Embedded Test (ET) Capability, an "A to Z" Test and Evaluation Tool for the Ground-Based Midcourse Defense (GMD) System

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ABSTRACT:

Within large-scale programs such as the Ground-Based Midcourse Defense (GMD), which is a system of systems, there are many different levels of test and evaluation. Test requirements are flowed down from the GMD System Specifications to all elements, and subsequently to each of the element hardware and software items. The specifications and design to meet each element's software and hardware requirements must be supported with the collection of applicable data. Identification of verification tools and methodologies are critical to the success of meeting the test requirements at the elements level and also at the system level. The element specifications along with the hardware and software specifications describe how each element's requirements will be verified and tested at the element labs. The System Specification describes how the system requirements will be verified and tested in both lab configuration and fielded configuration. It also includes the requirements that will be verified and tested using inspection and analysis with the aid of simulations. The large size and complexity in such a "system of systems", presents challenges to each facet of the requirements verification, and test and evaluation process. In this paper we will explore the test and evaluation challenges for GMD and present a set of cost efficient solutions for meeting these challenges.

The test and evaluation, and verification of GMD system requirements require that multiple test frameworks and configurations be used at many different levels. They include test and evaluation from lowest fidelity to highest fidelity, from lowest level (component) to highest level (integrated system) using different test drivers, tools, hardware and software models, emulations, and simulations. Using the Embedded Test (ET) capability as a forcing function to maintain one "unique" test tool/driver to support "all" test venues from component, to element, to system, involves early planning, and coordination, as well as buy-in from many different stakeholders. To be successful requires good, disciplined system engineering practices and establishment of test and evaluation goals early in the life of the project. Key techniques and methods must be implemented during the early development process to support different test venues.

Lessons learned, and techniques, will be described to include the use of multiple test frameworks at multiple levels, the use of legacy and commercial software, and selection of hardware to accommodate many different test venues.

1. INTRODUCTION

1.1 Purpose

This paper provides a discussion of the Ground-Based Midcourse Defense (GMD) program and its integrated testing strategy, and addresses the role of Embedded Test (ET) in integration, interoperability, and system performance assessments across multiple test venues.

1.2 Overview

This paper addresses the needs and requirements that have led to the development of the Embedded Test to serve as the GMD system common framework for system-level integration and testing. A discussion of the ET architecture and key functions is described, along with the application and intended uses of the ET. Utilization of the ET in laboratory, field test, and flight test venues is considered. The paper addresses:

- *Program Description*. Information on the Ballistic Missile Defense (BMD) mission and the BMD system sets the stage for the follow-on discussion.
- *GMD Embedded Test*. The objectives, components and operating modes of the ET capability are described.
- *Application of ET in GMD Performance Assessments*. A discussion of the use of ET in ground and flight test in support of the GMD acquisition program is provided. Verification, validation, and accreditation (VV&A) needs for the models and simulations (M&S) used in ET are laid out.
- *Confidence in Embedded Test*. The challenges and opportunities of using simulations to support an acquisition program are discussed to address credibility needs and issues associated with ET capabilities functions.
- *Final Observations and Conclusions*. The utility of ET and the challenges in its use are extended to the broader T&E domain.

2. PROGRAM DESCRIPTION

Ballistic missiles already pose a threat to the United States and to U.S. interests, forces, allies and friends.[1] The proliferation of ballistic missile technologies, materials, and expertise can also occur in unexpected ways, enabling potential adversaries to accelerate missile development or quickly acquire new capabilities. Missiles carrying nuclear, biological, or chemical weapons could inflict damage that far surpasses what the U.S. experienced on September 11, 2001. The events of that day underscored the vulnerability of our homeland, even to assault from distant regions.

The importance of layered defenses as well as new approaches to acquiring and deploying missile defenses emerged as a result of an extensive and vigorous missile defense review[2] conducted by the Department of Defense in 2001. This review was conducted to determine how best to fulfill the need to defend the U.S., its deployed forces, allies, and friends.

In January 2002, the Secretary of Defense (SECDEF) identified priorities for defense of the United States based on establishment of a Ballistic Missile Defense System (BMDS) that layers defenses to intercept missiles in all phases of their flight[3].

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1 Unclassified Fiscal Year (FY) 2003 Budget Statement of Lieutenant General Ronald T. Kadish, USAF, Director, Missile Defense Agency, 1000 Defense Pentagon, Washington, DC 20301-1000.

2 Quadrennial Defense Review Report, Department of Defense, September 30, 2001.

3 Memorandum, Subject: Missile Defense Program Direction, dated January 2, 2002, Secretary of Defense, 1000 Defense Pentagon, Washington, DC 20301-1000.

The SECDEF further directed that the BMDS program *not* be subjected to the traditional requirements generation process detailed in Chairman, Joint Staff Instruction (CJSI) 3170. In addition, the missile defense Operational Requirements Documents (ORDs) developed by the Services were *cancelled* since they were not consistent with the BMDS objectives specified by the SECDEF.

In lieu of these requirements, the Director, Missile Defense Agency (MDA) was charged with developing a process that would set initial BMDS capability standards, engage the participation of future users early and throughout development, and permit capability trades across all BMDS elements. In addition, the MDA was assigned responsibility for Developmental Testing and Evaluation (DT&E) of the BMDS and its elements. An Operational Test Agent will be designated and an Operational Test and Evaluation (OT&E) will be conducted once a decision is made to transition a BMDS configuration item to a particular Service for procurement and operation.

These materiel acquisition and test initiatives are profound. They represent fundamental changes to the Defense Department's standard business operations and acquisition system and associated processes[4]. DoD's management framework for translating mission needs and technological opportunities, based on validated mission needs and requirements, will also undergo revision[5].

The absence of an Operational Requirements Document however, does not diminish the capabilities verification and test and evaluation functions. In fact, it requires a process and supporting infrastructure to be put in-place to gage progress and assist in establishing the actual and projected capabilities of the BMD elements currently under development.

Based on the results of last year's rigorous missile defense review and the SECDEF guidance, the Department of Defense moved away from an independently managed, element-centric ballistic missile defense approach and established a single program to develop an integrated BMD System (BMDS). The BMDS is the operational integration of all missile defense elements, including sensors, weapons, and battle management/ command and control capabilities, regardless of which Service operates them.

The Missile Defense Agency (MDA) will incrementally develop a Ballistic Missile Defense (BMD) System that layers defenses to intercept ballistic missiles in all phases of flight-boost, midcourse, and terminal. To categorize the capabilities to intercept a hostile missile during each phase of its flight, the Missile Defense Agency speaks in terms of three defense segments: a Terminal Defense Segment, a Midcourse Defense Segment, and a Boost Defense Segment. Sensors are grouped under a fourth segment.[6]

The BMDS program will be executed such that demonstrated capabilities can be fielded in limited numbers when available. Production decisions for BMDS elements will be based on their initial performance as demonstrated through credible testing, availability of system alternatives, and consideration of the evolving threat.

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4 DoD Directive 5000.1, "The Defense Acquisition System"; 23 October 2000.

5 DoD Instruction 5000.2, "Operation of the Defense Acquisition System"; 4 January 2001.

6 Unclassified Statement of Lieutenant General Ronald T. Kadish, USAF, Director, Missile Defense Agency, "On the Reorganization of the Missile Defense Program", Presented to the Senate Armed Services Committee Strategic Forces Subcommittee, 13 March 2002.

2.1 The Midcourse Defense Segment (MDS) and How GMD Fits Within It

The Midcourse Defense Segment (MDS) will provide the capability of countering ballistic missile threats in the midcourse stage of flight. The MDS program of work is divided into multiple elements including Ground-based Midcourse Defense (GMD) Systems and Sea-Based Midcourse Systems, which are the successors to the National Missile Defense and Navy Theater Wide programs. The current GMD development effort has three crucial objectives[7]:

- First, to develop and demonstrate an integrated system capable of countering known and expected threats.
- Second, to provide an integrated test bed that provides realistic tests and reliable data for further system development.
- Third, to create a development path allowing for an early capability based on success in testing.

The GMD system is composed of space-based and ground-based sensors, ground-based interceptors, and associated Battle Management / Command, Control, and Communications (BMC3) capability. The GMD mission functions include detection, acquisition, track, discrimination, intercept, and kill assessment; and collateral and theater support operations.

During this initial development phase, the GMD program will build-up an integrated BMD system, further demonstrate a "hit-to-kill" capability, and develop an RDT&E test bed capability. Each capability block will develop GMD technologies to counter increasing threat complexity.

The GMD JPO is developing an RDT&E, ground-based, Test Bed available in the FY 2004 time frame. The Test Bed will initially employ the GMD assets and later expand to integrate other BMDS capabilities. As conceived, this Test Bed will enhance the overall test infrastructure and GMD system maturation. Over time this Test Bed may expand to include weapons and sensor capabilities from throughout the BMDS as they become available.

2.2 GMD Testing Strategy

The GMD Joint Program Office (JPO) of the MDA is managing the GMD Program. The Boeing Company is the GMD Prime Contractor and has responsibility for managing the development and integration of the GMD Elements to deliver the GMD Segment. In addition, the GMD Prime is responsible for the execution of the DT&E and System Verification programs.

In view of the diversity of ballistic missile threats, environments and conditions under which GMD must operate, there is no practical, cost-effective method to assess system capabilities through physical (open air) testing alone. The GMD JPO's approach to capabilities assessment, therefore, is to integrate models and simulations (M&S) into its ground and flight test program. These M&S are the lynch pin to an effective test framework that will be used at many different levels and venues. They include test and evaluation from the lowest fidelity to highest fidelity, from lowest level (component) to highest level (integrated system) using different test drivers, tools, hardware and software models, emulations, and simulations that are embedded into the system. The Embedded Test (ET) serves as a forcing

7 "The Missile Defense Program", Lieutenant General Ronald T. Kadish, USAF, Director, Missile Defense Agency, in his Fiscal Year 2003 Budget testimony to Congress.

function to maintain one “unique” test tool/driver to support “all” test venues from component, to element, to system. This embedded test capability will be invaluable to assessments of GMD system capabilities against scenarios and threats that cannot be tested due to physical testing (range, safety and environmental) limitations and cost constraints.

3. GMD EMBEDDED TEST

The ET is a common framework intended to provide test execution control, sensor element stimuli, and analysis capabilities supporting integration, check out, and performance analysis of the GMD system. This common framework permits development at a single location by a single development team. This is a major factor in minimizing costs, ensuring development efficiency, reducing errors arising from requirements interpretation across a number of development organizations, and simplifying development project management and control.

ET provides in a controlled laboratory environment and fielded configuration the following functionality:

- Test execution and control.
- Element stimulus and emulation.
- Analysis capabilities for integration testing.
- System checkout of the GMD System.
- Performance analysis of the GMD System.

3.1 ET Description / Overview

The ET is a computer-based apparatus used to integrate GMD elements into a system configuration and drive elements of that system with realistic data and scenarios. It will support both software-in-the-loop (SWIL) and hardware-in-the-loop (HWIL) integration and testing. Use of a common simulation architecture to drive SWIL and HWIL reduces development risks by demonstrating early prototype capabilities in the ET. The design of the ET software will enable testing of elements co-located at the System Test Laboratories (STL), and at remote sites. Its distributed nature will allow for scalability in performance as Element capabilities and the nature of threats evolve.

The ET will support system verification through ground testing when installed in the System Test Laboratories (STL). The ET will support monitoring of live fire and non-live fire flight tests when installed at Reagan Test Site (RTS). When fielded, the ET will assess the contingent operational capability of the Test Bed to perform a GMD mission. The ET provides the capability to establish test scenarios, define test environments and control system level testing of the GMD System. The ET will provide the users with the ability to conduct system integration of the elements into TB04, to assess TB04 hardware and software upgrades, to conduct distributed ground tests, and to monitor flight tests.

The ET will consist of two major components, the Test Execution controller (TEC) and the Test Framework Unit (TFU). Each of these components is discussed in greater detail in the sections below.

3.1.1 Test Execution Controller

The TEC provides the ET with a centralized command and control capability for all test activities. It exchanges messages with the controlling Battle Management Command and Control (BMC2) node to prepare for, execute, and terminate tests. It controls the execution of the test via the ET TFUs. The TEC provides the human interface to the ET, pre-test preparation and test setup, post-test data collection, data storage, and the security to prevent unauthorized use of the ET. The TEC provides the tools needed for post-test data analysis. The TEC will contain element representations for all of the elements/Test Bed components except for the BMC2. (The BMC2 must be present for the operation of the Test Bed and the ET.) Element representations will be used to represent any component that is not available.

3.1.2 Test Framework Units

The TFUs provide the ET with the Element and site specific interefaces. The TFUs issue commands to the elements in response to TEC direction, inject scenario data to appropriate elements to stimulate the system engagement operations, receive and pass element health monitoring information to the TEC, and pass recorded data to the TEC for post-test analysis.

As test and control requests are sent to each element, an element-specific TFU will receive those messages, reformat the messages to element specific structures, and send the reformatted messages to the element. The TFU will receive element responses including health and status (H&S) messages and reformat them to TEC specific formats, before sending the reformatted messages to TEC. The sensor element TFUs, in addition to test and control, will reformat MSG threat and environment information into an element specific data stream and inject this data into the element. It is here that "Truth" data is provided to the element. Local environmental conditions that may degrade sensor sensitivity, such as rain attenuation, are modeled in the sensor TFUs.

- **XBR/GBR TFU**: This TFU accepts messages from the MSG and converts them to the required input format of the XBR/GBR Element. The updates contain Scenario, Threat, and Environment (STE) truth data being presented to the XBR/GBR.

- **UEWR/UTA TFU**: This TFU accepts messages from the MSG and converts them to the required input format for the UEWR/UTA Element. The updates contain STE data being presented to the UEWR. This is the truth data provided to the element.

- **Air Vehicle TFU**: This TFU accepts messages from the MSG, the Command and Launch Equipment (CLE), and the Booster simulation in order to provide appropriate inputs to the Kill Vehicle (KV).

- **IFICS TFU**: The IFICS TFU provides a test stimulus to the GMD IFICS element software in either a lab environment or within the deployed distributed GMD architecture. The IFICS TFU also provides a simulated analysis of the RFLink communication between the IFICS element and the EKV element.

The TFUs will be collocated with the Elements and integrated via the GMD Communications Network (GCN) and Test Article local area networks (LANs).

3.2 Embedded Test Operations

The ET will have three operational modes: laboratory, fielded, and flight test. The laboratory mode will be capable of providing integration exercises for ground and flight tests. Integration activities include element-to-element interface assessment and interoperability exercises. The fielded mode links each element's development facility into a network that further supports integration, interface, and interoperability assessment activities. The flight test mode provides for monitoring and data processing for live-fire tests. Each mode is described in greater detail in following sections.

4. APPLICATION OF ET IN GMD SYSTEM PERFORMANCE ASSESSMENT

4.1 Laboratory Tests

The ET in the System Test Laboratories (STL) will be used for the integration of GMD system hardware and software; assessment of system interoperability; support of element development and troubleshooting; and determination of design breakpoints. Flight-like test configurations will verify system performance and provide fully integrated, end-to-end, system capability demonstrations using representative threat targets. Following Integrated Flight Tests (IFTs), the ET will be used to playback the collected flight test data. In addition, the ET will provide post-test data analysis, including "Quick Look" reports. The post-test data analysis tools will assist in the comparison of "truth" data with the "real-world test" data to evaluate the performance of the Elements.

4.1.2 Pre-Mission and Post-Flight Reconstruction Tests

Pre-Mission Tests (PMTs) are nondestructive, system-level tests representing the use of GMD Elements in their IFT configurations to provide pre-flight prediction data in support of flight test risk reduction. The PMTs focus on the engagement envelope for the system given range constraints and flight test scenarios. The ET's role is to exercise a number of different flight test scenarios and support identification and mitigation of risks to the successful execution of the flight test.

Post-Flight Reconstructions (PFRs), are designed to replicate the IFT as closely as possible, given available data and resource constraints. The ET is used to execute the test configuration from start-to-finish with initial flight conditions based on the Best Estimated Trajectory (BET) data and Radar Cross Section (RCS) signatures from the flight test.

4.1.2 Ground Tests

Ground tests use a combination of HWIL, SWIL, and digital models to assess the GMD engagement space and threat in a tactical environment. Ground tests are intended to validate the functionality and functional interfaces between the elements, subject the system to stressing environments and tactical scenarios, and evaluate target-intercept boundary conditions. However, ground tests must be conducted in controlled and repeatable environments in a non-destructive mode. Execution of these ground tests will help to identify "unknowns" in an interactive system context and verify interoperability of GMD system elements.

Integrated ground testing will be conducted using GMD Element hardware (processors) and software. The integrated ground tests will use simulated environments and "full-up" threat scenarios to evaluate capabilities and effectiveness of the prototype system and provide supporting data required for any contingency operation or deployment decision.

Test Bed Integrated Ground Tests in STL

Test Bed Integrated Ground Tests (TB IGTs) are high fidelity functionality tests of the Test Bed configuration performed in the STL to reduce integration risk for the Test Bed. At Test Bed System Test Readiness Review (STRR) in Sep 04, the Test Bed will possess specific levels of capability in terms of Element performance. The upgrade of any, or all of the GMD Elements, requires that the integration of the sensors, battle management and interceptors be maintained. The ET's role in Test Bed IGTs supports assessments that the GMD system integrity has been maintained and the anticipated improvements in capability have been realized.

Developmental Integrated Ground Tests

Developmental IGTs will address the capability of the Test Bed beyond the Flight Test regime (e.g., environments, geometries and quantities), support the implementation of Test Article/Test Bed Block Upgrades, and the continued evolution of BMD architecture(s). Developmental IGTs will employ Element labs, Elements, GMD integration facilities and GMD test configurations in the System Test Laboratories. The ET's role in Developmental IGTs is to support assessments of the operational capability of the GMD system by testing the engagement space and threat in a simulated tactical environment. ET will support validation of the functional interfaces between the GMD Elements and subject the integrated system to stressing environments and tactical scenarios.

4.2 Fielded Tests

The ET will have the capability to integrate geographically distributed test assets. Remote site support will be used to check-out representations of the tactical communications system and to verify element interfaces and interoperability prior to system integration activities. The ET will be physically incorporated into the operational system (operational hardware and software) to provide an inherent capability to assess the operational readiness of equipment and personnel to perform the GMD mission. It will be used for actual test operations, non-live testing (any testing of the missile system that does not include firing the missile or destructive testing) and readiness evaluation.

4.2.1 Element Tests

As each Element is installed and checked out at its test site, its corresponding TFU will also be installed at the test site. The TFU will be used to perform the Sub-System Checkout (SSCO) at the system level.

4.2.2 System Integration and Checkout Tests

As additional test articles are installed and SSCOs are performed successfully on each test article, they will then be integrated into the Test Bed. A System Integration Checkout (SICO) will then be performed. The ET will control the SICO, stimulate the test article being integrated, and emulate any missing elements.

Upon completion of the integration of the Test Bed, the ET will control and provide the test data (scenarios, environments, emulation of non-participating test articles, etc.) required for Recurring System Integrity Tests. This will ensure that the Test Bed test articles and GCN are operating as designed and capable of contingency operations, if required.

4.2.3 Distributed Ground Tests

ET will be used in the Test Bed for Distributed Ground Testing, and will support validation of the functional interfaces between the GMD Elements, subject the integrated system to stressing environments and tactical scenarios, and evaluate target intercept boundary conditions. The tests conducted in the Test Bed will result in a high fidelity, real-world capabilities assessment means that provides data to support GMD developmental and operational decisions. The DGTs will be conducted as part of, and in support of, flight tests, to verify Contingency Readiness, and to certify a Test Bed configuration ready for CTF test operations. In addition, ET will be utilized in DGTs to support assessments of the following: the effects of altering GMD CONOPS, the effects of altering the GMD element capability and lay down, new Missile Defense CONOPS, and the CONOPS of other BMD assets.

4.3 Flight Tests

Integrated Flight Tests (IFTs) will assess integrated GMD system performance and will demonstrate fully integrated, end-to-end system capabilities using threat-representative targets. They will provide test data to assess the level of the integrated element capabilities and verify that planned capabilities and performance objectives are being met. The ET will support monitoring of live fire and non-live fire flight tests when installed at RTS; however, the ET will be unable to command the firing of a target or interceptor). During flight tests, the ET will be used to monitor and record data, and provide real-time analysis of the test data. The ET will initiate its processes in conjunction with the Test Operations Control Center (TOCC).

5. CONFIDENCE IN EMBEDDED TEST

As illustrated, M&S will be used for system assessment, verification, and T&E. The ET is being developed as the common framework supporting all these instantiations: laboratory, fielded, and flight test. These venues will provide additional confidence in pre-mission testing, expand the envelope for assessment and test activities, and facilitate monitoring and analysis of data from live-fire tests.

To enable these applications the GMD JPO and Test, Training and Exercise (TTEC) Product Office are managing an M&S verification and validation (V&V) program whose emphasis is on accreditation of the ET capability. Significant to risk reduction efforts and GMD program quality, a deliberate program of V&V activities is being implemented to establish confidence in the fidelity, level of detail and ultimately, operation of the ET in the STL that support the GMD systems engineering and test program including both system Ground and Flight Tests. Incremental accreditation assessments are planned to ensure ET "produces realistic, unbiased, credible measurements of specific performance or suitability parameters"[8] and in those instances where such is not the case, to specifically identify the limitations on the use of data and analysis supported by the given model or simulation.

The goal of the TTEC PO's accreditation effort for ET is to gain the confidence of GMD user organizations that M&S outcomes within ET are representative of the real world, that the M&S used for ET are reasonably correct, and that the M&S used in ET are acceptable for the specific purpose for which they will be used. Accreditation procedures used by TTEC are the formal process by which the application sponsor will gain confidence in the M&S for its intended purpose.

Configuration management, configuration item traceability; element maturity; and proficiency of operating personnel are a few of the many factors that will be considered. Anything and everything that will assist in a scientifically plausible explanation of the differences in performance of the various test using models and simulations and live testing must be taken into account.

6. FINAL OBSERVATIONS AND CONCLUSION

As the ET capability for GMD is developed, and as element hardware and software evolve,

8 BMDO Directive 5002, "Test and Evaluation Verification, Validation, and Accreditation (VV&A) Policy for the Ballistic Missile Defense Organization", 14 March 1994.

the M&S that support ground and flight tests (including hardware/software and human-in-the-loop) will be used to provide data to support assessments of the system development through tests and demonstrations.

The TTEC Product Office, working through the GMD Prime Contractor, is developing the ET as the common framework to support integration and test of the GMD system elements. The ET will be implemented in the STL, the range environment, and embedded in the deployed system. This common framework will reduce program costs while facilitating the integration of GMD elements operating collectively in a common, synchronized, synthetic environment through the use of standard interface specifications to the test framework.

The overall ET strategy implemented by the TTEC PO is to evolve to an effective capability, which supports not only the development, but also deployment and sustainment (D&S) phases of the system life cycle, and evolutionary upgrade of the system through its life cycle. In support of these objectives, and to reduce costs and risks to the GMD program, the GMD JPO and TTEC Product Office have implemented a common simulation and test framework approach across ground tests, flight tests, and the deployed capability.

To ensure successful deployment and operation of the GMD system, the TTEC Product Office is working to ensure that the ET processes and planning are well coordinated across all aspects of the GMD program and that they support the phased, incremental design and integration approach being pursued for the system. Significant to risk reduction efforts and GMD program quality, a deliberate program of VV&A activities is being implemented. This will establish confidence in the fidelity, level of detail and ultimately, operation of the ET in test venues like the STL that support the GMD systems engineering and test program including both system Ground and Flight Tests.

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