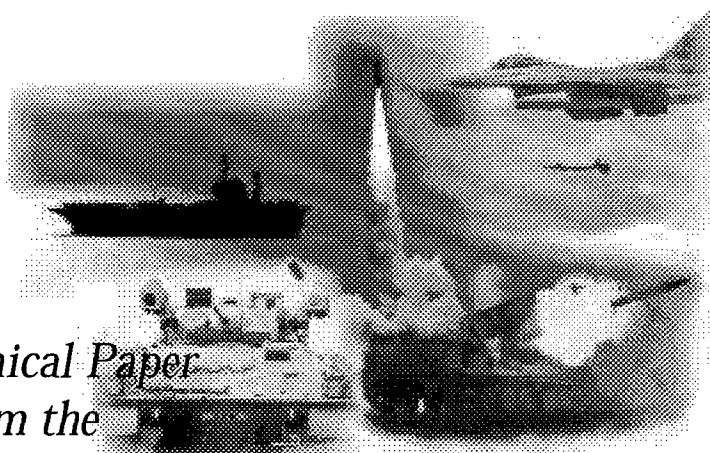




The Applicability of ADS to Precision Guided Munitions Testing



*A Technical Paper
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Simulation
Joint Test Force*

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ABSTRACT: *The Systems Integration Test (SIT) was executed by the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) and 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 SIT scenarios simulated a single shooter aircraft launching an air-to-air missile against a single target aircraft. Extensive testing was performed involving two different ADS architectures: (1) the shooter and target were represented by manned flight laboratories and the missile by an AIM-9M Sidewinder hardware-in-the-loop (HWIL) laboratory and (2) the shooter and target were represented by live F-16 fighters and the missile by an AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) HWIL laboratory.

Testing was completed in October 1997, and evaluation of the results supports the conclusion that each ADS configuration has utility for T&E of the corresponding air-to-air missile involved.

The applicability of ADS for the T&E of precision guided munitions (PGM) in general was assessed by extending the results and lessons learned from the SIT testing. The PGM classes considered were air-to-air missiles (AAMs), surface-to-air missiles (SAMs), air-to-ground munitions (AGM), surface-to-surface munitions, and subsurface munitions. In the ADS applications considered, the PGM could be represented by either a digital simulation model (DSM) or by an HWIL and the shooter and target could 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.

This paper describes the various PGM T&E applications for which the JADS JTF believes ADS has utility. Limitations in applying ADS to PGM T&E are identified, along with applications for which ADS is judged to have little or no utility. The benefits of using ADS for PGM T&E applications, for those cases in which there is utility in doing so, are also discussed.

1. 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 paper extends the results from 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 is shown in Figure 1-1 and 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 Sidewinder missile; and a test control center initially located at Point Mugu and later re-located in the JADS facility in Albuquerque, New Mexico. 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] through [4]).

The LFP distributed architecture, shown in Figure 1-2, 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 AMRAAM missile; and a test monitoring center at the JADS facility in New Mexico. 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] through [10]).

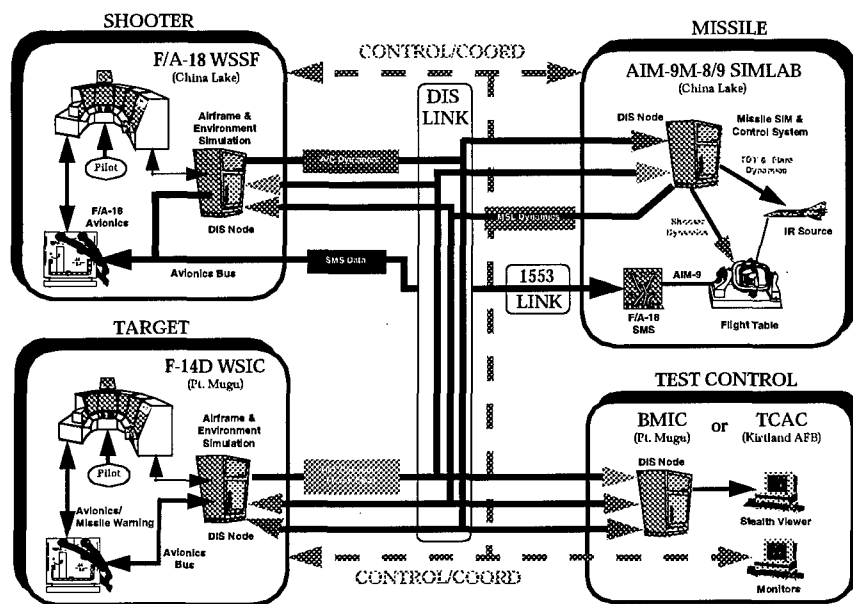


Figure 1-1. Linked Simulators Phase Test Configuration

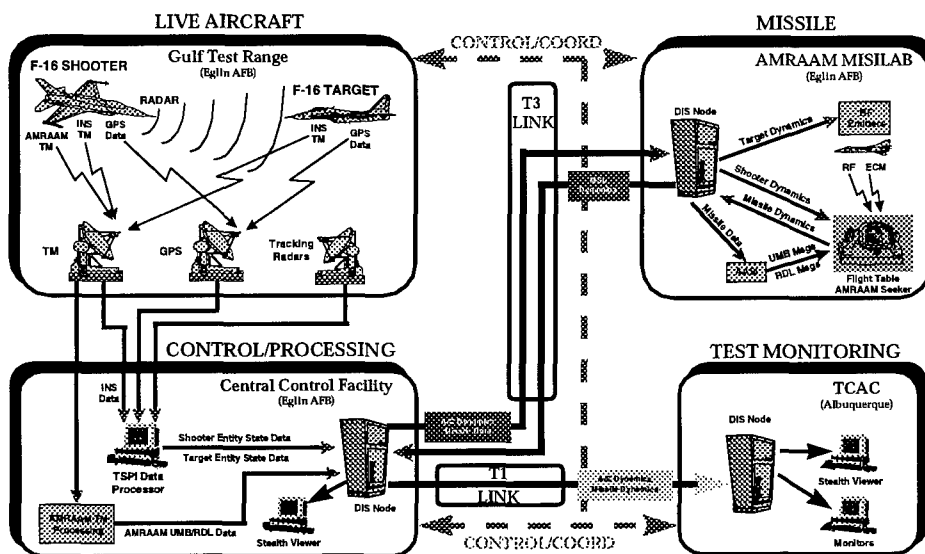


Figure 1-2. Live Fly Phase Test Configuration

2. SIT 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 air-to-air missile 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 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.
- The effects of latency and other ADS-induced errors can often (not always) be mitigated.
- Data synchronization is as much a challenge as latency management.
- Instrumentation and data management are more complex in a distributed test.
- 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. ADS Applicability to PGM Testing

3.1 ADS Applicability Assessment Approach

The results from the SIT LSP and LFP testing were generalized by considering other possible representations for the shooter, target, and PGM: The shooter and target can be represented by either digital simulation models (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 were 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 characteristics of the PGM, (3) the availability of adequate DSMs and HWIL laboratories for simulated players and instrumentation for live platforms, and (4) 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-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 time-space-position information (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. 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.
 - 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 electronic countermeasures (ECM) initiation), the amount of acceptable latency is typically about 50 milliseconds (Ref. [11]), 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.

3.2 ADS Applicability Assessment Results

The general PGM classes were 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. The general PGM classes are as follows:

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

3.2.1 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 3.1. 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. 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.

3.2.2 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 3.1. 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.)

- 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.

3.2.3 Air-to-Ground Munitions

These scenarios involve a dynamic shooter and either a stationary or slow moving ground 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 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). General considerations for applying ADS to this PGM class are given in Section 3.1. Special considerations are as follows:

- ADS implementation would be well-suited to the evaluation of AGM attacks on targets employing reactive countermeasures (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 fixed targets which do not maneuver, but only employ CM techniques such as flares, smoke, ECM, etc., the target representation at its node

could be simplified to only a shooter/launch detection and a CM deployment function, along with the target position and orientation.

- 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 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.

3.2.4 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 Follow-On To TOW (FOTT) testing (Refs. [13] and [14]), and the subsurface application is being investigated for torpedo testing and training (Refs. [15] and [16]). General considerations for applying ADS to this PGM class are given in Section 3.1. Special considerations are as follows:

- Most of the special considerations for AGM 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. [14]) 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 at the Naval Undersea Warfare Center in Newport, Rhode Island, is developing an HLA federation to link live submarines to a high-fidelity torpedo HWIL facility (Refs. [15] and [16]).

3.3 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, 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.
- 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 operational test and evaluation and an area in which ADS can improve the operational test environment (Ref. [17]).
- 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 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. [17]).

4. Summary and Conclusion

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 the test objectives, the characteristics of the PGM, the availability of adequate DSMs or HWIL laboratories for simulated players and instrumentation for live platforms, and the details of the test scenarios (such as whether the target reacts to the PGM or not).

This assessment gives 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 involved in SIT testing) have not been 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.

5. References

NOTE: References [1] through [10] are available at the Download Area of the JADS web site: <http://www.jads.abq.com/html/jads/techpprs.htm>

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Author Biography

DR. LARRY MCKEE has 26 years experience directing and performing R&D programs in DT&E, nuclear weapon effects, system survivability, neutral particle beam interactive discrimination, and high energy laser effects. This experience includes 20 years as an Air Force officer with duties in management of advanced R&D programs in directed energy weapon technology, R&D leadership at the Air Force Branch and Division levels, development and instruction of advanced graduate courses, and technical direction of underground nuclear tests. He joined SAIC in 1989 and currently supports the JADS JT&E as the technical lead for the System Integration Test, designed to evaluate the utility of ADS for the T&E of integrated launch aircraft/missile systems.

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