Transfer of Control between Operational and Tactical Environment Generators

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ABSTRACT

The 705th Exercise Control Squadron (EXS), the Air Force Distributed Mission Operations Center (DMOC), located at Kirtland AFB, New Mexico, conducts four Virtual Flag distributed training exercises each year. The exercises focus on Tactical Command and Control (C2) Mission Operations Training. The Air Force Command and Control Wing (CCW), formerly the Air Force Command and Control Training Innovation Group (AFC2TIG), located at Hurlburt Field, Florida, conducts four Blue Flag exercises per year, which support Operational C2 Mission Operations Training. A decision has been made to merge the Virtual Flag, tactical level exercises, with the Blue Flag, operational level exercises. The combined exercise will fulfill both operational and tactical training objectives.

To fulfill both training objectives, the environment generators that create air and ground tracks, or entities, must also merge. One way to merge these simulations is to transfer control of appropriate, selected air and ground entities from the operational environment generator to the tactical environment generator, thus taking advantage of each simulation's strengths. Transfer of control between operational and tactical simulations was demonstrated during Virtual Flag 03-3 and Joint Expeditionary Force Experiment (JEFX) 04 System Integration Test 1. The participating sites were the DMOC and the CCW. Control of Air Warfare Simulation (AWSIM) aircraft was transferred to the Next Generation Threat System (NGTS), using the Distributed Interactive Simulation (DIS) Transfer Control Request, Set Data, and Acknowledge Protocol Data Units (PDU)s. NGTS then applied higher fidelity engagement and radar models to the aircraft, and engaged tactical-level virtual simulators. Once tactical training was completed, the aircraft were transferred back to AWSIM to continue with operational training support. All aircraft and associated parameters were transferred successfully.

This paper presents how the AWSIM and NGTS simulations transferred control of aircraft, thereby, supporting both tactical and operational training requirements.

ABOUT THE AUTHORS

Mr. Sorroche has 16 years professional experience; 8.5 years experience in the Modeling and Simulation field. He currently works for Artic Slope Regional Corporation Communications (ASRCC) at the DMOC as the Exercise Director for distributed exercises, and has been the Engineering lead for the DMOC for EFX 98, JEFX 99, JEFX 2000, Millennium Challenge 02, JEFX 04, and many Blue Flag and Virtual Flag exercises. He is the Vice Chair for the Simulation Interoperability Standards Organization (SISO) Signal PDU Study Group, and the Chair for the Link 16 Product Development Group. Mr. Sorroche is a co-recipient of the Fall 2002 SIWZIE Award for paper 02F-SIW-119 titled "TADIL TALES." He has Bachelors and Masters of Science Degrees in Electrical Engineering from New Mexico State University. He is a member of Tau Beta Pi and Eta Kappa Nu Honor Societies.

Mr. Szulinski has 14 years of experience in the modeling and simulation field, and currently works for Lockheed Martin as a Principal Systems Engineer at the DMOC. During his career he has been involved with constructive, live and virtual simulation including rotary- and fixed-wing flight simulation, physics-based weapons effects modeling, live air combat maneuver ranges, mission rehearsal and exercise support for Navy's Fleet Battle Experiments and Air Force's Virtual Flag exercises. His primary area of expertise is within distributed simulation (DIS/HLA), visual simulation and computer networking. He holds a Bachelor of Science in Aeronautical Engineering from Embry-Riddle Aeronautical University. He has also co-authored and presented a paper at I/ITSEC titled "Using HLA in Physics-Based Weapons Effects Simulation."

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INTRODUCTION

The Air Force Distributed Mission Operations Center (DMOC), located at Kirtland AFB, NM, conducts four Virtual Flag distributed training exercises each year. The exercises focus on Tactical Command and Control (C2) Mission Operations Training in a simulated conflict. Virtual Flag's challenging scenarios facilitate strengthening individual, team, and inter-team skills through the use of increasingly difficult training blocks. Crews are immersed in a robust and dynamic shared simulation environment. These exercises are supported by several tactical constructive Computer Generated Forces (CGF) systems, which simulate the air and ground war with air and ground tracks, or entities. The Next Generation Threat System (NGTS) provides the semi-autonomous red air threat simulation.

The Command and Control Wing, located at Hurlburt Field conducts four Blue Flag exercises per year. Blue Flag Exercises have operational-level objectives that train the numbered Air Force wings as a Joint Force Air Combat Command (JFACC) at the operational level of war and gain air component battle staff experience in a realistic Command, Control, Communications, Computers and Intelligence (C4I) environment. Emphasis is on all C4I activities required to plan and execute air operations in the scenario of choice. The Air Warfare Simulation (AWSIM), which is an operational constructive CGF, supports these exercises.

Select Blue Flag and Virtual Flag exercises will be merging in the coming years in order to fulfill both operational and tactical level training needs simultaneously. To do this, the CGFs that support these exercises, AWSIM and NGTS, must do the same.

One way to merge these simulations is to transfer control of appropriate, selected air and ground entities from the operational environment generator to the tactical environment generator, thus taking advantage of each simulation's strengths. The Distributed Interactive Simulation (DIS) Standard defines a Transfer Control Request (TCR) Protocol Data Unit (PDU). Transfer of control between operational and tactical simulations was demonstrated during the Virtual Flag 03-3, and the Joint Expeditionary Force Experiment (JEFX) Systems Integration Test (SIT) 1 using the TCR PDU. Control of the AWSIM aircraft was transferred to NGTS. NGTS then applied higher fidelity engagement and radar models to the aircraft, and engaged virtual simulators. Once the tactical engagement was completed, the remaining aircraft were transferred back to AWSIM to continue with operational training support. All aircraft and associated parameters were transferred successfully.

This paper describes how the AWSIM and NGTS simulations transferred control of aircraft, thereby, supporting both tactical and operational training requirements.

TRANSFER OF CONTROL

There are many reasons why Transfer of Control would be used for any given number of simulations. For AWSIM and NGTS, it is to take advantage of the best features of each CGF system. AWSIM satisfies the operational-level training requirements through its large scenario capability, Theater Battle Mangement Core Systems (TBMCS) interface, Air Tasking Order (ATO) and route import. NGTS satisfies the tactical-level requirements by providing the high fidelity, high update rate realistic adversary maneuvers and threat generation to virtual and live players.

The NGTS is a tactical-level simulation, but lacks some of the features associated with operational-level simulations such as the AWSIM. A few of its limitations are as follows:

- Lacks operational level fidelity
- Lacks a TBMCS interface
- Creates a limited number of entities
- Does not have an ATO read capability

- Scenario generation is cumbersome

It is not feasible to use the NGTS for an operational-level exercise based upon its inherent shortcomings. Additionally, AWSIM lacks some of the features associated with tactical-level simulations, such as:

- Lacks tactical-level fidelity
- Response time to external stimuli is not sufficient
- Does not simulate some threat systems with adequate fidelity and accuracy
- Air engagement and evasive maneuvers are limited.

It is imperative that the above listed shortcomings are addressed when merging the operational and tactical level exercises, as done in the Virtual Flag. Furthermore, it became apparent that during the exercise execution, constructive entities, primarily aircraft, spend the majority of time executing low fidelity tasks. These include flying to and from Combat Air Patrol (CAP), and en route to and from targets, etc. During those times, the aircraft models fly along a predefined route, and decision-based maneuvers are not required. The existing operational-level simulation fidelity, i.e., AWSIM, is adequate for this part of the scenario execution. AWSIM is capable of generating thousands of entities and performing low fidelity tasks for each.

The challenge arises when the constructive entities come within a range of enemy forces, particularly virtual forces. These entities and their sensors and reactions would be required to engage and react to the virtual forces in a tactically and physically realistic manner. Reviews of these requirements show that there are three options:

1. Select a single CGF that satisfies operational and tactical requirements.
2. Create a new CGF system, which fulfills the both requirements simultaneously. This new system would employ some selective fidelity scheme to support multi-day, theater level constructive simulation, and also provide the high fidelity, high update rate needed for tactical level engagements.
3. Use the existing interoperable CGFs in capacities, which they perform best, and implement a mechanism to pass control of entities between them as necessary.

The first option was rejected, because an earlier DMOC study of CGFs showed that no single system exists, which fulfills both requirements. It was also determined that procurement of a system which could sufficiently satisfy operational and tactical requirements was not feasible at this time based on the required complexity of such a system. The second option was also therefore rejected.

The last option was selected. An ideal solution is to allow any entity generated by one CGF to be controlled by the other at anytime during the scenario execution. A process was designed to allow constructive entities to crossover between CGF systems as needed. Selecting this option retains all of the best qualities of the present systems and combines them into a single seamless environment.

To date, the DMOC has concentrated on transferring red air entities from AWSIM to NGTS. NGTS can provide a semi-intelligent, reactive enemy for the DMOC's F-15C virtual simulators, also referred to the Weapons Tactics Trainers (WTTs). The duration of the entity transfer would be long enough to conduct engagements against the virtual simulators. Once the engagement is completed, the entity, should it survive, is transferred back to AWSIM with the appropriate data, such as expended weapons and fuel. If the entity does not survive, it is eliminated and AWSIM deletes the entity, and updates the TBMCS accordingly.

The concept of transfer of control, present in both DIS and High Level Architecture (HLA), is the right technology for achieving this seamless integration. It allows for entities to originate in one CGF, and then to pass into another CGF as fidelity and resolution requirements change.

TRANSFER OF CONTROL DESCRIPTION

The transfer of control has been implemented at the DMOC using the existing IEEE DIS Standard 1278.1a-1998, Version 6. This section describes which DIS PDUs are used for the transfer of control process, how they are used, and the results from the Virtual Flag 03-3 Exercise, 19 – 23 May 2003, and JEFX 04 SIT 1, 8 – 12 December 2003.

DIS PDUs Used in DMOC's Initial Transfer of Control Capability

The transfer of entity control between AWSIM and NGTS uses three DIS PDUs. They are TCR, Acknowledge, and Set Record. These PDUs and their intended use are described in Ref 1, 2, and 3. It should also be noted that DMOC's initial implementation did not include the additional PDUs

required by the new SISO Transfer of Control Draft document (Ref 4). This functionality is being currently implemented.

As described in Ref 3, the current DIS standard defines the framework necessary to accomplish the transfer of control. However, several areas lack the specific details necessary to avoid non-interoperable solutions between different implementers.

One example are the Record Sets. The record sets can be contained in either a TCR PDU, or a Set Record PDU. They appear in the TCR PDU, if one simulation requests that another assumes ownership of its entity, a TCR *push*. The originating simulation notifies the receiving simulation of various data, which cannot be found in an Entity State (ES) PDU. The Set Record PDU is used for the same purpose in response to a TCR *pull* (Ref 3). This happens when a simulation desiring control issues a TCR to another simulation, to assume the control of its entity. The typical data contained in the Record Sets may include the following:

- Fuel status,
- Weapons load,
- Call sign,
- Chaff/Flare count, and
- Mission data.

Currently, there is an effort under the Simulation and Interoperability Standards Organization (SISO) guidance to standardize these Record Sets. The Record Sets design used for transfer of control is presented in later sections of this paper.

TRANSFER OF CONTROL PROCESS

Combining tactical and operational-level simulations requires assignment of responsibilities for each CGF. AWSIM is responsible for the overall theater-level scenario. It creates and controls all friendly and opposing force air entities. NGTS waits until its higher fidelity services are needed. This occurs when one or more of the AWSIM enemy forces come within engagement range of the DMOC's F-15C virtual simulators.

During normal operation, NGTS internally creates one or more entities to act as a constructive controller for the anticipated transferred entities. The controller is a constructive Ground Control Intercept (GCI), or AWACS entity. AWSIM proceeds with its scenario execution, and creates enemy and friendly airborne forces and broadcasts them onto the simulation network using the DIS protocol. These forces are shown at the NGTS console as external entities.

TCR Initiation

There are two ways the transfer of control can be initiated: Manual, and Automatic. In the manual mode, an NGTS operator selects an external entity generated by AWSIM. Next, the operator requests via a menu for an entity transfer to be initiated in the *pull* mode (Ref 3). The NGTS TCR menu is shown in Figure 1. This action is performed when an engagement with a virtual simulator is about to begin. Next, the NGTS software creates a TCR PDU in the *pull* mode with the recipient identified as AWSIM, and sends it to the DIS Local Area Network (LAN). NGTS generates one TCR PDU for each operator requested entity transfer. So, if the operator wants to transfer a flight of two AWSIM entities, they must request two individual transfers, and two TCR PDUs

Figure 1. **NGTS TCR Menu Options**

are generated. The DIS Site/Application/Entity fields are used to distinguish each individual entity.

The automatic mode shifts the monitoring responsibility from the NGTS operator to the application software itself. The system is initialized at start up with a list of all potential AWSIM entities that are eligible for the transfer of control and their criteria. The criteria include the range to the virtual simulators. A typical configuration file is shown in Figure 2. This configuration file indicates the transfer

of control will occur once the AWS_* entities are within 150 nautical miles of the WTT_01 entity. This is based strictly upon the slant range between the players.

AWS_CR_01	WTT_01	150	10
AWS_CR_02	WTT_01	150	10
AWS_CR_03	WTT_01	150	10
AWS_CR_04	WTT_01	150	10

Figure 2. Typical Configuration

TCR Transition Process

When the TCR PDU is issued, NGTS marks the given external entity as Pending TCR, in anticipation of the Acknowledge and Set Record PDUs. When the TCR PDU is received by AWSIM, it marks its internal entity as external, and sends the Acknowledge and Set Record PDUs back to NGTS. AWSIM ceases to propagate the entity and it simply reflects it as an external entity. The Acknowledge PDU follows the DIS standard protocol. However, the Set Record PDU is loosely defined in DIS, and some interpretation was required. The Set Record PDU conveys any necessary information to the simulation that is about to assume ownership of an entity. At this point, the only information NGTS has about the entity is what can be found in the Entity State (ES) PDU. The minimum additional information required from AWSIM is the weapons and fuel information, which is not contained in the ES PDU. It is assumed that the entity has a standard sensor suite as defined for that DIS enumeration.

The DIS standard does not adequately define the specific fields of the Record Sets contained in the Set Record PDU (Ref 3). They were defined by the AWSIM and NGTS developers to follow DIS as closely as possible. The SISO standardization process is currently filling these gaps.

Once NGTS receives the Acknowledge and Set Record PDUs from AWSIM, it can complete the transfer of control process. NGTS transfers the weapon and fuel data from the Record Sets to its internal structures. NGTS also begins to propagate the entity based on its last know course received in the ES PDU from AWSIM prior to the transfer of control. As per the DIS standard, NGTS retains the original Site/Application/Entity ID of the entity, to make the transition seamless to any other simulations.

NGTS realistically simulates operations, by automatically assigning a command and control entity (i.e. AWACS or GCI) to provide C2 to the transferred entity. The digital controller can now assign the transferred aircraft to engage virtual simulators. Usually two entities are transferred at a time to simulate a two-ship enemy force.

Since NGTS controls the entities and broadcasts their ES PDUs, they are reflected at AWSIM as external entities. They are seen, but no longer controlled by AWSIM. The site, application, and entity ID does not change after the transfer occurs. NGTS continues to send ES PDUs with AWSIM's Site, App, Entity Identification (ID). Only AWSIM and NGTS logically recognize that these have been transferred.

Transfer of Control Back to AWSIM

Once the constructive NGTS entities (transferred AWSIM entities) engage the virtual simulators, two outcomes are expected: The constructive enemy survives the fight, or it is destroyed. If the transferred entity is destroyed, then NGTS will send a DIS ES PDU with its appearance bit set to "destroyed". AWSIM receives this information, and removes the destroyed entity from the simulation and updates the TBMCS database. NGTS also removes the entity from its database.

If the transferred entity survives the engagement, NGTS transfers the entity back to AWSIM by issuing another TCR PDU. This time NGTS issues a TCR *Push* PDU, which indicates a request to relinquish ownership of the given entity, and return control to AWSIM. This PDU can be initiated manually by the NGTS operator, or automatically by the NGTS system. In this case, the TCR PDU contains two Record Sets to reflect the remaining weapon and fuel state. Once the transfer is completed, AWSIM will determine the proper action. AWSIM can return it to its original mission (i.e. CAP), or return it to base in accordance with the weapons and fuel status.

Once again, NGTS marks the entity as external, and treats it as such. The NGTS operator can only view the entity, but can no longer control it. The entity can, however, be transferred back to NGTS at a later time.

Virtual Flag 03-3 Test

The Virtual Flag 03-3 exercise was conducted May 11 – 14, 2003. Transfer of Control was demonstrated in two phases. The first phase was demonstrated after the training objectives for the scenario were completed, but the scenarios and simulations continued to run. Four AWSIM generated red entities were successfully transferred to NGTS. The entities were then directed by the NGTS AWACS controller to engage the two F-15 virtual simulators. Two DMOC F-15 pilots were directed by a virtual AWACS controller to engage the red threats. The two DMOC F-15 pilots engaged and destroyed two red air entities. The other two were not destroyed, and were returned to AWSIM, along with the remaining fuel and weapon data. AWSIM then directed the aircraft to return to base, due to expended weapons and low fuel.

The second phase was demonstrated at the end of the last scenario run. The training objectives were completed, but the exercise continued. Four AWSIM red air entities were transferred to NGTS. The F-15 simulators, flown by F-15 pilots, were directed by the AWACS controller to engage and destroy the red air threats. The F-15 Pilots engaged and destroyed two of the red air threats. However, the other two NGTS-controlled red entities terminated the engagement prematurely and were returned to AWSIM. This problem was traced to faulty NGTS engagement logic, and it was subsequently fixed.

JEFX 04 SIT 1 Test Plan

A transfer of Control test was proposed by the DMOC, to be conducted during JEFX 04 System Integration Test (SIT) 1, 8 –12 December 2003. A test plan was submitted and approved, and was divided into two parts: The technical test plan, and the operational test plan.

Technical Test Plan

The network was configured such that the TCR, Set Data, and Acknowledge DIS PDUs passed through the DMOC DIS Filter. The DIS Filter (Ref. 5) software was also modified to process the TCR, Set Data, and Acknowledge PDUs. The test equipment used was:

DMOC Test Equipment:

1. NGTS and IOS Software, DMOC Development Version
2. Redsim Data Logger
3. Master Simulation (MSIM) Gateway
   a. MSIM
   b. F-15C virtual simulators
4. DMOC DIS Filter
5. Scenario Toolkit and Environment Generator (STAGE) CGF
6. ASTi DIS Voice Equipment
7. T-1 between DMOC and AFCCW.

AFCCW Test Equipment:

1. AWSIM, Version 2.6.2
2. ASTi DIS Voice Equipment
3. Scenario: Southwest Asia
4. Exercise ID: 30
5. Red Aircraft: MiG 29
6. Armament: 4 AA-10s and 2 AA-11s.

The network diagram is shown in Figure 3.

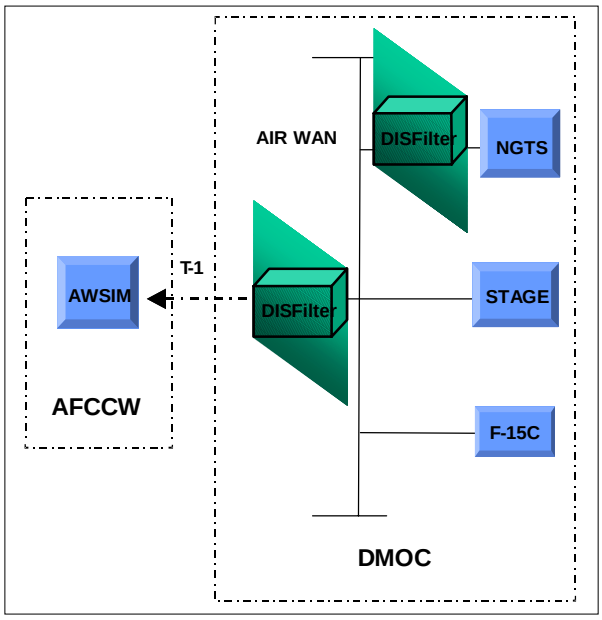

Figure 3. Transfer of Control Network Diagram

Operational Test Plan

The operational test plan would first establish a playbox, using a Southwest Asia (SWA) scenario location. The operational test was as follows:

a. Establish 4 CAPs for the red aircraft, MiG 29s. The MiG 29s would be carrying 4 AA-10s and 4 AA 11s.
b. Launch 4 four ship flights of red aircraft and proceed to designated CAPs

c. Rules of Engagement (ROE) for Red Aircraft is "weapons hold"
d. DMOC initiate manual transfer of control of designated AWSIM red aircraft and execute engagements.
e. DMOC F-15C Pilots notify and coordinate with Engagement Control Station (ECS) controllers. ECS controllers would monitor and coordinate engagement
f. If any red aircraft survive F-15C engagement, these will be transferred back to AWSIM. AWSIM controller will monitor weapons and fuel status on AWSIM Air Status Displays and report to DMOC NGTS operator to verify successful transfer.
g. Repeat steps d – f with a more complex air picture, including additional red and blue aircraft.
h. Repeat steps d – f, except use NGTS Automatic transfer of control function.

JEFX 04 SIT 1 Test Results

The transfer of control test execution was conducted 10 – 12 December 2003, during JEFX SIT 1. The test phases and results are described next.

Manual Transfer of Control Test Results

The NGTS operator first verified that the red entities were generated from AWSIM. Then, the NTGS operator selected an external entity via a menu for an entity transfer to be initiated in the pull (Ref 3) mode. Next, the NGTS software created and sent a TCR PDU in the pull mode with the recipient identified as AWSIM. NGTS generated one TCR PDU for each operator requested entity transfer. There were a total of 4 MIG 29s that were pulled from AWSIM to NGTS.

Next, STAGE blue entities engaged and killed 3 of the 4 NGTS entities. The fourth entity was transferred back to AWSIM. Weapons expended were 2 AA-10s and 2 AA-11s missiles. Fuel status showed approximately 4000 pounds of fuel was expended, which was verified by the AWSIM operator. Next, tests were conducted with the DMOC F15C WTTs in two main engagements. First, the F-15C was targeted against an 8-ship of AWSIM red air. The AWSIM red air consisted of a four-ship of Mig-23s and a four-ship of Mig-29s. The F-15Cs engaged the Mig-29s after NGTS initiated a manual transfer of control. During the engagement, NGTS did not appear to consistently shoot when within shot range, and the F-15Cs did not see launch indications, but received audible radar warning. The Mig-29 shot and killed one F-15C. The F-15Cs were reset and engaged a three-ship of Mig-29s. The lead Mig-29 merged head on with the F-15C but never fired. The F-15C then engaged the lead Mig-29 that did not appear to react. The trail Mig-29 then shot and killed the F-15C. The entities were not transferred back to AWSIM as they dropped out right after the engagement.

Automatic Transfer of Control Test Results

The automatic mode shifts the monitoring responsibility from the NGTS operator to the application software itself. The system is initialized at start up with a list of all potential AWSIM entities that are eligible for the transfer of control and their criteria. The criteria include the range of the virtual simulators. The configuration file used was similar to that shown in Figure 2, except that the engagement zone was modified to 60 nautical miles.

This configuration file indicates the transfer of control will occur once the AWS_* entities are within 60 nautical miles of the WTT_01 entity. The last column is the TCR Request time limit. This configuration file was used in the automatic transfer of control test. The automatic transfer of control engagement zone is shown in Figure 4.

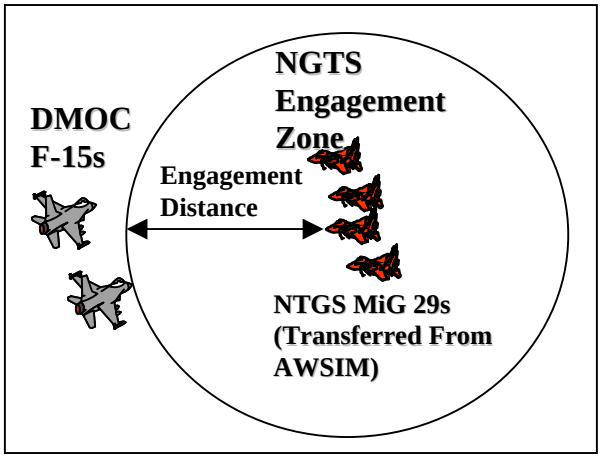

Figure 4. NGTS Engagement Zone

The initial automatic transfer of control engagements were conducted with STAGE blue air entities. When STAGE entities came within the 60-mile activation range of an AWSIM entity, AWSIM entities were automatically transferred from AWSIM to NGTS. During this test, four MiG-29s were automatically

pulled from AWSIM to NGTS. One of the pulled entities was flagged as transferred by AWSIM, but NGTS never assumed control of it. During this engagement, two of the transferred MiG-29s were killed, and one the STAGE F-15s was killed. All of the destroyed MiG-29s still controlled by NGTS continued to send out ES PDUs until deleted from NGTS. These ES PDUs marked the entity as destroyed, with 0 speed, and an altitude of 1foot. It appeared that for at least one of the pulled MiG-29s, NGTS was sending out ES PDUs with the marking field changed. The IOS was displaying the correct call sign, but the DIS Analyzer, RedSim, showed the entity state monitor was different (e.g. MG73 instead of MG30#4). Another test was conducted where a 4 ship of MiG 29s were transferred automatically. The DMOC F-15Cs engaged and killed 3 of the 4 MiG 29s. The fourth MiG was not killed so that the push function back to AWSIM could be tested. The fourth MiG 29 was pushed back to AWSIM, where remaining weapons and fuel were consistent with the engagement. The minor software problems discovered during testing were subsequently addressed.

Despite minor software-related glitches, both operational tests were deemed successful because they demonstrated the viability of transfer of control. The concept proved to be useful in merging operational and tactical CGFs. It was possible to move constructive entities between two simulations at will as fidelity requirements changed, while maintaining seamless environment.

Planned Enhancements and Other Transfer of Control Applications

The planned enhancements for transfer of control are:

- Refine and Standardize the DIS process,
- Transfer Blue Constructive Air Entities,
- Transfer Ground Entities, both red and blue,
- Transfer Virtual and Constructive Entities,
- Transfer additional simulation data (e.g. mission data).

The same challenges exist when reconciling the needs of large-scale operational-level simulation with tactical-level shooters.

CONCLUSION

Transfer of control between operational and tactical simulations was successfully demonstrated during Virtual Flag 03-3 and JEFX 04 Systems Integration Test I. The transferred air entities applied higher fidelity engagements to enhance tactical level training when required. The knowledge gained from this experiment is beneficial in many ways, but more work is required in refining the DIS process and standardizing the Set Record PDU.

Some NGTS fixes and enhancements will be incorporated for the next experiment, and the transfer of control process will again be tested. Additional results and information will be included in subsequent papers when they are available.

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