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JADS JT&E

JADS Executive Report on the Utility of Distributed Testing

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1.0 Purpose and Background

1.1 Report Purpose

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) was chartered to determine the utility of distributed testing. We have determined that there is utility, and the purpose of this report is to articulate our findings. This assessment was based on the results and lessons learned from JADS testing along with results from other related efforts. This report is targeted at the program manager and test manager level of responsibility. Detailed information to support the conclusions draw in this report is available in the reports listed in Section 6. For more information see the *JADS Final Report.*

1.2 Background

Distributed testing utilizes advanced distributed simulation (ADS) to link together live, virtual and/or constructive simulations. Live simulations are real players in a real environment. Open air ranges are considered live simulations because according to the Defense Science Board "anything short of war is a simulation." Virtual simulations are real players (or parts of a real player) in a virtual environment. Human-in-the-loop and/or hardware-in-the-loop laboratory facilities are examples of virtual simulations. Constructive models have virtual players in a virtual environment. Modular semi-automated forces (MODSAF), Janus and Suppressor are examples of constructive models. ADS is significantly different than what has historically been referred to as modeling and simulation (M&S) in two important ways. The common paradigm for M&S is constructive models only and does not include live or virtual models. The second significant difference concerns linking together simulations. The conventional view of M&S is for stand-alone simulations. These differences between ADS and conventional M&S are particularly relevant when using ADS to support test and evaluation (T&E). The conventional application of M&S to T&E is to use a stand-alone constructive model to predict system under test (SUT) performance. ADS links together a real (or partially real) system under test to a synthetic test environment created by linking live, virtual, or constructive players and measures system under test performance. The SUT and the test assets in the synthetic test environment can be geographically separated by small or large distances, thus creating a distributed test.

JADS was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation),[1] Office of the Under Secretary of Defense (Acquisition and Technology) in October 1994 to investigate the utility of ADS technologies for support of T&E. The program is Air Force led with Army and Navy participation and is scheduled for completion in March 2000.

JADS directly investigated ADS applications in three slices of the T&E spectrum: the System Integration Test (SIT) explored ADS support of precision guided munitions (PGM) testing; the End-To-End (ETE) Test investigated ADS support for command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) testing; and the Electronic

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[1] This office is now the Deputy Director, Developmental Test and Evaluation.

Warfare (EW) Test examined ADS support for EW testing. JADS also observed, or participated at a modest level in, ADS activities sponsored and conducted by other agencies in an effort to broaden conclusions developed in the three dedicated test areas.

2.0 Supporting Activities and Results

2.1 Utility for Precision Guided Munitions Testing

The SIT investigated the ability of ADS to support air-to-air missile testing. The test included two sequential phases, a Linked Simulators Phase (LSP) and a Live Fly Phase (LFP). Both phases incorporated one-versus-one scenarios based upon profiles flown during live test activities and limited target countermeasure capability.

The LSP distributed architecture incorporated four nodes: the shooter, an F/A-18 manned avionics laboratory at China Lake, California; the target, an F-14 manned avionics laboratory at Point Mugu, California; a hardware-in-the-loop (HWIL) missile laboratory at China Lake that hosted an air intercept missile (AIM)-9M missile; and a test control center initially located at Point Mugu and later relocated to the JADS facility in Albuquerque, New Mexico.

The LFP distributed architecture linked two live F-16 aircraft (a shooter and target) on the Eglin Air Force Base, Florida, Gulf Test Range; the Eglin Central Control Facility; an HWIL missile laboratory at Eglin that hosted an AIM-120 missile; and a test monitoring center at the JADS facility in New Mexico.

2.1.1 System Integration Test Results and Conclusions

Within the narrow confines of the SIT data, our assessment is that the two architectures we employed have utility for support of T&E. The JADS data indicate that activities ranging from parametric analyses to integrated weapons system testing are both practical and cost effective. Our broad conclusions and lessons learned can be summarized as follows.

- For T&E applications, the technology is not at the "plug-and-play" stage. While practical and cost effective in many cases, implementation is more challenging than many people think. Plan for a lot of rehearsals and "fix" time.
- The effects of latency and other ADS-induced errors can often (not always) be mitigated.
- Synchronization is as much a challenge as latency.
- Instrumentation and data management are challenges.
- ADS has great potential as a T&E support tool: It is a valuable addition to the tester's tool kit. ADS will not obviate, but in some cases it may reduce, the need for live testing.
- Our data suggest test savings are possible.

2.1.2 Observations for Precision Guided Munitions T&E

Through a process of inductive reasoning we can transfer some of the SIT-based specifics to the general class of PGM. In the general case, the elements of the SIT architectures are basic to all PGM cases. There are (1) a launch platform or shooter, (2) a PGM, (3) an intended target, (4) an operating environment (to include countermeasures), and (5) a test control center.

The shooter, PGM, and target can be represented in any of the three forms associated with distributed simulation: live, virtual, or constructive. SIT looked at an AIM-9 and an AIM-120. The physical dynamics of the problem are comparable with any class of PGM. The physics associated with detection, tracking, and guidance may differ significantly depending upon bands, techniques, and the operational medium a missile operates in. We do not see a one-for-one transfer of SIT techniques to other tests. Each test has specific requirements, often peculiar to the particular SUT. We do see a transfer of the principles, design processes, and methodologies used in SIT.

Countermeasures were only represented in rudimentary form in the SIT, but we see no technical impediments at the conceptual level to implementing high-fidelity countermeasures in ADS. The devil will be in the details, and costs and technical challenges will be very case specific. Complex environmental details associated with atmospherics, space, oceanography, etc., are more challenging. In the SIT case, the LFP, since it involved flying open air, incorporated real atmospheric effects.

A test control center is a requirement for all testing, distributed or not. Fortunately, the SIT experience suggests that the control center can function from almost anywhere. The inference is that an existing control center somewhere may well meet a specific tester's needs.

The SIT program was budget and schedule constrained. Consequently, there were important aspects of PGM testing which SIT did not explore. From a single shooter perspective, some of these included multiple launches against a single target, single launches against clustered targets, and multiple launches against multiple targets. SIT did not examine few-on-few or many-on-many scenarios. Our expectation, unsupported by hard data, is that few-on-few implementations are possible. The difficulties and costs would be extremely sensitive to the fidelity requirements and the availability of existing facilities, e.g., HWIL facilities or installed systems test facilities.

The SIT results strongly suggest that ADS has good potential for improving PGM testing. The implication is that test planners should consider the technology as a relevant tool for their program until an objective assessment suggests otherwise. Bottom line: Know ADS is there, and assess how, or if, it should be used in a specific program.

2.2 Utility for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Testing

The ETE Test evaluated the utility of ADS to support testing of C4ISR systems. The test used the Joint Surveillance Target Attack Radar System (Joint STARS) as one component of a representative C4ISR system. The ETE Test also evaluated the capability of the JADS Test

Control and Analysis Center (TCAC) to control a distributed test of this type and to remotely monitor and analyze test results.

The ETE Test consisted of four phases. Phase 1 developed or modified the components needed to develop the ADS test environment. Phase 2 used the ADS test environment to evaluate the utility of ADS to support developmental test and evaluation (DT&E) and early operational test and evaluation (OT&E) of a C4ISR system in a laboratory environment. Phase 3 transitioned portions of the architecture to the E-8C aircraft, ensured that the components functioned properly, and checked that the synthetic environment correctly interacted with the aircraft and actual light ground station module (LGSM). Phase 4 evaluated the ability to perform test and evaluation of the E-8C and LGSM in a synthetically enhanced live test environment.

The test concept was to use ADS to supplement the operational environment experienced by the E-8C and LGSM operators. By mixing available live targets with targets generated by a constructive model, a battle array approximating the major systems present in a notional corps area of interest was presented. By constructing a network with nodes representing appropriate command, control, communications, computers and intelligence (C4I) and weapon systems, a more robust cross section of players was available for interaction with the E-8C and LGSM operators.

The TCAC, in Albuquerque, New Mexico, provided test control.

The ETE Test used the Janus 6.88D simulation to generate the entities representing the elements in the rear of a threat force. The U.S. Army Training and Doctrine Command Analysis Center (TRAC) at White Sands Missile Range (WSMR), New Mexico, provided the Janus scenario feed.

Bravo Company, 303d Military Intelligence Battalion represented the LGSM and target analysis cell (TAC). Fire support, in the form of the Advanced Field Artillery Tactical Data System (AFATDS), was represented by soldiers from the 4th Infantry Division (Mechanized).

Communications among these systems employed such doctrinally correct means as the CGS-100, a subsystem of the Compartmented All Source Analysis System (ASAS) Message Processing System (CAMPS), remote workstations (RWSs), and AFATDS message traffic.

The Tactical Army Fire Support Model (TAFSM) simulation modeled the Army Tactical Missile System (ATACMS) battalion and sent the fire and detonate protocol data units (PDUs) to the Janus 6.88D simulation. Janus then modeled the engagement results and reflected them in the synthetic environment.

The Joint STARS E-8C simulation, called the Virtual Surveillance Target Attack Radar System (VSTARS), represented the radar subsystem of the Joint STARS E-8C in a laboratory environment. It was composed of a distributed interactive simulation (DIS) network interface unit (NIU), a radar processor simulator and integrator (RPSI) that contained the two real-time radar simulations with necessary databases, and various simulations of E-8C processes. VSTARS was operated at the Northrop Grumman Surveillance and Battle Management Systems facility in Melbourne, Florida.

2.2.1 End-to-End Test Results and Conclusions

Within the narrow confines of the ETE Test data, our assessment is that the architecture we employed has utility for support of C4ISR T&E. The JADS data indicate that DT&E and OT&E activities incorporating ADS technology are both practical and cost effective. Our broad conclusions and lessons learned can be summarized as follows.

An ADS environment can enhance C4ISR system DT&E and OT&E. In comparison with conventional tests, ADS allows testers to examine C4ISR systems under realistic conditions for longer periods of time, over far larger battlespaces, and at a much lower cost. This versatile technology can provide test environments that include large numbers of entities, entities operating under realistic but unsafe conditions, and joint and combined operations. ADS provides C4ISR system testers with greater flexibility in designing, executing, and analyzing their tests. During DT&E, ADS allows for more realistic compliance testing of C4ISR subsystems and efficient implementation of the test-fix-verify cycle for software development.

ADS testing provides dramatic abilities to test C4ISR systems or components in that system. For instance, in the ETE Test ADS environment, a developmental test could be performed on the Joint STARS operations and control subsystem using VSTARS as a stimulus. With a similar configuration, an operational test could be accomplished on an LGSM. The ETE Test ADS environment also provided ample opportunities to install new components for various types of testing. Links to airborne weapon system simulators, complimentary sensor feeds or other command and control structures can be easily accomplished. The development of an ADS test environment during system development greatly improves opportunities for C4ISR system training after the completion of the test. The same infrastructure developed for testing can be modified and transitioned to a training environment resulting in program savings. This technology allows C4ISR system operators to confirm current tactics, try "what-if" scenarios and new tactics, test the interoperability and compatibility of their equipment, and gain useful experience in a realistic operating environment containing multiple assets.

The ETE Test required only a small part of the available bandwidth and exhibited a low PDU latency rate. The ETE Test network was highly reliable during testing, due largely to the ETE Test team's extensive pretest risk reduction efforts.

Compared to conventional testing, ADS testing reduces the need for large numbers of fielded personnel and vehicles. The ability to automatically collect and analyze test data also reduces the number of people required for setup, execution, and analysis. ADS test success relies on well-organized test control and data management procedures. Distributed testing requires sophisticated instrumentation, trained personnel to operate and maintain that equipment, and funds to support personnel and equipment at distant test nodes.

Testers should carefully plan the development of the simulations and links comprising their ADS environment. During test execution, they must ensure that the time sources are synchronized and continuously monitor PDU traffic. The distributed nature of ADS testing necessitates special equipment for network checkout and verification and requires strict configuration control of analysis tools and collected data.

ADS test planning should be detailed enough to encompass key requirements at the earliest possible stages, yet flexible enough to accommodate unexpected situations during test execution.

A conservative development approach is recommended. Accomplish risk reduction activities before each ADS test and let each ADS test build on the success of earlier experiments. Successful test execution requires effective internode communication, test and resource control, and data management procedures.

2.2.2 Observations for C4ISR T&E

Through a process of inductive reasoning, we can transfer some of the specifics of the ETE Test to the general class of C4ISR systems. In the general case, the elements of the ETE Test architecture are basic to all mission-level testing of C4ISR systems. In other words, there are a sensor, a shooter, an intended target, an operating environment, and a test control center.

The sensor, shooter, and target can be represented in any of the three forms associated with distributed simulation: live, virtual, or constructive. We do not see a one-for-one transfer of ETE test techniques to other tests. Each test has specific requirements, often peculiar to the particular system under test. However, we do see a transfer of the principles, design processes, and methodologies used in the ETE Test.

Technically, it's not impossible to develop a high-fidelity operating environment in ADS. However, the costs and challenges will vary from test to test and will depend on the desired level of complexity.

A test control center is a requirement for all testing, distributed or not. Fortunately, the ETE Test experience suggests that the control center can function from almost anywhere. Thus, a specific test may save resources by using an existing control center.

The ETE Test results strongly suggest that ADS has excellent potential for improving C4ISR testing. Thus, test planners should consider the technology as a relevant tool for their program, until an objective assessment suggests otherwise.

2.3 Utility for Electronic Warfare (EW) Testing

The EW Test evaluated the utility of ADS to support EW T&E. While the test used several efforts to examine ADS-based T&E, the cornerstone effort was a series of traditional and ADS-based test events using an airborne self-protection jammer (SPJ). This effort was called the SPJ test. The SPJ test defined a simple, repeatable test scenario. The scenario was executed in three traditional test environments to create a data baseline. The test scenario was then executed in two ADS-enhanced test environments. The first ADS-based test event used a real-time digital system model (DSM) interacting with manned threat simulators at the Air Force Electronic Warfare Environment Simulator (AFEWES) facility, Fort Worth, Texas. The second ADS-based test used the SPJ installed on an F-16 suspended in the anechoic chamber at the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF), Patuxent River, Maryland. The data from all tests were statistically compared in an attempt to quantify the impacts of ADS.

The other efforts used by JADS to examine the utility of ADS are

1) The Office of the Secretary of Defense (OSD) CROSSBOW Committee-sponsored Threat Simulator Linking Activity (TSLA) effort,
2) The Defense Modeling and Simulation Organization (DMSO)-sponsored High Level Architecture (HLA) Engineering Protofederation (EPF) effort, and
3) The Army's Advanced Distributed Electronic Warfare System (ADEWS) development effort.

Each of these efforts added to the SPJ test experience to provide JADS with a broader understanding of the utility of ADS to EW T&E.

2.3.1 EW Test Results and Conclusions

Within the confines of the SPJ test data, JADS concluded that ADS architectures that allow the capabilities of geographically separated facilities to be combined to create a realistic test environment for EW devices can be designed. This allows the same test environment to be used for SUT representations ranging from DSMs to operational equipment. Testing in a common ADS-based environment represents a significant departure from the traditional sequential EW test process.

Key Results

- Designing ADS architectures requires a close team comprised of several technical experts spanning several disciplines directed by a system integrator.

- The architecture produced valid results for both the DSM and actual jammer hardware.

- Latency within the closed-loop interaction was aggressively managed, and JADS was able to meet its objective for more than 95% of the runs.

- The HLA appears to be a feasible method for linking simulations for T&E. It is appropriate to use HLA to link to other HLA-compliant simulations/simulators, but the T&E community should not view it as the only architecture to consider when designing distributed tests.

- Two of the eleven EW test facilities surveyed in 1996 as part of the TSLA effort that were appropriate for ADS-based testing have been closed. While this is a significant erosion in the infrastructure needed to design and execute ADS-based tests, it already limits the traditional EW testing process.

2.3.2 Observations for EW T&E

JADS assessment, based on the different EW Test efforts, is that ADS has varying levels of utility for EW T&E. These levels of utility depend on the nature of the EW device being tested and the availability of suitable test facilities. Single function EW devices and federated EW systems are expected to benefit least from an ADS-enhanced test process. Only radio frequency (RF) jammers may see sufficient benefit to outweigh the additional cost of an ADS-enhanced test process. Integrated EW systems may see significant benefits where a single test facility is not capable of providing all the stimulation (including the closed-loop SUT versus manned threat interaction for systems that include RF jammers) needed to simultaneously test all the particular integrated EW system's functions. Systems of systems testing such as that required for electronic support (ES) systems should see significant benefits in ADS-based testing.

ADS allows the test designer to construct tests that address objectives beyond the capability of a single facility. While connecting facilities can be beneficial, not all EW testing requires the use of ADS. Single device and federated systems testing are generally adequately supported by the sequential facility testing paradigm (the progression from DSM to system integration laboratory [SIL], SIL to hardware-in-the-loop [HITL], HITL to installed systems test facility [ISTF], ISTF to open air range [OAR]) recommended in Department of Defense EW test process description. Testing integrated EW systems and systems of systems does not readily conform to the sequential facility testing paradigm. The requirement for testing these systems is to create an operationally realistic single environment in which all integrated EW functions, including closed-loop interaction with manned threat simulators, are simultaneously tested while interacting with the host platform, the host platform operator(s), and the appropriate blue and red players. Any less stringent test increases the risk of fielding a flawed system. Highly integrated avionics systems such as the F-22 share resources. The only way to fully understand the effects of resource sharing is to test all system functions at the same time in the operationally realistic single environment described above.

To be tested, all integrated EW systems may not require ADS. If a single facility is capable of providing all the stimulation (including the closed-loop SUT versus manned threat interaction for systems that include RF jammers) for the particular integrated EW system, then ADS is not needed. However, if no facility exists, ADS offers an alternative to potentially expensive facility modifications or expansion. The development and integration of distributed test facilities (such as AFEWES and ACETEF) capable of simultaneous EW sensors stimulation and closed-loop threat interaction present the facility designer with the same problems of latency, data loss, and out-of-order data that confront the ADS architecture designer.

Systems of systems testing is not likely to be practical or affordable in a single facility or on a single OAR. Simple cooperative jamming tests against single threats can be accomplished using the sequential testing methods described in the OSD EW test process. More complicated systems of systems testing on an OAR is constrained by the limitations the single facility or the limitations of the range selected and the cost of bringing the required platforms together for the test event.

The EW Test results stongly suggest that ADS has good potential for improving some types of EW testing. The implication is that test planners should consider the technology as a relevant tool for their program until an objective assessment suggests otherwise.

3.0 Overall Utility

3.1 General Role of Distributed Testing

Roles for distributed testing can be identified for both DT&E (in which the general objective is to determine the SUT's ability to meet specifications using preproduction subsystems) and OT&E (in which the general objective is to determine the SUT's ability to meet user's operational effectiveness and suitability requirements using production-level systems in realistic combat scenarios). The underlying ADS technology can support DT&E and OT&E equally well.

3.1.1 DT&E

Early DT&E of complex systems frequently focuses on stand-alone components, subsystems, or systems testing. This testing is essential and in most cases can be adequately conducted in stand-alone test facilities. Distributed testing becomes a valuable DT&E tool when you start to integrate the components, subsystems and systems together. The use of ADS can result in much better system integration evaluations. High-fidelity integration can begin prior to having flight/soldier-ready systems. In those cases where live only testing is deemed necessary in addition to distributed testing, the distributed test environment can be used to provide realistic test rehearsals, to refine test scenarios, and to verify data collection and analysis equipment and processes. Distributed testing can also ease the transition to OT&E testing. OT&E test scenarios are frequently more complex than DT&E scenarios. Distributed testing provides the capability to affordably test early versions of the system under test in a complex synthetic test environment. This capability not only eases the transition to OT&E, but more importantly, it identifies failure modes earlier in the test process when they can be fixed cheaper and in less time than when they are discovered in OT&E.

3.1.2 OT&E

The key contribution of distributed testing to OT&E is that it enables affordable system of systems or mission-level testing. Currently, cost and safety constraints limit the density of forces in typical OT&E to much less than would be found in battle. Also, it is usually impossible to obtain the actual threat systems that the system under test would operate against and have them operate in a realistic "unconstrained" manner. The use of distributed testing can greatly augment the force density during testing with either manned simulators or DSMs representing the additional forces. When used in conjunction with live only tests, distributed testing can be used to provide realistic test rehearsal, including refinement of live fire scenarios in order to ensure test objectives are met. It can also be used for post-test analysis and can aid in resolving anomalies observed in live fire testing.

3.1.3 Acquisition Process

In the not too distant past, the acquisition process was marked by waterfall development of systems and required independent DT&E and OT&E. Clearly the trend in acquisition is to spiral development, increase contractor testing, and combine or merge DT&E and OT&E. Simulation Based Acquisition (SBA) is designed to accelerate this trend. Distributed testing is ideally suited to support these changes in the acquisition process because it allows evolving SUT representations to be tested in a common synthetic test environment throughout the entire acquisition process. The system under test and the test assets (live, virtual, and/or constructive) that make up the synthetic test environment can be distributed over large geographic distances. If the system under test is itself a system of systems, these systems can also be geographically distributed and linked to the synthetic test environment. This supports a continuum of development and testing as opposed to discrete test events and milestones. It allows specification testing and requirements testing to be conducted in the same test environment that will allow the relationship between specifications and requirements to be closely defined. The linked environment also will support collaborative engineering and collaborative analysis within and between contractor and government organizations independent of location. Maximum benefits and cost savings will only be realized when distributed testing is used throughout the entire acquisition process from requirements definition to training.

3.2 General Utility Assessment

3.2.1 Benefits

Three areas or categories of benefits were identified and demonstrated by the JADS JT&E.

<u>The ability to overcome current test limitations.</u> During the feasibility study prior to the JADS JT&E, a survey of existing conventional development and operational test limitations was conducted. Three hundred and sixty-one limitations were extracted from test reports and test and evaluation master plans. A triservice panel of testers was convened to validate the limitations and loosely rank them. The top developmental and operational limitations are presented below. A double check signifies that JADS demonstrated the capability to overcome that limitation in one or more of the JADS test cases. A single check signifies an inferred capability to overcome the test limitation.

Potential for ADS to overcome traditional developmental test (DT) limitations

√√ Inability to integrate avionics testing
√ Limitations to testing special access programs
√√ Incompatibility of collected data
√√ Human interaction not represented
√√ Nonrepresentative force levels
√√ Inadequate quantity and types of threat systems
√√ Electronic combat testing not allowed, is limited or restricted
√ Lack of systems for compatibility testing
√√ Real-time modeling/simulation not available

Potential for ADS to overcome traditional operational test (OT) limitations

√√	Inadequate quantity and types of targets
√√	Inadequate quantity and types of threat systems
√√	Inadequate quantity and types of friendly systems
√	Electronic combat testing not allowed, is limited or restricted
√√	Nonrepresentative force levels
√√	Human interaction not represented
√√	Insufficient test articles
√√	Unrealistic test scenarios
√√	Insufficient number of test events

Clearly ADS has the potential to overcome many conventional test limitations.

<u>The ability to identify failure modes earlier</u>. ADS provides the capability to link a representation of the SUT to a distributed test environment. The distributed test environment can be held relatively stable while the SUT evolves and matures through its development cycle. The first representation of the SUT may (should) be a digital system model, followed by prototype hardware and software in the contractor's laboratory, followed by a full-up system in an installed systems test facility. The ability to test evolving SUT representations in a common test environment has several advantages. First, it reduces the number of changing variables across test phases. In conventional testing, it's not unusual to change the test environment when the SUT representation changes. Another significant advantage is the ability to identify SUT failure modes earlier in the development cycle when they can be fixed quicker and more cheaply. ADS is particularly well suited to identifying interoperability problems early in the acquisition process, especially when real-world communications links are an integral part of the linked test configuration. The ability to create a robust test environment with realistic sensor and communications inputs also enables the early identification of hardware and/or software data processing problems. The ability to incorporate human operators early allows human factors issues, concepts of operations, tactics, techniques and procedures, and training to all be resolved before OAR testing begins. The ability to identify and address suitability issues early is limited by the realism of laboratory and installed systems test facility operating environments. Linking to SUTs in climatic laboratories is being investigated and will improve this capability.

<u>The ability to conduct end-to-end testing</u>. The accomplishment of most military tasks requires the successful coordination and integration of several systems. Decision makers are asking for mission-level or system of systems test information in order to support acquisition milestones. Conventional testing has focused on individual system tests and makes significant assumptions concerning the performance and interoperability of other systems. ADS provides the capability to link and test the capability of a system of systems to successfully execute a mission task within a single test environment. This approach has fewer assumptions and requires fewer leaps of faith in the analysis and evaluation of test results. The JADS ETE Test is an excellent example. Historically the Joint STARS (E-8C aircraft and common ground station), command and control nodes (TAC and fire support element) and the ATACMS weapon systems would all be tested

separately. Analysis would be used to combine the results and predict the number of target kills supported by Joint STARS. The JADS ETE Test linked these systems together and created a single test environment that provided much greater insight into interoperability, timelines, tactics, techniques and procedures (TTPs), and traceability of causes and effects.

3.2.2 Costs

Costs can be broken into two categories - cost savings and cost avoidance. The MITRE Corporation developed an ADS in T&E work breakdown structure (WBS) in support of JADS. The top-level WBS is presented in Table 1. The ADS cost impact column is an assessment of costs relative to a conventional test. The increased complexity of an ADS test results in a small to medium increase in the cost of most categories. The cost drivers under the design and development category are simulations and interfaces. If a new or modified simulation must be developed, the cost can be medium to high. A significant cost to the JADS ETE Test was the development of a high-fidelity representation of the Joint STARS radar system. Both Simulation Based Acquisition and the simulation, test, and evaluation process advocate that the system developer be required to deliver a digital system model early in the acquisition process and maintain and update the model throughout the system life cycle. This should reduce or eliminate the cost of this simulation to testers. The cost impact of a new or modified interface based on JADS experience is judged to be medium to medium high. It should be noted that communications links were not found to be significant cost drivers, and that these costs are expected to decrease in the future. The cost impact on test execution and analysis runs the gamut from medium increases to large cost savings. The cost of test assets is directly related to the fidelity of the asset representation. In most cases a live asset costs the most, a virtual asset less, and a constructive asset the least. ADS allows the tester to obtain the required fidelity at minimum cost. A related issue that can result in cost savings is test asset availability. In this case, live test assets are generally the least readily available, virtual more, and constructive the most available. Availability of test assets drives the test schedule, especially when modifications and retesting are required.

Table 1. ADS Cost Impact

WBS Element	ADS Cost Impact
Planning	Low increase
Concept Development	Low - medium increase
Design and Development	Medium increase
Installation, Integration and Test	Medium increase
Text Execution and Analysis	Large decrease - low increase

Cost avoidance can be thought of as unplanned for cost savings. ADS supports or enhances cost avoidance in several ways. By identifying SUT problems earlier, you can not only avoid the expense associated with fixing the problems later, you also avoid the expense of failing a more expensive test later. Similarly, the ability to identify TTPs, training, data processing, and analysis problems earlier can help avoid the cost of expensive OAR test failures later. The Live Fly Phase of the SIT provided a good example of cost avoidance that could be attributed to ADS. The advanced medium range air-to-air missile (AMRAAM) initial operational test and evaluation failed a simultaneous, multiple shot test event. The cause was an interoperability problem concerning the rear data link information going from the launch aircraft fire control radar to the AMRAAM. This interoperability problem would have been found in a LFP ADS test. The costs that would have been avoided include numerous tests and missiles to demonstrate that the fix worked; the dollars associated with the program delay; and the additional gray hairs for the program manager and test manager. Cost savings will be very program specific and closely related to the complexity of the test environment (potential for increased savings) and the number of new simulations and interfaces that need to be developed instead of being reused. The potential for cost avoidance can be judged to be high, but the ability to predict the amount for any given program is low.

3.3 General Concerns, Constraints and Limitations

3.3.1 Concerns

When JADS entered the joint test there were several areas of concern. The technical concerns were network latency, network data quality, and network reliability. Programmatic concerns were network costs and verification, validation and accreditation (VV&A) costs. A key finding of the JADS program is that in most cases these areas were indeed only concerns. They never became constraints or limitations in the execution of our tests and shouldn't be for future programs if the JADS test planning methodologies are followed. Costs remain a concern. Most existing facilities were not designed to be linked and require some modification along with appropriate interfaces before linking is possible. This cost can be significant but can be amortized over all phases of the acquisition process.

3.3.2 Constraints and Limitations

The lower limit of latency is fixed by the speed of light. A small percentage of test programs involve very tightly coupled interactions between the SUT and other players in which latency will be a constraint. In some cases these limitations can be overcome by collocating critical components of the interacting systems, as done in the EW Test, but this will not always be possible. Other technical constraints are the ability to present representations of synthetic targets to live players and a limited ability to represent dynamic environmental effects among live and virtual players. These can be considered exotic constraints and limitations because they will not occur for most programs. Currently, the most prevalent distributed testing constraint is the availability and capability of current simulations. An assumption at the beginning of the joint test was that high-fidelity constructive, virtual and live simulations existed and that the challenge would be in linking them together. The JADS experience has been that this was not an accurate assumption. There is not an overabundance of live, virtual, or high-fidelity constructive simulations and those that do exist are heavily used. The challenge for JADS was as much to find and schedule these test assets as to link them together. This constraint was exacerbated by the lack of common business practices across services and between test facilities and test ranges.

While not a show stopper, this lack of common business practices hinders the efficiency with which distributed testing can be conducted, adding unnecessary time and cost overhead burdens to the process.

3.4 General Requirements

3.4.1 Standards

DMSO, the Simulation Interoperability Standards Organization (SISO), Foundation Initiative 2010, and many other government and commercial organizations are developing open systems standards for technical interoperability among live, virtual, and constructive simulations. Operational system interoperability standards are also being developed, and the distinction between operational interoperability standards and simulation interoperability standards is very slight in many cases. Multilevel security standards and distributed test control standards are areas which require additional attention. Although technical standards have a long way to go, an adequate process appears to be in place to develop them. A similar process needs to be put in place to develop programmatic standards that will support distributed testing across all phases of the acquisition process. As in the technical standards, these programmatic standards need to also support international distributed testing and training.

3.4.2 Networking

Network requirements (i.e., expected data rate, latency budget, communications protocols, control and management of the network) need to be defined early in the process. These requirements must be clearly defined and forwarded to the Defense Information Systems Agency (DISA) for evaluation of how they can best support the requirements, either through DISA common user networks (i.e., Defense Simulation Internet (DSI), Secret Internet Protocol Router Network (SIPRNET), Defense Research and Engineering Network (DREN), etc.), or by granting a waiver exempting use of common user networks in order to build a private network suitable for the requirements. It should be noted that if DISA's common user networks are used, DISA will allow connection to only one of the networks. These networks cannot be interconnected because of security, interoperability, and tariff constraints. Thus, it requires close coordination with DISA to ensure the network of choice will support all requirements.

Time is of the essence. Careful planning and consideration must be given to the schedule for implementing the communications network. On average, once the requirements are defined and a networking solution is decided upon, it will take a minimum of 120 days (if a DISA common user network is to be utilized, it could take more than 180 days) to procure and install the necessary communications circuits and networking hardware. Also, it will take a minimum of 90 days to obtain the necessary communications security (COMSEC) equipment and keying material to encrypt the data. It may take longer if a COMSEC subaccount needs to be established. In addition, time must be allocated in the schedule to install, test, and validate communications network performance. On average, JADS allocated one week per site to accomplish these tasks.

3.4.3 Expertise

Distributing testing requires expertise in many disciplines, and the JADS experience has been that very few organizations have the required depth and breadth of expertise required to efficiently conduct a successful distributed test. JADS had to develop a combination of government and contractor expertise to support each of the JADS tests. In doing so, centers of distributed testing expertise were established, but both the government and contractor expertise is very perishable. There is a critical requirement to establish persistent centers of excellence within OSD and the services to support distributed testing, or we will be required to reinvent the proverbial wheel many more times.

3.4.4 Leadership Support

Continued leadership support is required to facilitate the use of distributed testing as a widely accepted and used test tool. In particular, middle management needs to be strongly encouraged to seriously consider the use of distributed testing to support future complex acquisition programs. The previously listed requirements are areas that require immediate and sustained leadership support.

4.0 Summary

The utility of distributed testing is case specific, but for many complex systems, we believe it provides the only affordable means of conducting adequate system of systems or mission-level testing. We see a big payoff for tests that involve systems integration, interoperability, and jointness. Distributed testing also appears to be essential to support current trends in acquisition reform. Current technology, in most cases, is adequate to support distributed testing and the technology is evolving rapidly. Current business practices, however, are not adequate and need to be improved to gain maximum utility from this powerful new tool.

5.0 Abbreviations and Acronym List

AIM	air intercept missile
ACETEF	Air Combat Environment Test and Evaluation Facility, Patuxent River, Maryland; Navy facility
ADEWS	Advanced Distributed Electronic Warfare System; Army sponsored
ADS	advanced distributed simulation
AFATDS	Advanced Field Artillery Tactical Data System
AFEWES	Air Force Electronic Warfare Evaluation Simulator, Fort Worth, Texas; Air Force managed with Lockheed Martin Corporation
AMRAAM	advanced medium range air-to-air-missile
ASAS	All Source Analysis System
ATACMS	Army Tactical Missile System
CAMPS	Compartmented ASAS Message Processing System
C4I	command, control, communications, computers and intelligence
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
COMSEC	communications security
CROSSBOW	Office of the Secretary of Defense committee under the Director, Test, Systems Engineering and Evaluation
DIS	distributed interactive simulation
DISA	Defense Information Systems Agency
DMSO	Defense Modeling and Simulation Organization, Alexandria, Virginia
DREN	Defense Research and Engineering Network
DSI	Defense Simulation Internet
DSM	digital system model
DT	developmental test
DT&E	developmental test and evaluation
EPF	engineering protofederations
ES	electronic support
ETE	JADS End-To-End Test
EW	electronic warfare; JADS Electronic Warfare Test
HLA	high level architecture
HITL	hardware-in-the-loop
HWIL	hardware-in-the-loop
ISTF	installed systems test facility
JADS	Joint Advanced Distributed Simulation, Albuquerque, New Mexico
Janus	interactive, computer-based simulation of combat operations
Joint STARS	Joint Surveillance Target Attack Radar System
JT&E	joint test and evaluation
LGSM	light ground station module
LFP	live fly phase
LSP	linked simulators phase
M&S	modeling and simulation

MITRE	company that provides engineering services
MODSAF	modular semi-automated forces
NIU	network interface unit
OAR	open air range
OSD	Office of the Secretary of Defense
OT	operational test
OT&E	operational test and evaluation
PDU	protocol data unit
PGM	precision guided munitions
RF	radio frequency
RPSI	radar processor simulator and integrator
RWS	remote workstations
SBA	Simulation Based Acquisition
SIPRNET	Secret Internet Protocol Router Network
SISO	Simulation Interoperability Standards Organization
SIL	system integration laboratory
SIT	system integration test; JADS System Integration Test
SPJ	self-protection jammer
SUT	system under test
T&E	test and evaluation
TAC	target analysis cell
TAFSM	Tactical Army Fire Support Model
TCAC	Test Control and Analysis Center, Albuquerque, New Mexico
TRAC	Army Training and Doctrine Command Analysis Center
TSLA	Threat Simulator Linking Activity
TTPs	tactics, techniques, and procedures
VSTARS	Virtual Surveillance Target Attack Radar System
VV&A	verification, validation, and accreditation
WBS	work breakdown structure
WSMR	White Sands Missile Range, New Mexico

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6.1 PGM Testing

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