

Results of Distributed Tests With Integrated Live-Virtual-Constructive Elements: The Road to Testing in a Joint Environment

Col Eileen A. Bjorkman, USAF

Joint Test and Evaluation Methodology, Suffolk, Virginia

Frank B. Gray, Ph.D.

Joint Test and Evaluation Methodology,

Kirtland Air Force Base, New Mexico

The phrase “testing in a joint environment” refers to testing military weapons and supporting systems in the joint mission environments in which those weapons and systems are expected to operate. The Office of the Secretary of Defense chartered the Joint Test and Evaluation Methodology project to institutionalize testing in a joint environment by improving the ability to conduct tests, across the acquisition life cycle, in realistic joint mission environments. Specifically, the project was directed to develop methods and processes for using distributed live-virtual-constructive joint test environments to evaluate system performance and joint mission effectiveness. In 2007, the project completed a series of such tests to assess an initial set of methods and processes. Tests of network-enabled air-to-surface weapons and ground-launched surface-to-surface precision attack missiles were used to provide context for system performance evaluations. Joint mission effectiveness was evaluated by conducting Joint Fires and Joint Close Air Support with the above weapons and other supporting systems. These tests were accomplished as part of the 2007 INTEGRAL FIRE event sponsored by the Air Force Integrated Collaborative Environment program. This article describes results after methods and processes for testing in a joint environment were used by experienced testers to design and assemble an actual distributed joint test environment. Results identified improvements to the processes as well as recommendations for test organizations. To streamline routine test planning for distributed testing, we recommend test organizations consider procedures such that each acquisition program has a lead test organization designated for distributed testing. We also recommend that test organizations consider establishing formal relationships to manage the distributed test environment as a single facility.

Key words: Testing in a joint environment; distributed testing; live-virtual-constructive; LVC; joint test environment.

The Joint Test and Evaluation Methodology (JTEM) project was chartered to investigate, evaluate, and make recommendations to improve the ability to test across the acquisition life cycle in realistic joint mission environments. Specifically, JTEM was charged with developing, testing, and evaluating methods and processes for defining and using a distributed Live, Virtual, and Constructive (LVC) joint test environment to evaluate system performance

and joint mission effectiveness. JTEM's initial set of methods and processes were developed in 2006. In 2007, the INTEGRAL FIRE test event was used to evaluate those methods and processes, which were used to plan and conduct tests of two systems as participating elements in an overarching system of systems. In this article, we describe those tests and how JTEM methods and processes were used to plan and execute them. The section “Testing in a joint environment” provides some background information on the vision within the

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE MAR 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Results of Distributed Tests With Integrated Live-Virtual-Constructive Elements: The Road to Testing in a Joint Environment				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Joint Test and Evaluation Methodology,Suffolk,VA,23432				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 11	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Department of Defense for improved testing in defense acquisition, including the notion of testing in a joint environment and the genesis of the JTEM project. The section “Methods and processes for testing in a joint environment” describes the specific methods and processes used during INTEGRAL FIRE planning and execution. Sections “Applying the methods and processes” and “Results and discussion” explain system performance and joint mission effectiveness tests resulting from the application of JTEM’s methods and processes. The “Results and discussion” section explains the ability to evaluate the results of the systems performance and joint mission effectiveness tests as an indication of the effectiveness and suitability of JTEM’s methods and processes. The final section summarizes our conclusions and recommendations.

Testing in a joint environment

What is testing in a joint environment? Why is it important? The short answer to both questions: to test as we fight. For most of the twentieth century, the U.S. Air Force, Army, Navy, and Marines fought wars together by coordinating separate air, land, and sea operations. Such separate operations preserved traditional service roles but did not always take advantage of synergies among service capabilities. Starting in 1991, with Operation Desert Storm, and continuing through today’s operations in Afghanistan and Iraq, commanders from one service have been compelled by circumstances to conduct operations jointly with other services. While such joint operations have clearly proven to be more effective than separate service operations, joint operations also reveal incompatibilities of individual service systems (hardware, software, or procedures) with one another. To eliminate incompatibilities in future systems, the Secretary of Defense changed the way new military systems are justified, developed, and tested. This new requirements initiation system (Department of Defense, 2003a) uses a capabilities-based approach to identify gaps in the Services’ ability to carry out joint missions. The Services must identify new systems to fill the gaps and must test those systems to determine whether they can support joint operations. Testers will need joint environments in which to conduct such tests.

In his strategic planning guidance for 2006 to 2011, the Secretary of Defense directed his staff to determine what actions would be necessary to create new joint testing capabilities and to institutionalize the evaluation of joint mission effectiveness. The resulting *Testing in Joint Environment Roadmap* (Department of Defense 2004) identifies policy, procedures, and test infrastructure changes that would allow the services to routinely conduct test and evaluation in joint environ-

ments. Parallel policy changes require frequent testing of all systems to demonstrate joint capabilities throughout development. Procedural changes adjust the traditional methods and processes testers use to define test environments, design test events, determine measurement requirements, and establish evaluation products. Infrastructure changes are needed to overcome facility and force-availability limitations. Large forces are seldom available to participate in testing because of real-world commitments. Even if forces were available, most test facilities are simply too small.

Authors of the *Testing in Joint Environment Roadmap* quickly concluded that testing in joint environments was generally not possible at any single test facility. They saw modern networks and rapidly improving simulations as the means to overcoming single-facility limitations. Networks can make several different and geographically separated test facilities appear as one. Networks also allow operator- or hardware-in-the-loop simulators (sometimes called “virtual” simulations) to substitute for live systems, and digital computer simulations (called “constructive” simulations) to substitute for live or virtual systems in a joint environment. Combinations of live, virtual, and constructive systems—linked through networks into a single distributed environment—could form LVC joint mission environments for testing. An added benefit is that system developers can test early constructive models in an LVC joint mission environment. Those developers can continue to use the same environment for testing virtual and live prototypes as development work progresses toward production. *Roadmap* authors see the LVC mission environment as a key enabler to “testing as we fight” across the acquisition life cycle.

Traditional tests conducted by the military services have focused on verifying system-level performance requirements specified in operational requirements documents. The military services have little experience testing new systems as participating elements in a joint system of systems. As a result, processes and methods for designing and executing tests of systems of systems in joint mission environments are neither well defined nor understood. Nor is there a clear understanding of how to assess system performance as it pertains to capabilities supporting joint missions. The Director of Operational Test and Evaluation (DOT&E), as the lead Secretary of Defense staff agency for the *Roadmap* and its implementation, chartered JTEM to address the methods-and-process components of implementation.

Methods and processes for testing in a joint environment

The initial set of methods and processes developed by JTEM, and evaluated during INTEGRAL FIRE, is

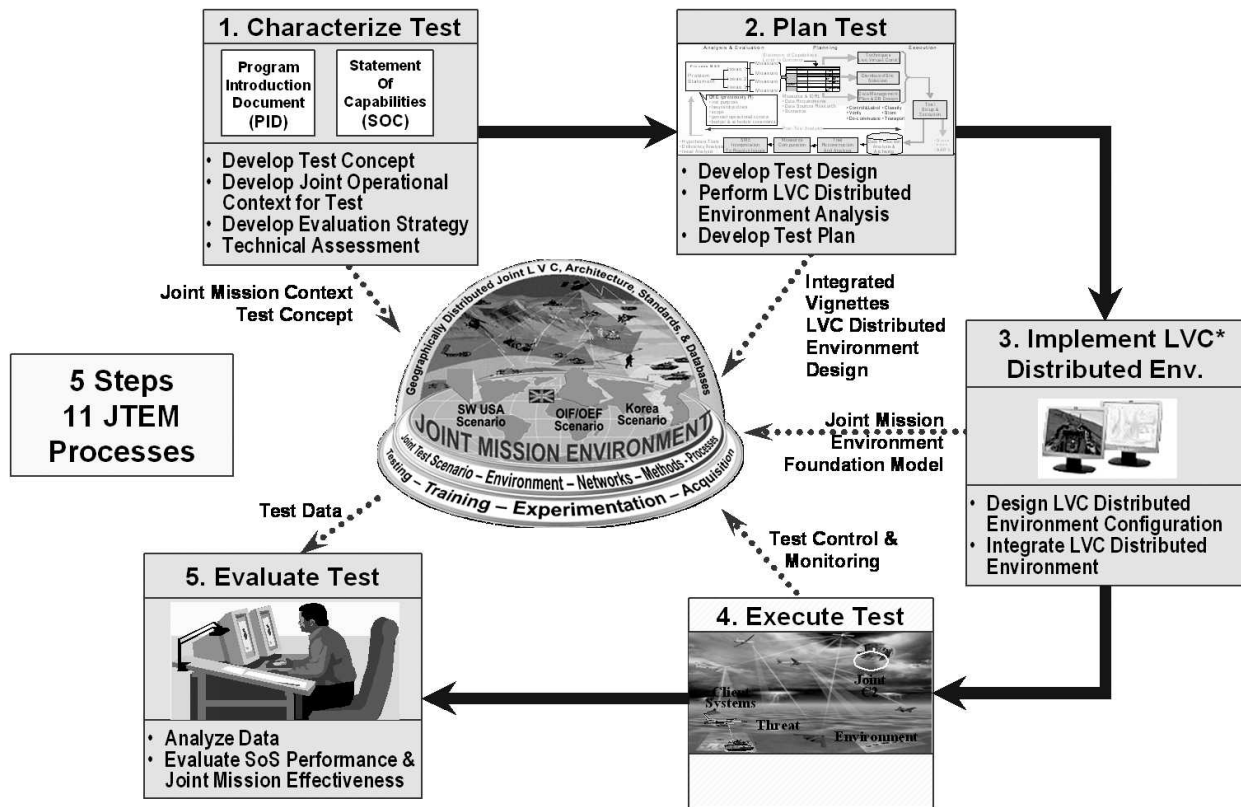


Figure 1. Capability Test Methodology version 1.0 used during INTEGRAL FIRE.

called the Capability Test Methodology (CTM) (Department of Defense, 2007a) because it goes beyond individual systems. CTM is the foundation for templates, handbooks, and other best practice guidance JTEM will ultimately deliver to test organizations and acquisition program managers regarding testing in a joint environment. *Figure 1* shows the five steps and eleven processes of which the CTM is composed. Of course, this serial depiction is a simplification of what occurs in practice. Most CTM processes are iterative in nature; many are performed in parallel, and outputs are fed back into other processes.

Nine (out of eleven) processes were the focus during INTEGRAL FIRE. These nine processes, in CTM

steps 1 through 3, are important to the design and execution of systems of systems tests in a distributed LVC joint environment. JTEM did not develop step 4 processes. The other two processes, in CTM step 5, deal with evaluations of system performance and joint mission effectiveness. These were addressed during 2008. *Table 1* shows the first three CTM steps and the various output products produced by the processes. These output products were used to assemble the particular distributed live, virtual, and constructive joint mission environment for INTEGRAL FIRE.

The first two CTM steps are derived from the current processes for planning tests at a single Major Range and Test Facility Base (MRTFB) (Department

Table 1. Primary CTM steps, processes, and output products evaluated during INTEGRAL FIRE

CTM steps	CTM methods and processes	Output products
CTM 1 Characterize test	<ul style="list-style-type: none"> Develop test concept Develop joint operational context for test Develop evaluation strategy Technical assessment 	<ul style="list-style-type: none"> Program Introduction Document (PID) Statement of Capability (SOC)
CTM 2 Plan test	<ul style="list-style-type: none"> Develop test design Perform LVC DE analysis Develop test plan 	<ul style="list-style-type: none"> Test plan
CTM 3 Implement LVC distributed environment	<ul style="list-style-type: none"> Design LVC DE configuration Integrate LVC DE 	<ul style="list-style-type: none"> Joint Mission Environment (JME) foundation model

of Defense 2002) location. Early planning negotiations between distributed test organizations and their customers (typical program managers, for example) are conducted during CTM step 1, Characterize Test. Program characterization processes conducted by customers include development of joint operational contexts for tests, development of test concepts, and development of the evaluation strategies. Test capability characterization processes are conducted by test organizations. These processes include technical assessments that produce initial estimates of distributed test facilities needed to implement test concepts and programmatic assessments that produce initial schedule and cost estimates. Program Introduction and Statement of Capability Documents produced by CTM 1 follow formats defined by the Range Commanders' Council (Department of Defense 1997). During CTM 2, the test planning phase, test concepts are developed into more detailed test plans. Test planning processes include designing distributed tests in joint environments; refining LVC distributed test environments; and synthesizing these activities into overall test plans. In CTM version 1.0, we assume that program introductions, statements of capability, and test plans reflect the requirements of a single customer.

Joint mission environments are assembled and used to support multiple test plans (e.g., customers) during CTM steps 3, 4, and 5. Implement LVC Distributed Environment processes are concerned with technical systems engineering activities for automatic distributed LVC implementation. These processes include the design of distributed configurations, assembly of distributed components, and integration of components into a distributed LVC "test range" that meets customer requirements. In CTM step 4, the Execute Test phase, tests are conducted according to procedures and data are collected. Schedules are developed and test events are run using test planning products as inputs. This phase produces test data for customers and reusable information for future joint mission environments. Though joint mission environments are assembled to support multiple customers, tests do not have to be run concurrently. Sometimes, individual customers may separately schedule only those parts of the joint mission environment they need to meet their own objectives for testing in a joint environment. Other times, multiple customers may share a joint mission environment at the same time, for convenience or as a result of hard programmatic requirements. The latter situation was assumed during INTEGRAL FIRE. In the final step, Evaluate Test, data are processed, analyzed, and evaluated. These processes turn test data into knowledge of what happened during tests, including evaluations of joint mission effectiveness

and the contributions of individual systems to joint missions.

Applying the methods and processes

We used the 2007 INTEGRAL FIRE event to develop, test, and evaluate JTEM methods and processes when those processes were used by typical test organizations under operationally representative conditions. INTEGRAL FIRE (Department of Defense 2007b) was a joint capability integration event intended to support joint test activities while working to establish persistent joint test environments. The event was jointly sponsored by Secretary of the Air Force, Warfighter Integration Directorate (SAF/XC); U.S. Joint Forces Command, Joint Systems Integration Command (JSIC); the Joint Mission Environment Test Capability (JMETC) program; and JTEM. SAF/XC conducted an assessment of the Warplan-to-Warfighter Forwarder System and its ability to support dynamic targeting. JSIC conducted a technical assessment of digital interoperability during the processing of immediate requests for Joint Close Air Support. The JMETC program coordinated network connectivity and middleware for assembling the joint test environment. JTEM test activity provided context in which to apply the CTM. INTEGRAL FIRE was coordinated through the Air Force Integrated Collaborative Environment program. Event management, led by the U.S. Air Force Simulation and Analysis Facility, was conducted collaboratively across several distributed test organizations. The test organizations that supported JTEM activity are shown in *Figure 2*.

The particular test activity planned and conducted with the CTM was intended to represent typical testing in a joint environment during early system development. As such, it was assumed the overall testing in a joint environment objective was to evaluate the contributions of two developmental weapon systems to joint mission effectiveness when those weapon systems were employed together as participating elements in an overarching system of systems. Contributions to joint mission effectiveness would then be used to determine which of the tested system design alternatives warranted further development. Constructive models of a surface-to-surface fire support platform (FSP) and an air-to-surface network-enabled weapon (NEW) were used to represent the two developmental systems. Joint Fire Support (Department of Defense 2006), including aspects of Joint Close Air Support (Department of Defense 2003b), was chosen as the joint mission. We assumed joint mission effectiveness was determined by the ability to deny employment of enemy forces (timeliness of attacks) and the ability of the system of systems to

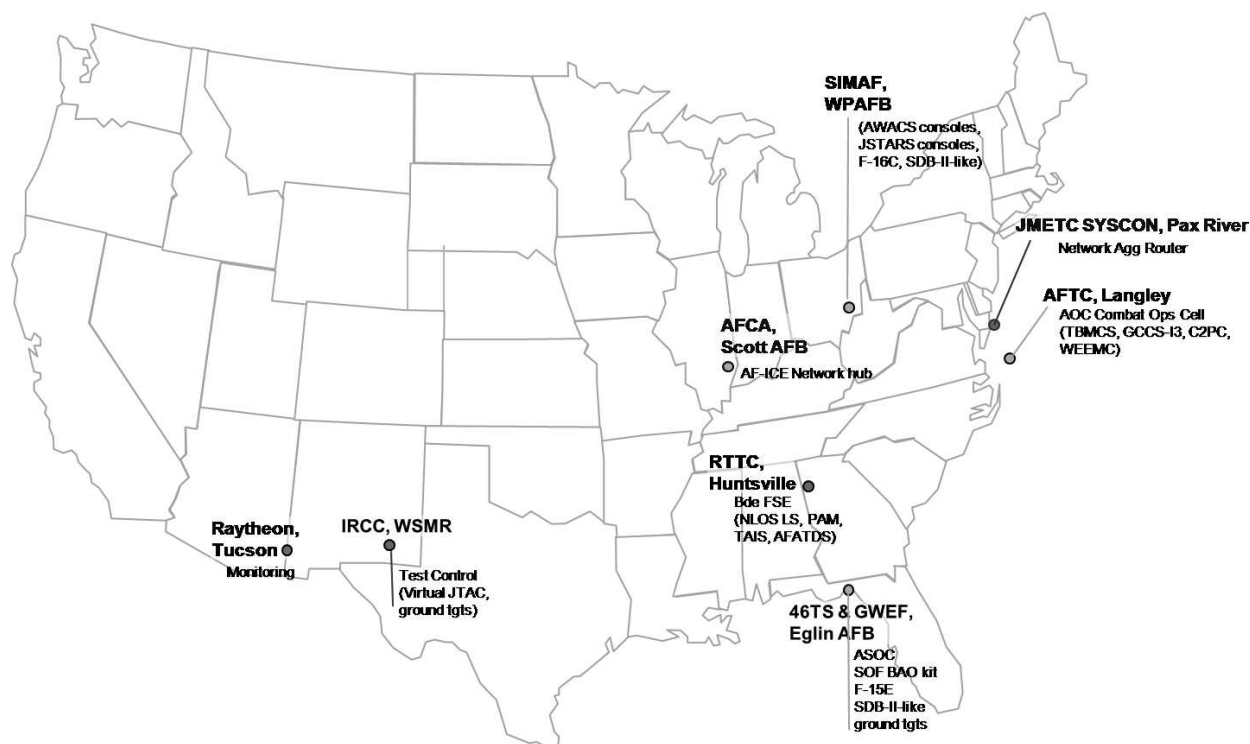


Figure 2. Distributed test organizations used to apply JTEM processes during INTEGRAL FIRE.

attack enemy combat assets (continuity of target location accuracy across network nodes). Weapon design alternatives were defined by different data link message implementations. Different joint tactics, techniques, and procedures were used to evaluate the robustness of design alternatives to varying methods of employment—in this case different airspace coordination procedures when NEW and FSP were employed concurrently.

INTEGRAL FIRE was managed using an integrated product team and senior steering group structure. Team leaders were responsible to the overall event leader who was responsible to the senior steering group. There were six integrated product teams. The analysis team translated evaluation objectives into specific data requirements and refined joint operation contexts and conditions under which the data needed to be collected. The LVC team defined and coordinated distributed components to assemble the joint mission environment. The infrastructure team was responsible for all technical and nontechnical aspects of the networks used to connect LVC components. A security team coordinated classification guidance and assisted the infrastructure team with security accreditation. An operations team was responsible for implementing the joint operational context for test activities, including specific sequences of activities conducted by systems under test and supporting

systems of systems during actual testing. Finally, an integration team provided facilitation and coordination among the other teams. All six teams applied various parts of all CTM steps. As discussed later, this has implications regarding future, persistent organizational structures for testing in a joint environment.

Planning and coordination across distributed INTEGRAL FIRE test organizations was accomplished through weekly conference calls and three face-to-face planning conferences. Each integrated product team conducted its own conference call between Monday and Thursday. Each Friday, all team leaders participated in a conference call with the integration team and event leader to coordinate actions across the integrated product team structure. The event leader also facilitated a monthly conference call composed of senior steering group members. Face-to-face conferences brought together most event participants (approximately 100 test engineers, managers, and analysts from 21 different test organizations) to bring everyone to a common understanding of overall planning status and issues and to conduct detailed planning and integration discussions. In terms of the JTEM Capability Test Methodology, the initial planning conference focused on processes in CTM 1. The midproject and final planning conferences concentrated mostly on CTM 2 and 3, respectively. JTEM used all of these interactions among distributed

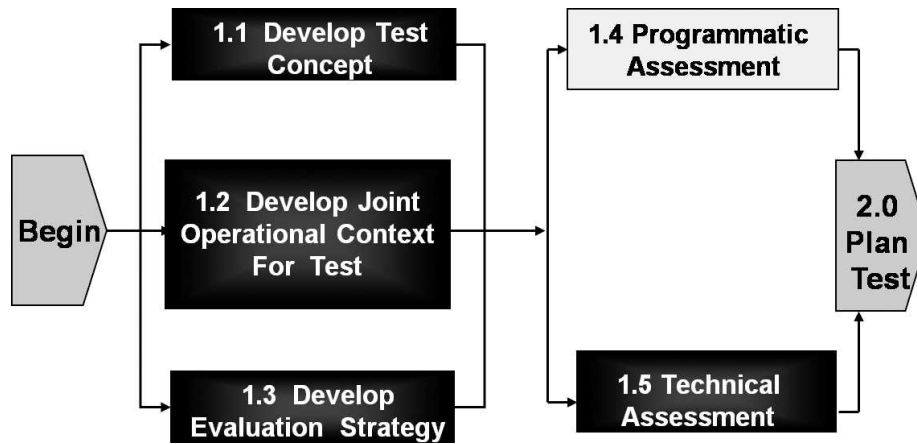


Figure 3. CTM 1 Test characterization processes used during INTEGRAL FIRE.

participants to evaluate the effectiveness and suitability of CTM version 1.0 processes, as well as to assess the applicability of the INTEGRAL FIRE organizational structure to a permanent state in which distributed tests regularly occur.

Results and discussion

CTM 1 processes, shown in *Figure 3*, were accomplished before and during the initial planning conference. JTEM personnel provided input information in the form of a test concept, joint operational context, and an evaluation strategy for focused developmental testing in a joint environment. After some iterations and negotiations between JTEM and the integrated product teams, the teams completed a technical assessment that produced an initial estimate of the distributed joint test environment.

For example, *Figure 4a* shows one of the test-concept depictions used in early program introduction information submitted to INTEGRAL FIRE teams for technical review. With assistance from JTEM engineers, the integrated product teams took this concept, along with additional information about required joint operational contexts and evaluation strategy, and produced the operational view shown in *Figure 4b*. The LVC team also produced an initial estimate of the distributed facilities needed to assemble the environment shown in *Figure 4*, and the operations team developed an initial sequence of actions to be accomplished during each test trial. It was found that current CTM 1 processes for developing joint test concepts, joint operational contexts, and joint mission evaluation strategies are too important to be confined to test characterization by distributed test organizations. Rather, these processes should be accomplished when acquisition managers are preparing the overall test and evaluation strategies or master plans. That

way, testing in a joint environment can be integrated with other development and operational testing throughout acquisition phases. Another important finding was that none of the integrated product teams could produce a cost estimate for *distributed* tests. This was due, at least partially, to a lack of formal relationships among test organizations to allow for routine distributed testing. Formal agreements will likely also be needed to decide which test organizations should participate in distributed testing in a joint environment for any particular acquisition program.

CTM 2 processes used to produce a test plan for INTEGRAL FIRE are shown in *Figure 5*. These processes were executed iteratively by the analysis, LVC, and operations teams. The integration team then pulled information together from these three teams to produce an actual test plan document. The midplanning conference was the primary face-to-face meeting, augmented by several smaller meetings before and afterward. *Figure 6* shows two example outputs produced by CTM 2 processes. Here, the operational architecture in *Figure 4b* was developed into an experimental design (Gray 2007) and a detailed test vignette by the Develop Test Concept process. In addition, Perform LVC Distributed Environment Analysis processes produced a refined LVC design with detailed information about facilities and individual simulated or live entities located at each facility. In INTEGRAL FIRE, test customers (SAF/XC, JSIC, and JTEM) approved their own test plans, and participating facilities produced and approved test plans according to local procedures. We concluded that this method was too cumbersome for frequent distributed testing in a joint environment. Test organizations should consider a construct in which each acquisition program has a lead test organization designated for distributed testing. Each participating

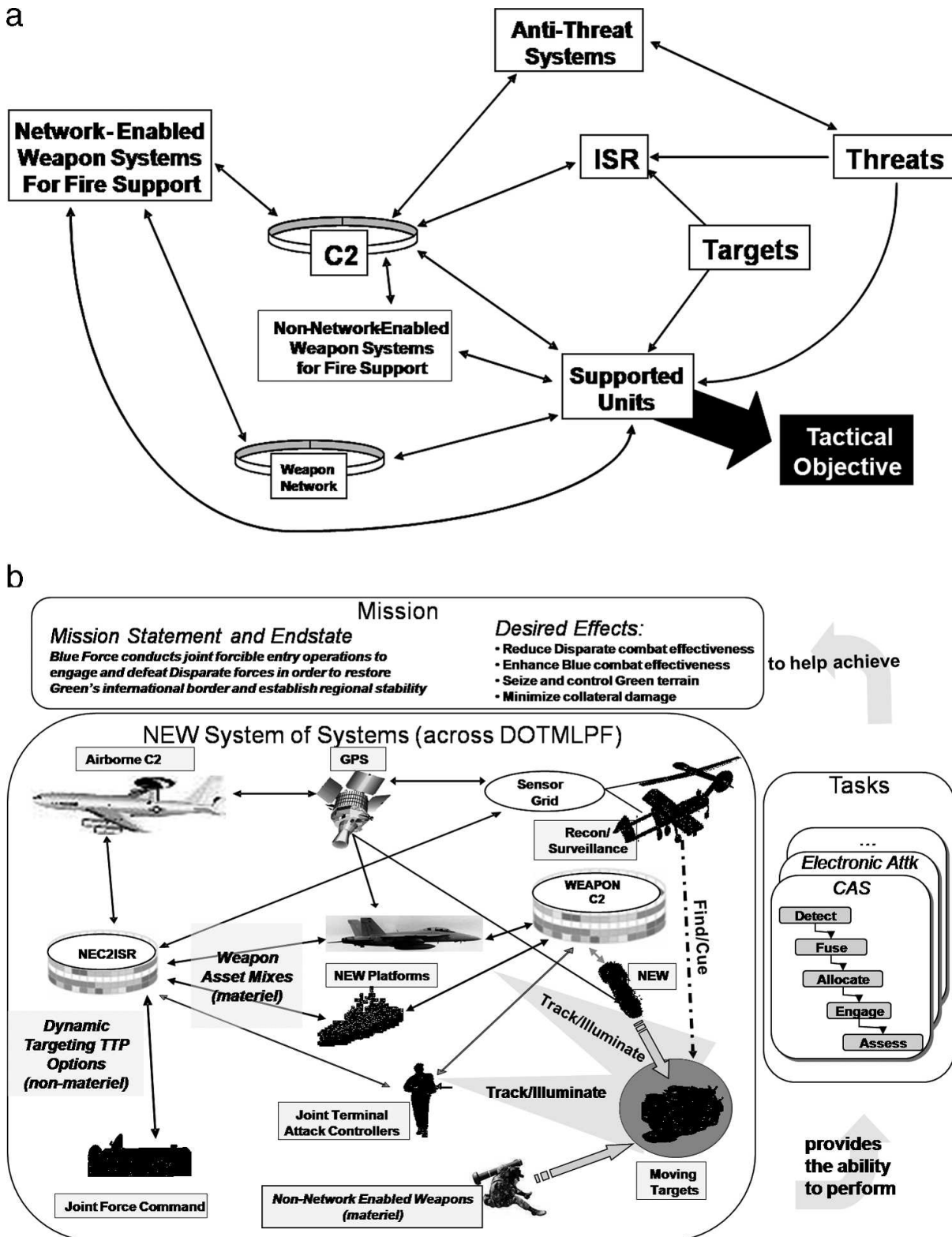


Figure 4. Inputs and outputs of technical assessment process during INTEGRAL FIRE. (a) A test-concept depiction used as input to technical assessment process. (b) Operational architecture output from technical assessment process.

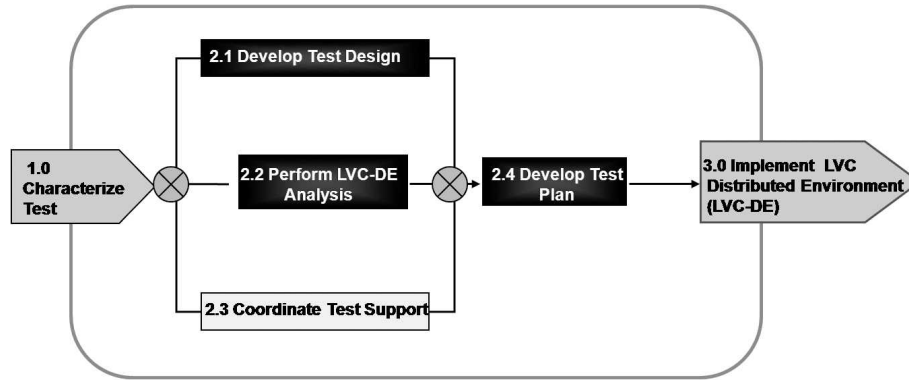


Figure 5. CTM 2 Test planning processes used during INTEGRAL FIRE.

a

Trial	ACV	Initial Airspace Assignment	First in Order	Third Party Source
1	Small	CAS	NLOS	JTAC
2	Small	CAS	NEW	Second Aircraft
3	Small	Fire Support	NLOS	Second Aircraft
4	Small	Fire Support	NEW	JTAC
5	Large	CAS	NLOS	Second Aircraft
6	Large	CAS	NEW	JTAC
7	Large	Fire Support	NLOS	JTAC
8	Large	Fire Support	NEW	Second Aircraft

b

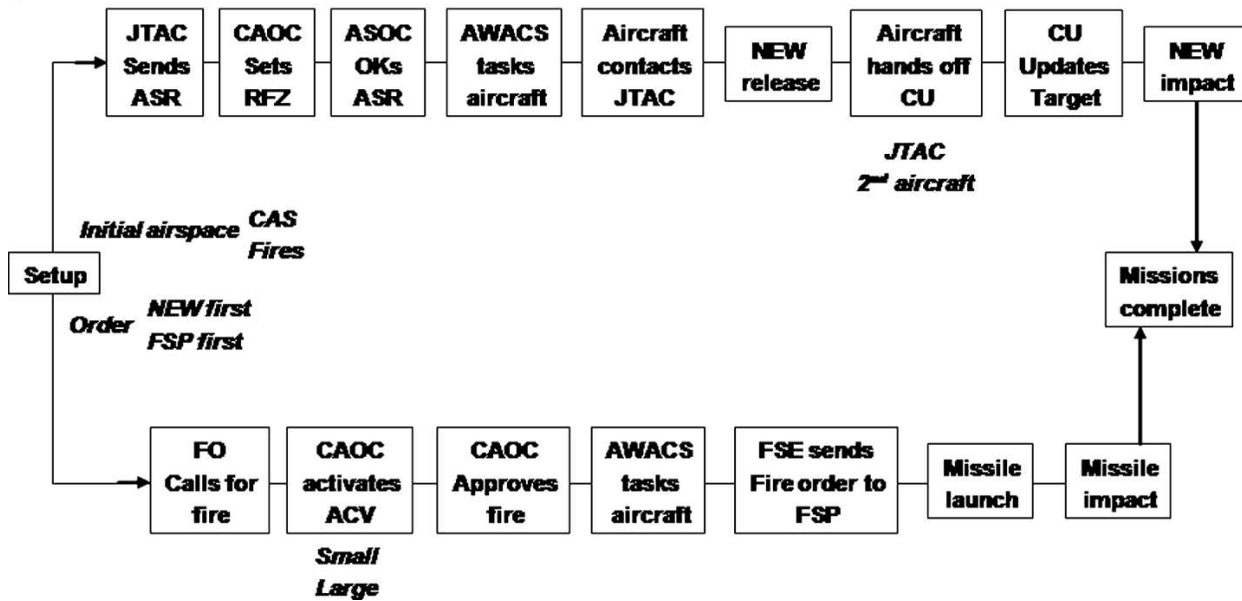


Figure 6. Outputs of develop test design process during INTEGRAL FIRE. (a) Experimental design produced by the develop test design process. (b) Vignette details produced by the develop test design process.

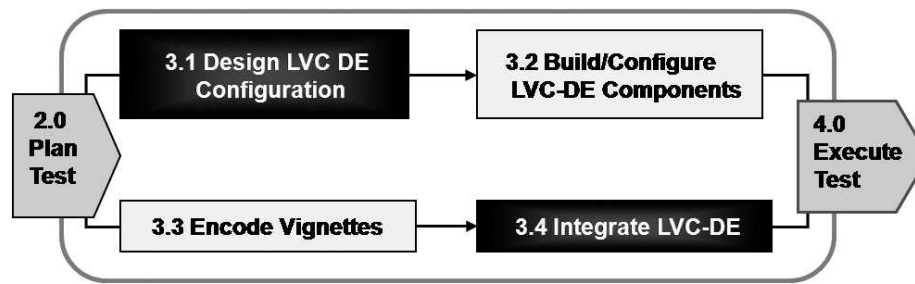


Figure 7. CTM 3 implement LVC distributed environment processes used during INTEGRAL FIRE.

test organization could produce a test plan according to local formats and procedures, with added sections to accommodate JTEM-recommended methods and processes for distributed testing in a joint environment. The overall distributed test plan could be an augmented version of the lead test organization's plan. Participating test organizations could approve their own plans, while the lead test organization commander would provide "distributed approval" by mutual agreement. Such a concept might better suit situations in which tests in a joint environment are integrated seamlessly into other developmental and operational tests. The lead test organization should be the organization responsible for most nondistributed testing for that program.

CTM 3 processes used to produce the final LVC distributed environment are shown in Figure 7. A final planning conference and two week-long distributed integration periods were needed to execute these processes. Table 2 shows a simple depiction of the LVC distributed configuration produced by the Design LVC Distributed Environment Configuration process. Figure 8 shows the LVC distributed environment produced by CTM 3 processes. This distributed environment was assembled to support all INTEGRAL FIRE customers. Customers used only those parts of the environment needed to accomplish their individual test objectives. Specifically, INTEGRAL FIRE was able to schedule JSIC testing for the first week and JTEM and WWF testing during different times the second week. This is directly analogous to configuring an open-air test range to accommodate a set of test customers, then

scheduling various parts of the range separately or concurrently to conduct each customer's testing. But distributed testing, such as in INTEGRAL FIRE, requires multiple test facilities to be set up and managed as though they were a single test facility. The good news is that much of the work producing CTM 3 products was simply due to the lack of a persistent distributed test environment and standing organizational relationships to manage that environment. INTEGRAL FIRE made significant progress toward persistence. Test organizations should consider establishing formal relationships—the integrated product team structure used in INTEGRAL FIRE is a sensible place to start—so that the distributed test environment can be managed as a single facility. Evidence suggests that such things as standard data products, permanent configuration control, and a full-time verification and validation group would have substantially reduced the effort needed to assemble the INTEGRAL FIRE test environment.

Conclusion

Substantial improvements were made to our methods and processes by having experienced testers use them to plan and conduct actual test activity. Processes currently in CTM 1 for developing joint test concepts, joint operational contexts, and joint mission evaluation strategies were found to be too important to be confined to test characterization by distributed test organizations. Figure 9 shows CTM version 1.1 in which these processes are moved to a sixth step, CTM 0, for acquisition managers to prepare overall test and evaluation strategies and master plans. A lack of persistent formal relationships among test organizations led to problems with cost estimation and increased workload in assembling a distributed joint test environment. Implementation of test planning processes during INTEGRAL FIRE was too cumbersome for frequent distributed testing in a joint environment. As a result, we recommend test organizations consider a construct where each acquisition program has a lead test organization designated for distributed testing. We also recommend test organizations consider establishing

Table 2. LVC distributed configuration produced by design LVC distributed environment configuration

Function	Primary configuration	Backup configuration
JTAC	WSMR	Eglin
NEW	SIMAF	Eglin
Launch aircraft	SIMAF	Eglin
NEW targets	WSMR	SIMAF
CAOC	Langley	Langley
FSP	Redstone	Redstone

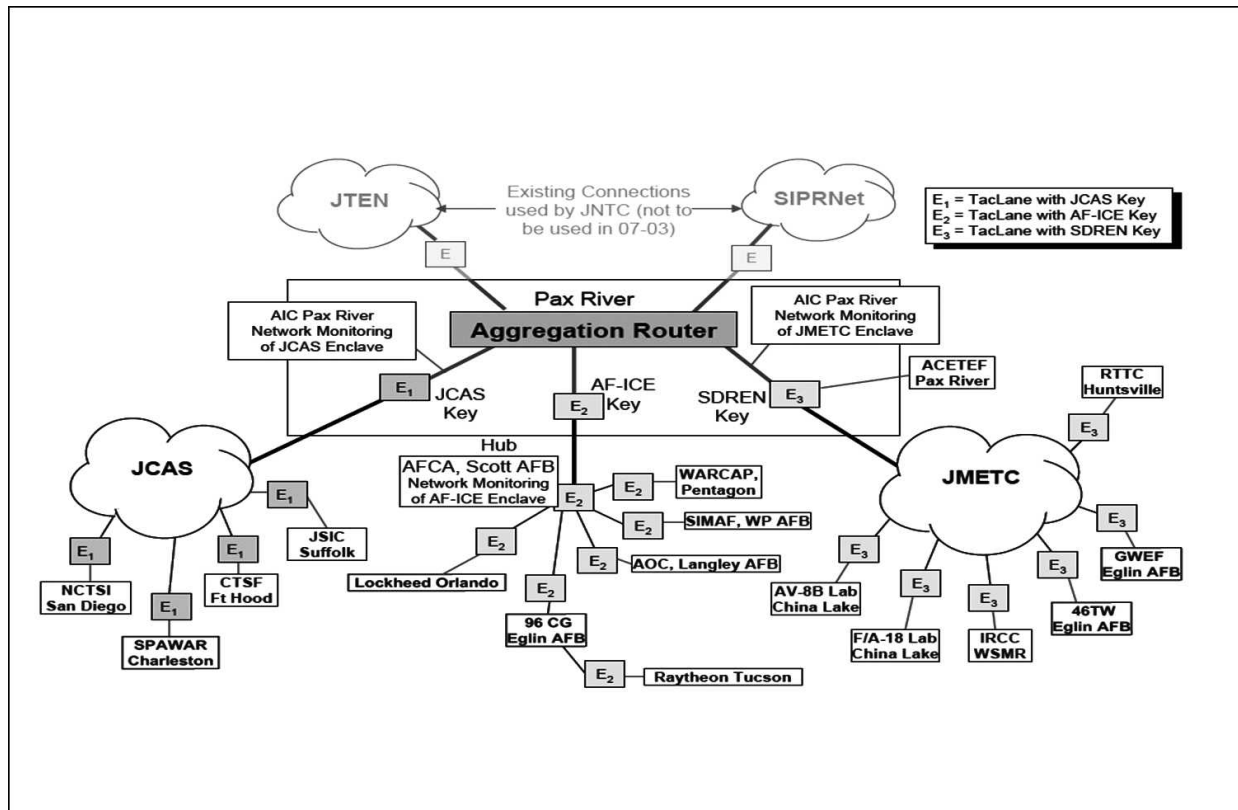


Figure 8. LVC distributed environment produced by integrate LVC-DE process.

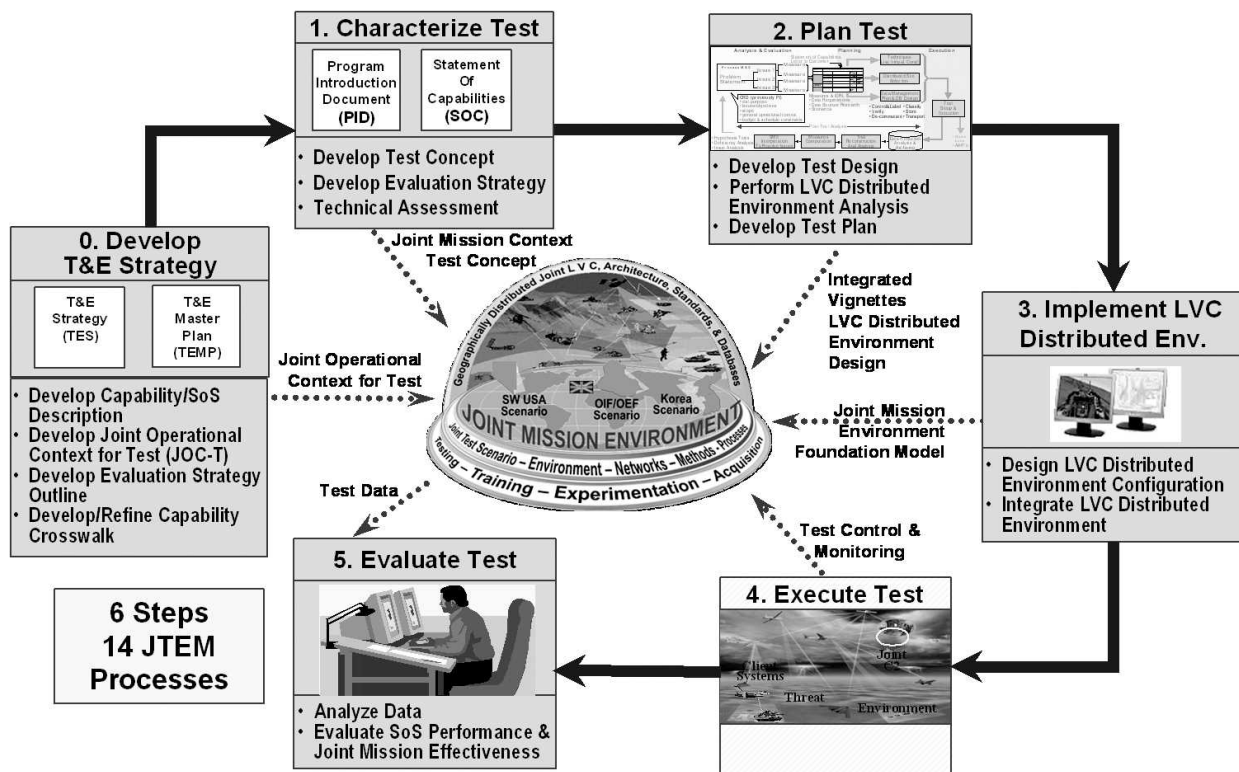


Figure 9. Capability Test Methodology version 1.1 reflecting lessons learned during INTEGRAL FIRE.

formal relationships so that the distributed test environment can be managed as a single facility. JTEM released version 2.0 of the Capability Test Methodology in early 2008 and used those updated processes to plan and conduct another set of distributed tests. The department's ultimate goal is to test and evaluate requirements as part of the overarching acquisition process in realistic joint mission environments and institutionalize testing in a joint environment. □

COL EILEEN BJORKMAN is the Chief, Modeling and Simulation Policy Division, Secretary of the Air Force Office of Warfighting Integration and Chief Information Officer. She recently completed an assignment as Joint Test Director for the Joint Test and Evaluation Methodology (JTEM) Joint Test and Evaluation project. She is a flight test engineer graduate of the USAF Test Pilot School and has a bachelor's degree in Computer Science and bachelor's and master's degrees in aeronautical engineering. She has held a wide variety of development test and evaluation assignments and several staff positions in modeling, simulation, and analysis. Her professional affiliations include ITEA, MORS, and SFTE. Email: eileen.bjorkman@pentagon.af.mil

DR. FRANK GRAY is Air Force Deputy for the Joint Test and Evaluation Methodology (JTEM) Joint Test and Evaluation program at Kirtland AFB, New Mexico. He is a graduate of the USAF Fighter Weapons School and the USAF Test Pilot School, and has bachelor's and master's degrees in aeronautical engineering from the Ohio State University and a doctorate in industrial engineering from New Mexico State University. His test and evaluation awards include the ITEA Richard G. Cross Award, the Air Force Association David C. Schilling Award, and the Raymond L. Jones Award from the USAF Test Pilot School. Dr. Gray's professional societies include ITEA, MORS, Institute of Industrial Engineers, American Society for Quality, Society for Engineering and Management Systems, and American Statistical Association. Email: frank.gray@jte.osd.mil

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Acknowledgments

This work was sponsored by the Office of the Secretary of Defense, Director of Operational Test and Evaluation, Joint Test and Evaluation Program.