INNOVATIVE C2 TRAINING SOLUTIONS FOR AIR FORCE MODULAR CONTROL SYSTEMS

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ABSTRACT

Although the importance of command and control (C2) training has grown in recent years, many C2 organizations are having difficulty in meeting training requirements. A number of solutions have recently been proposed to provide effective training for the Air Force (AF) battle management crews responsible for tactical-level command and control (C2) in the Theater Air Control System (TACS) Modular Control Equipment (MCE). Some proposed solutions include intelligent tutors and stand-alone systems. Stand-alone systems currently do not provide training for the complete TACS MCE functionality. The most effective way to provide TACS training is to have the trainees employ the equipment they actually use, interfaced with other entities, and all operating in a realistic synthetic battlespace. Although it has been possible to interface several operational modular control units together for operator training, these Systems Training Exercises (STEs) have typically involved a large investment of time and manpower for planning, scenario generation, and operation. In addition, these training exercises have been expensive. Joint Service Training Exercises (JSTEs) have involved an even greater investment of time, manning, and funding. The JSTE cost is so great that operators do not have an opportunity to participate on a regular basis. This paper will focus on the use of innovative training tools that could result in enhanced C2 training with minimal investment of time, manpower, or funding. This paper will report the success of a low-cost interface of the MCE with Joint Semi-Automated Forces (JSAF) and Distributed Mission Training, the use of this interface in an operational STE, the combination of this interface with a virtual reality capability for training, and future plans for expanded MCE training using these innovative tools.

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Although the importance of command and control (C2) training has grown in recent years, many C2 organizations are having difficulty in meeting training requirements. A number of solutions have recently been proposed to provide effective training for the Air Force battle management crews responsible for tactical-level C2 in the Theater Air Control System (TACS) Modular Control Equipment (MCE). Some proposed solutions include intelligent tutors and standalone systems. Standalone systems currently do not provide training for the complete TACS MCE functionality. The most effective way to provide TACS training is to have the trainees employ the equipment they actually use, interfaced with the other entities, and all operating in a realistic synthetic battlespace. Although it has been possible to interface several operational modular control units together for operator training, these Systems Training Exercises (STEs) have typically involved a large investment of time and manpower for planning, scenario generation, and operation. In addition, these training exercises have been expensive. Joint Service Training Exercises (JSTEs) have involved an even greater investment of time, manning, and funding. The JSTE cost is so great that operators do not have an opportunity to participate on a regular basis. This paper will focus on the use of innovative training tools that could result in enhanced C2 training with minimal investment of time, manpower, or funding. The paper reports the success of a low-cost interface of the MCE with Joint Automated Forces (JSAF) and Distributed Mission Training, the use of this interface in an operational STE, the combination of this interface with a virtual reality capability for training, and future plans for expanded MCE training using these innovative tools.

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INTRODUCTION TO THEATER AIR CONTROL SYSTEMS/ MODULAR CONTROL EQUIPMENT

The AN/TYQ-23 MCE provides the Air Force with a transportable TACS automated air C2 system for controlling and coordinating the employment of aircraft and air defense weapons. A complete description of the MCE may be found in the following references: Janes (1994), Litton (1995a, 1995b), and Defense Information Systems Association (DISA) (1997). The Air Force version of the MCE uses the AN/TPS-75, three-dimensional, long-range, high-power, air defense radar.

The basic system element of the MCE is the Operations Module (OM). A single OM is comprised of a six-meter enclosure and contains the C2 equipment, including a full range of tactical digital datalinks to perform the air defense function. System sensors and power supplies are external to the shelter. Figure 1 shows an operator inside the OM, and Figure 2 shows the MCE with two OMs.

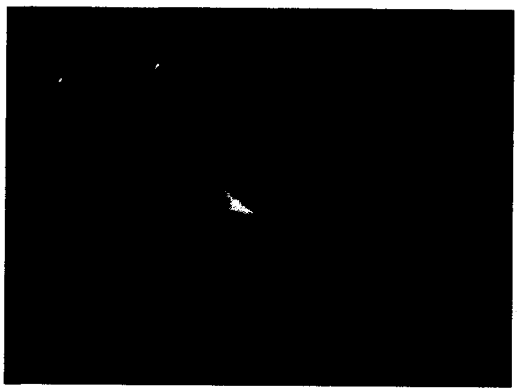


Figure 1. Inside the Operations Module.

Up to five OMs can be interconnected through the use of fiber optic cables to provide variable OM configurations at locations of up to 500 meters for tactical or terrain advantages. Typical configurations are four OMs for the Control and Reporting Center (CRC) and two OMs for a Control and Reporting Element (CRE) configuration. The local radars can be located up to two kilometers from the OM and are connected using fiber optic cable. Remote radars can be located at various distances and are only limited by the capability of the medium being used to transmit data to the OM.

Figure 2. Modular Control Equipment.

Automatic target detection, acquisition, and tracking are accomplished by an automatic radar/Identify Friend or Foe (IFF) capability in the AN/TPS-75 radar system. The tracker software is installed in the MCE Interface Group (MIG) located in the radar shelter. An external tracking capability called the Modern Tracking System (MTS) performs similar functions as the MIG, but integrates one external sensor feed into the MCE. The MCE surveillance tasks include the correlation of tracks reported from the MTS with other system tracks and with tracks received from digital data links from other sources. Automatic identification (friend, unknown, hostile) and classification (fighter, bomber, tanker) are also performed by the surveillance function. This function performs automatic threat evaluation and classifies aircraft and air-to-surface missile tracks according to their potential threat to defended assets. Within the OM, the weapons control function provides the capability to exercise positive control of fighter aircraft employed in tactical operations: Air defense, counter-air, interdiction, close air support, reconnaissance, refueling, search and rescue, and missions other than war.

Inside each OM are four multicolor operator monitors for four C2 operators. These displays provide real-time information about the various tracks on the planned position indicator displays in regard to range and azimuth as well as IFF and jamming status. The display shows superimposed track symbols, map or overlay lines, and alphanumeric data. There is a monochrome auxiliary display presenting stored alphanumeric data to supplement the situational display. Touch sensitive screens allow the operator system control.

CURRENT TRAINING SYSTEM DEFICIENCY

The MCE has an embedded training capability known as MC SIM (Litton, 1995b) that allows the OM to be put in a training mode where target tracks and raw video are simulated. An update to MC SIM added an external workstation that emulates the OM's operator control unit and provides an instructor remote control over the embedded simulation programs and scenario generation. This allows all four of the consoles in the OM to be dedicated to the training exercise. Without this update one of the OM consoles would be required to execute the embedded simulation and would be unavailable for operator training.

The MC SIM is difficult to use and inadequate for preparing operators for theater and full-mission duty (Chubb, 1997). The existing simulation and portrayal of the synthetic forces is not scalable and does not provide realistic autonomous behaviors. There are other disadvantages associated with MC SIM. *First,* it requires operators to run the simulation, and they are not proficient in console inputs, so they are not able to maintain the tempo required. *Second,* the Operational Training Officer (OTO) has no ability to insert events in the synthetic battlespace that were not already preprogrammed to occur. *Third,* "kills" and "drop track" commands do not occur as rapidly as their real-system counterparts, creating an unrealistic situation display. *Finally,* the existing training options and portrayal of synthetic forces is not easily or cost effectively interoperable with other distributed simulations.

When an MCE "Schoolhouse" was established in 1999, it was stood up with limited funding and an immediate training need. The existing training system described earlier is not sufficient to meet the requirements of the "Schoolhouse." Therefore, any technology or training strategy designed to assist the Schoolhouse in meeting their training requirements had to be low-cost, and available as soon as possible.

PAST RESEARCH AND PROTOTYPES

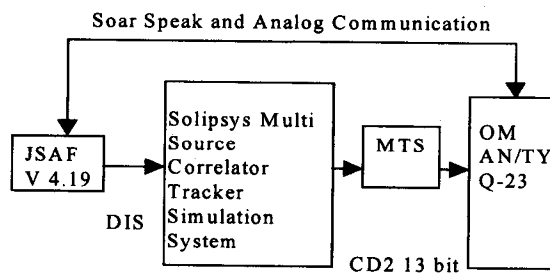
AFRL has been experimenting with stimulation of the actual MCE equipment over the past few years (George, Brooks, Conquest, & Bell, 1998; George, Brooks, Bell, Breitbach, Steffes, & Bruhl, 1999). Stimulation requires the use of actual operational equipment. In stimulation, an external synthetic battlespace provides target state, behavior, and environmental effects that would normally be represented by the radar and detection algorithms. Ideally, the operator should not perceive any difference between the real and stimulated systems. Stimulation has the advantage of easily supporting upgrades to the operational hardware, training at site, and providing a training environment that the operator is accustomed to.

This concept has been partially demonstrated with the stimulation of the MCE with Joint Semi-Automated Forces (JSAF). JSAF has been integrated to the MCE system via the Litton gateway providing tracks on the operator displays. The proprietary gateway used with the embedded training system allows simulated entities to be communicated and then displayed in the OM. The interface software in the Distributed Interactive Simulation (DIS)/MCE translator uses DIS 2.0.4 protocol to communicate with JSAF. Much of the interface software was reused from the AFRL Network Interface Unit software developed for the Distributed Mission Training (DMT) testbed and hosted on a Sun Sparc workstation. The radar system and tracking functions are simulated using entity state data from the computer generated forces (CGF). These tracks also have the simulated video from the Remote Interface Unit (RIU). The raw video functionality is from the existing embedded simulation system. The ability to display JSAF tracks was demonstrated in June 1998.

The MCE stimulation program was further extended to the RoadRunner '98 DMT exercise that was conducted by AFRL in the summer of 1998. JSAF was hosted by AFRL at Mesa, AZ, and provided synthetic entity state information for the two remote sites to the 107th Air Control Squadron (ACS) in Phoenix, Arizona, and the 133d ACS in Fort Dodge, IA. This prototype evaluation indicated that the use of the proprietary gateway and reverse engineering the interfaces was not the best approach in regard to overall cost and in providing a full training capability. The use of existing interoperable simulation techniques and interfaces proved to be a more cost-effective and lower risk approach to provide an immediate "Schoolhouse" training solution.

DESCRIPTION OF CD2 CONVERSION AND MCE INTERFACE

In order to stimulate the OM, the synthetic battlespace/CGF data must be translated into a format that OM Digital Data Bus (DDB) can use in its native format. This requires a translator from the DIS



context to the OM format. Based on proven performance during JEFX, a reusable low-cost translator developed by the Solipsys Corporation and known as the Multi-Source Correlator Tracker (MSCT) Simulation System was investigated. The MSCT takes DIS data from interoperable simulations and converts to the Federal Aviation Administration (FAA) standard Common Digitized 2 (CD2) format, which can then be connected directly to the MCE OM. The simulator is personal computer (PC)-based and is a cost-effective approach to MCE stimulation using existing hardware and software assets. A proof-of-concept test of this solution was done at the 133d ACS (Iowa Air National Guard) in December 2000 and will be discussed in the next section.

JSAF was selected as the initial CGF, although any DIS-compatible CGF could have been used. For example, the Joint Interim Mission Model (JIMM) might have been used instead. JSAF was selected based on our past experience with this system, a very user-friendly scenario generation capability, and the availability of highly autonomous AF entities (the Air Synthetic Forces (AirSF) portion of JSAF) using the SOAR (Taking a State, applying an Operator And generating a Result) expert behaviors (Johnson, et al., 1994). These types of autonomous entities are desirable to reduce the workload on role players. Entities from AirSF perform their missions autonomously and integrate seamlessly to the virtual simulators. Once briefed, they plan and execute their missions in conjunction with the virtuals using appropriate doctrine and tactics.

Even though each entity is autonomous, it is not acting in isolation. Individual entities coordinate their actions using existing doctrine and Command, Control, Communications, Computers, and Intelligence (C^4I) systems. They use shared knowledge of doctrine, tactics, and mission objectives as well as explicit radio communication to achieve common goals. As the mission develops, entities may change roles dynamically as in the real world.

AirSF provides behaviors for most commonly flown air roles and missions including: air-to-air (Defensive Counter Air (DCA), Offensive Counter Air (OCA), and escort), air-to-ground (strike and Suppression of Enemy Air Defenses [SEAD]), control (Forward Air Control (FAC), Air Electronic Warfare (AEW), Ground Control Intercept (GCI), reconnaissance, and refueling. It can provide friendly, opponent, or neutral forces. As illustrated in Figure 3, JSAF provides DIS entity, emission, and event Protocol Data Units (PDUs) to the translator

Figure 3. The Stimulation System Block Diagram.

The translator interfaces directly to the MTS. The MTS operates with any radar as a stand-alone system, accomplishes sensor integration with command and control centers, and supports multi-radar integration activities. Designed for continuous, unattended operation, the MTS automatically initiates and tracks targets throughout the surveillance volume of the radar. It adapts automatically to accommodate changing environments. Both air and surface targets with velocities from zero to 40,000 knots (kts) can be tracked. The MTS initiates tracks in clear, cluttered, and high-density regions, with a full air picture established.

Communication back to role players at the JSAF monitors is accomplished using normal communications channels from the OM. Currently the 133d ACS is exploring the possibility of interfacing SoarSpeak, which would provide voice control of synthetic, SOAR-based entities. SoarSpeak uses natural voice recognition and speech generation to direct and interact with synthetic, constructive entities controlled by the AirSF air behavior system. This capability allows such synthetic entities to maintain autonomy, flexibility, and realism. Rather than requiring a system operator to manually intervene to change an entity's behavior, SoarSpeak allows OM operators and relatively untrained role players to retask aircraft via voice directives, which will provide a realistic training capability.

RESULTS OF DECEMBER 2000 DEMONSTRATION

The Solipsys MSCT Radar Simulation System was delivered to the 133d ACS on 18 December 2000. This system was used to integrate JSAF to the MCE, fully stimulating the OM. Completed integration and testing was completed on 20 December 2000, illustrating the ease of integration. Photos of this equipment may be seen in Figures 4 and 5 below.

Figure 4. Solipsys MSCT Radar Simulation System on left and Litton MTS on right.

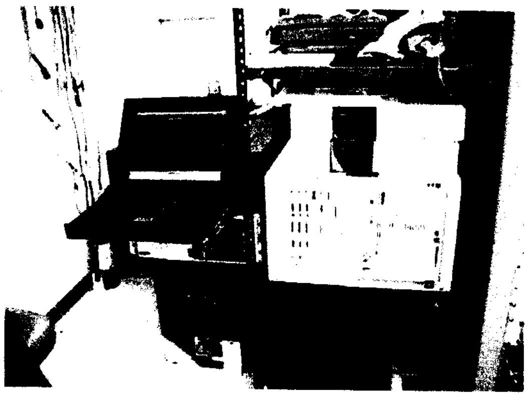


Figure 5. Solipsys MSCT Radar Simulation System with Flat Panel Dispay/Keyboard Drawer opened.

The MSCT Radar Simulation System consists of a collection of hardware and software programs that provide the impetus to stimulate external systems with radar data in the CD2 13-bit format. The software was pre-installed by Solipsys Corporation prior to shipping. The hardware platform provided by Solipsys Corporation with this delivery included a rack-mounted computer with the following specifications:

- Dual Pentium III 750 Mega hertz (MHz) Processors
- 512 Mega-byte (MB) Random Access Memory (RAM)
- 18 MB Removable Hard Disk Drive
- Viper II Video Card with 32 MB Memory
- 15" Active Matrix Rack Mount Flat Panel Display/Keyboard Drawer
- Internal Compact Disk (CD)-Read Only Memory (ROM)
- Internal 3.5" 1.44 MB Floppy Disk Drive
- PTI-334 RS-232 Synchronous Interface Card (4 serial ports)
- Windows NT 4.0 Workstation Operating System

The MSCT Radar Simulation System is configured to receive input from JSAF, which provides simulated synthetic battlespace. JSAF delivers DIS PDUs via User Datagram Protocol/Internet Protocol (UDP/IP) network packets. The MSCT Radar Simulation System successfully received all simulated entities and events, which were provided to the Solipsys Tactical Display Framework (TDF) for display. In addition, air assets within the coverage area of a user-defined simulated radar were then passed to the Litton MTS system for further processing.

The MSCT Radar Simulation System is used to output simulated radar data to the Litton MTS system. The MSCT Radar Simulation System outputs CD2 13-bit formatted messages via an RS-232 synchronous serial port. Due to the limited documentation for the internal workings of the Litton MTS system, several key elements to this interface had to be addressed on-site in a reverse engineering manner. To illustrate, it was discovered that each byte must be inverted prior to transmission to the Litton MTS system. The configuration and integration was completed successfully, with the Litton MTS system displaying plots and initiating tracks based on the MSCT Radar Simulation System output

The demonstration showed that several hundred simulation entities could be displayed in the OM. The operators received a week training in JSAF operation and scenario generation capabilities. This was sufficient for the operators to execute various missions and scenarios. The displayed tracks represented both highly autonomous entities based on AirSF behaviors as well as lower fidelity models based on standard ModSAF task frames. The demonstration further illustrated the ease of using reusable assets that promote interoperability and standardized interfaces. The gateway also provides the opportunity to interface virtual devices such as a four ship from the AFRL Warfighter Training Research Center manned simulation facility in Mesa, AZ.. This innovative concept and solution fits well into the Air Force's Distributed Mission Training (DMT) vision that ultimately will integrate live, virtual and constructive simulations.

POTENTIAL TRAINING ADVANTAGES

At this time, the MCE Schoolhouse personnel are anxious to obtain this capability because they feel confident that it will be valuable in helping them to meet their training requirements. The system that was demonstrated in December of 2000 provides the capability for immediate training. This solution provides a quick cost effective solution that the Schoolhouse needs today. Other anticipated training advantages of this solution include the following:

- JSAF and DMT provide higher fidelity of training
  - JSAF aircraft perform realistic maneuvers and have automatic kill removal.
  - JSAF allows rapid generation and archival of training scenarios to meet instructional objectives.
  - Manned cockpits in DMT provide practice in communication with actual pilots.
  - DMT allows all data to be recorded and played back for debrief.
  - DMT provides the opportunity to train as part of the combat team in the Joint Synthetic Battlespace.
- JSAF does not require many "sim drivers," which will result in reduced manning for simulation training.
- Training from your home unit via DMT results in Temporary Duty (TDY) cost savings and reduced scheduling conflicts.
- Creates potential to expand to include Systems Training Exercises (STE) and Joint Service Training Exercises (JTE).
- The ability to replay exercise scenarios from the MCE stimulation on full visualization equipment as employed in virtual reality systems.

VIRTUAL REALITY VISUALIZATION

Visualization technology is of critical importance for today's command and control, intelligence, surveillance, and reconnaissance operators. (Durban et. al. (1998), Rosenblum et. al. (1997)) Virtual reality may play an important role in C2 visualization training. Virtual Reality visualization may also provide critical information in a timely manner in future exercises and wars. Information has always been an important resource, and accurate, timely information with details on an enemy's location, strength, and intentions could influence the outcome of the battle. The complexities of C2 tasks require not only fast computers and communications systems, but also visualization systems that allow the operators to sift through and digest a large amount of data in a very brief time. Presentation of information in a clear, concise way depends on the development of new visualization technologies.

The Human Effectiveness Directorate and the Information Systems Directorate of the Air Force Research Laboratory (AFRL) are sponsoring an effort to investigate the effects of various types of virtual reality visualization technology on C2 operator training. As part of this effort, the Virtual Reality Applications Center (VRAC) of Iowa State University is supporting this effort through the interface of JSAF with the virtual reality devices at the VRAC. In addition, VRAC personnel have built an interface so that all VRAC technologies can accept Distributed Interactive Simulation (DIS) entities from DMT. This interface includes the devices depicted in figures 6-9.

The C6 (Figure 6) is a 10x10x10 foot room in which computer generated images of the synthetic battlepace are back projected on all four walls, the ceiling and the floor. In the C6, several participants can explore and interact with entites created by a synthetic battlespace or computer generated force.

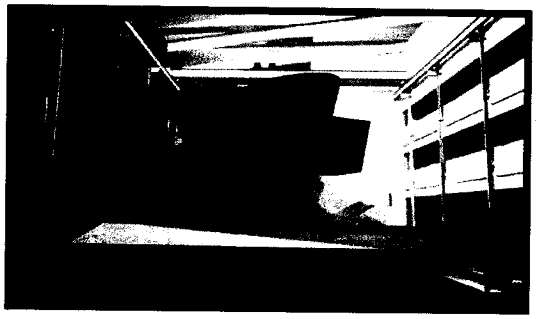


Figure 6. The C6.

The C4 (Figure 7) supports multiple screen configurations ranging from a cave-like environment to a 36 foot wide power wall. Multiple configurations are made possible by swinging the moveable sidewalls.

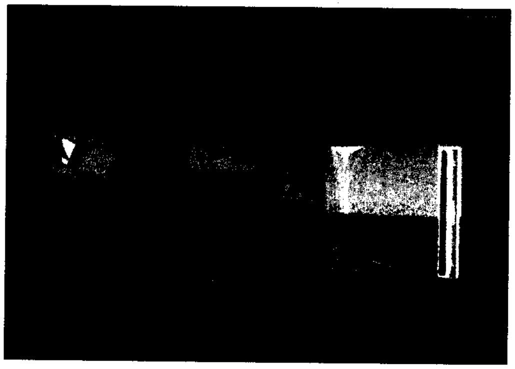


Figure 7. The C4.

The workbench (Figure 8) is an interactive virtual reality environment designed to support a team of users that would typically stand over a table or workbench as part of their professional routine.

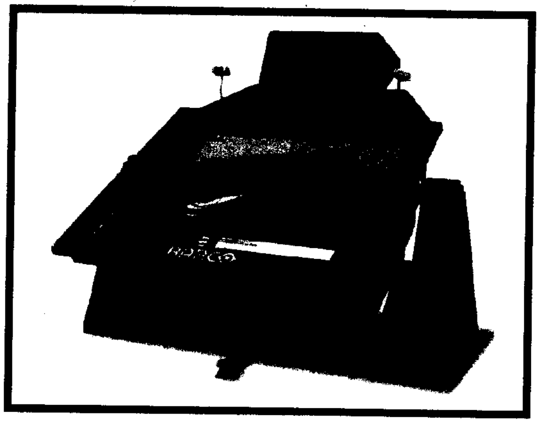


Figure 8. The Workbench.

The Lee Liu/Alliant Energy Auditorium shown in Figure 9 allows for a large group not directly in the visualization to view the activities that is being executed in the various display devices just described.

The VRAC has developed generalized software (VR Juggler) that can handle the various display mediums illustrated in Figures 6-9. Furthermore, this software supports DIS inputs. This allows the systems to use synthetic battlespace information directly from simulations or replay DIS data that may have been generated in STEs with the MCE stimulation. The additional virtual realities capabilities resulting from these interfaces offer a number of unique training capabilities for C2 operators. The replay capability is especially important in the sense that displays in the MCE Operations Module (OM) are two-dimensional and VR provides full, three-dimensional visualization. This allows MCE operators to see the scenarios experienced in the MCE to be replayed in full visualization following their "in box" training. During replay, operators have the opportunity to learn to visualize the scenarios encountered in the MCE OM in more than just two dimensions.

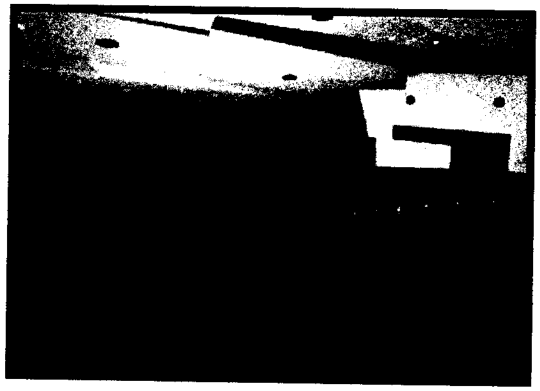


Figure 9. The Lee Liu/Alliant Energy Auditorium.

These capabilities currently exist in an early development stage and further human factors work is required to support C2 training research. Key issues include the types of human interface tools, icons versus computer imagery of simulated entities, types of displays required for various C2 functions and effects of time delays on human performance.

SYSTEMS TRAINING EXERCISE

A Systems Training Exercise (STE) was conducted in August, 2001 at the 133 ACS in Ft Dodge, Iowa. The system for MCE stimulation that was previously described was effectively used as the training medium. This training scenario was conducted in the OM with two-dimensional radar displays, containing over 50 entities. The STE DIS data packets were recorded and replayed at the VRAC at ISU on the following day. Observers were able to view the STE on the large screen in the VRAC auditorium and were also provided the opportunity to be completely immersed in the battlespace in the C6 virtual reality facility. This was the first time that the Solipsys MSCT was used to conduct an STE, and the first time that a training scenario recorded on operational equipment was replayed in the VRAC facility

JSAF scenarios can be developed in a few hours by personnel at the 133rd ACS. Using the embedded system that came with MCE, the generation required several hours to develop. A number of 133rd personnel spent four days in JSAF training for operational use of JSAF. This core then cross-trained other personnel. VRAC members also got this training as well as technical details of JSAF. The data from this embedded MCE system was not in a format (DIS) that supported interoperability and replay at the VRAC.

Immersion in the battlespace at the VRAC is depicted in Figure 10.

Figure 10. Immersion of C2 Operators in the C6 Battlespace.

The use of JSAF intelligent agents reduces the number of operators and role players required. This is particularly important since STEs can be personnel intensive for large scenarios. With a reduced requirement for operators and role players in order to conduct C2 training, more effective use of existing manning is accomplished.

Perhaps the most significant benefit is from a cost basis. The MCE MSCT solution leverages on reusable assets to create a DMT training capability for the MCE. The DIS interface to the VR systems were done by students at ISU that are very cost effective. The VR systems at ISU are also employed for several other projects, thus spreading the financial burden over those programs. The ability of Air Control Squadron personnel to generate their scenarios and data logs does not require contractor support, thus further reducing cost for STEs.

The use of both the MCE stimulation and the various VR systems provides further training and debrief capabilities for C2 operators. Although this first STE used the large scale fixed C6, more mobile types of VR will be explored in future research. Lower cost, workbench systems that could be employed at the unit sites will be investigated. Initial comments from the MCE operators has been positive with many suggestions of display formats to further enhance the visualization of the battlespace.

FUTURE DIRECTION

The concept of Distributed Mission Training (DMT) will be further expanded to fit the requirements of Distributed Mission Operations (DMO) which may be seen as a combination of DMT, Mission Rehearsal, test and evaluation, and Simulation Based Acquisition (SBA). The role of 133d ACS is as a test unit. Here, all aspects of DMO will be utilized to accomplish testing of MCE. The Control and Reporting Center (CRC) piece of DMO provides all levels of training and mission rehearsal. Testing and evaluation of MCE components and software is maximized in the distributed environment. In addition, SBA for future systems is maximized through validation of requirements. The Operations crew members maintain a high level of combat mission readiness through DMT and use mission rehearsal extensively during the experimentation process. Given the high price of large force employment training sessions, bringing in live and constructive elements of the air battle plan allows for multiple practices of a scenario without the cost of bringing together those weapons systems a few days before the operators deploy to overseas locations. The cornerstone of the ability to operate in the distributed environment is the Multi-source Correlator Tracker (MSCT) which allows MCE to plug into the DMO architecture and can be reused with system upgrades to network architectures. Further, the combination of the MCE stimulation with full visualization of training and test scenarios provides capability to integrate into all categories of DMO activity.

Plans are currently underway to develop additional capabilities to support C2 training using these unique training tools. Included are C2 performance measurement, effective operator interfaces for the virtual reality environment, and voice capability for the computer generated forces. In addition, a demonstration of the Distributed Mission Training portion of the MSCT interface is planned in FY 02. This capability to participate in DMT training will greatly enhance MCE training opportunities, and will allow participation in major DMT exercises such as Desert Pivot. More sophisticated STEs and Joint Service Training Exercises are planned for late FY 02 and FY 03.

CONCLUSIONS

This paper has described two separate but highly coupled training tools for C2 GTACS: MCE stimulation and use of VR for battlespace visualization/debrief. This powerful combination of simulation tools can be used for concept development, exploration of actual C2 visualization systems, using live feeds and numerous human factors issues.

Reuse of existing interface hardware and software that is fully interoperable has provided a cost-effective stimulation system that provides a training environment for the Modular Control System. The demonstration showed an effective solution that provides a "Schoolhouse" capability for the MCE operators. It immediately provides on-demand training for the majority of C2 training requirements in the setting and environment with which the operator is most familiar. The design leverages on interoperability standards that allow for full training scenarios of live, virtual, and constructive operation in a Joint Synthetic Battlespace which is part of the DMT vision.

The STE described focused mainly on training. However, future STEs can further expand the concept of DMO using both the stimulation and the ability to use virtual reality to visualize training exercises. Initial results of the STE showed that C2 operators get a better understanding for the battlespace after reviewing their two- dimensional training mission in the virtual reality environment.

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