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The Utility of Advanced Distributed Simulation for Precision Guided Munitions Testing

**Joint Advanced
Distributed Simulation
Joint Test Force**

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SYSTEM INTEGRATION TEST
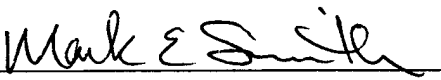## PRECISION GUIDED MUNITIONS (PGM) REPORT

MAY 1998

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The System Integration Test (SIT) investigated the ability of ADS to support air-to-air missile testing. This report describes the outcome of the SIT, the conclusions and lessons learned, and offers observations on the implications of SIT for the general class of precision guided munitions (PGM). SIT results indicate that activities ranging from parametric analyses to integrated weapons system testing are both practical and cost effective. Through a process of inductive reasoning we can transfer some of the SIT-based specifics to the general class of (PGM). In general, the elements of the SIT architectures are basic to all PGM cases. There is (1) a launch platform or shooter (2) 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. We do not see a one-for-one transfer of SIT techniques to other tests. We do see a transfer of the principles, design processes, and methodologies used in SIT. We see no technical impediments, at the conceptual level, to implementing high-fidelity countermeasures in ADS. The SIT suggests strongly that ADS has good potential for improving PGM testing.

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FOREWORD

In the early nineties, the proposition that Advanced Distributed Simulation (ADS) was the wave of the future for T&E was advanced. Reaction was mixed. At one end of the spectrum were people who believed the need for live testing would fade away, and at the other end were people who scoffed at the notion that ADS had any utility at all for testers. At the policy making level, expectations were high and skepticism was subdued. At the implementation level, expectations were low and skepticism was high.

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) program was chartered in October 1994 to conduct an objective assessment of the worth of ADS for support of T&E. While the Joint Test Force (JTF) work is not complete, they have shed considerable light on issues surrounding ADS use for T&E.

The JADS data suggests the reality about ADS lies between the extremes. Expectations that ADS would eliminate or drastically reduce live testing requirements were overblown. Similarly, expectations that ADS would eliminate the need for stand-alone models and simulations were unrealistic. On the other hand, expectations that ADS was essentially useless for T&E were clearly wrong. While the benefits and costs of ADS are very test program specific, the JADS data strongly suggests that ADS can be a cost effective test tool in many applications.

The emerging conclusion of the JADS JT&E is that we in the test community should seriously consider the use of ADS in the test concept development and planning processes. The costs and benefits of ADS will vary widely from program to program. There will be cases where it should be used, and cases where it should not. The ultimate decision to use, or not use, the technology will have to rest upon the program and test managers.

We believe that while ADS is relatively new, it can be a valuable addition to the tester's tool box. Our hope is that program and test managers will routinely include consideration of ADS use in their deliberations and planning activities. We challenge you to spend the intellectual effort to see where, how, and if ADS fits into your programs. We encourage you to examine the existing JADS data, identify missing data and work with JADS to identify cost effective ways of using ADS to support your test programs.

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EXECUTIVE SUMMARY

1.0 Overview

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation program was chartered by the Office of the Secretary of Defense in October 1994 to investigate the utility of advanced distributed simulation (ADS) technologies for support of test and evaluation (T&E). The JADS Joint Test Force (JTF) is Air Force led, with Army and Navy participation, and is scheduled for completion in 1999. This report addresses the first of three separate JADS tests, the System Integration Test (SIT), which was completed in October 1997.

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 which hosted an AIM-9M missile; and a test control center initially located at Point Mugu and later re-located in 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 which hosted an AIM-120 missile; and a test monitoring center at the JADS facility in New Mexico.

This report describes the outcome of the SIT, the conclusions and lessons learned, and offers observations on the implications of SIT for the general class of precision guided munitions.

2.0 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 a challenge.
- 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.

3.0 Observations for Precision Guided Muntions T&E

Through a process of inductive reasoning we can transfer some of the SIT-based specifics to the general class of precision guided munitions (PGM). In the general case, the elements of the SIT architectures are basic to all PGM cases. There is (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 system under test. 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 system test facilities.

The SIT results suggest strongly 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.

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1.0 Purpose and Background

1.1 Report Purpose

This report summarizes the assessment of the utility of advanced distributed simulation[1] (ADS) for the test and evaluation (T&E) of precision guided munitions (PGM). This assessment was based on the results and lessons learned from the Joint Advanced Distributed Simulation (JADS) System Integration Test (SIT) testing, along with results from other related efforts.

This report also considers the benefits of ADS-based T&E of PGM systems including Follow-On To TOW (FOTT), Evolved Sea Sparrow Missile (ESSM), AIM-9X, AIM-120C, Joint Direct Attack Munition (JDAM), High-speed Anti-Radiation Missile (HARM), Joint Stand-Off Weapon (JSOW), Joint Air-to-Surface Standoff Missile (JASSM), and Standoff Land Attack Missile - Expanded Response (SLAM-ER). Also addressed is the use of ADS for the integration of PGM systems to advanced launch platforms such as F-22, F/A-18E/F, Joint Strike Fighter (JSF), and Commanche.

The assessment presented in this report gives general guidelines for implementation of ADS-based testing of various classes of PGM using various ADS architectures. Detailed requirements for linking specific PGM systems using specific architectures (other than the AIM-9M and AIM-120 missiles addressed by the SIT) were not developed. The extrapolation of SIT results to PGM classes other than air-to-air missiles is based on informed conjecture without rigorous analysis or supporting data. Applications are assumed to be feasible unless there is evidence to the contrary.

1.2 JADS Overview

The JADS Joint Test and Evaluation (JT&E) was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation), 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 five years.

The JADS JT&E is directly investigating ADS applications in three slices of the T&E spectrum: the System Integration Test (SIT) which explores ADS support of PGM testing, an End-To-End Test (ETE) which explores ADS support for command, control, communications, computers, and intelligence (C4I) testing, and an Electronic Warfare (EW) Test which explores ADS support for EW testing. The JADS Joint Test Force (JTF) is also chartered to observe, or to participate 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.

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[1] ADS is a networking method which permits the linking of constructive simulations (digital computer models), virtual simulations (man-in-the-loop or hardware-in-the-loop simulators), and live players located at distributed locations into a single scenario. Such linking can result in a more realistic, safer, and/or more detailed evaluation of the system under test.

2.0 Supporting Activities and Results

2.1 System Integration Test Overview

The SIT evaluated the utility of using ADS to support cost-effective testing of an integrated missile weapon/launch aircraft system in an operationally realistic scenario. The purpose of the SIT also included the evaluation of 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 SIT consisted of two phases, each of which culminated in fully linked missions simulating a single shooter aircraft launching an air-to-air missile against a single target aircraft. In the Linked Simulators Phase (LSP), the shooter, target, and missile were all represented by hardware-in-the-loop (HWIL) laboratories. LSP testing was completed in November 1996, and results were documented in the final report for that phase [Ref. 1] and other technical papers [Refs. 2-4]. In the Live Fly Phase (LFP), the shooter and target were represented by live aircraft and the missile by an HWIL laboratory. LFP testing was completed in October 1997, and results were documented in the final report for that phase [Ref. 5] and other technical papers [Refs. 6-9].

Missile systems selected for the SIT were the AIM-9 Sidewinder for the LSP and the AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) for the LFP.

2.1.1 SIT Linked Simulators Phase Summary

2.1.1.1 LSP Approach

The LSP test concept was to replicate a previous AIM-9M-8/9 live fire profile in an ADS configuration and compare missile results for the LSP trials to those from the live fire test. The LSP test configuration is shown in Figure 1.

The F/A-18 Weapon System Support Facility (WSSF) at China Lake, California and the F-14D Weapon System Integration Center (WSIC) at Point Mugu, California, were the shooter and target, respectively. The shooter "fired" the AIM-9 in the Simulation Laboratory (SIMLAB) HWIL facility at the target which could respond with countermeasures. Runs were controlled from a test control center which ensured all nodes were ready for each run, issued start/stop directions, and processed data packets for real time analysis of system performance. Test control was exercised from the Battle Management Interoperability Center (BMIC) at Point Mugu while the JADS Joint Test Force was physically relocating. Control switched to the JADS TCAC in Albuquerque, New Mexico, after the move was complete.

Information was exchanged among participants in the form of distributed interactive simulation (DIS) protocol data units (PDUs). Entity state data (positions, velocities, accelerations, attitudes, and attitude rates) at the output node were converted from simulator format to PDUs and reconverted at the receiving end into simulator format. An exception was the link between the stores management system (SMS) of the shooter and the missile in the SIMLAB which used 1553 data bus format.

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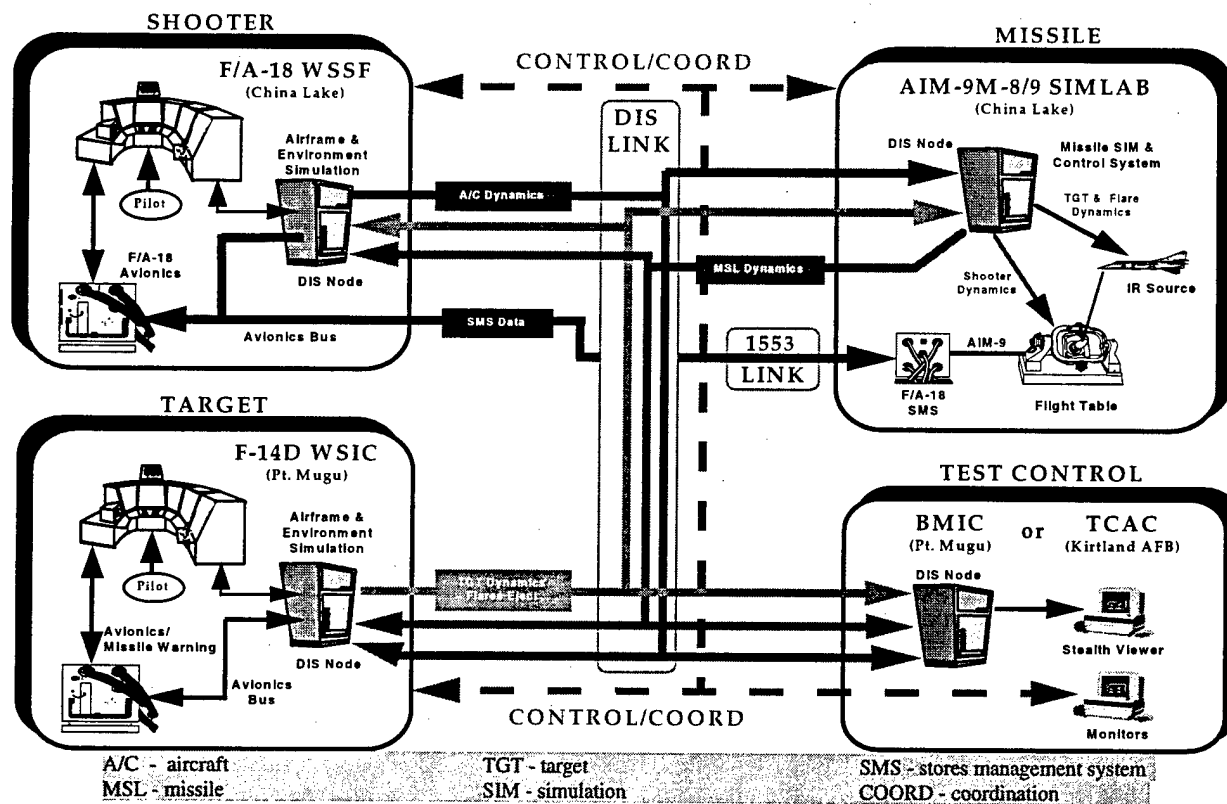
Figure 1. Linked Simulators Phase Test Configuration

2.1.1.2 LSP Test Results

The key results from LSP testing were as follows:

- The simulation facilities were properly linked, and the missile flyouts were valid for the target representation in the SIMLAB. However, this target representation differed somewhat from the target data originating from the WSIC.
- The manual method for replicating a given profile resulted in very good run-to-run reproducibility of the engagements.
- The average latency of all entity state data during the final mission was relatively small (<100 milliseconds from simulation to simulation) and consistent run-to-run. However, relatively large random latency variations were often observed which resulted in an uncertainty in the target location as perceived in the SIMLAB.
- The ADS network provided ample bandwidth and no loss of connectivity during testing.
- There were no significant ADS-induced errors.
- The reliability of the long-haul network was very good, and the availability of the complete LSP ADS configuration was on the order of 85%.
- Test control procedures were refined throughout the preparation process and worked well during testing.

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2.1.1.3 LSP Lessons Learned

The key technical lessons learned were as follows:
- Synchronization of activity in a network is difficult and is best provided by a "master clock" built into the architecture.
- Commonality of ADS hardware and software is desirable.
- Understand what the latency requirements are before designing a distributed architecture. Incrementally build to satisfy them.
- Special test instrumentation and tools are required to support distributed testing. The tool set must support rapid identification and characterization of network problems.

The key infrastructure and process lessons learned were as follows:
- ADS requirements must be developed early, understood by all parties, and thoroughly documented.
- The communications required to exercise test control must be identified early.
- System under test (SUT) experts must be involved from the outset.
- The architecture build-up must be incremental, beginning with check out of the ADS elements in a standalone mode, and evolving, step by step, to the fully integrated configuration.
- Problem solving/fixes frequently require verification in a full-up network environment.
- Detailed planning for data management is a necessary precursor to testing.
- Contracting to support ADS should most often be on a cost plus basis in the near term. There are currently too many unknowns to make fixed price contracting a viable option.
- Centralized test control processes have to be integrated with established local processes and procedures.
- Configuration control in a distributed architecture is difficult, but essential.

2.1.1.4 LSP Conclusions

The LSP ADS configuration has utility for
- Missile weapon/launch aircraft system integration T&E.
- Parametric studies, due to good pilot manual reproducibility of the profiles.
- Rehearsal and refinement of live engagement scenarios.
- T&E with closed-loop shooter/target interactions (e.g., prelaunch tactics evaluation).
- T&E with open-loop missile/target interactions (e.g., the missile reacts to the target, but the target does not react to the missile).

The LSP ADS configuration has potential utility for closed-loop missile/target T&E if the latency and latency variations can be reduced sufficiently such that the uncertainty in the perception of one player's position by the other does not cause disagreement on whether or not the target was "killed." The amount of acceptable positional error is a function of the design of the test and the systems involved.

The development of a distributed T&E architecture is not a "plug-and-play" exercise. In the near term, the elements available for linking into a given architecture are almost certainly not

designed to be linked. That means that the burden for making linked architectures work falls upon the interfacing and integrating activities. The network interface units, the translation software, the geographical transforms, etc., are the interface components which allow distributed systems to function with existing players today.

2.1.2 SIT Live Fly Phase Summary

2.1.2.1 LFP Approach

The LFP test concept was to replicate previous AMRAAM live fire profiles in an ADS configuration and compare missile results from the LFP trials to those from the live fire tests. In the LFP, ADS techniques were used to link two live F-16 aircraft (flying on the Gulf Test Range at Eglin Air Force Base, Florida) representing the shooter and target to an AMRAAM HWIL laboratory (also at Eglin) representing the missile. This configuration allowed data from live sources to drive the HWIL laboratory for more realistic missile results and is shown in Figure 2.
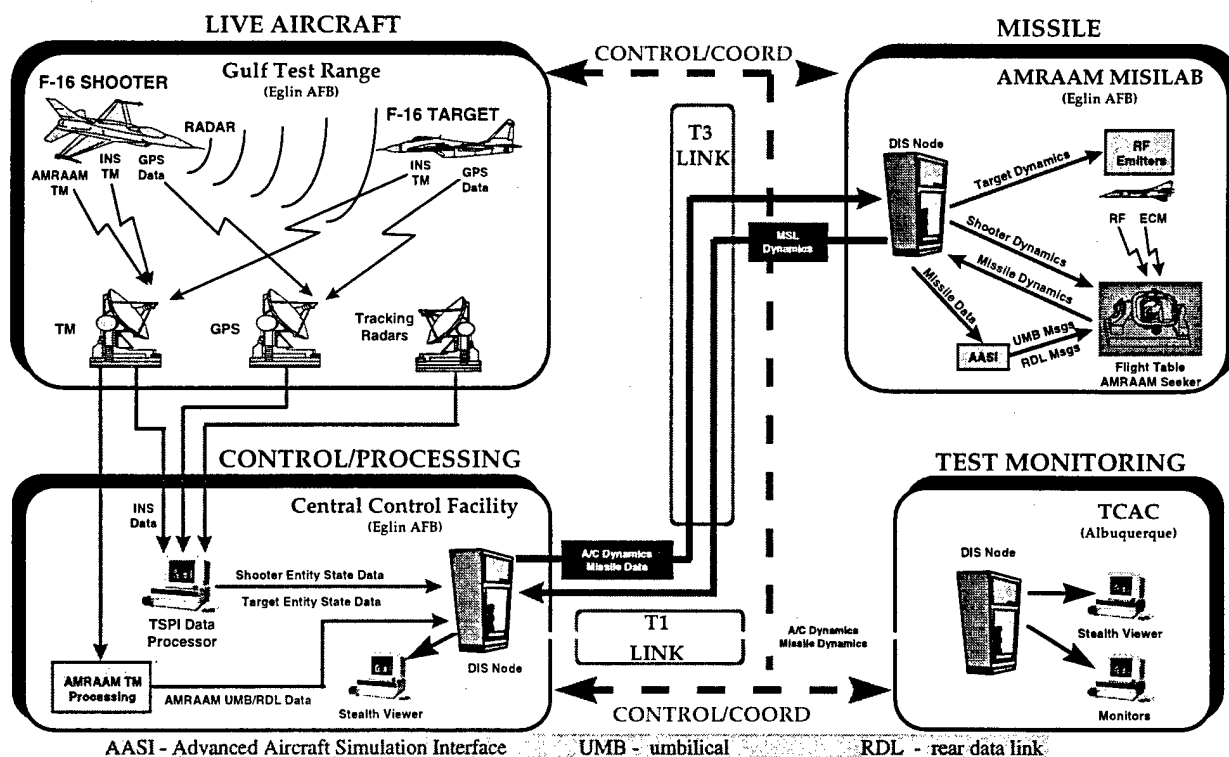
Figure 2. Live Fly Phase Test Configuration

Global positioning system (GPS) and telemetry (TM) data were downlinked from the aircraft and passed to the Central Control Facility (CCF) at Eglin. GPS, inertial navigation system (INS), and tracking radar data for each aircraft were combined by the TSPI (time-space-position information) Data Processor (TDP) in the CCF to produce optimal entity state solutions. The

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aircraft entity state data were transformed into DIS PDUs and transferred to the AMRAAM HWIL simulation at the Missile Simulation Laboratory (MISILAB) over a T3 link.

The shooter aircraft "fired" the AMRAAM in the MISILAB at the target and provided data link updates of the target position and velocity to the missile during its flyout. The AMRAAM seeker was mounted on a flight table and responded to radio frequency (RF) sources in the MISILAB which simulated the seeker return from the target, the relative motions of the target and the missile, and electronic countermeasures (ECM). A link between the CCF and the JADS TCAC allowed JADS personnel to monitor and record the simulated intercepts.

2.1.2.2 LFP Test Results

The key results from LFP testing were as follows:
- The live aircraft were properly linked to the missile HWIL laboratory, and the MISILAB generated valid AMRAAM data during the engagement.
- The TDP generated accurate TSPI solutions, 1-3 meters in position and 1 meter per second in velocity. This met the MISILAB accuracy requirements.
- The shooter and target TSPI data were properly synchronized to each other and to the umbilical and data link messages for input to the MISILAB simulation.
- Latencies during testing were relatively stable and consistent, but fairly large. The total latency of the MISILAB simulation was about 3.1 seconds. This large value of latency was due to the processing and buffering of the TSPI data to produce accurate and smooth solutions and to the synchronization technique used.
- The ADS network provided ample bandwidth and no loss of connectivity during testing.
- There were no significant ADS-induced errors.
- Test control procedures worked well during testing with centralized test control exercised from the CCF.

2.1.2.3 LFP Lessons Learned

The key technical lessons learned were as follows:
- Standalone simulation facilities can require significant (and time consuming) software changes before effective linking is possible.
- Live fully linked risk reduction missions were needed for effective integration testing.
- Linking may require special purpose interfaces, and their development must be factored into test planning.
- A full understanding of telemetry limitations was needed.

The key infrastructure and process lessons learned were as follows:
- Ground replays provided effective rehearsals and were helpful for troubleshooting.
- Existing range procedures had to be modified for ADS.
- A premission briefing is needed before each mission, as it was critical for coordinating the many network and flight test issues.
- Live aircraft operations with linked facilities required more contingency planning to quickly decide on alternatives.

- Live aircraft must be locally controlled, as the test range safety policy required that tactical control of aircraft over their airspace be performed at the Eglin CCF.

2.1.2.4 LFP Conclusions

The LFP ADS configuration has utility for:
- Missile weapon/launch aircraft system integration T&E, especially evaluation of the targeting messages supplied to the missile by the shooter.
- Rehearsal and refinement of live engagement scenarios.
- Tactics development involving closed-loop interactions between the shooter and target.
- Efficient testing utilizing an analyst-in-the-loop for timely feedback during the mission.

This test architecture would not support testing of closed-loop interactions between the missile and target due to the large latencies experienced. However, this shortcoming does not limit current AMRAAM testing, because essentially all live fire testing involves open-loop scenarios in which the target drone executes scripted (i.e., nonreactive) profiles.

2.2 Supporting Studies Summary

In addition to the SIT results, other studies were performed both inside and outside of the JADS JTF. The findings of those studies which are relevant to PGM ADS applications are summarized as follows:
- The transfer of weapon-related data between the shooter aircraft and the missile required a dedicated T1 link for the LSP architecture [Ref. 10].
- The use of a dedicated T1 link is preferred over the use of the Defense Simulation Internet (DSI) for transferring PDUs between a remote domed flight simulator and the SIMLAB AIM-9M HWIL laboratory. This conclusion was based on data latency requirements [Ref. 10]. Also, the DSI system can be extremely unreliable [Ref. 11].
- Linking between manned flight simulators and missile HWIL laboratories requires latencies of less than 100 milliseconds, synchronization of the simulators using absolute GPS time, and the use of dead reckoning algorithms [Refs. 12-18]. Latency requirements for some discrete events (e.g., missile launch and detonation) can be as small as 50 milliseconds [Ref. 18].
- Latencies between linked domed manned flight simulators have been measured in the range of 200 to 700 milliseconds [Refs. 19-21]. Such latencies limit somewhat the use of domed simulators for evaluation of the closed-loop interaction between air-to-air missiles and target aircraft (see Appendix A).
- Departures from DIS standards may be necessary in live applications [Ref. 22]. Such departures are readily accommodated by implementing high level architecture (HLA) concepts [Ref. 23].

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- The use of HLA[2] overcomes many limitations and undesirable features of DIS standards by allowing data protocol flexibility, eliminating unnecessary coordinate transforms, and reducing the amount of data transmitted between nodes by only transmitting entity attributes which have changed [Ref. 23]. An HLA-compliant air intercept missile federation (similar in architecture to the SIT LFP) is being developed by the Air Force Developmental Test Center (AFDTC) under Foundation Initiative 2010 [Ref. 25].
- ADS has been used to support virtual prototyping [Ref. 26] and surface-to-air missile (SAM) T&E [Ref. 12]. Programs are underway to implement ADS for virtual PGM testing [Ref. 27], FOTT T&E [Ref. 28], and torpedo testing and training [Refs. 29, 30].

3.0 Overall Advanced Distributed Simulation Utility Assessment

3.1 JADS Issues

The JADS JT&E program was chartered to investigate the utility of ADS for both developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). The charter letter identifies three issues to be addressed [Ref. 31]:
- Investigate the present utility of ADS, including DIS, for T&E. The utility assessment includes evaluating the validity of data from tests using ADS and the benefits of using ADS in T&E.
- Identify the critical constraints, concerns, and methodologies when using ADS for T&E.
- Identify the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future.

The ability of ADS to support PGM T&E will be assessed in terms of these issues.

3.2 General Utility of ADS for Precision Guided Munitions T&E

3.2.1 General Utility Assessment

ADS has utility for PGM DT&E and OT&E because ADS-supported tests can provide valid PGM performance evaluations in a number of areas addressed by both DT&E and OT&E (see Section 3.2.3) and because there are benefits to using ADS for PGM T&E (see Section 3.2.2). The applications for a specific PGM system (see Section 4.2) depends on (1) the test objectives, (2) the characteristics of the PGM, (3) the availability of high-fidelity PGM digital simulation models (DSMs) or HWIL laboratories, and (4) the details of the test scenario. Guidelines for implementing ADS-supported testing for a specific PGM system are provided at Appendix C.

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[2] HLA is replacing DIS as the standard protocol for linking distributed simulations [Ref. 24]. HLA uses a standard set of rules, tools, and a runtime infrastructure (RTI) to allow simulations to send and receive information. HLA allows the simulations to treat communications in a more abstract manner by providing a common interface specification and isolating the simulations from communications protocol implementations. Because simulations can be less aware of each other, HLA should encourage reuse of existing models for different applications. There are also no standard data formats analogous to DIS PDUs. Users can form their own messages based on their needs. Likewise users can use PDUs if they feel that the PDUs represent the data necessary for their simulation. In most cases, the conclusions from DIS-based testing should directly apply to HLA-based distributed testing.

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3.2.2 General ADS Benefits

The benefits of ADS-supported testing are best realized when this technique is added to a total PGM testing program. ADS-supported tests are not meant to replace any of the current testing techniques, including live fire tests, but rather to supplement current techniques and provide a more comprehensive evaluation of a PGM system. When the appropriate mix of testing techniques is used (see Section 3.2.3), the following benefits are realized from the addition of ADS-supported testing:

- Cost savings benefits.
  -- A PGM testing program which uses ADS-supported tests to supplement live fire tests can be more cost effective than live fire testing alone. In a limited number of cases, relatively inexpensive ADS-supported tests can replace costly live tests. Generally live tests are not replaced; instead, the proper use of ADS can result in a higher success rate for the live tests by identifying failures before the fact (cost avoidance) and can aid in the optimal selection of live test scenarios and associated measures. A methodology for determining the cost benefit of mixing ADS missions into a PGM testing program is given in Appendix B, along with an example of applying the methodology to one phase of AMRAAM testing.
- Improved testing benefits.
  -- Testing using a linked laboratory ADS architecture (similar to the LSP architecture) is more reproducible than live fire testing, because scenario conditions are more readily controlled and trials can be replayed for additional PGM responses. This allows more trials to be combined for analysis, giving greater confidence in evaluation results.
  -- ADS-supported testing allows the evaluation of certain classified techniques in which the ECM device cannot be permitted to radiate its RF emission on an open range. Rather, the ECM emissions can be restricted to the PGM HWIL laboratory where they are screened from unauthorized observation and where the effects of the ECM on PGM performance can be immediately observed by analysts.
  -- ADS allows the force density of the scenario to be increased. The number of friendly and threat systems can be increased by representing them with either manned laboratories (if realistic man-in-the-loop control of the systems is needed) or DSMs (if scripted behavior is acceptable). The inability to evaluate system performance in combat-representative environments is a common limitation in OT&E and an area in which ADS can improve the operational test (OT) environment [Ref. 32].
  -- ADS-supported tests exhibit more realism than either analytical simulation models (because actual hardware is used) or standalone HWIL laboratories (because realistic shooter and target inputs are provided).
- More efficient testing benefits.
  -- Testing using a live shooter-target ADS architecture (similar to the LFP architecture) is more efficient than live fire testing because the analysts get immediate feedback on each pass of a multiple pass mission. This allows adjustments to be made to the remaining test matrix, if necessary, while the live shooter and target platforms are still on range. This "analyst-in-the-loop" feature of ADS testing would be especially

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useful in efficiently progressing through an ECM testing matrix which involves varying a number of ECM-related parameters.

-- Live fire tests can be realistically rehearsed using ADS. This would ensure the proper setup of the scenario and reduce wasted live fire attempts in which the proper scenario conditions are not achieved. This use of ADS would also reduce the risk of a live fire testing program by identifying scenarios which cannot be correctly executed or which cannot achieve the stated objectives [Ref. 32].

3.2.3 General Role of ADS in PGM T&E

As stated in Reference 33, "The goals of missile system T&E are achieved through the proper use of all the means of test and analysis at hand. The most desirable T&E approach is to use realistic flight tests (launches) to produce the required technical data. However, this is not practical for all missile systems. The unit cost of the missile, the cost to conduct a flight test, the program schedule, or all three may limit the number of flight tests that can be performed. In some instances the desired conditions or environment can only be represented in a laboratory environment. As a result, other test techniques must be developed and used to complement the data available from launches." The techniques used for PGM T&E are described in Table 1 (based on Table 2 from Ref. 33).

Table 1. PGM Performance Evaluation Techniques.

Technique	Description
Analytical Study	Review and understanding of technical documents, drawings, schematics, and other materials to the extent of complete understanding of the system. This results in the determination of strong and weak points, assessment of potential performance, and definition of the specifics for testing.
Laboratory/Field Test	Operation of the system or subsystems in a controlled open-loop laboratory/field environment to define specification data, threshold data, and basic subsystem performance.
Simulation Techniques	
Analytical (DSM)	Mathematical representation of the PGM system/subsystems in closed-loop operation. The analytical simulation is normally programmed on a digital computer. The most commonly used analytical simulations are (1) the trajectory simulation, and (2) the lethality simulation.
HWIL Laboratory	Closed-loop analytical/hardware representation of the PGM system used to evaluate PGM performance as affected by guidance/seeker/signal processing. Sophistication and realism are obtained by integrating as much of the PGM hardware as possible in place of analytical models. Hardware integration provides a valid, realistic, and complete representation of the PGM operation that cannot be achieved in analytical simulations.
ADS-Supported Test	Uses ADS techniques to link live platforms, HWIL laboratories, or DSMs representing the shooter and target to an HWIL laboratory or DSM representing the PGM. Provides more realistic inputs to the PGM simulation, resulting in a more valid, realistic, and complete representation of the PGM operation than can be achieved by the PGM HWIL laboratory or DSM in standalone operation.
Flight Test Techniques	
Captive Carry Tests	Tests where the PGM is carried aloft into a representative environment (i.e., live targets, countermeasures, chaff, clutter). The tests are of open-loop configuration.
Launches	The PGM is launched in a representative environment. This is the most realistic and desirable of the data sources.

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Each of the techniques given in Table 1 has a role in supporting PGM T&E. Table 2 (based on Table 8 from Ref. 33) defines which testing techniques will likely be used to determine missile system performance as a function of missile areas of performance. As Reference 33 states, "Taken individually, the data from each type of test may be revealing. However, a successful evaluation is dependent on the appropriate utilization of each technique as defined in an integrated missile-system T&E plan."

Note that the unshaded area (i.e., traditional unlinked testing techniques) in Table 2 shows the following:
- No single testing technique is the primary data source for all performance areas.
- Traditionally, analytical (or digital) simulations provide the primary data for more performance areas than any other technique.
- Although live fire tests provide data for almost all performance areas, these tests are the primary data sources for only four areas. Note that the primary data source for lethality assessments is analytical simulations, rather than live fire tests.

In Table 2, ADS-supported testing is divided into two categories depending on whether the representation of the PGM system is by a DSM or by an HWIL. For either of these two PGM representations, the shooter and target can be represented by either live platforms, HWIL laboratories, or DSMs. The choice of shooter, target, and PGM representation depends on the test objectives, the details of the scenario, and the performance area and type of PGM being evaluated. Guidelines for the appropriate ADS architecture will be discussed for specific PGM types in Section 4.

Table 2 was constructed from Table 8 in Reference 33 by adding the shaded ADS-supported testing columns. The assumption in adding these columns was that ADS tests using a DSM to represent the PGM would be able to evaluate all the same performance areas as using a DSM alone and ADS tests using an HWIL to represent the PGM would be able to evaluate all the same performance areas as using an HWIL alone. However, testing based on ADS configurations can allow more realistic evaluations, assuming that an ADS configuration is possible and can produce valid PGM data, and ADS-supported tests would be the preferred source of primary evaluation data in such cases (as indicated by entries with "P*" in the table). Also, there are some cases in which the ADS-supported test allows performance areas to be evaluated which could not be evaluated using only the PGM simulation in a standalone configuration. An example is evaluation of fire control system errors using an LFP-type architecture (in which the actual targeting messages from the live shooter tracking the live target are input into the PGM HWIL laboratory). This linked configuration allows the missile message and initial conditions accuracy to be evaluated, as shown by results of LFP testing [Ref. 5], but the PGM HWIL laboratory by itself cannot evaluate this.

Roles for ADS-supported testing can be identified for both DT&E (in which the general objective is to define PGM capabilities using preproduction PGM subsystems) and OT&E (in which the general objective is to determine the PGM system's operational effectiveness and suitability using production-level PGM systems in realistic combat scenarios).

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Table 2. Performance Evaluation Matrix.

Performance Area	Study	Lab Test	Digital Sim	HWIL Lab	ADS-Supported Test		Captive Flight	Launch
					DSM	HWIL		
Launch Acceptability Regions	X		P	X	P*	X		X
Relative Range (F-Pole)	X		P		P*	X		X
Safe Separation/Launch Envelope			P		P*			P
No-Escapes Zones			P		P*			X
Stability and Control	X		P	X	P*	X		X
Adaptive Gain Control	X		P	P	P*	P*		X
Aerodynamic Performance	X		P		P*			X
Body Bending	X	P						X
Propulsion Management	X	P	P		P*			X
Warhead		P						X
Formation Target Capability	X			P				X
Multiple Target Capability	X			P		P*		X
ECCM Capability				P		P*	X	X
Maneuvering Targets			P	P	P*	P*		X
Lookdown/Shootdown Capability								
RF Background	X			P		P*	P	X
IR/EO Background							P	X
Threat Radar Cross Section	X			P		P*		X
Threat Glint	X			P		P*		X
Threat Signature Polarization	X			P		P*		X
Threat IR/EO Emissions							P	X
IR/EO CCM Capability		X					P	
Chaff							P	
Weather							P	X
Inertial Reference	X	X					P	X
Midcourse Guidance Performance	X		P	X	P*	X		P
Acquisition (Seeker Range)	X	P					P	X
Terminal Guidance Handover and Search	X			P		P*		X
Fuzing		P						P
Lethality (Probability of Kill)			P		P*			X
Weapon System Integration								
Safety of Operation				P		P*		X
Weapon System Operation				P		P*		P
Weapon System Assessment								
Single Aircraft/Missile System	X		P	X	P*	X	X	X
Tactical Environment	X		P	X	P*	X		X
Fire Control System Errors								
Missile Message Accuracy	X		P		P*	P*		X
Initial Conditions Accuracy	X		P		P*	P*		X
Software Assessment	X		P		P*			
Independent Software V&V			P		P*			X

P = primary data source without ADS testing   **P*** = primary data source when ADS testing is valid
X = supporting data source

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DT&E evaluation areas which can utilize ADS include [Ref. 33]
- Evaluation of the guidance section influence on PGM system performance. Currently, this evaluation uses the PGM HWIL laboratory in a standalone configuration. The use of ADS will result in more realistic evaluations.
- Definition of integrated launcher/PGM weapons system capabilities. Currently, this is done with simulations only. The use of ADS can result in much better system integration evaluations. High-fidelity integration can begin prior to having flight/soldier-ready systems.
- Support of live fire tests.
  -- ADS can be used to provide realistic test rehearsals, to refine test scenarios, and to analyze post-test results.
  -- ADS can be used to better extrapolate live fire results to different scenarios.

OT&E evaluation areas which can utilize ADS include
- Evaluation of the PGM system in the tactical environment with representative battlegroup tactics and realistic threat representations. 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 PGM would operate against and have them operate in a realistic "unconstrained" manner. The use of ADS can greatly augment the force density during testing with either manned simulators or DSMs representing the additional forces, as discussed in Section 3.2.2. (DSMs could represent those threat systems for which there is no actual hardware.)
- Support of live fire tests.
  -- ADS can be used to provide realistic test rehearsal, including refinement of live fire scenarios in order to ensure test objectives are met.
  -- ADS can be used for post-test analysis. In particular, ADS can aid in resolving anomalies observed in live fire testing.
  -- ADS can be used to supplement live fire tests. ADS can be used for those scenarios for which it provides valid results, along with live fire tests, to support a cost-effective total testing program (see Table 2 and Appendix B).

3.3 Critical Constraints, Concerns, and Methodologies for PGM T&E

Certain constraints limit the applicability of ADS to PGM T&E. Some of these constraints are due to the HWIL facilities or DSMs used to represent the PGM and are common constraints for both ADS-supported testing and standalone testing. Other constraints result from linking requirements and are related to ADS implementation. The constraints are summarized as follows:
- PGM HWIL limitations.
  -- Limited fidelity of seeker scenes and background.
  -- Restrictions on line-of-sight rates due to seeker table motion limitations.
  -- Limited seeker field of view due to seeker scene presentation.
- PGM DSM limitations.
  -- Limited fidelity of PGM representation and response (since hardware is modeled).

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- Only DSMs which run in real time can be linked to live platforms or manned simulators.
- ADS-related constraints.
  - Real-time applications using the linked laboratory ADS architecture.
    - Maximum allowable latency restricted to 100 milliseconds for highly dynamic missile-fighter aircraft interactions due to dead reckoning limitations. The importance of certain discrete events (e.g., missile launch and detonation) to the engagement fidelity can further restrict the maximum latency to 50 milliseconds.
  - Live target-shooter applications.
    - Testing closed-loop interactions between a simulated missile and a live target aircraft is generally not possible because means do not currently exist for linking the response of the missile to the live target. Techniques are needed to take the missile entity state and seeker emissions data output from the HWIL laboratory (or DSM) and transmit these to the target. Also, the target needs the added capability to receive the transmissions and to use them to drive detection/warning systems and/or to drive automatic countermeasures (CM) responses.
    - Current range safety policy requires control of live range assets to be exercised at the range. While this may be acceptable when only one range is involved, future tests may involve live assets at more than one range or even at off-range locations. Current policy would prevent centralized asset control, which could result in ineffective test control.
  - Currently, only architectures involving a single shooter engaging a single target with a single PGM have been investigated by JADS for PGM T&E applications. In principle it should be possible to link multiple shooters, targets, and weapons. However, there will be latency and synchronization issues to be addressed, along with implementation challenges yet to be discovered (i.e., the "unknown unknowns"). Also, if ADS is used to augment scenarios involving live players with simulated entities, the augmented scenario will only be experienced by the simulated entities and not by the live players, due to the general inability to provide live platforms with useful information on simulated entities.

There are concerns which must be addressed for the proper implementation of ADS. These include the following:
- The cost of implementing ADS. 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 (e.g., about $2 million for LFP), but can be amortized over all phases of a PGM development and testing program.
- The launcher/PGM interface. Those PGM systems which use launcher support require special purpose interfaces for launcher-generated messages passed between the launcher and the PGM HWIL laboratory. Interface requirements must be determined early during ADS implementation planning to permit testing schedules to be met.
- Performing PGM integration testing for advanced launch platforms. Some advanced fighters are being designed to carry missiles internally and do not have external telemetry antennas. This configuration will make it difficult to implement the live shooter-target ADS architecture using the type of instrumentation employed during the LFP testing. It

will likely be necessary to specially modify one of these launch platforms to collect the necessary telemetry data and permit its transmission to ground receivers.
- Determining which standards to use for data exchanges among the ADS nodes. DIS PDU standards do not support all required data exchanges and are not always the best choice. This concern is best addressed by tailoring data protocols for each specific application and implementing the principles of HLA.
- Use of dedicated links. The use of dedicated leased lines may be justified, rather than using existing networks such as DSI, due to latency and reliability requirements and scheduling constraints [Refs. 10, 11]. Each linking application must evaluate its requirements and justify the use of commercial links when appropriate.
- Programmatic concerns.
  -- Management and scheduling are more complex and challenging with distributed tests.
  -- ADS implementation programs should consider forming a separate or special program office with dedicated personnel to handle the financial, contractual, and mission support issues.
  -- A formal agreement or memorandum of understanding should be established between the testing organization and the providers of test support (e.g., test ranges or HWIL facilities).
  -- Security can be a major concern when linking facilities with different security requirements.

A number of methodologies apply for ADS implementation. These are to be developed by the JADS JTF at some later date and are simply listed here:
- Test planning (including cost benefit analysis).
- ADS architecture and instrumentation design.
- Verification and validation (V&V) of the ADS configuration.
- Integration of linked assets.
- Test control.

4.0 ADS Applicability to T&E of Specific PGM Types

4.1 ADS Applicability Assessment Approach

The results from the SIT LSP and LFP testing are generalized by considering other possible representations for the shooter, target, and PGM: The shooter and target can be represented by either DSMs, HWIL laboratories, or live platforms and the PGM can be represented by either DSMs or HWIL laboratories. Linking requirements and constraints learned from the SIT testing are applied to other ADS architectures where appropriate.

The following principles are used to determine the best ADS architecture for a given test:
- The choice of representation for each player depends on (1) the test objectives, (2) the availability of adequate DSMs and HWIL laboratories for simulated players and instrumentation for live platforms, and (3) the details of the test scenarios.
  -- The advantages of DSMs include low cost, good availability, and high reproducibility of results. The disadvantages include the difficulty in adequately modeling human-in-

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the-loop decisions and actions (DSMs usually only model scripted shooter/target profiles) and their lower fidelity compared to HWIL laboratories or live platforms.

-- The advantages of HWIL laboratories include moderate cost, availability, and reproducibility of profiles and the use of human/hardware-in-the-loop. The replay ability of HWIL laboratories makes them especially advantageous for parametric studies. The disadvantages include lower fidelity than live platforms, especially for environmental effects.

-- The advantages of live platforms include the use of real shooter and target platforms in real environments. Realistic testing of shooter data link support to the PGM and tactics development are best done with live shooter/target platforms. The disadvantages include high cost, low reproducibility of profiles, general lack of PGM feedback to the live platforms, and limited TSPI accuracy for dynamic platforms without significant processing latency.

- Some combinations of player representation may not be possible.

-- The linking of a live shooter (or target) with a simulated target (or shooter) may not be possible when the shooter and target are both manned and interact with each other because the means of providing the live platform operator with realistic information/cues on the simulated entity do not exist, in many cases. However, if the target does not react to the shooter, a live target executing a scripted nonreactive profile could be linked to a manned shooter laboratory [Ref. 34]. Such a live target/ simulated shooter combination could be useful in augmenting live scenarios by adding an additional simulated shooter to a few-on-few scenario in which the other players are live.

-- DSMs can be interactively linked with HWIL laboratories or live platforms only if the DSMs run in real time. If the player represented by the DSM does not interact with other players (e.g., a missile fired at a nonreactive target), then the DSM does not have to run in real time.

- High-fidelity results require synchronization between the players.

-- If the players must interact with each other in real time (closed-loop case), this synchronization is best achieved by using second order position dead reckoning (which uses the entity's velocity and acceleration to predict its position) and second order orientation dead reckoning (which uses the entity's attitude rates and angular acceleration to predict its orientation). The dead reckoning is performed at the frame rate of the receiving entity based on absolute time and uses extrapolation to correct for latency and latency variations.

-- If the players do not interact in real time (open-loop case), this synchronization is best achieved by buffering the data exchanged and interpolating it at the frame rate of the receiving entity based on absolute time stamps. Since interpolation is more accurate than extrapolation, this synchronization technique results in more accurate data being provided to the receiving entity. The buffering results in additional latency, but does not affect results for open-loop cases (e.g., scripted target profile).

- Closed-loop interactions require acceptable latencies, dead reckoning corrections, and the means for feedback between players.

-- The amount of acceptable latency for a closed-loop interaction depends on the nature of the reactions involved.

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--- For maneuver reactions, the amount of acceptable latency depends on the rates of change of the translational and rotational accelerations of the entities involved (since second order position and orientation dead reckoning is used) and the allowable position and orientation errors. For highly dynamic missile-fighter aircraft interactions, the allowable latency is on the order of 100 milliseconds.

--- For nonmaneuver, discrete event reactions (e.g., flare, smoke, or chaff deployment or ECM initiation), the amount of acceptable latency is typically about 50 milliseconds [Ref. 18], independent of the motion of the entities involved.

-- The requirement for closed-loop interactions may constrain the types of player representations which can be used.

--- If the shooter and target react to each other prior to PGM launch (a typical scenario), then typically the representation for both must be either manned HWIL laboratories or live platforms.

--- If the target reacts to the PGM, then typically the representation for the target must be a manned HWIL laboratory (since feedback to a live target platform is generally not possible).

- The use of DSMs may simplify the ADS architecture if the DSM can be hosted on the computer controlling another simulated entity. In this case, linking between the DSM and its host is not necessary. For example, many manned aircraft simulators have embedded air-to-air missile DSMs.

4.2 ADS Applicability Assessment Results

The general PGM classes are examined to determine which linking configurations can support testing of each class. For each class, the basic engagement of one shooter engaging one target with one PGM is considered. (The basic engagement can be augmented using ADS, as previously discussed.) The general PGM classes are as follows:

- Air-to-air missile (AAM).
- Surface-to-air missile (SAM).
- Air-to-ground munitions (AGM) and air-to-subsurface munitions.
- Surface-to-surface and subsurface munitions.

4.2.1 Air-to-Air Missile Applications

AAM scenarios involve a highly dynamic shooter and target. This PGM class was directly evaluated during the LSP and LFP testing. Current examples of this class are AIM-9X and AIM-120C. General considerations for applying ADS to this PGM class are given in Section 4.1. Special considerations are as follows:

- If the target interacts with the missile (reactive target) in a closed-loop fashion, the shooter and target should be represented by manned HWIL laboratories and the missile by either an HWIL laboratory or a DSM.

-- If the shooter HWIL laboratory is linked to a missile HWIL laboratory, a special purpose interface will be required to pass initialization, launch, and targeting messages to the missile.

-- Low latencies are required (<100 milliseconds) with second order dead reckoning.

-- The nature of the cues used by the target pilot to react to the missile may dictate the type of simulator needed for the target. For example, if visual cues are needed, a domed aircraft simulator with a high-fidelity, out-the-window display may be required (see Appendix A). However, if the pilot primarily relies on a missile warning system without visual cues, a domed simulator would not be needed.

- A live shooter-target ADS architecture (live shooter and live target linked to HWIL or DSM missile) is best used to evaluate aircraft engagement tactics and data link support to the missile.

-- If the live shooter is linked to a missile HWIL laboratory, a special purpose interface will be required to pass initialization, launch, and targeting messages to the missile.

-- Evaluation of the data link message accuracy may require highly accurate shooter and target TSPI data (TSPI accuracy should be about a factor of ten better than data link message accuracy), and required processing times may prevent this architecture from running in real time.

-- If shooter support is provided via fire control radar (FCR) illumination of the target for semi-active RF guidance, there is no real advantage to using the live shooter-target configuration for evaluating the quality of support. This is because both the shooter FCR return from target and the direct shooter reference signal received by the missile cannot be directly measured in the live environment and must be simulated at the missile node.

4.2.2 Surface-to-Air Missile Applications

SAM scenarios involve a stationary or slow moving surface launcher and a highly dynamic, reactive target. This ADS application has been investigated in previous studies [Ref. 12]. General considerations for applying ADS to this PGM class are given in Section 4.1. Special considerations are as follows:

- The shooter (launcher) may or may not have to be represented as a separate entity.

-- The launcher and its radar are often part of the SAM simulation. In this case, linking between the shooter and SAM is not required.

-- If the launcher is mobile, it may be desirable to use a manned HWIL laboratory or live platform for the shooter, depending on the nature of the scenario and the test objectives (e.g., if the shooter maneuvers in response to the target before launching the SAM or if a human decision is needed to launch the SAM).

-- A live shooter can be linked to a simulated target in this case because the shooter only relies on radar detection, and this can be simulated.

- If the target reacts to the missile, the target should be represented by a manned HWIL laboratory and the missile by either an HWIL laboratory or a DSM.

-- Low latencies are required (<100 milliseconds) with second order dead reckoning.

-- As for the AAM application, the nature of the cues used by the target pilot to react to the missile may dictate the type of simulator needed for the target.

- If the target reacts to the shooter radar by employing ECM, but does not react to the missile, either a linked laboratory or a live shooter-target ADS architecture can be used. (The ECM can be designed to affect both the shooter radar and the SAM seeker, but its employment is a reaction to the shooter radar only.)

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-- The linked laboratory architecture would have all three players represented by HWIL laboratories (the shooter and SAM might be represented by the same HWIL laboratory). The target would determine when the ECM begins, but the actual ECM would be applied in the shooter/PGM HWIL laboratory.

-- The live shooter-target ADS architecture would use a live shooter radar tracking a live target aircraft with an ECM pod. The live players would be linked to a SAM HWIL laboratory for the missile flyout, and ECM would also be applied in the laboratory if the ECM is designed to affect the SAM, as well as the shooter radar.

- A live shooter-target ADS architecture is best used to evaluate realistic shooter radar performance against a real target which may be employing ECM against the shooter.

-- Evaluation of the launcher radar tracking accuracy requires highly accurate target TSPI data, and required processing times may prevent real-time operation.

4.2.3 Air-to-Ground Munitions and Air-to-Subsurface Munitions Applications

These scenarios involve a dynamic shooter and either a stationary or slow moving ground or subsurface target. Some types of these munitions require shooter support, such as laser illumination of the target or data link messages. Also, the support can be from a platform other than the shooter (third party support). Current examples of AGMs are JDAM, HARM, JSOW, JASSM, SLAM-ER. General considerations for applying ADS to this PGM class are given in Section 4.1. Special considerations are as follows:

- ADS implementation would be well-suited to the evaluation of AGM attacks on targets employing reactive CM.

-- The shooter would best be represented by a manned HWIL laboratory and the AGM by either a DSM or an HWIL laboratory.

-- The target representation required would depend on whether the target is fixed or mobile and whether maneuvering is part of its reaction. (In general, these targets are slow moving so that maneuvering would not be an effective CM.) For targets which do not maneuver, but only employ CM techniques such as flares, smoke, ECM, etc., the target representation could be simplified to only a shooter/launch detection and a CM deployment function.

-- CM designed to counter the AGM would be added to the seeker scene in the AGM DSM or HWIL laboratory when employed by the target. Latency requirements would depend on the nature of the CM and scenario details and must be analyzed on a case-by-case basis.

- A live shooter-target ADS architecture is best used to evaluate realistic support of the AGM by laser illumination of the target.

-- The laser hit spot on the target and the reflected laser energy would be measured by a detector. The measurement would be used to dynamically scale and position the laser energy presented to the AGM seeker in an HWIL laboratory.

-- The laser energy detector could be located on the shooter, but would generally be at an independent (possibly fixed) location. When the detector is at an independent location, a separate node would be added to the ADS architecture.

-- If the laser illumination is provided by a third party, entity state or other data may be required for this additional player. In this case, another node would be added to the

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ADS architecture for the third party. (However, the AGM and shooter may not need to "know" anything about the third party, but only the intensity of the reflected laser energy. In that case, no data may have to be passed directly from the third party.)
- A live shooter-target ADS configuration could also be appropriate if target CM are directed against the shooter rather than the AGM.

4.2.4 Surface-to-Surface and Subsurface Applications

These scenarios involve a slow or stationary shooter and target. As for AGM, some types of these munitions require shooter support. The surface-to-surface ADS application is currently being investigated for FOTT testing [Refs. 28, 35], and the subsurface application is being investigated for torpedo testing and training [Refs. 29, 30]. General considerations for applying ADS to this PGM class are given in Section 4.1. Special considerations are as follows:
- Most of the special considerations for AGM and air-to-subsurface munitions applications also apply to these PGM classes.
- The live shooter-target ADS architecture cannot be used to test wire-guided munitions, in general, since feedback between the shooter and the PGM is needed.
- Wire-guided munitions are best tested using linked laboratories with the shooter and PGM represented by HWIL laboratories and the target by either a DSM or HWIL laboratory. This is the architecture currently being developed for FOTT testing at Redstone Arsenal, Alabama, [Ref. 35] although future planned enhancements will slave a live shooter (soldier) on a test range to the shooter HWIL laboratory.
- The Synthetic Environment Tactical Integration Virtual Torpedo Project (SETI VTP) at the Naval Undersea Warfare Center (NUWC) in Newport, Rhode Island, is developing an HLA federation to link live submarines to a high-fidelity torpedo HWIL facility [Refs. 29, 30].

5.0 Summary

The findings from the two phases of SIT testing were extrapolated to PGM classes other than AAM, and it was determined that various ADS architectures appear to have utility for supporting PGM T&E in general and that there are benefits to using ADS when it is appropriate. The shooter and target can be represented by live platforms, manned HWIL laboratories, or DSMs, and the PGM can be represented by either HWIL laboratories or DSMs. The choice of player representation depends on (1) the test objective, (2) the availability of adequate DSMs and HWIL laboratories for simulated players and instrumentation for live platforms, and (3) the details of the test scenarios (such as whether the target reacts to the PGM or not).

The assessment gave general guidelines for ADS implementation for various classes of PGM. Detailed requirements for linking specific PGM systems (other than the AIM-9M and AIM-120 missiles addressed by the LSP and LFP) were not developed. Also, some characteristics of specific PGM systems may have been overlooked which could impact the ADS architecture design and feasibility of implementation. The extrapolation of SIT results to PGM classes other than AAM was based on informed conjecture without rigorous analysis or supporting data. Applications were assumed to be feasible unless there was evidence to the contrary.

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6.0 Abbreviations and Acronym List

A/C   aircraft
AAM   air-to-air missile
AASI   Advanced Aircraft Simulation Interface
ADS   advanced distributed simulation
AFB   Air Force Base
AFDTC   Air Force Developmental Test Center
AGM   air-to-ground munitions
AIM   air intercept missile
AMRAAM   Advanced Medium Range Air-to-Air Missile
ASC   Aeronautical Systems Center (at Wright-Patterson AFB, OH)

BMIC   Battle Management Interoperability Center (control facility at Point Mugu, CA)
BVR   beyond visual range

C4I   command, control, communications, computers, and intelligence
CCF   Central Control Facility (at Eglin AFB, FL)
CCM   counter-countermeasures
CM   countermeasures
COMSEC   communications security
coord   coordination
CSU   channel service unit

DIS   distributed interactive simulation
DISA   Defense Information Systems Agency
DISN   Defense Information Systems Network
DMSO   Defense Modeling and Simulation Office (Alexandria, VA)
DoD   Department of Defense
DRA   dead reckoning algorithm
DSI   Defense Simulation Internet
DSM   digital simulation model
DSU   data service unit
DT&E   developmental test and evaluation

ECCM   electronic counter-countermeasures
ECM   electronic countermeasures
EO   electro-optical
EOA   early operational assessment
ESSM   Evolved Sea Sparrow Missile
ETE   End-To-End Test
EW   electronic warfare

FCR   fire control radar
FEDEP   Federation Development and Execution Process

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FOM	federation object model
FOT&E	follow-on test and evaluation
FOTT	Follow-On To TOW (Tube-launched Optically tracked Wire-guided)
FOV	field of view
F-Pole	range between the launch aircraft and the target aircraft at the time an air-to-air missile intercepts the target
GPS	global positioning system
HARM	High-speed Anti-Radiation Missile
HLA	high level architecture
HQ	headquarters
HWIL	hardware-in-the-loop
INS	inertial navigation system
IOT&E	initial operational test and evaluation
IR	infrared
IRIG	Interrange Instrumentation Group
JADS	Joint Advanced Distributed Simulation
JASSM	Joint Air-to-Surface Standoff Missile
JDAM	Joint Direct Attack Munition
JSF	Joint Strike Fighter
JSOW	Joint Stand-Off Weapon
JT&E	Joint Test and Evaluation
JTF	Joint Test Force
lab	laboratory
LAN	local area network
LFP	Live Fly Phase
LSP	Linked Simulators Phase
MISILAB	Missile Simulation Laboratory (AMRAAM HWIL lab at Eglin AFB, FL)
MOA	memorandum of agreement
msl	missile
NTP	network time protocol
NUWC	Naval Undersea Warfare Center (Newport, Rhode Island)
OA	operational assessment
OT	operational test
OT&E	operational test and evaluation
OTW	out-the-window
PDU	protocol data unit

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PGM	precision guided munitions
POC	point of contact
RDL	rear data link
RF	radio frequency
RTI	runtime infrastructure
RWR	radar warning receiver
SAM	surface-to-air missile
SETI VTP	Synthetic Environment Tactical Integration Virtual Torpedo Project (at NUWC, Newport, Rhode Island)
sim	simulation
SIMLAB	Simulation Laboratory (AIM-9 HWIL lab at China Lake, CA)
SIPRNET	Secure Internet Protocol Router Network
SIT	System Integration Test
SLAM-ER	Standoff Land Attack Missile - Expanded Response
SMS	stores management system
SUT	system under test
T&E	test and evaluation
TCAC	Test Control and Analysis Center
TDP	TSPI Data Processor
tgt	target
TM	telemetry
TOW	Tube-launched Optically-tracked Wire-guided
TSPI	time-space-position information
umb	umbilical
V&V	verification and validation
VV&A	verification, validation, and accreditation
WAN	wide area network
WSIC	Weapon System Integration Center (F-14D manned flight lab, Point Mugu, CA)
WSSF	Weapon System Support Facility (F/A-18 manned flight lab, China Lake, CA)

UNITS OF MEASURE

°	degree
g	acceleration due to gravity $\cong$ 32 ft/s^2 or 9.8 m/s^2
m	meter
ms	millisecond

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APPENDIX A

USE OF DOMED FLIGHT SIMULATORS FOR MISSILE TESTING

A study performed by the JADS JTF System Integration Test Team

USE OF DOMED FLIGHT SIMULATORS FOR MISSILE TESTING

A.1.0 Introduction

A major limitation in open air range live fire testing of AAMs or SAMs is the inability to evaluate target reactive CM due to prohibitions against firing a live missile at a manned target. ADS can provide such a testing capability by linking manned flight simulators to missile HWIL laboratories or DSMs. However, the simulators must be capable of providing all essential visual, aural, and sensor cues to the target pilot. In particular, the target pilot should receive visual launch cues and cues from missile warning systems [Ref. A-1].

This study evaluates the value to AAM and SAM T&E of providing visual cues to the target pilot by use of a domed manned flight simulator and the feasibility of existing domed simulators to provide realistic visual cues and to support AAM and SAM T&E.

A.2.0 Value to Air-to-Air Missile and Surface-to-Air Missile T&E

The primary value to AAM and SAM T&E of providing realistic visual cues to the target pilot is that more realistic evaluations of the effectiveness of target CM tactics would be possible (or, conversely, the effectiveness of missile reactions to target CM tactics could be evaluated). Visual cues would be useful for the following:
- Prelaunch maneuvering against the shooter (AAMs only). The best defensive tactic for the target is to prevent the shooter from achieving a favorable launch geometry. This is especially true for short range AAMs (e.g., AIM-9) launched within visual range. A high-fidelity, out-the-window (OTW) display in the target simulator would allow realistic simulation of such maneuvering for short range visual engagements. However, it should be noted that most radar-guided missiles (e.g., AMRAAM and Sparrow) are normally launched beyond visual range (BVR), so that visual prelaunch cues will not be available for the target pilot in such cases.
- Missile launch cues. The most reliable launch cue is nonvisual and comes from the target's radar warning receiver (RWR). For BVR shots there will be no visual launch cue. For AAM shots within visual range the target will use visual cues to maneuver in response to the shooter up to and through launch. For both AAM and SAM launches within visual range the target may get a visual launch cue such as a puff of smoke or flash from the missile or may see the missile leave the launcher. These cues from the missile itself are unreliable, as they depend on environmental conditions and the launch occurring within the target pilot's field of view (FOV).
- Cues for post-launch evasive maneuvering. The target pilot will generally not get visual cues from the missile during its flyout, unless the launch is at night or the missile emits visible smoke. For a smokeless missile (typical of modern AAMs) launched during daylight, the target pilot will be unable to discern the missile until its range is so small (and its remaining time of flight is so short) that human reaction times prevent the pilot from responding in time. For an AAM engagement within visual range, the target pilot will continue to maneuver in response to the shooter using OTW visual cues, such as the

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angle of the horizon and ground references, in executing high-acceleration evasive maneuvers. A high-fidelity, OTW display would provide these cues.

The conclusion is that a domed manned flight simulator with a high-fidelity, OTW display would add realism for pre- and post-launch evasive maneuvering and would provide launch cues in some (but not all) engagements. The presence of visual missile launch and flyout cues and their value in aiding the target pilot depends on the type of missile, environmental conditions, and engagement scenario details, especially launch range.

A.3.0 Domed Simulator Requirements

In order for a domed manned flight simulator to be able to support AAM and SAM T&E, it must meet requirements for realism of the visual display and allowable latency for real-time linking.

A.3.1 Visual Display Requirements

The OTW display provided to the target pilot must provide realistic cues for the missile launch and for effective evasive maneuvering. The suitability of displays for these purposes is best judged by experienced fighter pilots. The relevant display qualities were defined by pilots in an Aeronautical Systems Center (ASC) technical report [Ref. A-2] and are summarized as follows:

- Full FOV. A full FOV, including the periphery, is needed by the pilot to perform the visual tasks encountered during combat. Anything less than full FOV viewing limits combat tasks that can be performed in a flight simulator. The display must respond to pilot head and eye movement without requiring exaggerated and unrealistic head movement.
- Adequate resolution and detail. The resolution of various scene features needs to be sufficient to provide essential visual cues to the pilot.
  -- There must be adequate resolution in the periphery.
  -- The visual display of missiles and aircraft must be sufficiently detailed.
  -- Ground features must be presented with adequate detail (resolution) and texture to allow the pilot to determine altitude visually.
- Realistic contrast. The visual display of threat aircraft must be realistic in contrast against the background to properly aid in pilot detection and tracking.
- Realistic entity presentation. The visual display of missiles and aircraft must be realistic in color, relative size, detail, and any relevant emissions (e.g., smoke or fire).
- Minimal latency. The display must not have a perceptible lag (i.e., latency).

A.3.2 Latency Requirements

The processing of data at ADS nodes and the transmission of data among nodes results in delay or latency in the receipt of data. Latency, if not properly compensated for, can prevent an accurate interaction between simulation entities. In particular, latency and its variance compromise spatial correlation.

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In a study of latency effects on aircraft simulations, a testbed was constructed using DIS-compatible F-15 simulations [Ref. A-3]. DIS PDU output of an F-15 was passed to a network, subjected to a variable delay, and then passed back to the network interface just as though it had been received from the network. The position and orientation of the entities received from the network were compared to that of the internal models and the average and maximum differences were recorded. Dead reckoning algorithms (DRAs) were used to reduce the position and orientation differences, and the smallest differences were for DRAs which used second order position dead reckoning (which uses the entity's velocity and acceleration to predict its position) and first order orientation dead reckoning (which uses the entity's attitude rates to predict its orientation). Resulting errors when the aircraft simulation was executing highly dynamic maneuvers (with instantaneous accelerations up to 9 g) are given in Table A-1 for various network delays.

Table A-1. Aircraft Simulator Errors for Highly Dynamic Maneuvers Versus Network Delay (second order position, first order orientation DRA used) [from Ref. A-3].

Network Delay (ms)	Average Position Error (m)	Maximum Position Error (m)	Average Orientation Error (°)	Maximum Orientation Error (°)
0	0.43	2.4	0.89	4.57
100	0.57	3.79	1.5	8.26
200	0.87	6.03	2.55	13.5
300	1.46	8.71	4.23	21.03
400	2.16	10.25	5.99	29.21
500	3.13	13.56	8.01	38.03

The results in the table show that the total latency must be no larger than about 200 ms if average position errors are to be less than 1 m and no larger than about 100 ms if average orientation errors are to be about 1°. However, position errors up to almost 4 m and orientation errors up to more than 8° can occur for a latency of 100 ms. Reducing the maximum orientation error to 1° or less will require the use of second order orientation dead reckoning (which uses the entity's attitude rates and angular acceleration to predict its orientation). These results apply to two aircraft maneuvering against each other.

For the situation of a missile interacting with a target fighter, the latency requirement for position accuracy can be analyzed based on the use of a second order position DRA and the maximum missile acceleration. From LFP data, the largest missile acceleration was about 20 g. Then, the total latency must be no larger than 100 ms if the missile position error is to be 1 m or less [Ref. A-4].

The criterion for the allowable position error is that the maximum error must be a fraction (10% to 50%) of the missile's lethal radius, so that the missile and target do not disagree on whether or not the target was killed. Based on this criterion, the latency must be less than 100 ms and

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second order position and orientation dead reckoning must be used. However, certain event information (e.g., missile launch) cannot be predicted, and latency compensation cannot be provided for these events. For such events, there are absolute latency requirements which depend on the scenario details, such as how the target processes launch notifications. A rule of thumb is that allowable latencies for discrete events are about 50-100 ms [Ref. A-4].

The conclusion is that end-to-end latencies between a missile simulation (either an HWIL laboratory or a DSM) and a manned domed aircraft simulator must be 50-100 ms.

A.4.0 Domed Simulator Evaluation

Current manned domed aircraft simulators are now evaluated against the requirements identified in Section A.3.

A.4.1 Visual Display Requirements Evaluation

The conclusion of the ASC technical report [Ref. A-2] was that current systems do not provide adequate resolution, contrast, and brightness to allow realistic air-to-air engagements. Some of the specific deficiencies are as follows:
- A number of tasks could not be adequately performed. These include visual lookout, detect visual threats, single ship threat reactions, and low altitude intercept.
- Most simulators did not have realistic threat presentations, including:
  -- Threats were too easy to see due to their exaggeration and/or bright false color.
  -- Threats did not have proper contrast to the background.
  -- Threats lacked sufficient detail to allow judging range, closure rate, and aspect angle.
- The ground presentation was not realistic, so that the pilot's altitude could not be judged based on visual cues.
- Some simulators did not respond to eye movement and required exaggerated head movement to view scene details.
- The helmet-mounted display evaluated did not allow pilots to easily cross-check cockpit instruments and restricted the pilots' head movements for checking aft areas.
- The pilots reported noticeable lags (latency) in the visual scene response to head movements.

All visual systems had at least one of these deficiencies, so that none were judged to be adequate. The ASC report included recommendations for improving the visual systems in future aircraft simulators.

A.4.2 Latency Requirements Evaluation

A number of measurements of the latencies of linked domed manned aircraft simulators have been performed. When existing simulators are linked with no attempt to reduce processing times or improve interfaces, latencies as high as 700 ms have been measured between the initiation of a maneuver at one simulator and the observation of the maneuver at another simulator [Ref. A-5]. By modifying the image generation system and upgrading interfaces, Wright Laboratory, Wright-

Patterson Air Force Base, Ohio, was able to reduce the latency of the image response to a maneuver from about 500 ms to about 225-250 ms for an unlinked domed simulator [Ref. A-6].

Even with special modifications, the latency of a linked domed aircraft simulator significantly exceeded the requirement of 50-100 ms.

However, if a lower fidelity DSM representation is used for the missile, rather than an HWIL laboratory, it should be possible to reduce the latency between a domed aircraft simulator (representing the target) and the missile DSM to the required range, especially if the missile DSM is hosted on the same computer that controls the aircraft simulator. The target domed simulator could be linked to a shooter man-in-the-loop simulator (which could be a domed simulator for AAM testing) for realistic pre- and post-launch maneuvering against the shooter and shooter initiation of the launch. The shooter-target link would have relaxed latency requirements (compared to the 50-100 ms value between the target and missile) which should be achievable with existing simulators.

A.5.0 Conclusions and Recommendations

Current domed manned aircraft simulators are inadequate for supporting AAM and SAM T&E in which closed-loop interactions between the missile and target aircraft are investigated. The visual displays do not provide realistic cues, and the latencies of domed simulators are too large when linked to a missile HWIL laboratory.

The use of domed simulators with suitable performance attributes would provide added value to the investigation of closed-loop interactions. Hence, it is recommended that progress in future domed simulators be monitored for potential implementation in ADS-based testing involving missile HWIL laboratory.

In the meantime, there are two lower fidelity options for evaluating closed-loop target-missile interactions:
- The use of a DSM for the missile linked to a domed simulator for the target.
- The use of manned aircraft laboratories which do not have high-fidelity visual displays (nondomed laboratories) linked to a missile HWIL laboratory. In this case, the cue for the target pilot is provided by a missile warning system or other nonvisual means. The latencies for nondomed aircraft laboratories are significantly smaller than for domed simulators; during LSP testing, the average latency between the WSIC target laboratory and the SIMLAB AIM-9M HWIL simulation was 70 ms [Ref. A-7].

Either low-fidelity option could permit the development of missile warning system requirements (e.g., how much warning time is required to increase target survivability?) or evaluation of the effectiveness of missile responses (i.e., counter-countermeasures) to reactive target CM cued by a missile warning system.

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APPENDIX B

COST BENEFIT ANALYSIS FOR ADS-BASED TESTING

A study performed by the JADS JTF System Integration Test Team

COST BENEFIT ANALYSIS FOR ADS-BASED TESTING

B.1.0 Introduction

The SIT LFP and LSP ADS architectures provided valid results for air-to-air missile T&E and have been judged to have utility for several types of missile performance and launcher integration evaluations. Because of the high cost of expending missiles and destroying target drones in live fire tests, a high-fidelity, non-destructive ADS-based test of the missile has the potential to save significant money, especially if ADS-based testing is utilized over several phases of test.

This appendix lays out a general methodology for determining the cost effectiveness of implementing ADS-based testing in a PGM test program and provides a cost savings analysis example. Two approaches to cost effectiveness are addressed: (1) a cost savings approach and (2) a more effective test approach. For the first approach total testing costs are reduced by replacing a limited number of live fire tests with ADS-based tests. In the second approach, ADS-based tests are added without eliminating any live fire tests, so that the total testing costs are higher, but with some compensating qualitative benefits.

B.2.0 General Methodology

The general cost-effectiveness methodology focuses on qualitative benefits as well as quantitative cost factors. The outline of the methodology is as follows:
- Analyze the appropriate use of ADS in the total acquisition and testing program.
  - -- Estimate the potential benefits of implementing ADS-based testing.
  - -- Determine any probable testing constraints which might limit ADS implementation.
- Estimate costs with and without ADS implementation.
  - -- If ADS-based testing results in lower testing costs, quantify cost savings and assess benefits and deficits of ADS use. (Slight deficits may be outweighed by significant cost savings.)
  - -- If ADS-based testing costs about the same, determine the benefits or deficits of using ADS.
  - -- If ADS-based testing results in higher total testing costs, determine if the benefits justify the increased costs or if other program costs can be traded off.
- Structure an optimal/near optimal ADS-enhanced testing program based on the appropriate balance between cost savings and qualitative benefits.

The following subsections describe each of the methodology steps in more details.

B.2.1 Appropriate Use of ADS

The general role of ADS in PGM T&E was discussed in Section 3.2.3, and Table 1 from that section identified the various performance evaluation techniques used for PGM T&E, including ADS-supported tests. Although the discussion in that section focused on the role of ADS in PGM DT&E and OT&E, ADS can support the other testing phases, including early operational

assessment (EOA), operational assessment (OA), initial operational test and evaluation (IOT&E), and follow-on operational test and evaluation (FOT&E). This is illustrated in Figure B-1.
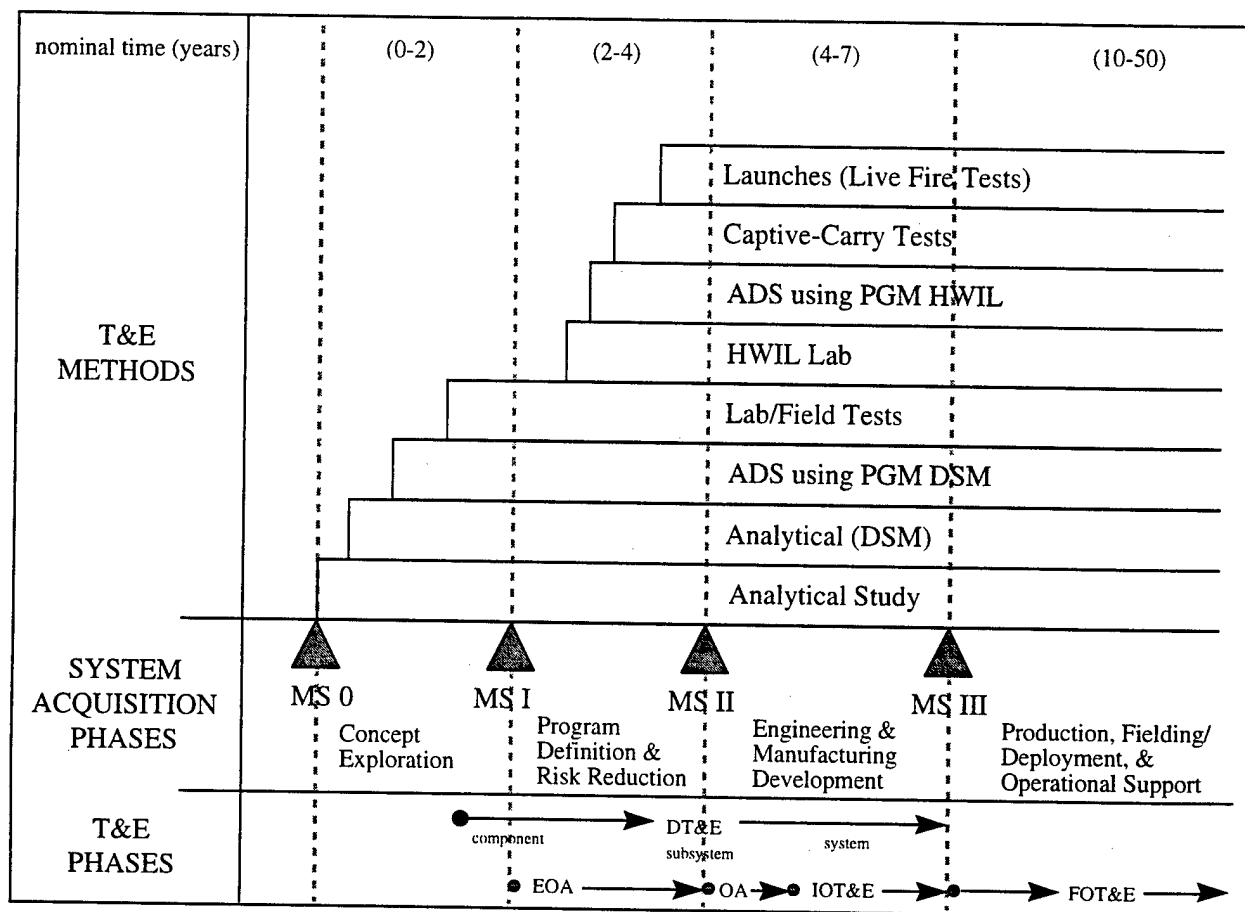
nominal time (years)	(0-2)	(2-4)	(4-7)	(10-50)

T&E METHODS

Launches (Live Fire Tests)

Captive-Carry Tests

ADS using PGM HWIL

HWIL Lab

Lab/Field Tests

ADS using PGM DSM

Analytical (DSM)

Analytical Study

SYSTEM ACQUISITION PHASES

MS 0 — Concept Exploration

MS I — Program Definition & Risk Reduction

MS II — Engineering & Manufacturing Development

MS III — Production, Fielding/ Deployment, & Operational Support

T&E PHASES

component → DT&E — subsystem — system →

EOA → OA → IOT&E → FOT&E →

Figure B-1. Role of ADS-Based Testing During PGM System Acquisition and Testing Life Cycle.

As Figure B-1 shows, a PGM DSM normally becomes available during the initial system acquisition phase, so that ADS-based evaluations which use a PGM DSM can begin during this phase (e.g., for requirements development), even before formal T&E begins. As soon as prototype PGM hardware is developed during the second acquisition phase, all T&E methods can begin to be used, as appropriate. As system acquisition proceeds, all T&E methods can continue to be used to test the evolving PGM system and subsystems. The optimal use of the various methods depends on the PGM performance areas being evaluated, as Table 2 in Section 3.2.3 shows. Note from Figure B-1 that ADS-based testing can be used throughout the system acquisition and testing life cycle as PGM simulation resources are developed and refined, and considerations for applying ADS to PGM T&E are discussed in Section 4.

B.2.1.1 ADS Benefits

In analyzing the appropriate use of ADS in the total testing program, the potential benefits of adding ADS should be evaluated. General benefits were discussed in Section 3.2.2 and fall into the categories of cost savings, improved testing, and more efficient testing. Potential cost savings are determined in the next step, but any benefits from improved or more efficient testing should be considered before proceeding. These are repeated from Section 3.2.2 and expanded.

- Improved testing benefits.
  - Testing using a linked laboratory ADS architecture is more reproducible than live fire testing, because scenario conditions are more readily controlled and trials can be replayed for additional PGM responses. This allows more trials to be combined for analysis, giving greater confidence in evaluation results.
  - Testing using manned shooter and target simulators linked to a PGM DSM or HWIL laboratory can be used to realistically evaluate man-in-the-loop reactive CM. This cannot be done in live fire testing due to obvious safety constraints.
  - ADS-supported testing allows the evaluation of certain classified techniques in which the ECM device cannot be permitted to radiate its RF emission on an open range. Rather, the ECM emissions can be restricted to the PGM HWIL laboratory where they are screened from unauthorized observation and where the effects of the ECM on PGM performance can be immediately observed by analysts.
  - ADS allows the force density of the scenario to be increased. The number of friendly and threat systems can be increased by representing them with either manned laboratories (if realistic man-in-the-loop control of the systems is needed) or DSMs (if scripted behavior is acceptable). The inability to evaluate system performance in combat-representative environments is a common limitation in OT&E and an area in which ADS can improve the operational test (OT) environment.
  - ADS-supported tests exhibit more realism than either analytical simulation models (because actual hardware is used) or standalone HWIL laboratories (because realistic shooter and target inputs are provided).
  - The live shooter-target ADS architecture can be used for realistic engagement tactics development and evaluation.
- More efficient testing benefits.
  - Shooter/PGM integration can be effectively evaluated using ADS configurations.
    - Integration check out can begin early in the acquisition cycle before a complete PGM system is available by using the linked laboratory ADS configuration and including only key PGM subsystems in the PGM HWIL laboratory. Note that this same configuration can also be used to verify the integration of a new shooter platform to an existing PGM system.
    - If the PGM receives data link support from the shooter during its flyout, the live shooter-target ADS configuration can be used to accurately evaluate the quality of the support messages.
  - Testing using a live shooter-target ADS architecture is more efficient than live fire testing because the analysts get immediate feedback on each trial of a multiple trial mission. This allows adjustments to be made to the remaining test matrix, if necessary, while the live shooter and target platforms are still on range. This

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"analyst-in-the-loop" feature of ADS testing would be especially useful in efficiently progressing through an ECM testing matrix which involves varying a number of ECM-related parameters. (Up to 15 trials were executed during each two-hour SIT LFP mission.)

-- Live fire tests can be realistically rehearsed using ADS. This would ensure the proper setup of the scenario and reduce wasted live fire attempts in which the proper scenario conditions are not achieved or would result in anomalies (i.e., cost avoidance). This use of ADS would also reduce the risk of a live fire testing program by identifying scenarios which cannot be correctly executed or which cannot achieve the stated objectives.

Also, ADS implementation may benefit other parts of the PGM acquisition program besides testing. ADS using a DSM to represent the PGM may aid in requirements development, and resources developed during ADS implementation may be useful for training. Such benefits of ADS implementation which are beyond the normal scope of testing should also be considered in this determination.

B.2.1.2 ADS Implementation Constraints

Constraints and limitations in applying ADS must be considered when determining the appropriate use of ADS-based testing. These include any constraints in using the candidate PGM simulation being considered for linking and any ADS-related constraints, as discussed in Section 3.3. The result of considering these constraints will be a determination of which PGM test scenarios and conditions can be adequately evaluated using ADS-based testing (i.e., which scenarios/conditions are viable candidates for ADS-based testing).

B.2.2 Test Program Costing

As discussed in Section 3.2.2, the benefits of ADS-supported testing are best realized when this technique is added to a total PGM testing program and is used to supplement, rather than replace, other testing techniques. Therefore, a total testing program should be developed with and without ADS-supported testing. Major cost elements for each testing technique are as follows:

- Non-recurring costs. Each testing technique will require development and verification before PGM testing can begin. The cost of implementing ADS-based testing can be significantly reduced if ADS is planned for as the other testing resources are developed (so that no major modifications of other resources, such as HWIL laboratories, will be needed for ADS implementation and interface costs will be minimized).
- Live fire tests. The most significant recurring costs are for the PGM, target drone, and test range support.
- Captive-carry tests. The main recurring cost is for test range support, including use of the shooter and target platforms and the captive-carry PGM pod.
- Standalone HWIL tests. The main recurring cost is for HWIL facility operation.
- ADS tests using live shooter-target configuration. The recurring costs combine the cost of a captive-carry mission and standalone HWIL tests with the cost of any additional real-time processing of the data transferred from the live platforms to the PGM HWIL

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laboratory. As a result, this type of ADS test will usually cost more than just a captive-carry mission combined with a standalone HWIL test in which data captured from the captive-carry mission are replayed to drive the HWIL laboratory post-mission.

- ADS test using linked HWIL laboratories. The recurring costs will be the sum of the costs for operating each laboratory plus the cost of any additional real-time processing of the transferred data.

The cost elements are combined with proposed testing programs which either implement or do not implement ADS-based testing in order to determine the total costs of the two candidate programs (with and without ADS).

B.2.2.1 Cost Savings Case

The largest potential cost savings occur when ADS-based tests are used to replace some of the live fire tests. Typically, the cost of the PGM and the target drone is much more than the range support cost (e.g., the AMRAAM missile and QF-106 drone cost about $550,000, compared to about $50,000 for range support). The replacement of a live fire test with an ADS-based test essentially saves the cost of the PGM and target, since the range support cost for the live test is nearly the same as the recurring cost of the ADS test.

However, there are limitations in eliminating live fire tests, because public law requires some live PGM testing and because there is usually a minimum number of live shots needed to evaluate the PGM reliability. If the number of live shots is already at the minimum needed for the reliability evaluation, then none of the live shots can be replaced with ADS-based tests. In this case, the blending of ADS into the PGM testing program will normally result in increased cost (unless the ADS-based tests can replace some of the non-ADS simulation testing at no additional cost), and the benefits of using ADS-based tests must be carefully evaluated against the increased costs.

If some of the live fire tests can be replaced with ADS-based tests without impacting other testing requirements (e.g., the reliability determination), then the maximum allowable number of replacements is determined. The test matrix/scenarios/conditions are then examined to determine which of these are best accomplished using live fire tests and which can be adequately tested using ADS (see Section B.2.1.1), up to the maximum allowable number of replacements. Note that each live fire test can only evaluate a single scenario, but that each ADS-based test mission can usually evaluate multiple scenarios (e.g., during LFP testing, a single two-hour mission consisted of about 15 separate passes, each of which could have used a separate profile/scenario) or repeat the same scenario multiple times for added confidence. Hence, there can be considerable leverage in replacing live shots with ADS-based tests (more test conditions/trials can be evaluated at a lower cost).

B.2.2.2 No Cost Savings Case

For testing programs in which no live fire tests can be eliminated, it may be possible to add ADS-based testing without increasing the total testing costs. This would be done by replacing some of

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the tests using standalone simulation techniques with ADS-supported tests. As discussed in Section 3.2.3, there are some cases in which ADS-supported tests allow PGM performance areas to be evaluated which could not be evaluated using the PGM simulation in a standalone configuration. This is especially true for those cases in which it is necessary to provide man-in-the-loop shooter and target inputs to the PGM simulation.

In general, each ADS-supported test will cost more than the corresponding standalone simulation test. Thus, in order to keep the total testing costs constant, it will be necessary to only replace a fraction of the standalone tests, and the ADS-supported test cases must be carefully selected to be only those which require linking for valid results.

Even in those cases in which some live fire tests can be replaced with ADS-based tests, the preference may be to keep the total testing costs constant by adding the appropriate number of ADS-based missions to replace each live test. This would allow many more test scenarios/conditions to be evaluated during the testing program. For example, results from the SIT LFP show that when the cost of an AMRAAM missile and a QF-106 drone are considered, a single live AMRAAM live fire test could be replaced by about ten ADS-based tests which use the LFP ADS architecture at no additional cost. Further, each of these two-hour ADS missions can normally execute about 15 passes. Hence, for this example, it would be possible to trade off one live fire test profile against 150 ADS-supported test profiles. The result would be greater confidence in the results of the PGM evaluation.

B.2.2.3 Cost Increase Case

When ADS-based tests are merely added to a total testing program without replacing any of the other testing techniques, then the total testing costs will increase. In this case, as in the "no cost increase" case, it is necessary to carefully select test scenarios/conditions for ADS implementation and to thoroughly evaluate the added benefits of using ADS in the testing program versus the increased costs. A potential benefit which should be considered by the PGM program manager is cost avoidance due to reduced risk. If improved testing in any program phase would result in a significant reduction of the risk of redesign or redevelopment, the program manager could trade off the cost avoidance against the investment in ADS-based testing.

Using ADS-based testing would not necessarily result in an increase in the total cost of the PGM acquisition program in this case. Because of the benefits of adding ADS-based testing, the PGM program manager should consider trading off other program costs (e.g., those for requirements definition or training, since ADS configurations may be able to assist in these areas) in order to implement ADS-based testing without increasing the total program cost.

B.2.3 Optimal ADS-Enhanced Testing Program

After completing the analysis in the previous methodology step, it should be straightforward to construct the optimal ADS-enhanced testing program. The resulting program would be justified by cost savings, qualitative benefits, or a combination of these.

B.3.0 Cost Benefit Examples

B.3.1 Cost Elements Example

Cost data were collected during the SIT LFP for the costs of implementing the LFP ADS architecture, conducting AMRAAM testing using this architecture, and conducting AMRAAM testing using traditional, non-ADS testing techniques. The approximate costs for executing each testing technique are as follows (test planning and data analysis costs are not included):

- Live fire test cost: about $600,000, including the cost of the AMRAAM and target drone ($600,000 per pass).
- Captive-carry flight test cost: about $24,000 for a two-hour mission which can perform 15 passes ($1600 per pass).
- Standalone HWIL mission cost: about $7,000 for a two-hour mission which can nominally perform 25 runs ($280 per run).
- LFP ADS mission cost: about $44,000 for a two-hour mission which achieves 15 passes (~$2900 per pass).
- LFP ADS implementation cost: about $2 million, including the cost of developing the AASI special-purpose interface, modifying/upgrading Eglin range capabilities and facilities, and integration testing. Note that a portion of the cost was for upgrading Eglin range capabilities (e.g., TDP improvements) and that these costs would not normally be borne by the PGM testing program.

Cost data are also available for the linked laboratory ADS configuration, as implemented in the SIT LSP. In comparing to LFP costs, it should be remembered that the LSP configuration included an AIM-9 Sidewinder, rather than an AIM-120 AMRAAM, HWIL laboratory.

- LSP ADS mission: about $20,000 for a four-hour mission which achieves 80 runs (~$250 per run).
- LSP ADS implementation cost: about $1.2 million, including the cost of modifying Point Mugu/China Lake facilities and integration testing. This cost reflected the need to retrofit the existing facilities so that they could be linked. If the requirement for linking were planned into the facilities design, it is believed that the cost of implementing linking would have been significantly lower.

B.3.2 Testing Program Cost Example

As an example of estimating the cost of a testing program with and without ADS-based testing, a live fire test program without ADS is compared to a test program in which (1) some of the live tests are replaced with ADS-based tests and (2) an ADS configuration is used to rehearse the live tests.

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For the specific example, the AMRAAM FOT&E[3A] test plan[3] was examined to determine the maximum number of launch profiles for which the SIT LFP ADS architecture could provide valid data. Criteria for selecting candidate profiles included F-15 or F-16 shooter, no multiple shooters with simultaneous launches, fighter drone targets, resolved targets (if multiple targets were involved), no target beam maneuvers during missile intercept, and no chaff CM. Out of 29 live profiles, three met the screening criteria and were viable candidates for ADS implementation. In other words, a maximum of three FOT&E[3A] profiles could be performed using the LFP ADS configuration, rather than live fire. For each live fire profile replaced with an ADS mission, the cost savings is about $550,000. Thus, about $1.65 million could be saved if all three live profiles were performed with ADS missions. (Note that even though each ADS mission can include 15 passes, it was not possible to combine all three live profiles into a single ADS mission. This was because of differences in shooters and other key scenario features in the three profiles.)

The live fire profiles in FOT&E[3A] were rehearsed using captive-carry missions. Data collected from the captive-carry missions were normally used after the mission as inputs into an AMRAAM DSM for the purpose of verifying the launch profiles and missile flyouts. If this were done using the LFP ADS configuration instead, the MISILAB HWIL laboratory would provide higher fidelity missile flyout results during the mission, allowing real-time verification and refinement of the live fire profiles. For each captive-carry mission replaced by the ADS configuration, the additional cost is about $20,000. Assuming all three live profiles which could be replaced by ADS were indeed replaced and the 26 remaining live profiles were all rehearsed using the ADS LFP configuration, the additional cost for the rehearsals would be about $460,000 (three profiles which would have been rehearsed using captive-carry missions were eliminated, saving about $60,000), and the net cost savings from reducing the number of live shots would be about $1.2 million.

Note that the non-recurring implementation cost for the LFP ADS architecture was about $2 million. When this investment cost is also considered, the maximum use of ADS in support of FOT&E[3A] would have cost an additional $350,000 if ADS were only used to replace three of the live profiles and an additional $870,000 if ADS were also used to rehearse all live profiles.

This example illustrates that if ADS is only used to support one phase of testing involving a relatively small number of live fire tests, cost savings may not be possible. If ADS-based testing is instead implemented over all phases of testing, cost savings would be expected. For example, the analysis of the FOT&E[3A] profiles showed that about 10% of them could be replaced with ADS-based tests. If this same percentage is applied to a total missile testing program consisting of 100 live shots, then the number which could be replaced would be ten. In this case (assuming the same costs as for AMRAAM FOT&E[3A] and the SIT LFP), there would be a cost savings of about $1.9 million (after accounting for the $2 million ADS implementation cost) if the ADS configuration was also used to rehearse all 90 live profiles and a cost savings of about $3.7 million if the ADS configuration was not used for rehearsal. The increased cost savings with

[3] Richter, G. and Volk, P., AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) Follow-On Operational Test and Evaluation, Phase 3, Part A Test Plan, Air Combat Command, Nellis AFB, Nevada, August 1996.

each replaced live shot is illustrated in Figure B-2 (for the case of not using the ADS configuration for rehearsal). Note that the break-even number of reduced live shots is four (i.e., this number of reduced shots is required to recover the $2 million ADS development cost).

The examples in this section are meant only to illustrate the application of the cost benefit analysis methodology and should not be considered as general results. Each specific PGM program must be analyzed to determine the cost effectiveness of ADS implementation. In particular, if ADS implementation is properly planned for early in the acquisition and testing program, the cost of implementation may well be significantly lower than the $2 million ADS development cost in these examples. (Note that implementation costs are indeed strongly dependent on the specific ADS architecture -- the SIT LSP development cost was about $1.2 million versus about $2 million for the SIT LFP.)

B.4.0 Conclusion

A general methodology has been presented for analyzing the cost-effectiveness of implementing ADS-based testing in a PGM testing program. The application of this methodology should always be done in a total program sense in which ADS is blended into the entire PGM acquisition and testing program. If the strengths and benefits of ADS-based testing are properly exploited, it should be possible to design an improved, more thorough, and higher confidence test and evaluation program, while still remaining within budgetary constraints.

100 Live Shot Program - Millions of $
(tradeoff Live Shot for ADS mission)

Relative Costs

Absolute Costs

$9 $8 $7 $6 $5 $4 $3 $2 $1 $0

$62 $61 $60 $59 $58 $57 $56 $55 $54 $53

Baseline costs: $60M

Cost of ADS missions

Cost of live shot missions

$2M ADS Up-front Development Cost

Live Shot Reductions and ADS Live Fly Add Ins

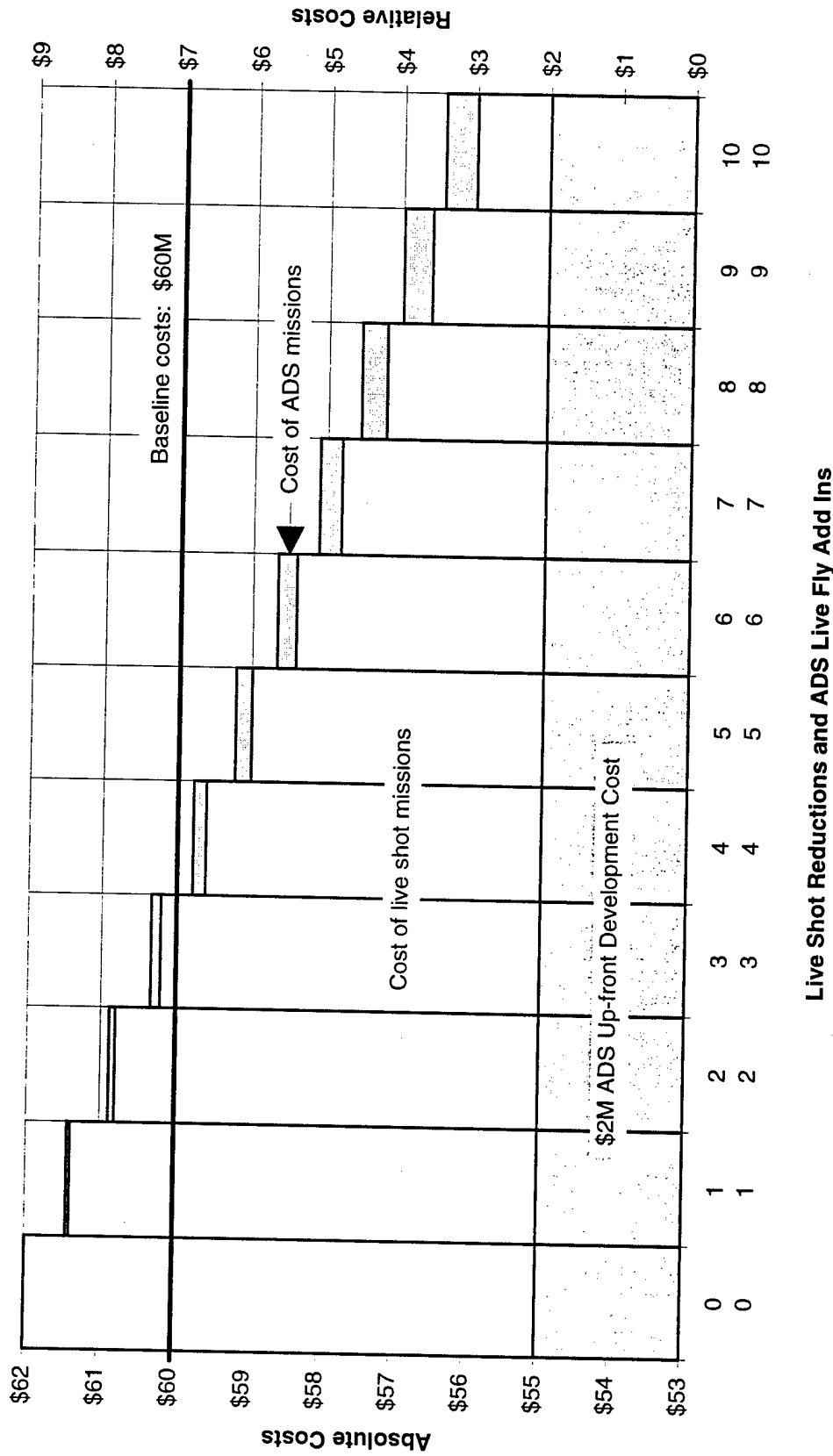0 0 1 1 2 2 3 3 4 4 5 5 6 6 7 7 8 8 9 9 10 10

Figure B-2. Levels of Program Costs/Savings with Varying Numbers of ADS Replacement Missions.

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APPENDIX C

ADS IMPLEMENTATION GUIDELINES

ADS IMPLEMENTATION GUIDELINES

This appendix outlines the steps in implementing ADS-based testing in which a shooter entity, target entity, and PGM entity are linked. It follows the steps given in the HLA Federation Development and Execution Process (FEDEP) model [Ref. C-1]. In comparing these guidelines with the FEDEP model note that the term "ADS architecture" used here equates to the term "federation" in the FEDEP model, and the terms "facilities" and "live entities" used here equate to the term "federates" in the FEDEP model.

STEP 1: Requirements Definition.
Activity 1.1: Sponsor Needs Identification.
- Describe critical systems of interest.
- Determine resources which will be available to support ADS implementation (e.g., funding, personnel, tools, facilities).
- Determine any known test constraints (e.g., due dates, security requirements).
Activity 1.2: Objectives Development.
- Determine test objectives, scenarios, conditions, and which PGM performance parameters (e.g., measures of effectiveness) are to be evaluated.
- Develop an ADS architecture/network development plan including approximate schedule and major milestones.
- Develop a configuration management plan.
- Determine operational context constraints or preferences, including geographical regions, environmental conditions, threats, and tactics.
- Identify security requirements, including estimated classification level and possible designated approval authority or authorities.
- Develop initial verification, validation, and accreditation (VV&A)/test plans.
- Select tools to support scenario development, conceptual analysis, VV&A and test activities, and configuration management.

STEP 2: Conceptual Model Development.
Activity 2.1: Scenario Development.
- Identify major entities that must be represented.
- Describe capabilities, behavior, and relationships between major entities over time (e.g., shooter and target profiles and shooter support of PGM).
- Specify relevant environmental conditions which impact or are impacted by the entities.
Activity 2.2: Conceptual Analysis.
- Evaluate entity characteristics, relationships, and interactions.
- Determine if ADS implementation is appropriate.
-- In general, ADS implementation is necessary if entities interact with each other and if linking is necessary to permit the interactions.
- Determine appropriate representation for each entity.
-- Choice of appropriate representation depends on the availability of simulation facilities, the capabilities of range instrumentation and data processing, the nature of

entity interactions (e.g., whether or not the target reacts to the PGM), and the objective of the testing (see Section 4 in main report).

-- Choice depends on requirements and must be determined in parallel with a detailed requirements determination. For example, live entities may not have sufficiently accurate TSPI (due to range instrumentation and processing limitations), or sufficiently small latencies (due to data processing times), or feedback from the PGM simulation to the live target may not be possible.

--- Choice depends on degree of realism (fidelity) needed: Live shooter/target provide more realistic inputs to the PGM simulation than virtual (manned lab) shooter/target; PGM HWIL provides more realistic PGM performance than PGM DSM.

--- Choice of DSM or HWIL for PGM also depends on PGM performance areas to be evaluated (see Table 2 in main report).

- Determine ADS architecture requirements.

 -- Data requirements.

  --- Determine data types which must be exchanged among entities to permit interact.
   ---- Entity state data
   ---- Data exchanged between shooter and PGM before launch.
   ---- Data provided by shooter to PGM after launch.
   ---- PGM launch indication.
   ---- PGM detonation indication.
   ---- Target CM (e.g., flares, smoke, ECM) deployment indication.
   ---- Trial start and stop notification.

  --- Determine data required to achieve test objectives.
   ---- Data exchanged among entities and recorded at multiple locations. Identify data source and each required recording location. Document with interface control document.
   ---- Data not exchanged but recorded at originating node.
   ---- Data required for test control.

  --- Determine rates of data exchanged among entities (in bits per second).
   ---- Determine if data will be sent out of the simulation interface at the rate it is received by the generating entity or if dead reckoning will be used to reduce data rates over the wide area network (WAN) (because of WAN bandwidth restrictions).

  --- Determine TSPI accuracy and smoothness requirements for live entities. This depends on test objectives and on which PGM parameters are being evaluated.

  --- Determine requirement for data time stamp accuracy.

  --- Determine classification of data and security handling requirements.

 -- Latency requirements.
  --- Acceptable latency and latency variations.
  --- Closed-loop interaction requirements.

 -- Data quality requirements.
  --- Acceptable level of ADS-induced errors (e.g., dropout rate, missing PDUs).

 -- Synchronization requirements.
  --- Entity state data synchronization.
  --- Shooter support message synchronization to entity state data.

--- Determine if any other data types must be synchronized for input to receiving entity.
-- Real-time data processing requirements.
--- Determine processing necessary to achieve TSPI accuracy (for live shooter/target) and synchronization requirements and to compensate for latency effects (if possible).
-- Post-test data management requirements.
--- Determine data sources and amounts.
--- Determine data handling requirements.
--- Determine data storage requirements (based on data requirements) at each site, as well as central data storage.
-- Data analysis requirements.
--- Determine analysis approach for all types of data.
--- Identify commercial or government off-the-shelf statistical analysis tools and other post-processing tools to be used for data analysis/reduction.
--- Determine requirements for any custom data analysis/processing tools.
-- Network requirements.
--- Determine protocols to be used.
---- Decide if standard protocols (e.g., DIS PDUs) are to be used or if it would be advantageous to keep data in formats generated by entities. If transmitting and receiving entities use the same coordinate system (which is different than the geocentric DIS coordinate system), processing time and coordinate transformation errors would be reduced by not using DIS PDUs.
---- Identify prelaunch data exchanged between the shooter and PGM (e.g., SMS data) which is best kept in its tactical protocol.
--- Determine if HLA will be implemented. The use of HLA will affect the choice of protocol and simulation interface design and requires an appropriate RTI.
--- Determine if data from node will be broadcast or transmitted point-to-point. HLA implementation is a factor in this determination.
--- Determine data encryption requirements based on classification of data to be passed over WAN.
-- Interface requirements.
--- Simulation interfaces.
---- Determine coordinate transformation requirements to convert from coordinate frame of transmitting entity to coordinate frame of data protocol used over WAN (e.g., DIS PDUs) and to convert from coordinate frame of data protocol used over WAN to coordinate frame of receiving entity.
---- Determine dead reckoning requirements. Determine if dead reckoning will be used at the transmitting node, as well as at the receiving node. Determine if second order or first order dead reckoning is required based on position and orientation accuracy requirements and estimated latencies.
---- Determine requirements for simulation interfaces to synchronize received data to receiving entities. May require simulation interface to dead reckon entity state data to receiving simulation frame rate.
--- Special-purpose interfaces.

   ---- Determine if special interfaces will be required to transfer synchronized shooter-generated data to the PGM simulation. Such data may be required to initialize and launch the PGM and to provide it with targeting updates during its flyout.
  -- Test control and monitoring requirements.
   --- Develop test control concept.
    ---- Determine central control location.
    ---- Determine test coordinator and location at each distributed node/facility.
   --- Determine live entity control technique.
    ---- Determine if local range control is required (due to safety considerations or policy).
    ---- If remote live entity control is possible, determine monitoring/ communications requirements.
   --- Determine display and monitoring requirements.
    ---- Determine requirements for monitoring status of entities.
    ---- Determine requirements for monitoring status/performance of distributed network.
   --- Determine voice communications requirements and adequacy of existing telephone systems.

STEP 3: ADS Architecture Design
Activity 3.1: Design Architecture
 - Determine location of nodes.
  -- Select simulation facilities based on fidelity, availability, cost, and schedule.
  -- For live shooter/target configurations, select test ranges based on instrumentation quality and quantity, data processing capability, availability, cost, and schedule.
 - Conduct surveys of each site (node location).
  -- Determine facility communications architecture and requirements.
  -- Determine physical space requirements for tester-supplied equipment and personnel.
 - Determine security approach.
  -- Designate security point of contact (POC).
  -- Perform security risk assessment and develop concept of operations.
 - Determine WAN bandwidth requirement.
  -- Determine average and maximum aggregate data rate by adding rates from each entity broadcast over the WAN.
  -- Bandwidth requirement is given by the aggregate data rate plus a 50% - 100% margin for overhead and unanticipated traffic.
 - Select WAN/LAN.
  -- Determine if DoD-sponsored network will support requirements or if commercial leased lines must be used.
   --- Consolidate network requirements.
    ---- Acceptable latency limits.
    ---- Aggregate data rates.
    ---- Network management/control.

--- Submit requirements to Headquarters, Defense Information Systems Agency (HQ DISA)/D36 for determination of whether Defense Information Systems Network (DISN) common-user services (e.g., DSI, Secure Internet Protocol Router Network (SIPRNET)) will support the requirements or if a waiver to policy is justified [Ref. C-2].
--- If a waiver to policy is justified, survey commercial line lease rates.
---- Determine if dedicated (full-time) leased lines are required or if on-demand leased lines will suffice.
---- Contract for leased lines.
- Select network hardware.
-- Select type(s) of router(s), channel service units (CSUs)/data service units (DSUs), mulitplexers, etc.
--- If possible, select same type of router for all nodes.
--- Determine router addressing scheme (see Ref. C-3 for details).
-- Select type(s) of encryptor(s).
- Select test control hardware and software.
-- Determine communications requirements.
--- Determine data communications requirements.
--- Determine voice communications requirements.
-- Determine test control center physical space requirements and layout.
- Determine data collection/instrumentation requirements based on data requirements.
-- Select instrumentation types and data logging software.
-- Determine instrumentation locations.
-- Determine hardware requirements for data storage and handling (e.g., tape drives, CDs, optical disks).
-- Determine data handling procedures for collecting and storing data from the distributed network.
- Determine time synchronization method(s) (e.g., method for synchronizing time stamps for data loggers – see Refs. C-3 through C-5 for details).
-- Determine hardware required (e.g., IRIG, GPS).
-- Determine software required (e.g., network time protocol (NTP)).
- Develop formalized plan for architecture development and integration.

Activity 3.2: Develop Architecture.
- Procure and/or develop network analysis/monitoring tools.
-- Determine required extent of analysis/monitoring.
--- Troubleshooting only versus collecting and analyzing data.
--- Bandwidth monitoring.
---- All versus some links.
---- Monitor local area networks (LANs) locally versus remote.
--- Hardware requirements (using simple network monitoring protocol).
---- Communications monitoring hardware.
---- Simulation monitoring hardware.
-- Obtain permission (from appropriate authority) to monitor or collect data.
- Develop procedures for secure/encrypted operations and obtain designated approval authority approval for their use.

- Coordinate security memoranda of agreement (MOAs) between organizations involved.
- Get accreditation for networks, facilities, rooms, etc.
- Get communications security (COMSEC) account.
- Order keying material.
- Implement strict hardware and software configuration control.
- Develop data protocols to be used.
  - If HLA is to be implemented, a federation object model (FOM) must be developed (see Section 3.6 of Ref. C-1 and the DMSO HLA website for more details).
- Design and build/procure necessary interfaces in accordance with requirements.
  - Simulation/network interfaces.
  - RTI for HLA implementation.
  - Special-purpose interfaces.
    - Interfaces for tactical prelaunch data exchanged between shooter and PGM (e.g., exchange of stores management system data).
    - Synchronization interfaces.
- Determine and implement facility modifications.
  - Determine and implement simulation modifications necessary to utilize external inputs.
    - Modifications necessary to distribute incoming data to all required hardware systems and software programs.
    - Modifications necessary to input data into simulation code in real time.
    - Modifications necessary to meet synchronization requirements.
    - Modifications necessary to control PGM attitude prior to launch.
  - Determine simulation modifications necessary to generate required outputs.
    - Determine and implement method for achieving data time stamp accuracy requirement.
  - Determine and implement range data processing modifications necessary to meet TSPI accuracy, smoothness, and latency requirements.
  - Determine and implement facility modifications required for replay capability to be used during integration testing.

STEP 4: ADS Architecture Integration and Test.
Activity 4.1: Execution Planning.
- Develop integration test plan which incrementally checks out configuration during build-up.
  - Initially test each WAN link separately.
    - First test at CSU/DSU level to make sure communications work at lowest level.
    - Use ADS protocols to test routing.
    - Use pings to check for connectivity and loading problems.
    - Test simulation-to-simulation connections.
  - Test simulation-to-simulation connections with all nodes on the network.
    - Use network analysis/monitoring tools to troubleshoot the network.
    - Use ADS protocols to test routing.
- Develop test control procedures.

- Develop detailed execution plans.
  - -- For HLA implementation, see Section 3.7 of Reference C-1.
- For secure networks, develop security test and evaluation plan.

Activity 4.2: Perform ADS Architecture Integration and Testing.
- Install network hardware and software.
- Perform compliance testing.
  - -- Test each facility/node individually to ensure that ADS capability and any required modifications (including software) have been correctly implemented.
- Perform integration testing.
  - -- Check out interfaces and facility modifications with linking between pairs of nodes.
  - -- Baseline performance of network with no loading from the simulations/entities.
  - -- Test performance of critical portions of network under loading representative of test conditions to be used.
  - -- Use iterative "test-fix-test" approaches, including replay of trials to diagnose problems and verify fixes.
- Perform risk reduction missions.
  - -- Execute scenarios with fully linked test execution configuration (using live entities, if appropriate).
  - -- Include security certification, if required.
  - -- Evaluate test control and monitoring procedures.
  - -- Execute data collection and analysis procedures.

STEP 5: Execute and Analyze Results.
Activity 5.1: Test Execution.
- Execute test.
  - -- Develop test matrix based on test objectives.
  - -- Execute test matrix.
  - -- Exercise test control/management.
    - --- Monitor execution.
  - -- Collect data.
  - -- Maintain security posture of ADS architecture during execution.

Activity 5.2: Results and Feedback.
- Analyze execution outputs.
  - -- Apply statistical measures (if appropriate) and other data reduction methods to transform raw data into derived results.
  - -- Determine error estimates due to inaccuracies in measurements and sampling.
  - -- Use commercial or government off-the-shelf statistical analysis tools and other post-processing tools for data analysis/reduction.
- Perform feedback.
  - -- Use analysis results to determine if all test objectives have been met.
  - -- If all test objectives have not been met, identify corrective actions and implement them, as appropriate, during re-testing.
  - -- Identify legacy products and make them available to other programs.

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JOINT COMMAND & CONTROL WARFARE CENTER (Mr. Bill Swart)
HQ AMC/XP (MG Walter S. Hogle)
HQ USAF/XOC (General Charles R. Henderson)
HQ ACC/DR
ASC/LN (Mr. Henry)
ASC/SM (Col Richard Hayes)
HQ AFOTEC/XR (Col Baird)
HQ AFOTEC/CN
HQ AFOTEC/SA (Lt Col Reid)
HQ AFOTEC/SA (Mr. Dave Young)
HQ AFOTEC/TF (Col Kurey)
HQ AFMC / DOR (Maj Sambaugh)
46 TW/TSWW (Ms. Kathy Render)
68 ECG/TA (Mr. George Mantango)
HQ USAF/TEP (Mr. Bill Jimenez)
HQ USAF/TER (Lt Col Vince Albert)
412 TW/EWR (Col Wes Heidenrich)
AFEWES 412 TW/OL-AB
DET 4, 505 CCEG (TACCSF) (Lt Col Paul J. Burns)
HQ DA (ADCSOPS/DAMO-FDR (Ms. Liz Razel)
HQ DA, ODUSA (OR) (Mr. Vern Bettencourt)
HQ DA, TEMA (Mr. John Foulkes)
USAMSAA, AMXSY-CD (Mr. Tom Ruth)
AMSO (COL David Hardin)
USA TEST AND EVALUATION COMMAND (Mr. Raymond G. Pollard III)
USA TEST AND EVALUATION COMMAND (Dr. Dave Brown)
HQ OPTEC (Mr. Al Young)
HQ OPTEC (Dr. Henry Dubin)
PM ADS (Col Rogers)
USA WSMR, STEWS-ID (Mr. Mario Correa)
PM ITTS (Col Russell)
T&E MDL&SIM (N91) (Mr. Anthony Branch, Mr. Randy Taylor)
CNO-N6M 2000 Navy (CDR Lynn Gaudreau)
COMOPTEVFOR CODE 00T (Mr. Steve Whitehead)
COMOPTEVFOR (CDR Philip Nelson)
COMOPTEVFOR (CDR Kelly McBride)
COMOPTEVFOR (Mr. Neil McClenney)

Marine Corps OPERATION T&E AGENCY (Mr. Robert Bell)
N091 2D2 (CDR Brad Renner)
NAVSEA N091T (Mr. Andy Kristovitch)
PMA-272 (Capt Douglas Henry)
T&E TECH REQUIREMENTS (Mr. Lewis Lundberg)
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