaper. Moving into multi-echelon systems, AFRL has built the Joint Terminal Attack Controller-Training Research System (JTAC-TRS), a simulation dome for Close Air Support (CAS) training and the Joint Training Air to Ground Simulation System (JTAGSS) which is an Air Support Operations Center simulator. All these simulators are capable of being networked into AFRL's F-16 training LVC testbeds. The JTAC-TRS, F-16 testbeds, and PRINCE are all capable of being networked with the Distributed Mission Operation Network to participate in team-level military training exercises (Schill, Rowe, Gyovai, Joralmon, Schneck & Woudstra, 2014).

On the civil side, UND and SCC are developing a similar family of complementary trainers for civil unmanned flight instruction. UND operates two UAS training facilities; a UAS Training Laboratory at the Grand Forks International Airport and a UAS Training Center at the Grand Forks Air Force Base. UND operates a family of complementary trainers for unmanned system academic training from fundamental knowledge acquisition in the classroom to advanced simulation training. UND operates a Boeing Institu ScanEagle UAS. UND simulators include a ScanEagle Software in the Loop (SIL) simulator for undergraduate training, two Corsair IM3PUT training devices including one instructor station, a Mission Commander (MC) station used for training both undergraduate students and research subjects. These devices are integrated to provide mIRC chat across all simulators, MC with live video feed from all simulators (including video capturing software), real-time simulator/aircraft location tracking, weather feed, and internet access for Federal Aviation Administration (FAA) aeronautical charts. In addition, the Laboratory includes four ScanEagle standalone simulators/checklist trainers, five Predator tracker trainers/checklist trainers, and a ScanEagle maintenance facility. An L3 PMATS simulator is presently operational and AFRL's PRINCE simulator is scheduled to be installed very soon. UND's training capabilities represent the best effort on the civil side to fully develop a family of complementary trainers that meet the student's needs from fundamental to advanced pilot training. UND's family of trainers includes:

Corsair Integrated Multi-Mission, Multi-Platform Unmanned Aerial System (UAS) Trainer (IM3PUT®)
The Corsair IM3PUT® allows pilots, sensor operators, intelligence specialists, and management personnel to quickly learn core concepts and skills related to operation of MALE UAS Platforms, such as: 1) UAS capabilities and limitations; 2) Navigation, route, and search planning; 3) Airspace/traffic deconfliction; 4) Lost link, terrain, and weather avoidance; 5) Communications and crew resource management techniques; 6) Sensor utilization, search and tracking; 7) Situational awareness and aeronautical decision making. The game engine for the simulator is Envision$_{TE}$™. The simulator is Higher Level Architecture (HLA) compliant, allowing the IM3PUT to interface with other HLA compliant simulators for distributed, multi-echelon training.

In 2013, UND UAS training facility at the Grand Forks International Airport and Rockwell Collins, Inc. at Cedar Rapids, Iowa, demonstrated distributed training capability between the IM3PUT® simulators at both locations demonstrating the first distributed training capability for civil UAS training.

Corsair ScanEagle UAS Full Mission Training Device (FMTD®)
The FMTD's® game engine is the Envision$_{TE}$™ combined with integrated ground control station software provides simulation-based training and performance assessment. The system contains an integrated Instructor Operator Station (IOS) to support high-fidelity level immersive training utilizing complex scenarios.

The General Atomics Predator Mission Aircrew Training System (PMATS®)
The PMATS® flight simulator reproduces MQ-1 Predator and MQ-9 Reaper™ pilot and sensor operator aircrew stations, allowing students to master flying and operating a Predator-series UAS using actual flight hardware. While PMATS is not an embedded training system, the simulator represents best in breed standalone simulator capabilities with the actual operational Predator ground control station.

Sinclair Community College operates a first-of-its-kind UAS Classroom Training Suite comprised of a single instructor station and 10 student stations supporting both pilot and sensor operator training. Students may engage in scenario-based activities and training that caters to commercial and civil operations (i.e. industrial fire, precision agriculture, natural disaster assessment). This networked laboratory allows visualizations from any student station to be projected on larger local or external monitors via an Internet connection creating a distributed and interactive learning environment. The Sinclair facility's Internet connection is facilitated through a high speed fiber-optic connection allowing scalability for operations with high bandwidth requirements. Through collaboration with AFRL, significant capabilities have been added to the original software enhancing the effectiveness of the laboratory for student training and research purposes including those related to LVC environments. Combined with AFRL and UND, the shared capabilities of the partner systems represent a distributed, multi-echelon, family of complementary trainers supporting LVC, but has not yet evolved to the point of embedded training in the actual operational systems.

Complexity of the Training Environment and Curriculum Development

The history of unmanned aviation in the military environment began, in earnest, in the 1980s with development shrouded in secrecy. RPAs were primarily developed for Intelligence, Surveillance, and Reconnaissance (ISR) operations. Operator training for both pilots and sensor payload operators was conducted apart from other types of flying operations using pilots trained in manned aircraft tactics, techniques, and procedures (Stewart, Bink, Barker, Tremlett, & Price, 2011). Beginning in the late 1990s, the rapid expansion of RPAs by the military created a need for mass training in the U.S. Army and Air Force. The military has many training lessons-learned that can inform future training applications. Thus, there is much that training adopters can glean from the military in creating curriculums for RPAs in the National Airspace System (NAS). U.S. Army RPA pilots are most often enlisted and initially untrained. Therefore, the U.S. Army has created training specifically geared toward the novice. In contrast, the U.S. Air Force RPA pilots are officers and fully instrument-rated pilots when they begin their RPA training. Cooperative Agreements between universities and the military where the military provides subject matter-experts to help universities create training programs have so far proven to be fruitful endeavors. Universities and industry partners contribute back to the military by providing information on the new training paradigms and training innovations.

RPA training pioneers need to look beyond the typical ground school/flight time paradigm. Curriculums should have a broad focus. The first graduates from these programs will be looked to by early adopters to help them critically examine the capabilities unmanned flight has to offer. Specifically, curriculums should delve into how RPAs fit into and further the mission of the organizations for which they fly. This is particularly critical in the public sector arena where RPAs could be called to serve multiple and even conflicting missions such as wildfire suppression and surveillance of wildfire evacuation. Within the commercial sector, understanding how RPAs create value for the organization is critical to their successful utilization in the organization. For example, inspection of utility lines and facilities in remote areas could offer significant cost-saving in terms of manpower and increase the speed of repairs by putting the right repair team in place with the right tools quickly based on data gathered from the RPA mission. Another significant value could be reducing risk to humans in dangerous working environments such as crop dusting or weather/sea state monitoring for fisherman at sea.

Furthermore, RPA training pioneers need to ensure that their students understand the flight capabilities of the various RPA classes and provide information on the kinds of missions for which each class of RPA is best suited and the types of conditions in which they operate best. This rigor is necessary as organizations may turn to RPA operators for expertise during systems acquisition and upgrade. In this regard, RPA professionals will be the next generation responsible for setting organizational expectations for what can and cannot be accomplished. Depending on the size, complexity and mission of the organization, RPA operators may serve in a variety of capacities with regard to the systems they fly. Again, RPA training curriculum developers need to provide operators with competencies to handle a wide variety of roles. Topics that should be considered include mission planning, mission coordination (both internal and external to the organization), conduct of split operations, flight condition assessment, interaction with other aircraft, launch and recovery sites, position site selection and operations, positioning of ground control stations, and identification of appropriate payloads for the mission.

Another critical area is the sustainment of systems. While the current focus is on the operator, the sustainment of the system must be addressed. Airworthiness and maintenance go hand-in-hand. Unmanned systems are complex pieces of equipment and as adoption increases so will the demand for sustainment, training systems and programs availability to meet the demand. Finally, the interaction of RPA systems with air traffic control systems, manned aircraft, and airport systems must be addressed in curriculum development.

Within the family of complementary trainers concept, training complexities set the stage for the development of a system of trainers and training experiences that mimic the real world of RPA operators and RPA operations. An example training scenario might be a wildfire burning in North Dakota which threatens a nearby neighborhood and small civil airport. In this training scenario, air traffic control training systems are tied into RPA and manned aircraft training systems. Virtual and constructive entities could be developed for both the airspace and the ground scenario with payload operators passing information to the command and control operations center. The sustainment trainees are brought into the mix to keep the aircraft in the air for extended periods of time. The command and control center simulation and interaction with external and internal organizations during the scenario closes the loop to create a high-fidelity decision-making environment for training. This scenario can be accomplished through a mix of simulators with different levels of fidelity. When the conceptual family of complementary trainers is brought together in a scenario such as the one outlined above, the training environment and communication infrastructure created by the networked system enables training of communication and coordination at the highest level of fidelity possible, the team level.

Training Fidelity

The example training scenario represents a highly sophisticated, high fidelity, team training opportunity. Training fidelity is about more than just the fidelity of a specific piece of training equipment, it is also about the fidelity of the entire training system from simple, classroom desktop scenario role-playing activities to a multi-echelon complex of distributed, embedded LVC trainers. Choosing the right level of fidelity for the specific training objective is important. In the area of training, two early uses of the term “fidelity” tend to accompany many of the later refinements of the term. R. B. Miller (1954) introduced the term "engineering fidelity" to describe the degree to which a trainer duplicates the physical, functional, and environmental conditions of the operational system. The term "psychological fidelity" was introduced (Gagne, 1954) to represent the trainee's perception of the "realism" of the training simulation. As training systems evolve toward greater distributed, embedded, LVC training systems, the differences between psychological fidelity and engineering fidelity will merge and blur. Figure 1 depicts the evolution of the two different concepts of fidelity over time. The top image depicts current crossover between and merger of engineering and psychological fidelity. The bottom image depicts that as the overall fidelity of a training system evolves, the two fidelity components increasingly intersect. Assessing current engineering and psychological fidelity of current training systems provides information on how well today’s training systems fit into the scheme of a family of complementary trainers. As part of the ongoing efforts to fully develop this concept, AFRL, UND and SCC completed an engineering fidelity assessment of the game engines supporting three different unmanned aerial system trainers: AFRL’s PRINCE trainer, UND’s Corsair Trainer, and Sinclair’s Fundamental Unmanned Aerial Systems Trainer.

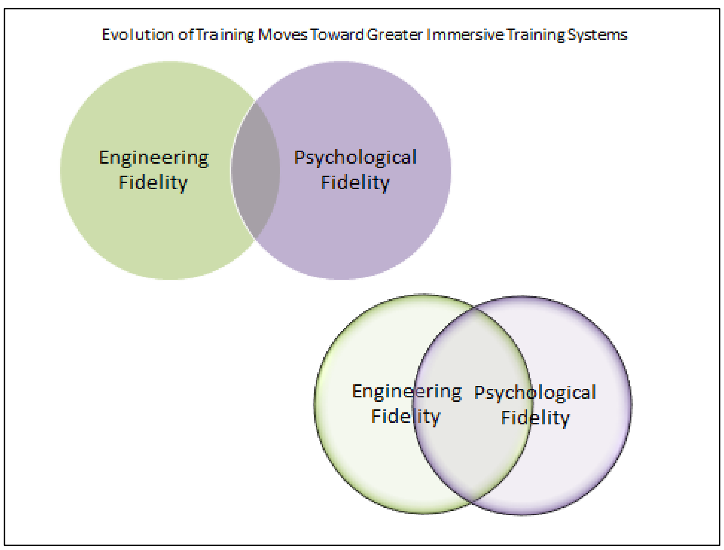

Figure 1. Depiction of concept of the evolution of fidelity from a family of complementary trainers concept. Top image depicts current crossover between and merger of engineering and psychological fidelity.As the overall fidelity of a training system evolves, the two components increasingly intersect.

EVALUATION CRITERIA

Previous research by the Gaming Research Integration for Learning Laboratory at AFRL (Winner, Nelson, Burditt, & Pohl, 2011) examined the system requirements necessary for different game engines to be incorporated into military training systems as a first step toward a concept of a family of complementary trainers. In the original evaluation, Winner et al. (2011) examined minimum criteria for inclusion of gaming technologies. The evaluation criteria included capabilities such as data availability, 3-D model correlation, ground database integration, internet dependency and digital rights management, cost, supportability, license restrictions, visual detail, animation control, specialized visual attributes, physics engine, artificial intelligence (AI) capability, scenario design and audio capabilities. Since this evaluation had not been conducted on civilian training systems, it was chosen as the first in a series of assessments to uncover the unique capabilities of each training system in the partnership and how these capabilities complement each other. In the current evaluation, we had expert users of systems being utilized in our respective training and training research programs assess the systems from AFRL, SCC and UND in terms of the original requirements for the family of complementary trainers' concept. We had each expert assess the criteria in terms of whether or not the individual system can and does currently meet those criteria using a yes, no, or yes with external plug-ins response. The evaluation criteria, details and each of the experts' responses are included below in Table 1.

DISCUSSION

The assessment of the gaming technologies underlying the family of trainers at AFRL, UND, and SCC is one step toward how well these systems complement one another, and how far these training platforms are advancing the notion of embedded training systems. The use of gaming technology drives down the costs of training platforms and allows engineers the ability to more easily embed training systems into operational systems. Game engines can accept and act on data coming in a wide variety of formats such as Test and Training Enabling Architecture (TENA), Higher Level Architecture (HLA), Distributed Interactive Simulation (DIS), which is vital in embedded training systems. The family of complementary trainers concept furthers the application of the radical constructive learning theory and general system theory of Glaserfeld and Le Moigne respectively. These theories support the concept of complex training scenarios such as those described above and gaming technology can support the insertion of these types of training scenarios and team training events through LVC.

Though the use of game engines technology has been exploited by training simulation developers, it is important to remember that game engines evolved under vastly different business objectives, namely to provide entertaining and profitable games to large audiences. Accordingly, considerable effort is required to deliver training scenarios based on specified learning objectives, deliver feedback to trainees, and to perform automated performance measurement. Although a commercial game engine cannot be expected to come equipped with these components, the game engine can be evaluated against the criteria relevant to implementing game engines within the context of the family of complementary trainers concept and used in AFRL's PRINCE, UND's Corsair, and Sinclair's Fundamental Unmanned Aerial Systems.

Simulation System Evaluation Criteria and Results

The evaluation criteria evolved through a number of experiences and iterations at AFRL to determine the capability of game engines to provide instructionally sound training experiences to students (Winner, Nelson, Burditt, Pohl, 2011). One of the required criteria was to provide a capability for inner-connectivity with other systems for training. Within military simulation, there are typically four intercommunication protocols used: DIS, HLA, TENA, and Common Image Generator Interface (CIGI). AFRL's PRINCE is DIS compliant while UND's Corsair and SCC trainers are HLA compliant. It is also important that simulation expose certain information to enable users to effectively join a scenario. Some examples of the data include: position, velocity, rotation, velocity of rotation, acceleration, entity health, and height of terrain for a given x, y location. Additionally, location data for both shot origin and destination are needed. Ideally, building position would also be available. Status variables, such as whether an entity is smoking or on fire, whether a player is crouching, prone, or standing, and whether a vehicle has a running engine, need to be available to create realism for complex training scenarios.

Availability of Data

The availability of simulator data enables or hinders automated performance measurement, the delivery of scenario feedback and after-action review to trainees (Winner, Nelson, Burditt, Pohl, 2011). For the Corsair simulator, basic flight data is available such as airspeed, altitude, heading, etc for the instructor to view. The $\text{Envision}_{\text{TE}}$™ software was rated as fairly capable in its ability to create realistic scenarios for students to practice on. The instructor can add entities such as people, cars, buildings, and limited objects like barrels or rubble. Those entities can be defined in a number of ways such as heading, route to travel on, and what action they do (walk, run, put their hands up). The software includes a way to program these entities to do certain actions at certain times and can be instructor controlled. Scenarios can also be created ahead of time and run by the instructor or the instructor has the option to create and modify entities "on the fly." $\text{Envision}_{\text{TE}}$™ has limitations including computational power that limits the number of additional entities in a given scenario such as extra cars driving around or people walking the streets to make the scenario more realistic. The evaluation results indicated that users rated the graphics as being blocky, animations as not smooth, and details on imagery are lacking. Envision$_{TE}$™ is based on Simigon's SimBox® developer tools. For AFRL's PRINCE, human entities can be developed in CryEngine® and data is available via flow graph nodes or custom developed C++ modules depending on needs. Flight dynamics are handled by X-Plane® and data are available via existing or customs C/C++ plugins. Anecdotal data from warfighters flying Predators and Reapers is that CryEngine® graphics are too clear and crisp compared to actual imagery from the operational systems. For the SCC trainer, data is available via custom C++ calls or modification to JSBSim open source directly.

Table 1. Simulation System Evaluation Criteria and Results

		AFRL	**UND**	**SINCLAIR**
Evaluation Criteria	**Details**	**PRINCE**	**Corsair IM3PUT**	**Fundamental UAS Trainer**
Availability of Data	Available position, velocity, rotation, velocity of rotation, acceleration, entity health, height of terrain, shot origin/destination, entity status variables (e.g. crouching, prone, standing, etc.)	Yes	Yes	Yes
3D Model Correlation	Players see the same model across systems	Yes	No	Yes
Terrain Database Integration	Require 1) Digital Terrain Elevation Data (DTED) format for digital terrain elevation, 2) High resolution terrain from all altitudes, 3) Ability to enhance satellite imagery	Yes	Yes	Yes
Internet Dependency / Digital Right Management	No constant internet connectivity to authenticate	Yes	Yes	Yes
Supportability	Balance of tech support from primary developer and user community	Yes	No	Yes
License Restrictions	Permissive licensing enables flexibility of game engines use	Yes	No	Yes
Visual Detail	Support of both Direct X (Direct 3D) and OpenGL	Yes	No	Yes
Animation Control	Smoothing algorithms to smooth model movement resulting from network protocols e.g. DIS, HLA	Yes	No	No
Specialized Visual Attributes	Visualization of infrared and night vision capabilities, rendered shadows, support all particle effects specified in DIS	Yes	No	No
Physics Engine	Can interpret and simulate physics-bound behavior of entities when given position and velocity information. Able to interpolate from DIS environment with minimal external coding	Yes	No	Yes
Artificial Intelligence (AI) Capability	Possess easy to implement AI Capability, behavior must be predictable to enable scenario repetition across trainees	Yes	No	Yes,
Scenario Design	User-friendly design tools, scripting capability for entity movement and timing, ability to repeat and alter a scenario for trainees easily on an as needed basis	Yes	Yes	Yes
Audio	Supports DIS Radio	Yes	No	Yes

3D Model Correlation

In distributed, LVC, training environments, multiple players have eyes on the same geographic area but may be looking at that area through different simulation or game-based systems (e.g., Envision$_{TE}$™, CryEngine®). Players, regardless of game or simulation system, who see an entity (e.g. truck) as it travels across the terrain, should see the same model (e.g. white, flatbed truck). Accordingly, there is a need to easily convert OpenFlight® models into a format to be imported into any system or game engine used. The SCC trainer is based on OpenSceneGraph® and supports loading most 3D models in open formats like OpenFlight. AFRL's PRINCE utilizes CryEngine® and MetaVR®. The models for these two software packages are proprietary and there are limited models and tools for converting to these formats. UND's Corsair trainer does not support 3-D model correlation limiting the simulator ability to work in distributed, LVC, training environments.

Terrain Database Integration

The Digital Terrain Elevation Data (DTED) file format for digital terrain elevation is commonly used in distributed simulation and training environments. The higher the resolution of the digital terrain imagery, the easier it is to present the appropriate level of realism with respect to the resolution of other models depicted in the simulated world. Scenarios should not contain terrain at a significantly lower resolution than that of the building models or objects within the scene. High resolution databases can be correlated to higher levels of accuracy (Winner, Nelson, Burditt, Pohl, 2011). Often, satellite imagery is overlaid onto terrain and training developers need the ability to enhance the visual appearance of the imagery to compensate for its low resolution. Within UND's Corsair software there are four default maps but more maps can be added. These maps are made from satellite images and DTED information. This information is packaged together so that the student sees satellite images but has terrain elevation wherever the computer mouse hovers. For PRINCE, CryEngine® requires the databases to be prebuilt using a commercial modeling tool. Elevation and imagery data can be imported with limitations. CryEngine® only supports flat earth terrain which causes distortions when coordinating locations with external simulations. There are severe limits on high resolution imagery inserts. The SCC trainer uses osgEarth® for on-the-fly terrain generation. The underlying mechanism uses GOAL (Geospatial Data Abstraction Library) to load elevation, feature and imagery data so osgEarth® can load any file format supported by GOAL. Terrain does not have to be prebuilt and the only limitations of image/elevation resolution are the limits of the machines memory/video card.

Internet Dependency and Digital Rights Management (DRM)

Game and simulation engines often require internet connectivity to complete updates, provide access to shared resources, and for digital rights management functionality. Engines requiring an internet connection to authenticate for each use are especially problematic for military trainers as connections are not always available. For the vision of distributed, embedded, LVC training, connections need to be available even if that means a deployable secure tower or satellite link. For PRINCE, CryEngine® requires constant internet connection for the free version. Paid developer versions do not require internet connection. X-Plane® requires a paid copy per instance, but a network connection is not required. The SCC trainer uses OpenSceneGraph®, osgEarth® and JSBSim® which are all free and open source. There are no DRM issues or required internet connection. The UND trainer does not require internet connection for any aspect of the simulation.

Supportability

Supportability refers to the amount of technical information and aid available to users and secondary developers through the primary developer and/or user community. Web forums and communities of practice are examples of such support. Supportability also refers the game engine's openness for supporting software such as plugins, enhancements, and third party applications. It can be a slow and expensive process to make changes to proprietary software that often must be done by the developer. On the other hand, open source engines are often less than cutting edge. As a result, some open engines may lack modern features that enable ease of use. A balance in supportability is found with an engine that is highly controllable while also being a product supported by a major company. When selecting an engine, it is important to balance cost, time, technology needs, controllability needs, and the desire for commercial entity involvement (Winner, Nelson, Burditt, Pohl, 2011). CryEngine®, X-Plane®, OpenSceneGraph®, osgEarth® and JSBSim® all have active user/developer communities. Additionally all also have professional support available for purchase. Corsair provides support for a fee.

License Restrictions

License restrictions are a factor for custom application work; therefore, the selection of an engine can be constrained by the license restrictions for the engine, even though it has nothing to do with the scenario generation capabilities the engine can offer (Winner, Nelson, Burditt, Pohl, 2011). For PRINCE, CryEngine® and X-Plane have restrictions as does $\text{Envision}_{\text{TE}}$™ for Corsair. The SCC trainer has no such restrictions.

Visual Detail

Depending on the selection of operating systems and other factors, game engines may support either OpenGL® or Direct3D (DirectX®). To support the vision of distributed, embedded, LVC, game engines would support a standard operating system which supports both Direct 3D and OpenGL as well as, future innovative software in this arena. DirectX® provides advanced rendering and lighting capabilities (e.g., tessellation and per pixel lighting) enhancing immersive training environments (Winner, Nelson, Burditt, Pohl, 2011). For PRINCE, CryEngine ® supports DirectX® on the Microsoft Windows® operating system. X-Plane® supports OpenGL®; however, OpenGL® is very cross platform and cross hardware friendly. For the SCC trainer, OpenSceneGraph® and osgEarth® support OpenGL as does $\text{Envision}_{\text{TE}}$™ for the Corsair trainer.

Animation Control

The use of network protocols such as DIS and HLA has implications for smoothing game engines graphics. These protocols may not give true location information for specific models at a refresh rate as high as that of game engines. Accordingly, the location updates received by the engine may result in "jumpy" movements of the model (Winner, Nelson, Burditt, Pohl, 2011). To provide for distributed, embedded LVC training, game engines would provide base system mechanism for dealing with this issue. None of the trainers evaluated in for this paper have animation control capabilities.

Specialized Visual Attributes

Specialized visual attributes add to training scenarios realism. In military scenarios, as well as some civil scenarios, the ability to visualize infrared and night vision capabilities accurately is an important component for UAS sensor operator training. Shadows are also important to discern meaning in visual imagery, as well as, particle effects such as dust trails behind moving vehicles, smoke, and flames. Without these effects in the game engine meaningful training is reduced. Game engines should accommodate these visual attributes as well as, others not mentioned. For AFRL's PRINCE and the SCC trainer, both CryEngine® and OpenSceneGraph® can generate shadows. CryEngine® has better support for real time shadow generation. OpenSceneGraph® requires some programmer interaction to enable. Programmable shaders allow for the appearance of alternate visuals. Night vision modes are fairly simple to produce with technically accurate results without extra data. Modes such as infrared require specialized data regarding heat emissions from entity components and material information. Most game engines fake infrared.

Physics Engine

The vast majority of game engines are equipped with a physics engine providing realistic simulation of physical systems within the gaming environment. For example, collision detection and appropriate response are necessary to accurately simulate the interaction between players, objects, and the gaming environment itself. For aviation applications, a game engine should be able to correctly interpret and simulate physics-bound behavior given only the position and velocity of entities. For DIS standards, the less information needed to translate the game-based physics the better. The game engine should interpolate information into the DIS environment with minimal external engineering work (Winner, Nelson, Burditt, Pohl, 2011). For PRINCE, CryEngine® has a built in physics engine. The SCC trainer uses OpenSceneGraph® which is a scene graph only and requires external applications such as open source software (e.g. OpenDynamicsEngine® or Bullet3D®) in order to simulate physics. The Corsair trainer uses $\text{Envision}_{\text{TE}}$™ which does not have nor does it support a physics engine.

Artificial Intelligence Capability

Critical to the training environment is the artificial intelligence capability of gaming technologies because they improve the role-based players in the environment from the actions of other aircraft to air traffic controllers to ground personnel. In military environments, computer-generated entities which respond appropriately as a scenario unfolds can serve as either red (enemy) forces or blue (friendly) forces, or as neutrals who simply complicate or add dimension to a particular scenario (Winner, Nelson, Burditt, Pohl, 2011). For the distributed, embedded, LVC training environment, a game engine must possess exceptionally realistic artificial intelligence capabilities such that the trainee has considerable difficulty detecting between live, virtual, and constructive environments. PRINCE's CryEngine® has a built in FlowGraph that allows simple or complex artificial intelligence. The SCC trainer relies on external DIS applications to generate artificial intelligence entities. UND's Corsair trainer does not have artificial intelligence capability.

Scenario Design

For the distributed, embedded, LVC training environment, creation of complex, operationalized, training scenarios is critical to maintaining and sustaining a ready workforce. In order for training to effectively equip the operational workforce, scenarios must reinforce the concepts and tasks which correlate to that role's required competencies, knowledge, skills, and experiences. (Symons, France, Bell & Bennett, 2006). Over the last 20 years, AFRL developed and validated a proven methodology for training Mission Essential Competencies (MECs™). MECS are higher-order individual, team, and inter-team competencies required for successful mission completion (Colegrove & Alliger, 2002). MECs are the result of a sophisticated, job analysis, technique that enables the determination of training requirements and the resultant mix of both live and virtual experiences necessary for training. Different components of the MEC-based approach such as the analysis of fundamental competencies enables collaboration between AFRL, UND and SCC to develop operators for both military and non-military applications. The fundamental competency set derived for UND determined the training requirements for non-military applications. This represents the first time the MEC process has been utilized for non-military operations. This approach should result in training that is centered on the true competencies required to develop UAS pilots. SCC training director notes that whatever the role of the student in a training scenario, it is important to consider the knowledge, skills, experiences required for success. With regard to selection of game engines, an engine should provide user-friendly tools (e.g. flow graphs) for scenario development and management. The engine's scripting capability should allow users to set specific parameters for entity movement and timing within a scenario, and have a mechanism to repeat or alter a scenario for a given training need (Winner, Nelson, Burditt, Pohl, 2011). For UND's Corsair simulator, scenario design is reasonably robust and user friendly. Scenario development for PRINCE is more complex and less user friendly. And finally, the SCC simulator requires an external DIS application to develop scenarios. The application is reasonably straightforward but not particularly user friendly for those with no programming background.

Audio

Audio capabilities of game engines are a vital factor in realistic training systems. Background audio of various entities such as vehicle engines, and communication chatter provides valuable feedback to the user. Ideally, a game engine used in distributed, embedded, LVC training environment would support DIS radio. For AFRL's PRINCE, DIS radio is support via plugin. The UND and SCC trainers do not support DIS radio out of the box, but they can be modified for it.

CONCLUSION

Overall, the results of this evaluation demonstrate that in terms of the engineering fidelity requirements for the family of complementary trainers concept, the training systems located at AFRL, UND and SCC are all sufficient with regards to the engineering requirements for this concept. The high-three topics from the original analysis by Winner et al., (2011) were availability of data, 3-D model correlation and the terrain database integration. As shown in Table 1, the three systems assessed here all possess the majority of those criteria with the exception of the Corsair system at UND which does not possess 3-D model correlation across systems. Top three, availability of data, 3-D model correlation and terrain database integration are seen as high priorities for incorporation into embedded training systems. Many of the engineering requirements for training have been included in validated systems used for the MEC-based training and training research discussed previously.

The top three criteria are especially important for training if they are intended to be networked with other simulators or included in LVC exercises. An absence of a capability here is not seen as a limitation as it simply changes the tasks that the system is capable of training. For example, the Fundamental UAS Trainer and the Corsair trainer do not currently have animation control or specialized visual attributes as described here. These are likely not going to impact training at the Associate and Undergraduate pilot training level that these systems are intended to be used at. Animation control and specialized visual attribute capabilities would be important attributes to have if the simulator was planned to be networked into DMO or LVC exercises, which PRINCE at AFRL is intended to do. It is also important to note that this evaluation does not address the training or task requirements that are a large and important component of the family of complementary trainers concept and that AFRL, UND and SCC are working to define and refine as the evolution of this concept continues. Future work will be geared to assess these training and task requirements that each of these systems can address as well as, the development of a scaffolded approach to training UAS pilots using the family of complementary trainers concept.

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