

DMT “Fair Fight” Temporal Triad: Weapon, Counter-Measures, Target via Distributed Ordnance Servers

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ABSTRACT

“Kill More, and Die Less” Description of Distributed Mission Training benefits from a current USAF F-16 Pilot.

Distributed Mission Training (DMT) is one of the key innovative modeling and simulation (M&S) systems focused on increasing and maintaining warfighter skills in the combat airforces. DMT is a rapidly evolving technology with many Air Force organizations and contractors working to provide the best training obtainable. However, to achieve Gen. Hawley's challenge for DMT Training to have a "Fair Fight with Sweaty, Smiling Pilots emerging from the simulator cockpits" some technological challenges still exist.

This paper presents a Distributed Ordnance Server potential solution for providing DMT "Fair Fight" that overcomes the kill/miss errors induced by long-haul physics/network latencies. Further, the Distributed Ordnance Server solution also provides standards for munitions performance that overcome the plethora of different fidelity weapons models built into simulation hosts over many years by many different engineers.

AFRL demonstrated through the ROADRUNNER and COYOTE exercises the benefits of a single common Ordnance Server and identified other problems yet to be solved. The initial AFRL single Ordnance Server Solution solves all of the munition standards technical problems as long as all the shooter and targets are in the same temporal space. However, when long-haul latencies become too large, disparities in the spatial positioning adversely affect the accuracy of the kill/miss outcomes.

This paper's key hypothesis investigated is, "Fair Fight" can be achieved insuring the weapon models, the target model and any countermeasure models interact in the same temporal space. The same temporal space is achieved by a "local" Distributed Ordnance Server positioned at long-haul locations that exceed the acceptable latency tolerances.

The new phase "Temporal Triad" was coined to describe these critical temporal interactions between target, weapon and counter measures. This paper presents solutions to critical problems associated with the DMT simulated "kill" inaccuracies that can occur due to network latencies. McKee (1997/98) utilized a elegant series of live fire experiments as a basis for DMT type testing with live and constructive models and found latencies of greater than 70ms too great for accurate weapon outcomes against a maneuvering target. The unique and innovative portion of this paper is, by architecturally adding distributed ordnance servers and transfer of ownership of weapons between Ordnance Servers, latencies of greater than 70ms can still accurately model "fair fight" outcomes.

Details of the Experimental Design and the subsequent Results are presented. Of particular use to the simulation and training communities are graphics that illustrate Network Induced latency of greater than 70ms weapon to target is too great for "fair fight". Further, the successful results mitigating the long haul latencies via multiple Distributed Ordnance Servers is presented. Conclusions and Future Research Directions are presented with current and anticipated benefits for future Fire & Forget, Directed Energy, Kinetic Energy, and GPS weapons.

About the Authors

Dr. Dutch Guckenberger is the Chief Scientist at SDS International, with 15 years of experience in the defense simulation and training systems. He has earned degrees in Computer Science, Physics, & Simulation and Training. Research interests include Distributed Mission Training, High Resolution PC-Based Visual Systems, Above Real-Time Training (ARTT), UAV and UCAV Research. He is a member of ACM, IEEE, SPMN, Human Factors Society and a Link Foundation Fellow in Advanced Simulation and Training.

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INTRODUCTION

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Distributed Mission Training (DMT) is one of the key innovative modeling and simulation (M&S) systems focused on increasing and maintaining warfighter skills in the combat airforces. DMT is a rapidly evolving technology with many Air Force organizations and contractors working to provide the best training obtainable. However, to achieve Gen. Hawley’s challenge for DMT Training to have a “Fair Fight with Sweaty, Smiling Pilots emerging from the simulator cockpits” some technological challenges still exist.

This paper presents a Distributed Ordnance Server potential solution for providing DMT “Fair Fight” that overcomes the kill/miss errors induced by long-haul physics/network latencies. Further, the Distributed Ordnance Server solution also provides standards for munitions performance that overcome the plethora of different weapons built-in to many different simulators, by many different engineers, over many years.

AFRL demonstrated through the ROADRUNNER and COYOTE exercises the benefits of a single common Ordnance Server and identified other problems yet to be solved. The initial AFRL single Ordnance Server Solution solves all of the munition standards technical problems as long as all the shooter and targets on the same temporal space. However, when long-haul latencies become too large, disparities in the spatial positioning adversely affect the accuracy of the kill/miss outcomes.

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This paper presents solutions to critical problems associated with the DMT simulated “kill” inaccuracies that can occur due to network latencies. McKee (1997/98) utilized a elegant series of live fire experiments as a basis for DMT type testing with live and constructive models and found latencies of greater than 70ms too great for weapon use against a maneuvering target. The unique and innovative portion of this paper is by architecturally adding distributed ordnance servers and transfer of ownership of weapons between Ordnance Servers, latencies of greater than 70ms can still accurately model “fair fight” outcomes.

Details of the Experimental Design and the subsequent Results are presented. Of particular use to the simulation and training communities are graphics that illustrate Network Induced latency of greater than 70ms weapon to target is too great for “fair fight”; The Graph of kill accuracy as a function of induced latency.; and successful results with multiple Ordnance servers each flying the weapon into its respective local target aircraft.

History AFRL / BMH Success with a single Ordnance Server – Standards Enforced

There have been many attempts to even the score and playing field, but none more than the value of the Ordnance Server.

The lack of validated, DIS compatible, high fidelity munitions models has plagued the DIS community for some time. Models with varying fidelities have been used in various simulation exercises. The persistent fidelity variations have caused many participants to claim that the simulations did not produce a fair fight. Quite honestly manipulating a data base could make the same missile with varying speed and capabilities to win the fight. The question becomes, “Why don’t simulation exercise participants simply share common munition models, to ensure a fair fight?” The problem lies in the fact that many munition simulations are integrated directly into the launching platform’s simulation, making it difficult to extract a model from one simulation and integrate it into another. Also, there is the problem of choosing a model to integrate, with many participants claiming to have the “best” model of a specific munition. To solve these and other problems, Manned Flight Simulator (NAWC AD) created the

Ordnance Server (OS), a stand alone munition simulator for one or more DIS entities.

The OS fly-out munitions in response to Fire PDUs (Protocol Data Units) output by the launching entity. Using the Fire PDU, the launching platform sends the OS detailed information describing the launch of the munition, including the specific type of munition launched (i.e. AGM-65E, AIM-7, etc.), its initial velocity, and the location it was launched from. When the OS receives a Fire PDU, it selects a fly-out model and aerodynamic parameters based on the munition type specified in the PDU, and simulates the munition according to these selections. When the munition has met its detonation criteria, ground impact, target impact,

etc., it issues a Detonation PDU, and completes the munition simulation.

DMTO&I Phase I Experience

The authors participated with CSC as team members on the DMTO&I Phase I contract. A portion of the effort was to devise and test methodologies to ensure the “fair fight”. These efforts centered on experimental finding associated from a DMT testbed built similarly to the DMT environment currently in use at AFRL/HEA (Mesa, AZ). See Figure 1 DMT O&E Testbed.

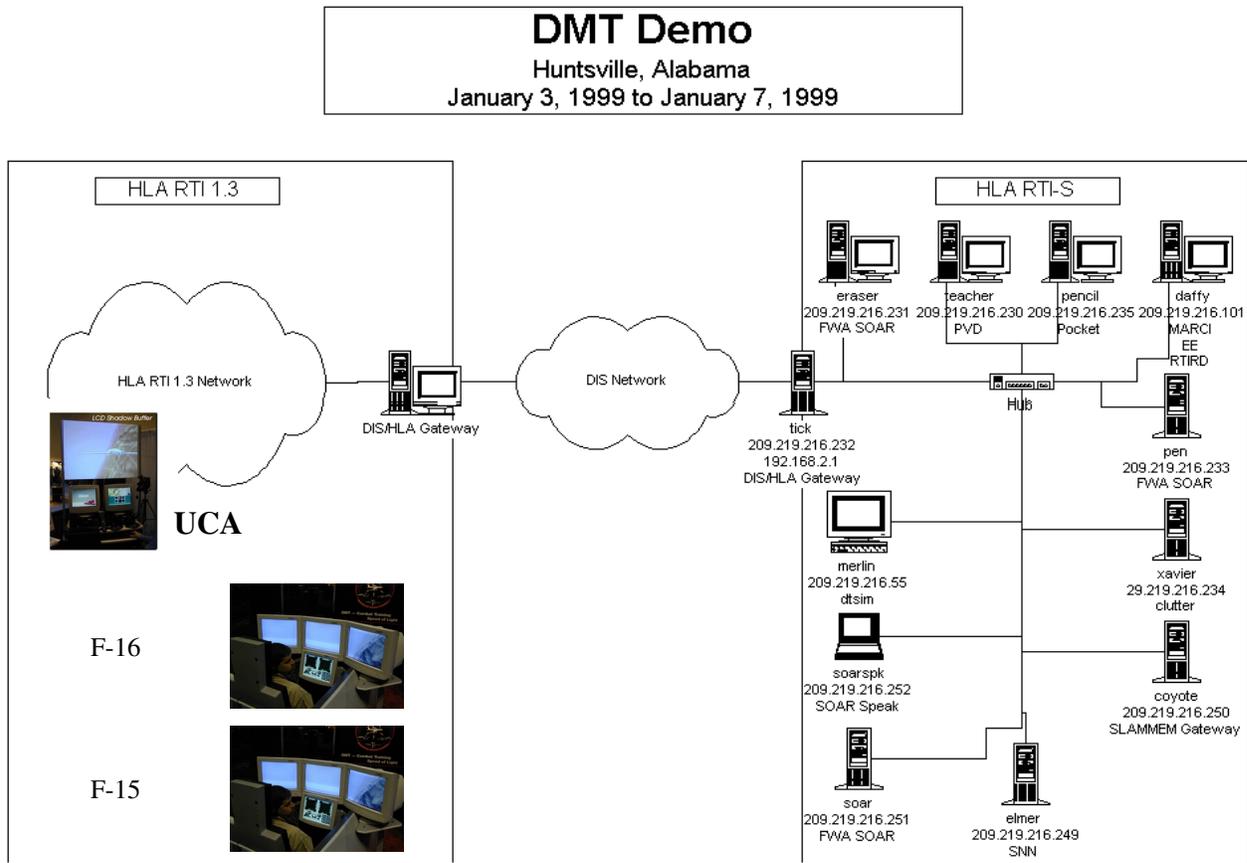


Figure 1 DMT Demo

The successes associated with the standardization of weapon performance via common use of the ordnance server were easily replicated. But an extensive

literature search found an excellent series of experiments by McKee demonstrating that latencies of greater than 70ms provided invalid results against

maneuvering targets (McKee 1997/1998). Essentially in the simplest case the spatial discrepancy associated with the temporal latency resulted in a difference greater than the kill radius of the weapon (McKee 1997/1998). The authors hypothesis to overcome this physics based latency was reasoned as, an Ordnance Server at each DMT Mission Training Center coupled with transfer of ownership of weapons would insure that the target, weapon and relevant countermeasures were all in the same temporal space. The term "Temporal Triad" was coined to characterize this critical trinity of interrelated entity actions and reactions. The key to the concept is not the elimination of latency but the proper placement of latency to ensure "fair fight". For example, in the status quo DIS or HLA engagement without ordnance servers, the firing aircraft flies-out the missile and its accuracy suffers the latency differential between the target aircraft and the missile which can erroneously detonate the missile where the target aircraft isn't due to its maneuvering. That is the shooter and his missile do not know the real location of the target aircraft due to temporal latency. So the latency between missile and target can easily lead to invalid results. Contrast that with the authors concept of distributed ordnance servers with transfer of ownership of the missile into the same "local" temporal space as the target will result in valid solutions up to the fidelity of the weapons module utilized. Latency still exists but it is in the relatively harmless domain of the between the target and the shooter aircraft not between the missile and the target and does not adversely effect kill/miss outcomes. (A case can be made that the shooter radar painting status of the target could potentially effect a last minute outcome. However, the training of pilots to shoot in the "sweet spot" of targeting parameters probably precludes this from happening very frequently).

Readers familiar with Einstein's Theory of Special Relativity may see parallels between the space/time view of a local observer with the local observer framework of the temporal triad for the target, weapon and countermeasures.

Distributed Ordnance Server Expected Outcomes

Upon startup, the OS loads a file containing the configuration data it needs to execute properly. For example, the OS can be configured to fly-out munitions for all launching entities from a specific site, or it can be limited to a specific application at a site. The configuration file also contains the data to properly model each type of munitions, including fly-out model to use, aerodynamic parameters, and detonation criteria. Configuration data is also accessible via a graphical user interface (GUI), allowing any of the parameters to be

changed during runtime and saved to a configuration file.

When the OS receives a fire PDU, it first determines if it is responsible for modeling the fired munition by comparing the site and application fields of the fire PDU's firing entity ID with the site and application values the OS is currently configured for. If the OS determines that it will model the specified munition, it creates a munition record using the data it has stored for the specific munition type it is modeling, and places the record on a list of active munitions. The OS calculates new state data for each munition on the active list based on the fly-out and guidance model selected to model a specific DIS munition type, and the position of the target entity, if applicable. As part of the munition update process, the OS checks to see if each munition has collided with another entity or the ground, was destroyed by a nearby detonation, or has met its own detonation criteria. If the munition collides with another entity, the OS issues a collision PDU. If the munition impacts the ground, is destroyed by another detonation, or detonates itself, a detonation PDU containing the appropriate detonation result is output. A detonation PDU with a result of none is output when an error condition in the OS is encountered, or a model aborts due to a loss of radar lock, inadequate closing velocity, or a similar condition.

The expected outcomes from the distributed OS architecture and execution will be to reduce the latency effects over a wide-area-network (WAN) and provide a solid framework for "fair fight". This latency mitigation strategy can be further improved in constructive and virtual simulation environments with the addition of predictive algorithms based on known router paths and WAN distances (time constraints). Displaying the miss-distances for specific weapons as time delays occur in the network (latency) and evaluating the placement of the OS as a central or distributed location should provide solid data to justify a distributed OS concept for DMT fair fight issues.

2) Fair Fight Issues Problem Statement:

- Physics Latency Constraints have been measured in DMT exercises on the order of 80ms and greater for some geographically distant locations. Illustrative examples are numerous though out the DMT and DIS/HLA literature. Dr. McKee excellent baseline research (1997/98) using live-fire criteria in DMT type exercise demonstrated that latencies of greater than 70ms precluded accurate hit/miss calculations against maneuvering targets.
- "Fair Fight" can be defined in many areas but to the fighter pilot it is using common

distributed munitions models. For the purposes of this paper (and to make length limitations) it is assumed that the historical difficulties associated with different weapons models from different vendors at different fidelity levels is overcome by the use of a common Ordnance Server. Even if problems and errors exist in the Ordnance server models the errors will be consistently applied to all entities using the Ordnance Server. The single Ordnance Server then becomes the munitions standard and mitigates all the potential differentials associated with multiple simulations that have multiple models.

- What has been lacking is a methodology to mitigate the adverse temporal hit/miss effects from long-haul latencies. This paper presents innovative solutions to critical problems associated with the DMT simulated “kill” inaccuracies that can occur due to such network latencies. McKee (1997/98) utilized live fire criteria as a basis for DMT type testing with live and constructive models and found latencies of greater than 70ms too great for weapon use against a maneuvering target. The unique and innovative portion of this paper is by architecturally adding multiple distributed Ordnance servers and transfer of ownership of weapons between Ordnance Servers latencies of greater than 70ms can still accurately model “fair fight” outcomes.

3) Prior Solution Attempts:

There is an extensive body of literature associated with attempts to overcome the latency problems. Most of the prior solutions included some method of correcting the temporal induced mistake via Prediction/Roll-Back Solutions, or a Monte Carlo smoothing of errors, or always defining the detonation in terms of the target coordinate system so that the shooter aircraft “space/time truth space” is enforced upon the target. All of these prior methods suffer from not accounting for the last efforts of the target aircraft and its countermeasures to induce misses in the tracking weapon. These failing of prior attempts have the adverse effect of not crediting pilots in simulation with misses they induced by proper application of countermeasures and evasive maneuvers. The authors submit that it is of critical importance that the end game be accurately modeled so that pilots that apply countermeasures and maneuver correctly against threats benefit with a correctly simulated miss and survival. Further, non-valid end games can result in negatively trained pilots by incorrectly calculated “hits” and

simulated deaths where “truth” should have been survival.

Initial Ordnance Server Efforts, Original Transfer of Ownership Hypothesis

The OS uses a modular architecture that neatly separates the DIS data from the internal representations of munition data. The main modules of the OS consist of a DIS module to communicate with the DG server, a position update module which determines munition positions, a detonation module which checks detonation criteria, and an executive shell which controls timing and synchronization. Munition data for each launched weapon, such as fly-out model, guidance model, aerodynamic parameters, and burn time are stored as records in one of two lists internal to the OS; the active munition list and the frozen munition list. The OS was designed from the start with the goals of being both expandable and maintainable. The architecture allows additional fly-out models to be easily added to the program. To add an external model, a model interface adapter is wrapped around existing fly-out models to convert fly-out model specific data to a format the OS can use. Using this method, existing fly-out models can be used without being modified. This is important when issues such as VV&A inevitably surface.

External Models

As described above, the OS was designed to be expandable. A model interface adaptor supporting Tactical Aircrew Combat Training System (TACTS) air-to-air missile simulations was added to the OS to support the Kernel Blitz exercise. The model interface adaptor translates between coordinate systems, and maps the probability of kill number returned from the TACTS simulation into the result field of the detonation PDU.

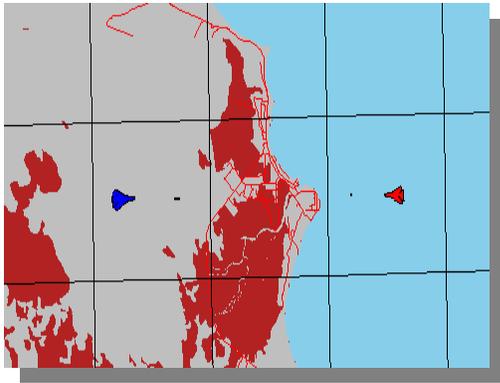


Figure 2 Blue on Red engagement

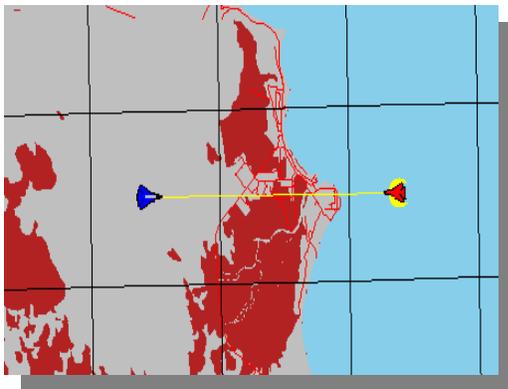


Figure 3 Blue kills Red

Support for TACTS air-to-ground and surface-to-air missile simulations, and Tomahawk and Harpoon simulations, are also included in OS models.

Currently, the OS uses the position and orientation of the launching platform to determine if the target of a semi-active missile is illuminated. Modifications are underway to allow the user to configure the OS to use emission PDUs instead of the launching entity's position and orientation in an effort to increase realism. Also, the OS supports laser guided weapons, and allows the user to enter a laser designation code. The OS is also being modified to accept and use signal PDUs output from the launching entity to pass pre-flight and in-flight data to munitions.

4) Hypothesis:

- Fair Fight can be achieved by insuring the weapon, target, and countermeasure models operate in the same temporal space - Temporal Triad operating in "local" Distributed OS via weapon Transfer of Ownership.

5) Experimental Design

SDS and BMH designed the DMTO&I Experiment based on McKee's work. Essentially, first repeating his combined Live and Constructive Simulation experiments in a virtual simulation emulation to verify his 70ms findings. Followed by use of a Latency Generator program running on a PC networked between the Shooters, Targets and Ordnance Server (See Figure 4 below for the a diagram of the different configurations tested.)

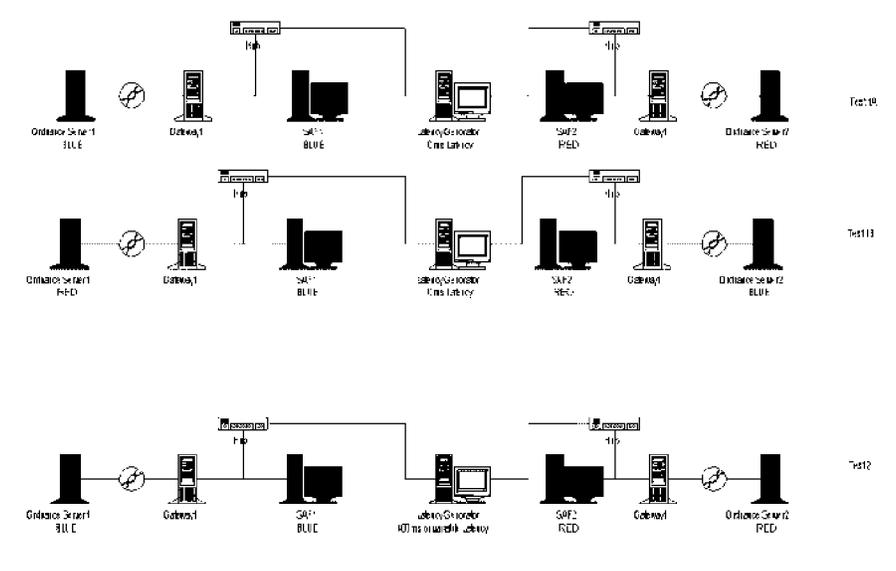


Figure 4 Ordnance Server and Constructive Simulation Latency Test Configuration

In the test runs, background noise and other entities were eliminated and the fighter and target were placed co-altitude and co-speed. AIM-7 Shots occurred at 25 miles and target mid-course maneuver was at 12 miles. The shooter –target geometry was run to look at co-altitude shots from head-on and direct stern as this configuration allows the fewest variables in the trial run. Specifically, the Rules Of Engagement (ROE) permits shots both ways and use the same missiles (AIM-7). AIM-7 chosen as the best candidate since it requires radar illumination till impact (TOF = 0). The experimental plan included 20K for the altitude so as not to compete with altitude lines from radar sensor. Co-speed head-on and + 30 knots for stern shots. This varied from the McKee parameters since the turning bandits may introduce more variable than the initial research budget could tolerate. Additionally, the shooters shot AIM-9M-9s in the McKee paper, which once it left the aircraft, no support was required.

The first runs with a LAN and the Latency Generator (LG) did not produce realistic data due to errors found in the LG and lack of documentation for the initial tests. The LAN was connected directly through the 10/100 hub. A alternate method using Ping PDUs over the LAN was determined to be the best method to conduct the testing and induce latency without incurring additional errors. The Plan for WAN utilized a multicasting to draw further conclusions.

The authors did not publish any Pk data as it could potentially drive classification issues.

The results could have been presented in terms of extrapolated miss distance for reporting results and graphics, however again the authors chose to error on the side of caution and report whether the OS “sees” a kill, though we think there may be some acceptable potential inaccuracies due to the interactions of OS and SAF reporting detonation and damage. The other data is being kept in a secure lab for reference if required. There were 20 runs at each aspect and each OS variant, were performed as an illustrative sample size.

JSAF constructive simulations are very precise in their weapons effects and provide immediate feedback in the form of entity state and damage information for each vehicle whether a platform operating in the various domains or a weapon interacting with the same. The key to evaluate the tactical significance of McKee’s work as it applied to constructive and virtual simulation was designing a basic scenario highlighting the tactical significance of latency in a weapons fly-out AND a mid-course target maneuver. Figure 4 provides comparative results to McKee’s work with an OS

positioned and latency increased with constructive simulation.

It is with these maneuvers that accentuate latency problems and if induced creates a wide miss and potentially false learning outcomes for the engagement.

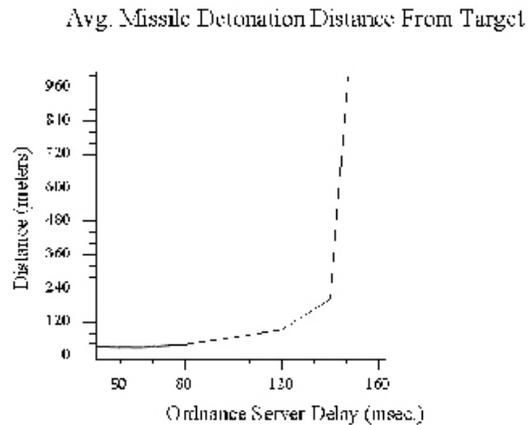


Figure 5: OS Constructive Simulation Latency Test Results

6) Discussion and results:

The initial results verified that Network induced latency > 70ms weapon to target is excessive for DMT - Graphs of kill accuracy vs. induced latency as previously reported by McKee (1997/1998). The initial results can be considered an independent simulation confirmation of McKee’s Live Fire and Constructive Simulation findings.

The control condition of minimal LAN induced latency produced results were 18 of 20 hits, the results of 140 ms induced latency produced only 9 out of 20 hits. While the same 140 ms induced latency utilized with two Distributed Ordnance Servers produced 17 out of 20 hits. This straightforward experiment demonstrates that at least for these shooter-target conditions the Distributed Ordnance Server mitigates latency error to nearly the same accuracy as the control condition associated with low latency local LAN connections. These initial experiments were done on BMH and SDS IR&D funding that limited the scope and duration of the study. The authors recommend that based upon the encouraging initial findings a full study be done in a larger DMT exercise.

The initial successful finding of multiple OS each flying the weapon into its respective local target aircraft

findings seem to indicate that the authors hypothesis topic that is currently being discussed is the use of the OS to increase munition end-game fidelity by reducing latency. Since the OS is standalone and can be running on any machine on the network, it can model the launching entity's ordnance at the *target entity's site*. By taking advantage of this feature, the user can minimize latency induced position error during end-game simulation.

The Ordnance Server provides a variety of benefits to the user. It takes a positive step towards guaranteeing a fair fight by allowing simulation users to share a common munition model. It can help reduce network latency problems by modeling a munition at the target entity's site. Most importantly, the OS can virtually eliminate duplication of effort by allowing munition models to be developed once and shared by all users.

There are several advantages in using an OS vice incorporating missile fly-out models in each individual simulation. Primary among these is using a central server which levels the playing field. Each simulation accesses the same fly-out models with the same level of capability. Centralized logging of termination notices by the OS can prove valuable in after-action-reviews by providing records of which munitions were used against which targets under what conditions of speed, range, target aspect, altitude, etc.

7) Conclusions & Future:

The authors conclude that a Distributed OS to mitigate physics based latency problems increasing "Fair Fight" execution for DMT exercise may have merit. The authors wish to emphasize the initial nature of our findings and urge further study.

The cost of not fixing these inherent latencies problem is Continental United States (CONUS) not being able to fight with remote sites such as ASAI. The requirement to train among different theaters of operations has not come of age, though its time will come due to the nature of the military drawdowns and increased deployment requirements. In the past, cross-command taskings very rarely occurred. In today's operations tempo and desire to "share the wealth (i.e., pain)," units routinely deploy out of their primary theater of operations necessitating more training opportunities to evaluate operational standards and interact with unfamiliar C2ISR and weapons capabilities.

With each new technological advance it seems to take a long time to overcome the inertia previously set up from habit patterns and the methodologies of "old" systems. This inertia must be overcome before new tactics and methods are embraced and employed. This adage applies to new weapons platforms and it certainly

applies to simulation training. The acceptance in M&S centers on realism in both the visual displays and of course the threat environment. The threat environment must replicate the platforms, weapons, sensors and the tactics employed. Threat execution needs a capability to adapt to the battlefield situation as it develops.

Weapons fidelity and scoring standards must be an accepted form in order to have credibility. It cannot depend on varying models being introduced from different sites or sources. Air Combat Maneuvering Instrumentation fly-out models are accepted in the training arena and are used in the JSAF OS. The OS uses the ACMI fly-out models for air-to-air, air-to-ground, and surface-to-air weapons for both Blue Air and Opposing Forces (OPFOR). Whenever a SF agent shoots a weapon, the ordnance server creates the weapon fly-out and displays/scores it for engagement resolution.

- The weapons fly-outs still require user requirements above the "accepted" parameters used over time but verified and validated to ensure it meets the user's expectations. A careful consideration for fly out integration should be examined to avoid any processing slow-downs or lock-ups using the fly out for all ordnance. For example, the fly-out for each bullet fired from a fighter aircraft may exceed processing capability if combined with visual systems and not run as a separate sever. This is most evident in a DIS environment. However, in HLA, both the subscription and interest management will alleviate these problems. In addition, placing a distributed OS at each site should reduce network traffic and provide a greater "fair fight" capability.

FUTURE RESEARCH DIRECTIONS

Eglin 46th Test Wing PRIMES, SDS and BMH are planning on developing an unclassified PC based Distributed Ordnance server for research purposes. This parameterized Ordnance Server will support research and experimentation of future Fire & Forget, Directed Energy, Kinetic Energy, and GPS weapons.

The first planned utilization of this unclassified PC based Distributed Ordnance is on the DMT UCAV Testbed under the direction of Dr. Elizabeth Martin at AFRL/HEA. Figures 5 and 6 illustrate some of the DMT UCAV Testbed.

- Other planned utilizations include but are not limited to:
- Intelligent tutoring systems for tactical aircraft testbed,

- Above Real-Time team training research
- Arch Angel real-time integrated Planner/ player - for joint Battlespace Infosphere research.

Figure 6 DMT LiteFlite UCAV Testbed SEAD Mission



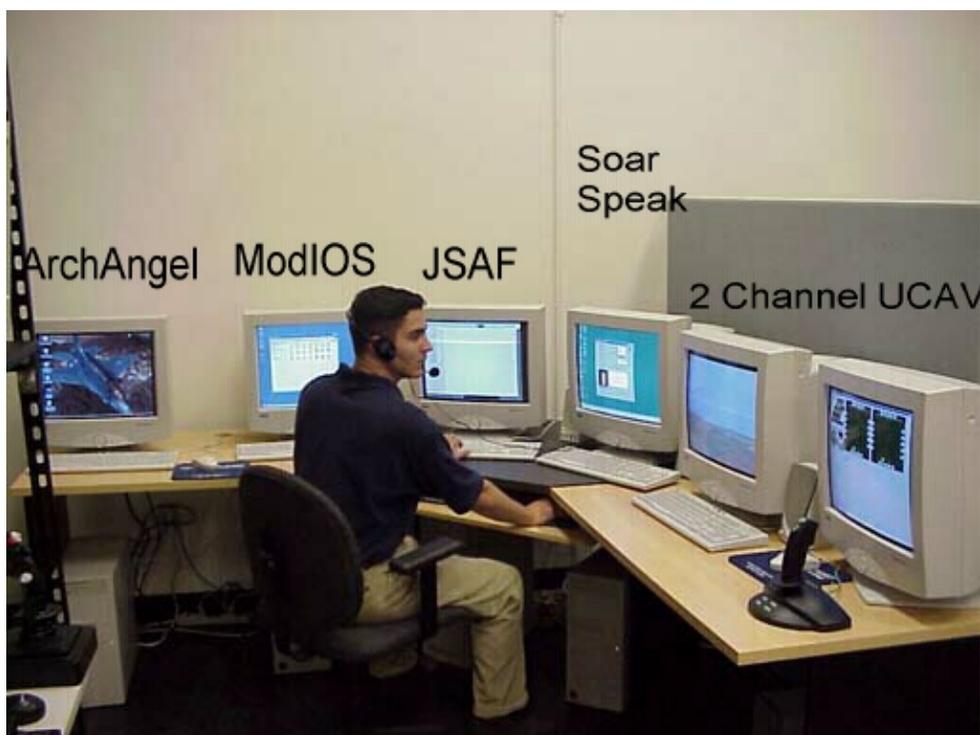


Figure 7 DMT UCAV Testbed Version

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These references maybe found in full at this web link: <http://www.sisostds.org/>

Dedication:

This paper is dedicated to the memory of NASA Dryden Flight Research Center's Mr. Jack Kolf, the father of "Fast Time Simulation" (ARTT Simulation), friend and mentor.

Dutch Guckenberger

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