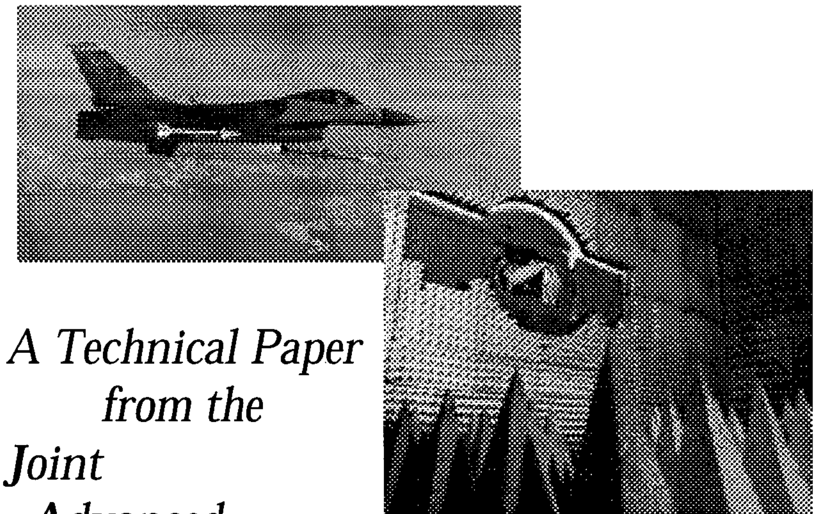
Lessons Learned from Executing an ADS Air-to-Air Missile Test in Near Real Time



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A Technical Paper from the Joint Advanced Distributed Simulation Joint Test Force

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ABSTRACT: *The Live Fly Phase (LFP) of the Systems Integration Test (SIT) was executed by the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) and the 46th Test Wing at Eglin AFB, FL during 1997. The purpose of the SIT is to evaluate the utility of using advanced distributed simulations (ADS) to support cost-effective testing of an integrated missile weapon/launch aircraft system in an operationally realistic scenario. The SIT missions simulate a single shooter aircraft launching an air-to-air missile against a single target aircraft.* (reference [1])

In the LFP, the shooter and target were represented by live aircraft and the missile by a simulator. ADS techniques were used to link two live F-16 fighter aircraft flying over the Eglin Gulf Test Range to the AMRAAM AIM-120 hardware-in-the-loop (HWIL) simulation facility at Eglin. In order to successfully integrate these assets for a near real-time test, the JADS team learned several lessons during the risk reduction and test execution phases. The lessons highlighted here concern test control aspects, computer processing, and telemetry issues. Control of a distributed test dealt with tactical aircraft control, scenario and data collection decisions, collocation of critical project personnel, and voice communications. Computer processing lessons dealt with simulated GPS data, pre-processing live GPS data from several aircraft pods, creation of an aircraft to HWIL-missile interface, and contingency planning for real-time malfunctions. Telemetry issues concerned aircraft and terrain shielding, and an implementation to handle random sensor dropouts.

These lessons would be applicable for other projects when coupling live and virtual assets for evaluation of fire control radars or precision guided munitions. Many lessons on control and processing also apply to simulation tests which link distributed facilities.

1. Background for Using Advanced Distributed Simulation

Testing of aircraft and missile systems has evolved into a combination of mutually supportive test events, such as open air flight tests, installed system tests, hardware-in-the-loop (HWIL) evaluations, and digital simulations. Each event would provide some insight for different objectives or measures of effectiveness. Their data and results would support predictions of performance for the next phase of testing, but for the most part, these events have been independent of each other.

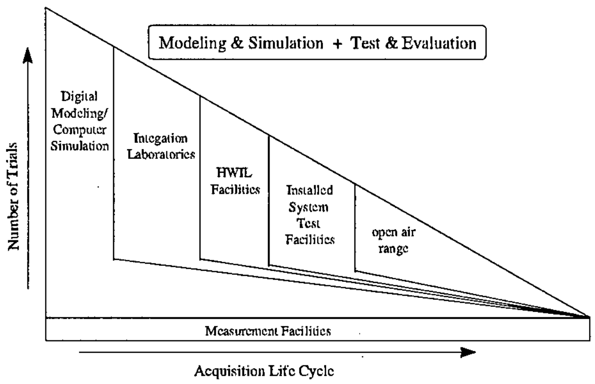

Figure 1.1 T&E Measurement Facilities
(see reference [2])

In the last decade, computer processing speed has increased drastically, and technology for connecting Local Area Networks (LANs) into Wide Area Networks (WANs) has become readily available. In an effort to utilize these advances, the testing community is investigating a new tool to enhance test and evaluation (T&E) realism and productivity, while possibly tying together some test events in a distributed network.

The JADS Joint Test Force (JTF) was chartered to investigate the utility of ADS technologies in support of Developmental Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E). (see reference [3]) The JTF has been investigating three representative slices of the T&E spectrum. The System Integration Test (SIT) has conducted two air-to-air missile phases, while the End-to-End (ETE) team will explore ADS utility for Command, Control, Communication, Computers and Intelligence (C4I), and the Electronic Warfare (EW) team will investigate distributed EW testing. (reference [1])

1.1 Overview of the SIT Live Fly Phase

As stated in the abstract, the purpose of the SIT is to evaluate the utility of using ADS to support cost-effective testing of an integrated missile weapon/ launch aircraft system in an operationally realistic scenario. The Live Fly Phase (LFP) combined an open-air flight test aspect (using two F-16 aircraft over the Eglin Gulf Test Range) with an HWIL facility (an AIM-120 Missile Simulation Laboratory (MISILAB) also at Eglin). These systems were chosen because of their high-technology, well instrumented, and readily available test platforms, which when linked together, are representative of a wide class of fighter aircraft with precision guided munitions.

ADS networking could benefit other projects which evaluate the effectiveness of fire control radars interfaced with air-to-air, surface-to-air, and air-to-ground missiles.

1.2 Aircraft Data

In the LFP, a single F-16 shooter acquired and tracked a single F-16 target. The shooter aircraft carried an instrumented pod which simulated an AIM-120 missile. Each aircraft also carried two instrumented Global Positioning System (GPS) pods (which were the four-channel prototype RAJPO HDIS models with real-time transmitters). Both the aircraft and the pods transmitted data to the ground in real-time, where telemetry

(TM) antennas on the Eglin coastline would receive and pass the data through to the Central Control Facility (CCF). This data flow is shown on the upper portion of Figure 1.2 (on next page).

1.3 CCF Processing

The CCF received and processed several sources of data.

Each aircraft sent data from its Inertial Navigation System (INS) at a 50 Hertz rate (i.e., 50 updates per second), as well as its altimeter and weapons select TM data. The two GPS pods on each aircraft telemetered their raw receiver measurements in a 1-8-1 mode (i.e., 1 navigation solution message, 8 pseudorange measurements, and 1 status message). Therefore, the 4 GPS pods transmitted 10 Hz data apiece. Meanwhile, the CCF also processed GPS ground reference receiver measurements (from atop their building) in order to differentially correct the data from the dynamically moving aircraft pods. The standard operating procedure for the Eglin range also mandated the processing of FPS-16 ground tracking radars, which sent azimuth, elevation, and range measurements on each aircraft to the CCF at a 10 Hz rate. The CCF pre-processed these sensor data through different real-time computers, mostly 1980's vintage Digital Equipment Corp VAX mainframes.

These computers sent the Time Space Position Information (TSPI) through to the TSPI Data Processor (TDP). This TDP combined the sources of INS, GPS, and FPS-16 data into a time-correlated entity state solution for each aircraft.

Meanwhile, on a separate TM data frequency from the TSPI, the CCF also processed the airborne missile pod data. The missile TM stream was processed, and the data were time-stamped (based on the missile clock counter) to an IRIG-B time standard.

1.4 ADS Conversion and Interface

Now in order for all this instrumented, open-air range data to work with any simulation language, it had to be converted into a standardized message format. For this ADS test, JADS chose to use Distributed Interactive Simulation (DIS) Protocol Data Units (PDUs). Both the missile data and the TDP solution data then were processed through a "network interface unit"; this took the range data and converted it into DIS PDUs. This conversion process took place in a Digital Equipment Corp. Alpha 600 machine in the CCF, and was deconverted in another Alpha machine in the MISILAB (shown in the center of Figure 1.2).

1.5 MISILAB Simulation Processing

After the MISILAB Alpha received the DIS PDUs, that network interface unit converted the message into the format used by the AMRAAM HWIL simulation. It also resynchronized the shooter and target data, and interpolated the data up to the 600 Hz frame rate used by the simulation.

The MISILAB then pre-processed and recorded the data out of the Alpha and into different mainframes. The MISILAB split off the live feed from the target aircraft to an anechoic chamber, where 22 antenna horns would emulate the target position and radio frequency (RF) return signal strength. The live feed for the shooter data was fed to the Gould master control computer; that calculated a relative position and velocity from the appropriate missile launch station to the target aircraft.

In the past, the HWIL missile used pre-recorded data files for its missile umbilical and rear data link (RDL) guidance messages. Now in order to process a near real-time ADS stream, the MISILAB had to acquire a special interface unit. Hughes Aircraft Corp. developed it, and called it the Advanced Aircraft Simulation Interface (AASI). The AASI controlled the AMRAAM sequence by synchronizing the missile data to the aircraft TSPI data when it arrived at the HWIL input ports, then injected the data in lockstep with the missile simulation.

1.6 Overview of Lessons Learned

All of this background information sets the stage for the topic of this paper: lessons learned executing an ADS test. In order to successfully integrate these assets for a near real-time test, the JADS team learned several lessons during the risk reduction and test execution phases. The lessons highlighted here concern test control aspects, computer processing, and telemetry issues.

Control of a distributed test dealt with tactical aircraft control, scenario and data collection decisions, collocation of critical project personnel, voice communications, and contingency planning for real-time malfunctions. Computer processing lessons dealt with simulated GPS data, pre-processing live GPS data from several aircraft pods, and creation of an aircraft to HWIL-missile interface. Telemetry issues concerned aircraft and terrain shielding, and an implementation to handle random sensor dropouts.

2. Lessons Learned in Test Control

2.1 Tactical Aircraft Control

Tactical control of Eglin aircraft had to be performed at the Eglin Central Control Facility, which proved to be the optimal location for other key project controllers and directors. This was significant because the original concept for the SIT was to link geographically distributed nodes at different test ranges. In the original concept, JADS explored the possibility of controlling the test from a remote site, e.g., either one of the ranges or from a third, neutral site. However, upon planning, there became a distinction between tactical control of live aircraft, and scenario control of test events. The test range inexorably maintained tactical control of their aircraft over their airspace. Further, early simulation tests found a 2-3 second delay in displaying the aircraft trajectories at a remote site; these early findings quashed any aircraft control alternatives because of safety concerns. The real lesson was that the range insisted on control of their aircraft, so the ADS implementation resulted in aircraft control from the range, not at a distributed site.

2.2 Project and Scenario Control

The second issue was where to locate project decision makers to control the scenarios and test events. The lesson was that getting a full suite of monitors and communications back to our project headquarters was impractical, so project control was performed at the test range. During early risk reduction tests, it became apparent that when handling developmental problems, there was much more discussion that was never transmitted via radio links. Much troubleshooting was still communicated face-to-face, or over local intercom, or via direct phone line. Even with some display monitors, personnel at remote sites would often hear about problems late, often with only partial explanations. Therefore, in order to be part of the decision making process, the test director had to be collocated with the instrumentation controller and the range aircraft controller. The CCF was the necessary choice to be centrally located with the critical personnel, all communication networks, and with the majority of system displays. This project control worked adequately, but could still be improved with more communication (see next paragraph).

2.3 Voice Communication Networks

Upwards of 30 distributed people necessitated the use of 3 voice communication networks, and a 4th network could have further aided decisionmaking. See Figure 2.3 for a communications plan diagram. The pilots and aircraft controllers necessarily used a UHF radio link, and no other personnel transmitted on that link. Another network linked the CCF and instrumentation nodes on a test range intercom system. In order to maintain communication discipline, only 6 people actively transmitted on this intercom, while all other personnel listened on speakers and interjected when necessary. A 3rd network linked only the JADS logger and wide area network personnel via teleconference on a DSN phone line. This DSN line was barely adequate for a 5-person conference call, as we never got the full 10 person capability, somebody would randomly get cut off of DSN during the 2-hour mission, and not all people could hear the other people adquately (usually one person had to repeat run calls, and we often bridged two conference lines).

Additionally, in post-mission discussions, project personnel agreed that a 4th voice network just for the 4 main SIT team members would have further aided decision making. Each of the members observed some critical part of the network puzzle, and in a wide area network, no one person had all of the information displayed in front of him. Therefore, a 4th phone or intercom network would have helped to provide more timely inputs between project personnel, and help to make quicker decisions about unforeseen problems.

2.4 Contingency Planning

Real-time operation required more contingency planning to quickly decide on alternatives. A great benefit for using an ADS linked network was having several "analysts in-the-loop" during the real-time mission. The test director had to make timely decisions between the aircraft passes in order to affect the outcome or productivity of the mission. Initially, a small list of Go / No Go criteria was made before the first live flight. This list included criteria on key aircraft components (INS, shooter radar, radios, etc), and on aircraft pods or ground systems. As the experience level increased after risk reduction missions, this list was expanded to include alternatives in case of failures or degraded assets. These alternatives included changing aircraft profiles, timimg of maneuvers, modes of the GPS pods, computer processor swapouts, etc. Having this contingency plan spelled out in advance truly helped the project director make rapid, well-informed decisions to get the most productive use out of the remaining mission time.

3. Lessons Learned in Computer Processing

3.1 Full Linked Ground Simulation not Maturely Developed Yet

The linked configuration of the Eglin PRIMES facility to the CCF was not adequate to accomplish our ground rehearsal objectives. PRIMES is a very good Installed System Test Facility (ISTF) when used in standalone mode, but there were some software interface problems in the ADS linked configuration. Specifically, the simulated TSPI inputs were not adequate to properly load the TSPI Data Processor (TDP), which necessitated the use of live aircraft for future integration missions.

The three TSPI sources were to be received and pre-processed in the CCF, then combined in the TDP. However, the simulated GPS data were either rejected or had very inaccurate residual errors. The simulated GPS configuration also cannot provide differential corrections, nor use the real-time satellite ephemeris data; therefore, only the pre-recorded raw GPS measurements from almanac data were used for a GPS solution. (Unresolved interface issues narrow down to the exact satellite almanac data used by PRIMES, the origin used by the GPS pods, and a probable difference in satellite modeling used by PRIMES and the TDP.) The simulated INS data was somewhat inaccurate during turns, and initially had problems with a time bias and a roll problem.

Although the vast majority of linking issues, data formats and aircraft connections are fully developed, these few TSPI interface problems need to be resolved between PRIMES and the CCF. Then, this will provide a valid and useful ISTF to HWIL simulation.

3.2 Limited Rate for GPS Processing

The VAX mainframe computers at the CCF could not process the full rate of GPS data from 4 pods, so the resulting lesson was that a degraded mode of operation was implemented to get GPS inputs. As explained earlier, each of the 4 GPS pods transmitted 10 data records per second to the CCF, and the CCF also processed ground reference measurements in order to make differential corrections. The JADS team was expecting 40 Hz input to give a 40 Hz processed output; however, in practice, only 12-15 Hz was achieved (about 3-4 Hz from each pod). The limiting factor turned out to be a computer throughput problem of the Multiple-object Tracking and Control System (MTACS). The MTACS is a network of VAX mainframe computers from the 1980's which performs GPS processing and other multi-lateration functions.

In order to workaround this processing limitation, the JADS team configured the GPS pods so that only one pod per aircraft would transmit its 10 Hz data, and the other GPS pod onboard was in standby mode. This configuration allowed the MTACS to usually provide 7-8 Hz GPS data from each aircraft. This rate proved adequate for the SIT implementation when it was combined with other TSPI sensors (discussed later in section 4.2).

3.3 Special Missile Interface Unit Required

A special purpose interface computer was necessary to link the aircraft telemetry to the HWIL missile in order to achieve near real-time processing. During test concept meetings, development of this unique asset was not planned for, so the lesson was that JADS had to slide the schedule and budget for this interface computer. This interface was needed to provide the HWIL missile with a real-time feed of initial targeting information and midcourse cueing updates.

As stated earlier, Hughes built the Advanced Aircraft Simulation Interface (AASI) to accept near real-time umbilical and rear data link information, and synchronize the launch event to the aircraft TSPI; see reference [4]. The AASI used a 133 MHz, Pentium-based computer, and only injected a necessary subset of the AMRAAM missile parameters. This development required an Interface Control Document (ICD) for these parameters between the CCF and the MISILAB, and because of funding and scheduling constraints, the AASI was not available before January, 1997. Now, a few AASI units are available and verified to accept the AMRAAM telemetry data and satisfy the near real-time run requirement for ADS.

4. Lessons Learned in Telemetry Issues

4.1 Telemetry Dropouts Required Workarounds

Early testing showed that even short INS telemetry dropouts or time stamping problems caused aborted or invalid passes; workarounds had to be made to obtain better telemetry reception. The lesson was that the aircraft configuration and range airspace usage were restricted in order to receive consistent telemetry.

During the first two live flight risk reduction missions, the telemetry or time problems directly caused 13 invalid passes out of the 28 total passes attempted. This caused a few workarounds and corrective actions to get better TM reception.

First, the two wing station fuel tanks on each F-16 were removed in favor of one centerline fuel tank; even this tank caused unacceptable shielding, so it was removed in favor of a "clean jet". This configuration provided better aircraft telemetry from both the INS and the simulated missile pod, but required an airborne refueling after about 45 minutes.

Secondly, analysis revealed that east-west profiles (which are parallel with the Eglin coastline) provided better TM reception than either north-south or diagonal profiles.

Third, the aircraft were flown at higher altitudes than originally desired. In order to achieve approximately line-of-sight TM reception, the aircraft were flown above 18,000 feet when 20-30 nautical miles offshore, and above 21,000 feet when 35-45 nautical miles offshore. This improved air to ground TM reception, and also helped the FPS-16 radars to consistently track the aircraft (the FPS-16s reduce multipath effects when the aircraft are over 3.5° above their horizon). (Aside: note that using an airborne TM relay platform, such as an E-9 aircraft, was out of scope for the JADS effort, but could help other projects which have low altitude scenarios.)

4.2 Merging Several TSPI Sources Advantageous

Eglin developed a TSPI Data Processor (TDP) to merge several TSPI inputs in near real-time. This robust implementation coasted through most dropouts to allow a more consistent (and ultimately accurate) solution of entity state data.

The TDP took advantage of real-time aircraft telemetry and availability of real-time GPS pods in order to calculate more accurate kinematic estimates. In the past, it was common to use a single source of TSPI on the Eglin range. In general, the FPS-16 ground tracking radars can be very inconsistent, especially in altitude tracking, and thus be somewhat inaccurate. When JADS and Dynetics evaluated the original TSPI from a live shot, the FPS-16s appeared to have an altitude error up to 100's of meters. Therefore, a more consistent and accurate TSPI solution was needed to drive the HWIL simulation.

The resulting lesson was that the TSPI Data Processor could provide a much better trajectory estimate by combining several sensor inputs. By merging the aircraft INS, GPS, and FPS-16 data, "the TDP solutions were estimated to be accurate within 1-3 m in position and 1 m/s in velocity". (reference [1]) Further, even though JADS experienced between 40-60% dropouts from the GPS telemetry data, the INS and radar data were available over 99% of the time. Therefore, "the periodic GPS dropouts did not significantly degrade the accuracy of the position solution, because the TDP used the accurate INS data to propagate the solution between GPS updates". (reference [1]) These results are consistent with the findings of Ball Systems Engineering Division in their TDP Final Technical Report from July 1994.

Therefore, by improving the TSPI accuracy from approximately 12 m to within 3 m, it allows the measurement tool to be much more accurate (by an order of magnitude) than a typical system under test. The impact of this improved accuracy allows a missile or radar analyst to make unprecedented, verified comparisons of missile seeker performance or aircraft radar tracking performance.

5. References

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Author Biographies

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MAJOR STEVE STURGEON, US Army, is the Team Leader for the System Integration Test at the JADS Joint Test Force, Albuquerque, NM. His duties were directing the test activities and managing the JADS and Eglin team members throughout all phases of development and test execution.

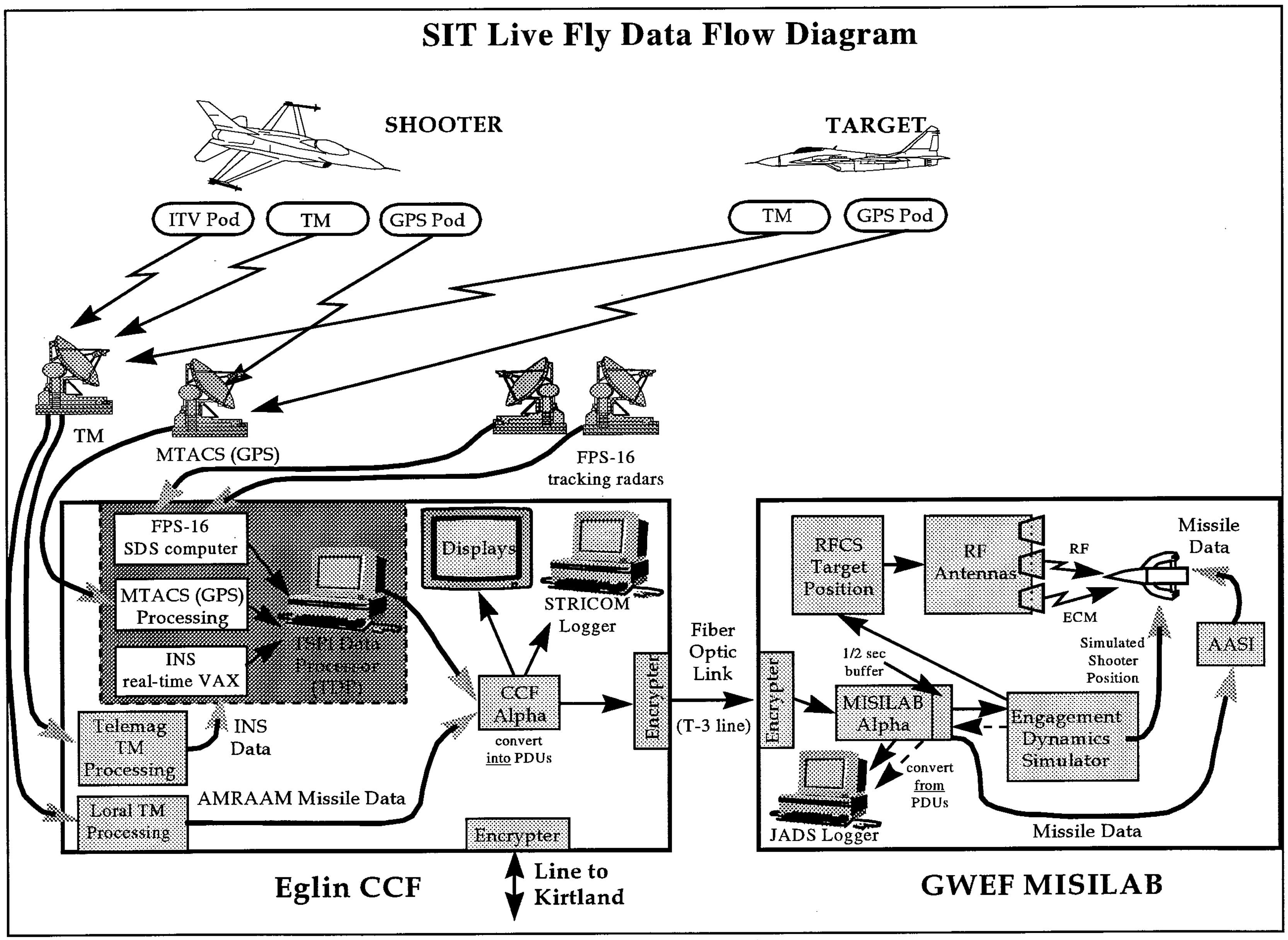

Figure 1.2 SIT Live Fly Data Flow Diagram

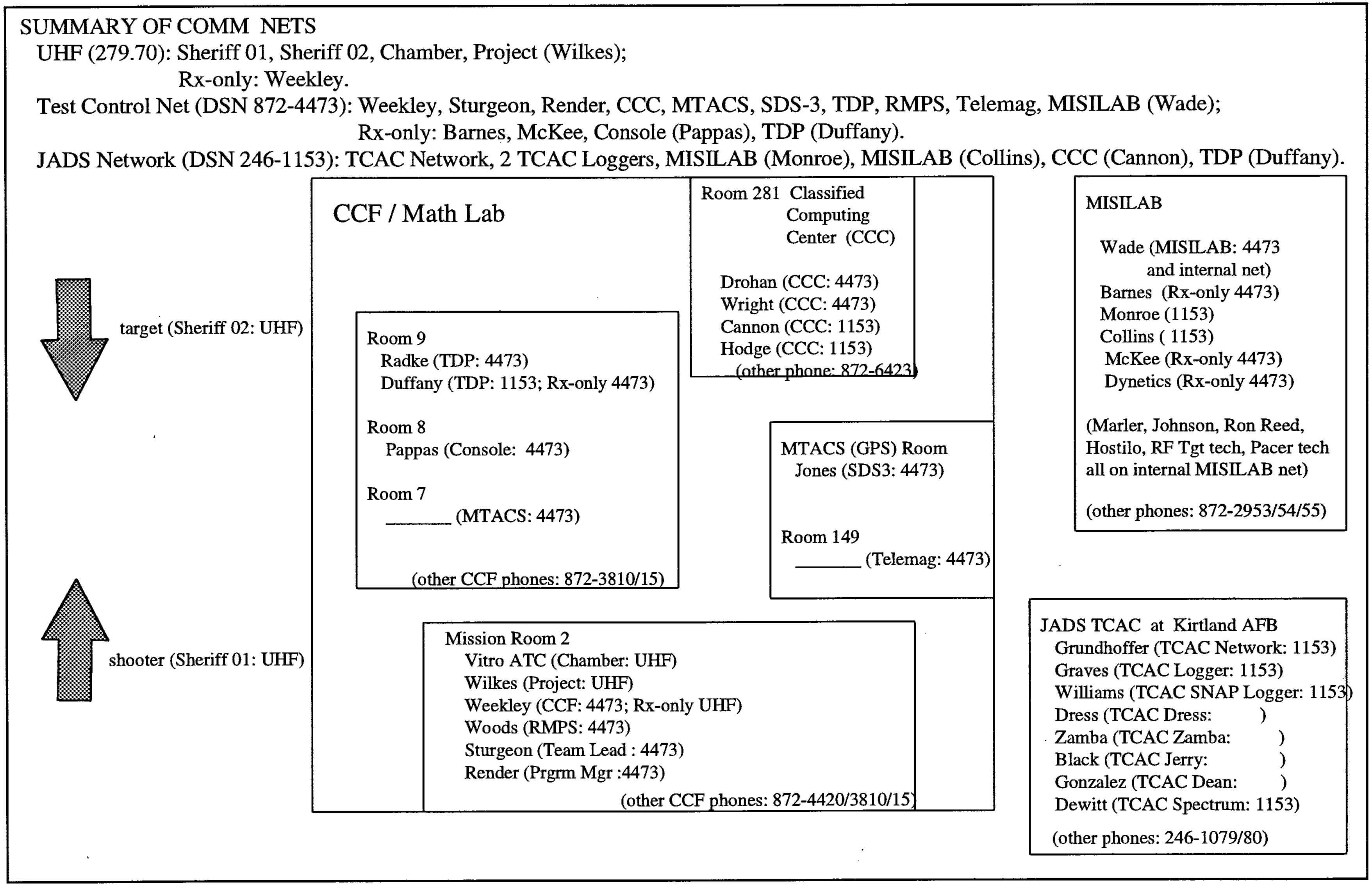

Figure 2.3 SIT Communications Plan Diagram

LESSONS LEARNED IN BUILDING AN ADS INFRASTRUCTURE

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Building an Advanced Distributed Simulation (ADS) is an extremely complex process for which no guidelines currently exist. The Modeling and Simulation (M&S) community is rapidly gaining insight into the ADS structure building process through experience in planning, organizing, and conducting several large ADS exercises. Experiences have ranged from "very good" to "very bad" with no one area of the ADS building process escaping serious pitfalls. This paper attempts to summarize the experiences encountered by TACCSF as a participant in several ADS projects. Planning is the key to success and forms the basis upon which a successful ADS must be built. Specific areas of the ADS process covered by this paper are: (1) planning, (2) system engineering, (3) connectivity, (4) communications security (COMSEC), (5) scenario development, and (6) data collection and analysis. The "lessons learned" discussed will aid the ADS planner of the future avoid the well traveled pitfalls discovered by past travelers.

Lessons Learned
in
Building ADS Infrastructure

INTRODUCTION

Building an Advanced Distributed Simulation (ADS) infrastructure is an extremely complex process. There are very few guidelines and most territory is uncharted water for any organization wanting to contribute to joint ADS capabilities. This fact must be emphasized; no one organization "builds" the ADS infrastructure, rather they contribute. Today, we want to share insights we have gained through **experience** with multiple ADS ventures (listed below).

- Joint Theater Missile Defense Simulation Network (JTMDSN)
- Joint Environment for Testing, Training, and Analysis (JETTA)
- Theater Missile Defense Wargames (TMD WG)
- Joint Air Defense Operations/Joint Engagement Zone (JADO/JEZ)
- Advanced Distributed Simulation Training Exercises (ADSTE)
- War Breaker (WB)
- Roving Sands 95
- Air Defense Initiative (ADI)

Our hope is that where we have approached the challenges with brute force, ingenuity, and even ignorance, others might benefit from our experience. Together, we can push the ADS infrastructure forward, while avoiding known pitfalls and fostering teamwork, to overcome the abundance of obstacles awaiting discovery.

PLANNING

Planning is the prerequisite to all else. It determines if and to what extent you succeed in building and using a distributed network. Figure 1 illustrates our approach. The five major areas of System Engineering, Connectivity, COMSEC, Scenario Development, and Analysis, capture 90% of the ADS picture which must be understood before preceding. **These five areas represent concurrent, interrelated activities, not sequential, discrete tasks.** When orchestrated toward a common objective, schedule, and budget, effective enhancements to testing and training capabilities can be realized.

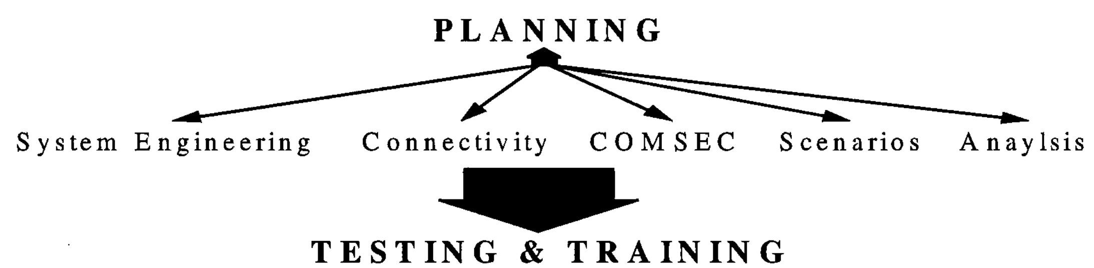

Figure 1

Planning is an investment in success. It must pervade all aspects of a project, address coordination of all project elements, be given adequate time, and must continue until completion of a project. To short-change planning results in direct cost increases, longer timelines, and a negative work environment governed by pressure, frustration, and confusion ...producing less than optimum results. The initial investment in project planning sets the direction and pace. Continued planning maintains the direction and ensures greater accuracy.

Two rules govern effective planning. The first is the one most projects willingly sacrifice and inevitably pay for it later - planning takes time. The old adage - "you can pay me now, or you can pay me later" applies universally to ADS. Our experience is that for a multi-organization distributed network, one year of extensive planning, upfront, is an excellent rule of thumb (ROT). This is not pragmatism, it is reality. We've violated this rule numerous times to meet customer timeline demands. Results vary from pulling out a last minute miracle to delays to total non-delivery. But when there is dedicated planning, the results do not vary - 100% success. A good example of this is the Combat ID project with Wright Labs (WL) and Electronic Support Center (ESC). From requirements to scenarios to technical development to test plan to operational relevancy, we formed teams that planned and executed systematically.

The second ROT which relates exponentially to the number of distributed participants is **honesty**. All participants must be honest and candid about why they are participating on the distributed network, and what they expect to gain from that participation. Experience has taught us - most customers don't know exactly what ADS can or can't provide, and/or aren't totally honest in revealing their agenda. That combination clouds and misdirects all planning efforts. Additionally, facilities accurately representing their capabilities and estimates of feasible development are essential to success. Without this basic trust, teamwork is impossible ,and thus connectivity of distributed simulations will be superficial.

The following discussion presents applications of the *planning philosophy*:

- Planning is bounded and guided by one thing - ***OBJECTIVES***. What are they? Is this a demonstration? A study? What are the goals? What are the Critical Operational Issues (COIs)? Determining objectives is a sponsor/user responsibility, but usually requires contribution from the entire ADS team.

- Establish working groups (WGs) for the major functional project areas. Functional experts, empowered to make decisions, must focus their group's taskings while ensuring information transfer between groups. As a minimum, there should be working groups to cover management (POCs), scenarios, test planning (data collection/analysis), systems development/integration, and concept of operations (CONOPs)/rules of engagement (ROE).

- For WGs to function as cohesive forces there must be structure. To borrow from Sun Tzu - *unity of command is essential.* One person with clear authority and responsibility must lead and direct each organization's single POC towards the commonly agreed upon objectives. We refer to that person as the project hammer.

- **Don't allow development to begin until requirements are definitized in writing and understood by those who have to meet them.** Distributed requirements complicate this point, but do not preclude realizing it . It cannot be emphasized enough; disciplined leadership and responsibility at each organization working toward fulfilling what has been agreed upon in writing is a basic requirement. This is potentially the toughest ADS component to ensure and enforce.

- Establish cut-off dates for all major tasks. Creating an integrated schedule is not sufficient; it must be enforced. Requirements creep or excessive software "tweaking" is always present and must be dealt with.

- Establish a configuration control management mechanism that correlates to the schedule. The challenge is that all organizations must adhere to the same rules 100% of the time - suggest it be in signed written form.

- POCs must be decision capable; workers must be committed to tackling the hard problems; and growing team depth in areas of critical expertise must be inherent to the plan. Single points of failure are unacceptable because good planning can prevent it.

In summary, plan up-front, plan continually, plan for success, plan for failure, and then plan some more.

SYSTEM ENGINEERING

System engineering in ADS is mainly concerned with system interfaces, specifically at the intersite level. The following emphasizes the basics underlying solid distributed system engineering.

Time: For any distributed exercise, it **always** takes more time for integration than is expected. Distributed exercises have an inherently high number of variables, and they always have some that you can't predict. A good ROT is pad your scheduled integration time by 50%. Test time must be identified to occur early and often. Connectivity testing <u>must take a building block approach</u>, i.e., adding one site at a time. It is the only way to isolate problems and control the variables.

Communication: Face-to-face Technical Interchange Meetings (TIMs) are far more beneficial than either Video Teleconferences (VTCs) or phone calls. The key is use any and all communication vehicles available, but show preference to the most effective means, despite costs. The key is to coordinate the system engineering activities of all participants. Use of the video conference capabilities on development terminals, such as the Silicon Graphics Indy system, is a growing communications option.

Requirements: When the initial requirements for a distributed exercise are laid out, they are usually very loose and subject to interpretation. This is in direct conflict with developer's need at each site to truly understand the technical tasks before tackling them. The requirements definition process is customer initiated, and project team refined - it should be a <u>technical manifestation of the operational objectives</u>. The following are a few ROT to the process:

- Describe the requirements for a specific node/system, rather than to simply say a node is needed. It is impossible for the project "hammer" to know the level of detail and the capabilities of each simulation in the exercise; therefore, each site POC should be responsible for providing a detailed set of written requirements. These must be feasible - only the site can make that determination. Non-delivery of a capability has a domino effect on ADS exercises. The customer's objectives and budget determine the fidelity of the solutions (75% solution? 100% solution?).

- Once each site has honestly defined its model capability, then the team must merge these into a cohesive technical plan which satisfies the objectives. The result should be clear agreement on which simulations are to be used, what development is required, and what the criteria are for adding simulations during the development phase. *Never add simulations or improvements once integration testing begins!!*

- Experience teaches that requirements continue to grow as a project progresses. Some of this growth is necessary for refinement and clarification, but often it is fueled by a site's hidden agenda or undisciplined customer. It is a natural desire for a site to show off new work and for a customer to get all he can for his money, but uncontrolled requirements creep, i.e., that which occurs without the hammer's approval, <u>will</u> result in constant increases and schedule delays. Be aware - fringe elements often create havoc in an otherwise well-structured exercise! <u>Distributed discipline is gained by evaluating the "perceived new" requirements against the original written requirements, and fully coordinating any decisions which result from that evaluation</u>.

DIS implementation: There are varying degrees and approaches to DIS implementation which equate to integration testing land mines . It is critical that the project team <u>develop a formal DIS guidance document</u> for two reasons. First, to establish a distributed DIS baseline, i.e., 2.0.3, or 2.0.4, and prohibit any hybrid or upgrade in progress because the effects are unpredictable. Second, detail which PDUs will be used in the exercise and cross-check each site's implementation against the DIS standard. This also provides a mechanism to work issues where DIS PDU standards don't exist.

Another problem area for ADS is non-standard database usage; for example, radar cross section (RCS) data. Since DIS does not transmit RCS data, each site is required to develop its own parametric data set for the cross section of an entity. The values of this type of data are almost never consistent between sites, which equates to distributed inconsistencies - whose version is correct? To avoid invalidating test results, the team should review the requirements to determine if use of the inconsistent data will have any negative impact. If it does, then the team must agree on a common data implementation; if not, the site is cleared to run its own version with everybody's blessing.

Using a common DIS gateway at all of the sites on the network is one way we've solved many ADS system engineering problems. This approach was taken for the Joint Theater Missile Defense Simulation Network (JTMDSN) and the Joint Evaluation for Training, Testing, and Analysis (JETTA) programs. Simplifying the problem this way is not always cost effective because it requires that all of the sites integrate their models into a single environment generator (EG).

CONNECTIVITY

Connectivity refers to the physical linking of individual simulation sites/facilities which make up the ADS architecture. Common means of linking include telephone lines (T-1 and T-3 lines), satellites, Defense Simulation Internet (DSI), and common STU-III telephones. Although several protocols used to transmit information are in use today, the DIS protocol is rapidly being established as the standard. The following is a list of considerations we have developed:

- Lead times to establish T-1 links, encryption procedures (KG-194), DSI Network, security Memorandum of Agreements (MOAs), and supporting link requirements usually require a minimum of 90 days, but may require as much as six months. Hardware requirements (interfaces, routers, etc.) will require at least four months from date of request to actual hardware in hand. Security procedures/MOAs are required by government directive. Suffice to say, these are total show-stoppers that must be addressed during initial ADS planning.

- System Loading: Each type of physical link is capable of transmitting data at a specific rate. As the rate increases, so does cost. Cost savings can be quite substantial if the time is taken up front to match load requirements with links available (T-1, T-3, STU-III, normal phone line). Figure 2 depicts a low-cost configuration used during Roving Sands to link low-bandwidth users. Additional consideration is that some KG devices serve as system choke-points. Proven bench marks indicate BReeze boxes can handle 50 dynamic entities, DSI (NESS) - currently 100, SATCOM - 400, and T-1s - 2000.

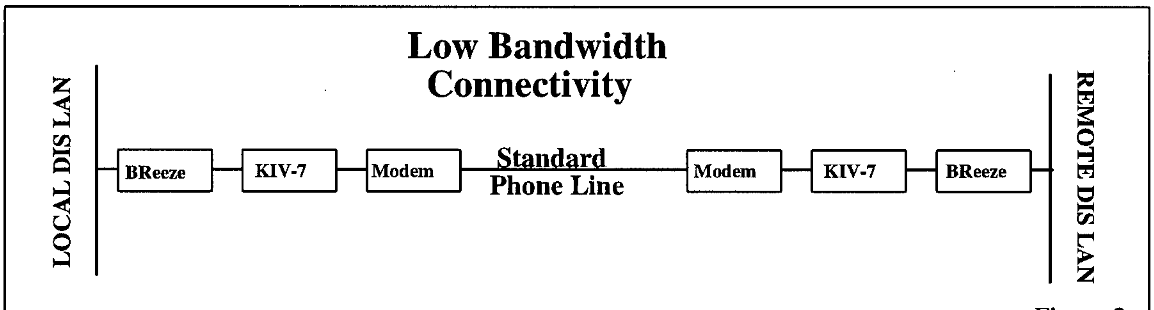

Figure 2

- Equipment: Purchase and use prebuilt, tested equipment (including connecting cables) whenever possible. Untested, built-on-the-fly parts will definitely cause major problems.

- DIS limitations: DIS Protocol Data Units (PDUs) are multicast in packets and the technology to route these packets does not exist. Bridging is the only capability currently available to connect remote sites, i.e., any site putting PDUs on the network's DIS LAN is effectively broadcasting to the world.

Ineffective DIS PDUs can quickly flood the network. Additionally, multi-project users of a single DIS network often unknowing impact each other. Already, there is a need for coordinated scheduling of ADS networks.

COMSEC

Communications Security (COMSEC) is not widely understood or appreciated by the majority of persons involved in developing an ADS infrastructure. Mixing of classified and unclassified information must be avoided. If a site on the network is transmitting classified data relating to a model, a scenario, CONOPs, ROEs, etc., all participants must be practicing COMSEC procedures compatible with the highest Security classification of the material involved. The consequences of ignoring COMSEC are very serious - a breach of National Security may certainly occur; or closer to home, your organization may be shut down. The following are the COMSEC issues requiring early and vigilant attention:

- An MOA defining COMSEC procedures to be practiced by all participants during an ADS project is a government requirement. An MOA between new sites typically requires at least 90 days to negotiate, sign, and be approved.

- The equipment and supporting material (such as keys and establishing accounts) required to implement COMSEC will require a minimum of 60 days from request to actual material delivery.

- Multi-level security filters require National Security Agency (NSA) approval. This entails a three to six month process, acquiring NSA approved system and certification.

SCENARIO DEVELOPMENT

The scenario is a key element vital to the success of an ADS project. The scenario working group must continuously communicate with all other participants (working groups) to insure the scenario is consistent with the parameters defining the ADS exercise. The following list identifies several areas which must be addressed during scenario development.

- The Scenario Group must remain cognizant of test objectives and COIs and build the scenario to provide necessary situations and events. A scenario that does not address the objective and COIs is doomed for failure.
- Scenario specific requirements (theater of operations, timeframe, platforms, tactics, etc.) must be well-defined upfront with fewer and fewer changes as the project progresses. These needs should take into consideration the strengths and limitations of the total architecture and the risks associated with new development.

- The Scenario Group should be established with representatives from sites, to include the operational customer. This group will establish and define scenario elements required to meet test objectives and requirements. Members should also be very familiar with the unique capabilities at their own site, and how these will play in the system architecture. Division of tasks should allow each site to contribute to the overall scenario. Connectivity and communications between exercise participants and models should be set up early and exercised regularly.

- As accurately as possible, the scenario should present a realistic set of conditions to the test participants; the scenario should strike a balance between triviality and robustness. In addition to developing the exercise's operational flavor, the Scenario Group should, during the course of scenario reviews, be cautious to remove as many non-real world situations as possible. The group should be cognizant of "sim-isms," which could affect test results or user credibility in the scenario. A Crew Aid discussing CONOPS, ROE, specific airspace, special instructions, and a connectivity diagram is key for all operators. Subsets of the actual exercise should be tested with crews similar to those who will participate in the final test to help identify unrealistic conditions or other items the test designers may have overlooked. These pre-trial runs should exercise as much of the system architecture as is available, to include data collection and processing for the final report.

- All sites contributing to the scenario must agree on a date when the scenario will be frozen. This date should be established far enough in advance of the experiment to allow for adequate testing, but not so far ahead that the system is still immature. Changes, if allowed, should be thoroughly tested for adverse impacts on the full system. Strict configuration management should be enforced to adequately understand the impacts at each site; regression testing should be performed in a logical order to isolate which site has corrupted the network.

- "Reality checks" should be conducted frequently to ensure realism, adequate addressing of test objectives, and the elimination of "sim-isms." The timeliness of these evaluations cannot be overemphasized: as soon as the system matures, testing should begin. Testing should exercise all subsystems to be used during the actual test; **"train like you plan to test."**

DATA COLLECTION AND ANALYSIS

DIS PDUs provide a common source of data collection for all ADS network sites, which complements any local data collection performed at the various models and simulators. Logging of PDUs with such tools as the STRICOM Logger is most useful for system debug and integration testing. The TACCSF Trial Event Generator (TEG), in addition, provides selection of PDUs with analytic interest, on-line merging of operator and system perceived events with entity truth data, and efficient storage of structured data records for analysis. These TEG-produced Trial Events can be processed by a commercial analytic software package called PV WAVE or can be loaded directly into a spreadsheet to compute test measures or plot timelines of critical operational events and network performance measures. Analytic software is being developed which can process these Trial Events and display mission performance measures in near realtime. The most challenging aspect of ADS data collection and analysis is the generation of data collection PDUs by participating models and simulators in order to capture key tactical events. Key entity truth events are already being captured by means of Entity State, Fire, and Detonate PDUs. A timeline analysis for Theater Ballistic Missile (TBM) attack operations could be produced from the following data collection sequence, for example:

EVENT	DATA SOURCE	PDU
Create TEL	TEL	Entity State
TBM launch	TEL	Fire
TBM detect	DSP, TPS-75, or Cobra Ball	Event Report
Launch Point Est.	DSP, Correlator, or Cobra Ball	Event Report
Joint STARS tasked	CRC or AOC	Manual
Allocate AWACS	CRC or AOC	Manual
Commit F-15E	AWACS	Manual
TEL moves	TEL	Entity State
Joint STARS update	Joint STARS	Manual
F-15E detect TEL	F-15E	Manual
EVENT	DATA SOURCE	PDU
F-15E engage TEL	F-15E	Fire
Weapon impact	F-15E	Detonate
TEL destroyed	TEL	Entity Stage

In addition to expanded data generation from network participants, other requirements for effective DIS PDU data collection and analysis include:

- Universal implementation of START/STOP PDUs to assist in exercise control and synchronization across sites using standard Global Positioning System (GPS) clock time.

- Improved enumeration management.

- Replace manual data collection with digital data collection wherever possible.

- Unified operational debriefs for geographically separated sites.

-Time stamps for Entity State PDUs must allow for values greater than one hour.

CONCLUSION

The number of ADS builders and users is growing rapidly. The age of ADS is here regardless if people or the technology are ready for it. Therefore, the learning curve is steep and, as constructive, virtual, and live environments merge, the grade doesn't show any sign of leveling out. The purpose of this paper is to communicate that the ADS challenges are global and unless there is an open sharing of the good, the bad, and the ugly, the learning curve will remain painfully steep for all. There must be a distributed mindset committed to planning. The project leadership principles, considerations, and common sense reminders provide a starting point to building a functional ADS infrastructure. The challenge is to tackle the issues of system engineering, connectivity, COMSEC, scenario development, data collection, and analysis as a distributed team focused on the project's objectives and equipped with a winning plan.

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