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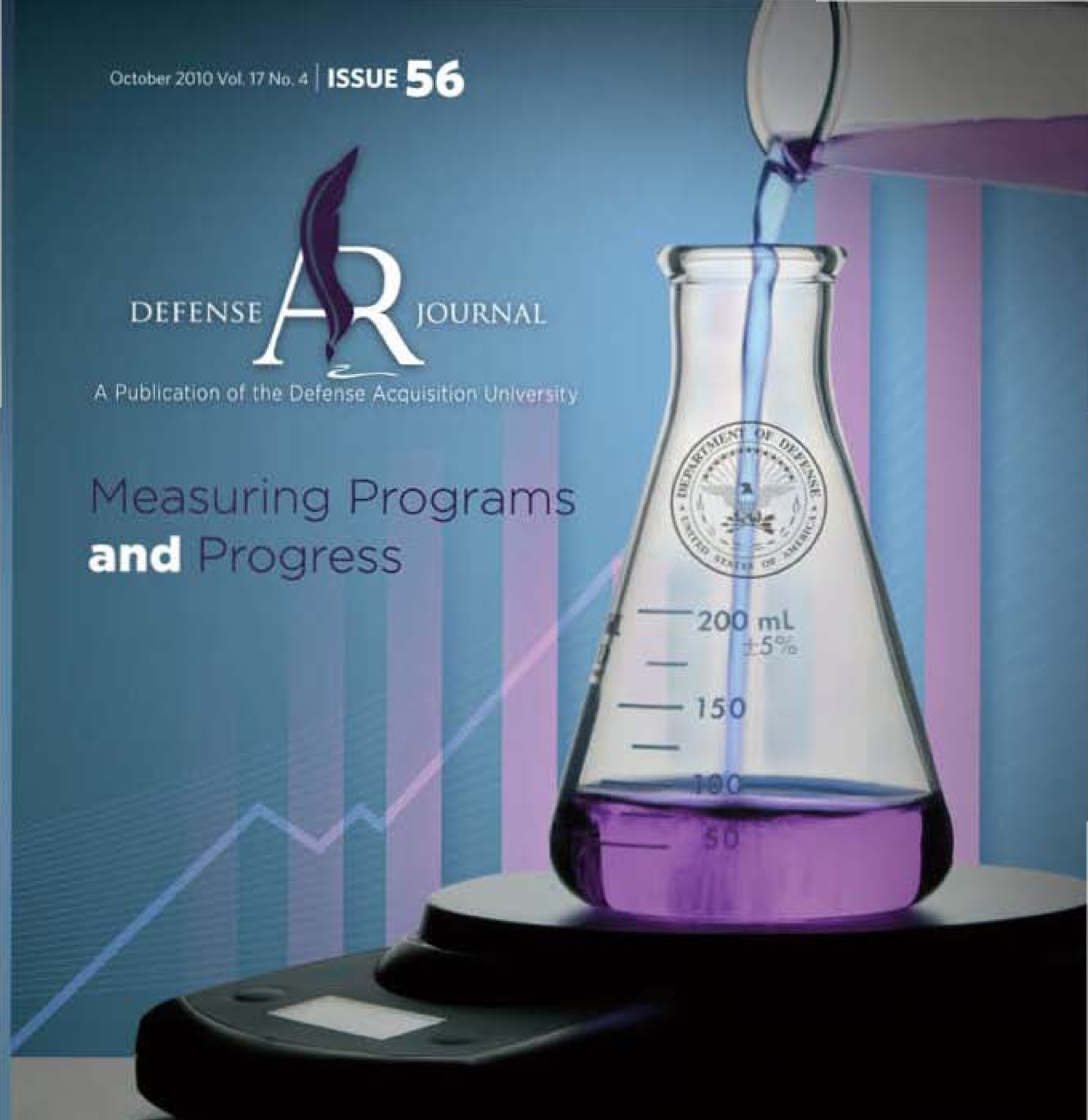
DEFENSE AR JOURNAL

A Publication of the Defense Acquisition University

Measuring Programs and Progress



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Measuring Programs and Progress

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Remarks
FROM THE EXECUTIVE EDITOR

"Measure what can be measured and make measurable that which cannot be measured."
—attributed to Galileo Galilei

The U.S. Department of Defense (DoD), which has seen a decade of growth in expenditures, now spends about $400 billion annually on acquiring systems and services, in roughly equal measures for each. The next decade will likely see a marked reduction in defense acquisition spending, as DoD leadership is aiming to save 2–3 percent annually through productivity enhancements and greater efficiencies. To realize these savings, DoD must first know what is being saved and how to measure it. But this is not simply a question of establishing some numerical target and comparing output against it. As Frank Kendall, Principal Deputy Under Secretary of Defense for Acquisition, Technology and Logistics said of a recent personnel initiative, "We are not measuring performance in terms of pure numbers...We want quality and we want the right kinds of people" (Brodsky, 2010, p. 2).

The idea of adopting broader ways of assessing defense acquisition is at the heart of this issue's theme, "Measuring Programs and Progress." Chiang H. Ren, Col Stephen Busch, USAF (Ret.), and Matthew Prebble begin their discussion by arguing for a "try-before-fly" approach to automated information system programs, by creating a soft start period to evaluate materiel solution concepts before committing to a Materiel Development Decision. Rick S. Thomas, N. Clark Capshaw, and Paul M. Franken examine how a spectrum of testing activities was used to assess, over a period of time, the evolutionary progress of a system-of-systems, to build up an integrated evaluation of its performance.

Of course, evaluating progress requires understanding which critical factors must be evaluated, as Steve Geary, Scott Koster, Wesley S. Randall, and Jeffrey J. Haynie explain in their article on Life Cycle Support Strategies. Ismail Cicek and Capt Gary S. Beisner, USAF, describe how they were able to save program time and money by exploring new test and analyses methods to assess aeromedical equipment for safety certification. The final article by Alan Haggerty and Roy Wood describes how a little-known company at the beginning of World War II (WWII) quickly developed the renowned P-51 Mustang by pulling together a series of technological developments into a well-integrated system; with no time for systematic measurement and testing, the engineers relied on their collective lifetimes of experience to field a capability that ultimately helped win the war.

By any measure, today's acquisition workforce is as experienced and as motivated as their forerunners in WWII. Those qualities will be needed in the years to come as we rise to the challenge of "doing more without more" in equal measure.

Dr. Larrie D. Ferreiro
Executive Editor
Defense ARJ

REFERENCE

Brodsky, R. (2010, June 2). Pentagon official searches for the source of contracting waste. *Government Executive*. Retrieved from http://www.govexec.com/dailyfed/0610/060210rb1.htm

Remarks
FROM THE MANAGING EDITOR

WE ARE CHANGING OUR NAME!

Our name will officially change from the *Defense Acquisition* ***Review*** *Journal* to the *Defense Acquisition* ***Research*** *Journal* effective January 2011—Issue 57. Although the acronym *ARJ* will remain the same, the name change is being implemented to reflect an overall commitment to refocus the Defense Acquisition University's research efforts on strategic alignment to meet the requirements of the Defense Acquisition Workforce.

Norene Fagan-Blanch
Managing Editor
Defense ARJ

The DAU Alumni Association (DAUAA), in support of the DAU Research Program, is proud to announce the fourth annual acquisition research paper competition.

DAUAA 2011 RESEARCH PAPER COMPETITION

THIS YEAR'S THEME:

MAKING EVERY DOLLAR COUNT— IMPROVING ACQUISITION OUTCOMES

Winning papers will receive a cash prize and will be presented at the 2011 DAU Acquisition Community Symposium.

Submissions are due by November 1, 2010.
For more information visit www.dauaa.org.

This competition has several purposes:

- to enhance the professional stature of DoD acquisition professionals
- to officially recognize outstanding research efforts within the acquisition community
- to facilitate learning and knowledge sharing in conjunction with the theme of the annual DAU Acquisition Community Symposium
- to generate acquisition-related research studies/articles for the *Defense Acquisition Review Journal (ARJ).*

Ground rules:

- The competition is open to anyone interested in the DoD acquisition system and is not limited to government or contractor personnel.
- Employees of the federal government (including military personnel) are encouraged to compete and are eligible for cash awards unless the paper was researched or written as part of the employee's official duties or was done on government time. If the research effort is performed as part of official duties or on government time, the employee is eligible for a non-cash prize, i.e., certificate and donation of cash prize to a CFC-registered charity of winner's choice.
- First prize is $1,000. Second prize is $500.
- The format of the paper must be in accordance with guidelines for articles submitted for the *Defense ARJ*, which can be found on the DAU Web site at http://www.dau.mil/pubscats/Pages/ARJ.aspx.
- The theme for 2011 is: "Making Every Dollar Count — Improving Acquisition Outcomes."
- Research papers are due November 1, 2010.
- Papers should be submitted to the DAU Director of Research: Dr. Larrie D. Ferreiro, 703-805-5423 or larrie.ferreiro@dau.mil.
- Papers will be evaluated by a panel selected by the DAUAA Board of Directors and the DAU Director of Research.
- Winners will be announced and papers will be presented at the DAU Acquisition Community Symposium in April 2011.

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DEFENSE ***ACQUISITION REVIEW*** JOURNAL

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IMPROVING THE INITIATION OF ACQUISITION ACTIVITIES FOR AUTOMATED INFORMATION SYSTEMS

Chiang H. Ren, Col Stephen Busch, USAF (Ret.), and Matthew Prebble

The success rate for acquiring automated information systems (AIS) continues to be a source of considerable interest to Congress and the Department of Defense. Building upon Defense Science Board recommendations, the authors' research identifies improvements for initiating information systems acquisition. Adding a soft start period prior to the Materiel Development Decision allows the acquisition community to negotiate with end users regarding system concepts that can satisfy the *materiel solution concept* and better manage the flexibility of AIS concepts to lower risks. This management is enabled through a newly formulated reference frame that maps the materiel solution concept to the system concept and allows the system concept to be reorganized and optimized prior to the analysis of acquisition approaches.

Keywords: *Major Automated Information System (MAIS), Information Technology (IT), Defense Science Board (DSB), Materiel Solution Concept, Materiel Development Decision (MDD), IT Acquisition Process, MAIS Initiation, Section 804 FY10 NDAA*

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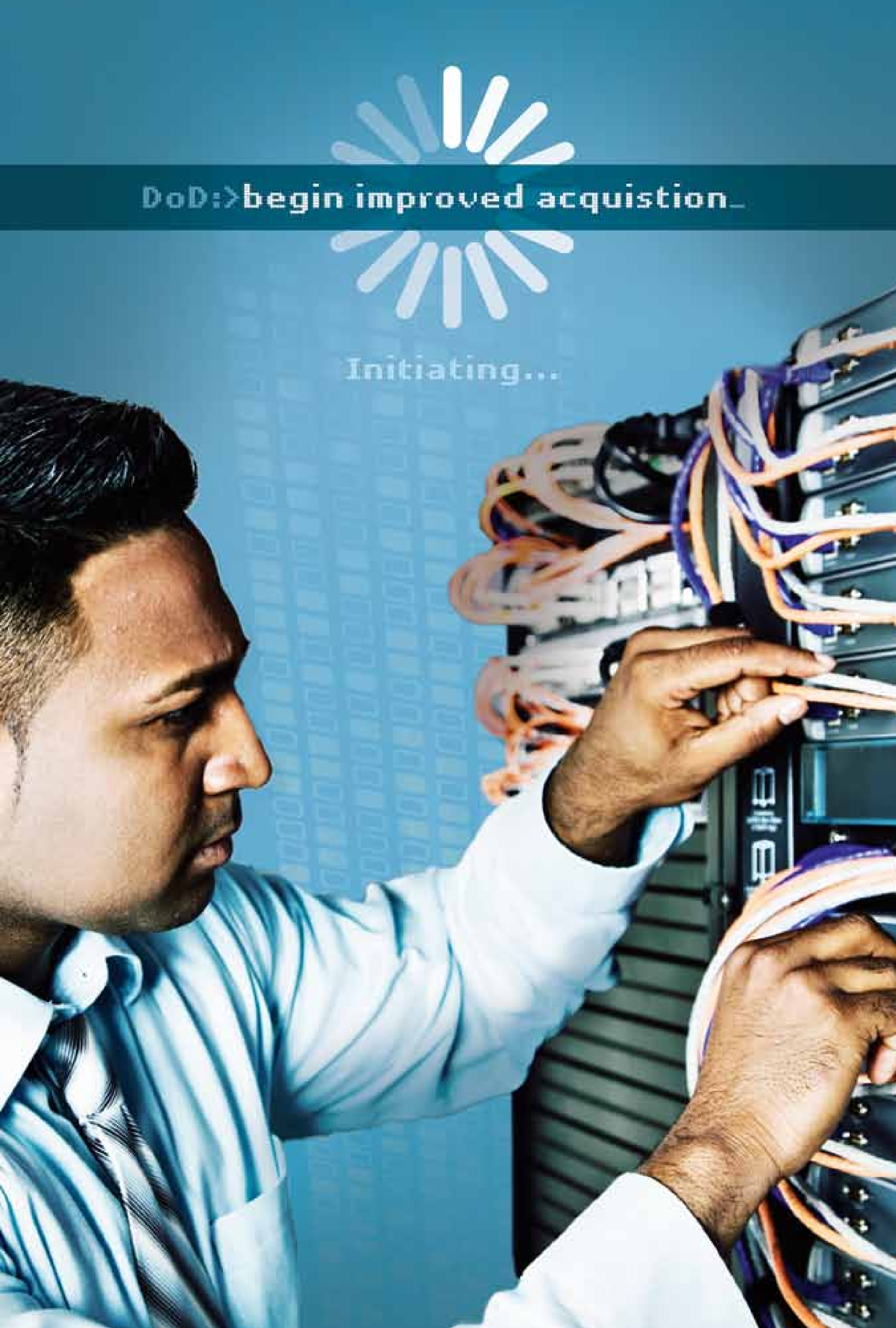
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Initiating...

The U.S. Congress established new reporting requirements and performance constraints for *Major Automated Information System (MAIS)* acquisition programs in section 816 of the FY 07 National Defense Authorization Act (NDAA, 2006). These requirements, codified in 10 United States Code (U.S.C.), chapter 144A, were later modified to include pre-MAIS programs and a completion standard of 5 years from first obligation of funds to full deployment decision.

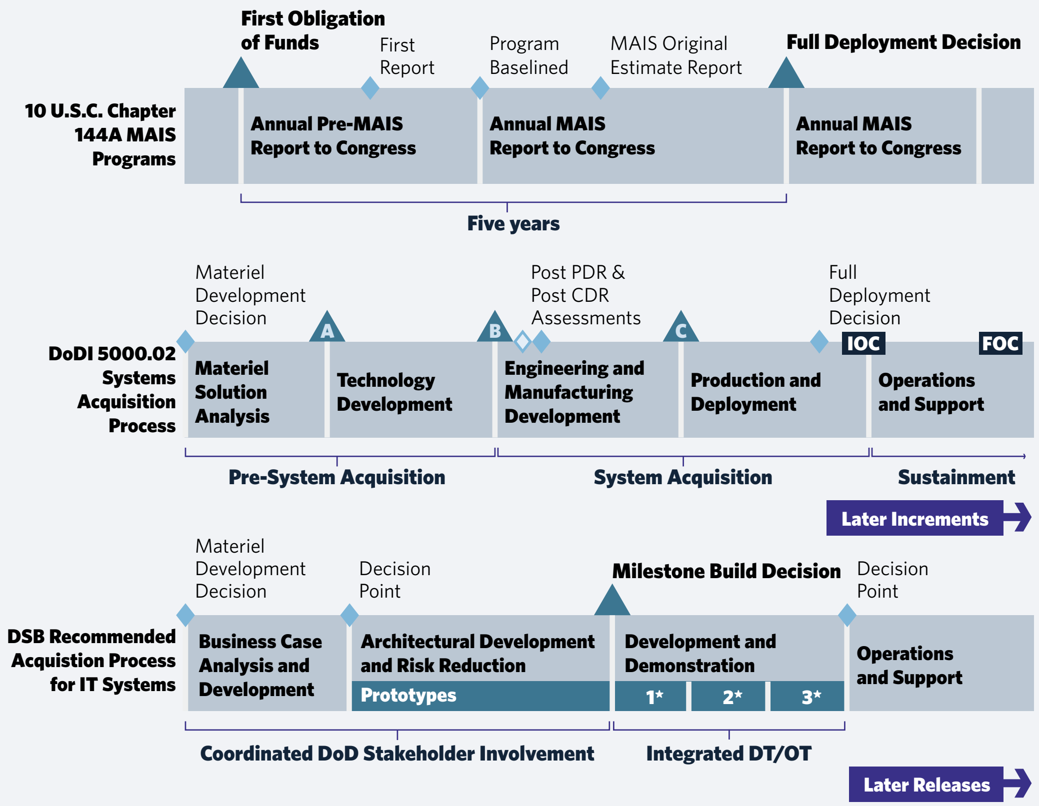
Defense Science Board and Acquisition of Information Technology

At the request of Congress, the *Defense Science Board (DSB)* then studied the DoD policies and procedures for the acquisition of *information technology (IT)* and recommended in their March 2009 report a new acquisition process for IT systems based on commercial worldwide best practices (Department of Defense [DoD], 2009a). This more streamlined process, primarily for stand-alone software development, progressively refines the software product based on continuous stakeholder participation and multiple iterations leading to a major release. The DSB task force further recognized that the current acquisition process for all DoD systems, as presented in the December 8, 2008, release of Department of Defense Instruction (DoDI) 5000.02, is still valid for IT systems acquisition, with substantial trade-offs in design, development of nonsoftware technologies, and integration with major weapon systems (DoD, 2008). The Congressional reporting process for MAIS programs and the current, as well as proposed, acquisition processes for satisfying congressional expectations are presented in Figure 1.

In Section 804 of the FY 10 NDAA, Congress officially called for the Secretary of Defense to develop and implement a new acquisition process for IT systems based on the DSB recommendations (NDAA, 2009). Regarding the selection of which acquisition process to adopt for a specific IT program, the DSB members in their report remarked, "One could argue that if the leadership and program managers cannot sort out this high-level decision, they have no chance of effectively managing or overseeing the programs."

Our research presupposes that this DSB remark actually strikes at the heart of the problem as to why so many IT programs have faced developmental problems in recent years. Identifying which IT programs involve nonsoftware technologies and embedding software into weapon systems, as governed by interoperability standards, are relatively straightforward. But, understanding which IT programs do not involve substantial trade-offs in design and approach can be

FIGURE 1. MAIS REPORTING, DoDI 5000.02, AND DSB RECOMMENDED PROCESSES



Note. CDR = Critical Design Review; DT = Developmental Testing; FOC = Full Operational Capability; IOC = Initial Operational Capability; OT = Operational Testing; PDR = Preliminary Design Review; * = Iteration

overtly or even covertly complex. Much of this complexity starts with how one defines the IT system to be developed.

The IT system can be one small application, a suite of applications, or a total solution for the enterprise because of the integrative nature of modern IT capabilities. Over the past decade, overly ambitious IT programs involving multiple integrated or flexible components have ultimately: (a) decoupled into independent development paths, (b) collapsed due to escalating baselines, (c) breached schedules and costs, and/or (d) failed to fully meet user expectations. At the same time, dozens of small IT programs have been initiated across the DoD with: (a) redundancies in development activities, (b) overlaps in functionality, (c) barriers toward integration or federation, and/or (d) limitations in scalability. Defining the IT system concept correctly at the initiation of acquisition activities is therefore critical to both the decision to use a streamlined *IT acquisition process* and the approach for leveraging the rigors of the current DoDI 5000.02 process to manage developmental risks. This article will explore methods for improving the initiation of acquisition activities through better concept definition of the IT system.

Analysis Methodology

The objective of this research endeavor is to determine acquisition process improvements for future automated information systems without dwelling on the program deficiencies and failures of the past. Therefore, a methodology of process decomposition and functional advancement is adopted in lieu of case studies. The first step in decomposition is to identify the point of disconnect between the IT materiel solution concept and IT system concept formulation within the current process. This point then permits the insertion of a transformation function, which maps the user materiel solution and the associated system concept to a common reference frame. This reference frame then enables the reorganization of the system concept for more effective acquisition while preserving connectivity to user requirements. An inductive analysis of current terminologies in the IT community is used to create the reference, and a deductive analysis of the relationships within the reference frame is used to establish the application methodology. Finally, recommended changes to the acquisition process are formulated using the analytical results.

Analysis Results

Currently, the initiation of acquisition activities for major IT systems within the DoD is based on a *Materiel Development Decision (MDD)* by the Milestone Decision Authority after consideration of requirements generated through the Joint Capabilities Integration and Development System (JCIDS) and the acquisition community's ability to satisfy the requirements (Joint Chiefs of Staff, 2007). The JCIDS process of capabilities-based assessments, functional area analysis, and functional needs analysis ensures that the established need for a materiel solution (physical system) results in an essential capability for the warfighter. The resulting Initial Capabilities Document must accurately address operational gaps, align with the integrated operational concepts of the regional and functional combatant commanders, and present validated requirements.

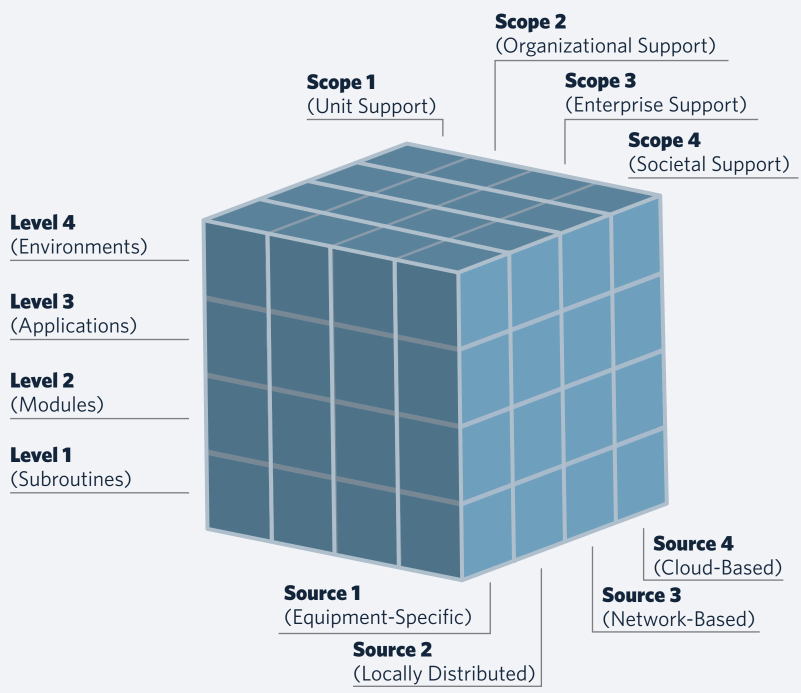
The analysis of the acquisition community's ability to satisfy the requirements must take into account technologies from all sources and explore solution options in the context of the DoD Architectural Framework (Wisnosky & Vogel, 2004). The DoD Architectural Framework used in capabilities-based analysis starts with a high-level operational concept graphic as the first operational view and then quickly progresses down levels of detail in operational understanding, systems definition and configuration, and technical standards.

The current acquisition initiation process, as presented, extends from a tradition of preserving the purity of user/warfighter needs, with the acquisition community responding to these needs. The concept of evolutionary acquisition allows the acquisition community response to evolve in increments driven by stages in technology maturation. However, the assumption is still that the user-defined materiel solution concept can easily extend to a system concept for acquisition. This assumption remains quite valid for mechanical systems. Obviously, it would be ridiculous if the warfighters want a plane and the acquisition community tells the warfighters that what they really want is some wings, avionics, and jet engines. Even when the warfighters want a system of systems, such as missiles, radars, and control centers, the nature of the systems is very clear.

The assumption of clear system concept is not necessarily true in IT acquisition. For example, if the warfighters want an integrated suite of applications to create an enterprise solution environment, it would not be silly for the acquisition community to tell the warfighters that the enterprise can be better supported by more loosely coupled applications developed as multiple programs. Essentially, when users have an IT solution concept, that single concept could equate to a single system, multiple systems, a system of systems, or even a mixture of systems and services. An eagerness of the acquisition community to rush down one path when given validated requirements can lead to great program risks. The complexity of the initiation process cannot be ignored.

A hierarchical architectural framework may not be sufficient to map the complex understanding of requirements into a paradigm where effective system or systems definitions can be formulated. To create a complementary framework, we examined the ways in which IT is described in industry and concluded that interlinked dimensions of characterization can be used to better define IT systems. These dimensions are not clearly elucidated in literature, in part due to the competing approaches and schools of thought in commercial software development. As a result, a better standardized and organized set of parameters for capturing the dimensions of DoD IT system characterization is still merited.

FIGURE 2. REFERENCE FRAME FOR MAPPING MATERIEL SOLUTION CONCEPT TO IT SYSTEM CONCEPT



Our research suggests that once a materiel solution concept with operational requirements has been formulated by the users, the acquisition community can place that concept into a three-dimensional reference frame as shown in Figure 2. Based on initial market research and technology assessment prior to MDD, the solution concept can be mapped across a range of blocks within the reference frame and be defined through the identification of activities in each block. The scalar parameters for establishing each of the three dimensions are proposed and explained in the discussion that follows. The methods of defining IT systems using this mapping of the solution concept are also presented.

Dimension 1: Mapping the Magnitude Level of the Concept

Software/computer codes, unlike mechanical devices, have a greater ability to be both decomposed into progressively smaller individual units and integrated into progressively larger overarching units. Therefore, defining a system based on bounding software in the modern era of distributed computing is almost as hard as finding boundaries within a continuous body of water. The current state of software technology does suggest that four levels of boundaries can be established. These boundaries are four parameters on a scale that indicate the levels and total magnitude of software organization. When mapping a solution concept to this scale, software organization can reach the point of being an application (Level 3) or creating an environment (Level 4) without first having an extensive number of modules (Level 2) or subroutines (Level 1).

Also, software modules and subroutines can sometimes become stand-alone applications, and software applications can sometimes be recategorized as being able to establish an environment. The distinctiveness of these four parametric levels, therefore, requires integration with the other two dimensions—Scope and Source. Otherwise, the description of activities at each level can become inconsistent from one acquisition effort to the next.

LEVEL 1 (SUBROUTINES)

Portions of code that perform specific tasks or functions within the context of an overarching program/executable file. Subroutines can be reused, and popular subroutines can be stored as a task library for easy access. In a program, subroutines can be within subroutines to form a nested structure and/or be integrated through commands and shared parameters (Fischer, 2001, pp. 1–8).

LEVEL 2 (MODULES)

Independently executable files/programs that perform functions capable of being organized and integrated through interfaces to satisfy the design capabilities of an application. Modules built on the principles of component-based engineering can be reused and rearranged to achieve multiple capabilities (Szyperski, 2002). Also, modules of foundational utility can be offered as a service through Service-Oriented Architectures (Bell, 2008).

LEVEL 3 (APPLICATIONS)

IT products that meet the performance of defined capabilities. Applications will generally have a functional architecture, and the architecture can be designed to be open to the reorganization, updating, and upgrading of constituent modules/components.

LEVEL 4 (ENVIRONMENTS)

IT infrastructures consisting of a network of applications including the core applications that sustain the environments. Environments are generally designed to satisfy the total mission needs of the entity they support. And, environments can be network-centric, highly restricted and compartmentalized, or centralized.

Dimension 2: Mapping the Utility Scope of the Concept

Once a concept has been mapped to levels of software organization, each level of the software can have different scopes in utility as defined in the following discussion. The most straightforward alignment is that: (a) a software environment can cover the entire society impacted by a DoD mission, (b) a software application within the environment can support a Service or joint enterprise, (c) a software module can address the functional needs of one or more organizations within the enterprise, and (d) a software subroutine can execute a specialized task for a specific unit of the organization. However, the scope of utility does not have to match the level of software organization in a parallel manner. A software environment or application can serve only the mission of a specific unit. A software subroutine or module can alternatively serve the mission of an entire enterprise or society.

A potential mistake in acquisition planning is overlooking the fact that the subroutines and modules used to create applications and environments may either have a more individually unique scope or a broader scope than the application to which they belong. An individually unique scope implies the need for greater fidelity in stakeholder participation, while a broader scope implies latent potential for DoD reuse or co-development. To better understand the varying scopes associated with the elements at each level, the relationship of levels and scopes can be captured in a four-by-four matrix.

SCOPE 1 (UNIT SUPPORT)

Tasks, functions, and/or capabilities are designed around supporting specific divisions within DoD. A high degree of specificity, characteristic of Scope 1, is tailored to the unique needs of small user groups.

SCOPE 2 (ORGANIZATIONAL SUPPORT)

Tasks, functions, and/or capabilities are designed around supporting major commands and agencies within DoD. Scope 2 places emphasis on meeting needs associated with the specific mission of the organization.

SCOPE 3 (ENTERPRISE SUPPORT)

Tasks, functions, and/or capabilities are designed around supporting the entire DoD community or a military service within the DoD. Scope 3 places emphasis on bringing the community into using a single conformance standard.

SCOPE 4 (SOCIETAL SUPPORT)

Tasks, functions, and/or capabilities are designed around supporting activities and awareness among all societal stakeholders in a DoD mission. Stakeholders can be other government agencies, state and local government organizations, international organizations, corporate entities, foreign governments, and/or U.S. as well as foreign citizens with a need to respond.

Dimension 3: Mapping the Delivery Sources for the Concept

After the solution concept has been mapped into the matrix of levels and scopes, each box in the matrix can then have a unique source for providing service to the user. As with scope, the source for elements at each level can be from one to all four of the following access methods. Further, the nature of access at higher levels may be different than access at lower levels. Software modules and subroutine libraries, for example, can be deployed at specific user sites and from user servers. However, once these modules or subroutines are integrated with other modules, the total resulting application can be accessible from DoD networks. Alternatively, software modules can be acquired as a cloud computing-based service or network-based tool. Then, these modules could be offered to users as a part of local or even site-specific applications. Sometimes, users may not even be aware that their application, with personalized features, may rely upon capabilities that are delivered across the Internet.

SOURCE 1 (EQUIPMENT-SPECIFIC)

IT system element resides within a single hardware associated with a specific user or group of users. For example, software loaded onto user desktops and portal devices.

SOURCE 2 (LOCALLY DISTRIBUTED)

IT system element resides within multiple, interconnected hardware equipment across the user facility (peer-to-peer connectivity) or is accessible by multiple hardware equipment through connection to central hubs (local area networks). For example, software with multiple user licenses offered through a local Intranet.

SOURCE 3 (NETWORK-BASED)

IT system element hosted at a DoD recognized facility that is accessible across an entire DoD validated network (wide area networks, router networks across the Internet, etc.). For example, DoD developed tools offered to the enterprise through DoD portals.

SOURCE 4 (CLOUD-BASED)

IT system capability accessible as a scalable service across the Internet (Knorr & Grumman, 2008). For example, commercial tools from multiple redundant sites that are available to DoD users in a device- and location-independent manner.

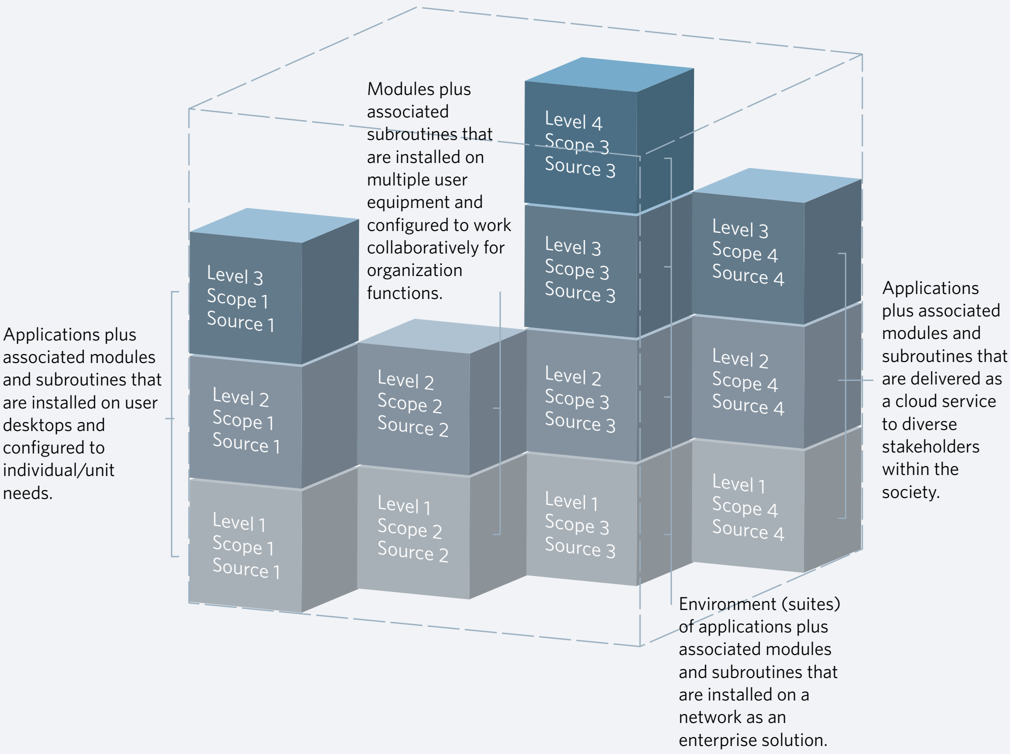
Application of the Reference Frame

The definition of the three-dimensional reference frame (Figure 2) permits a materiel solution concept to be mapped/decomposed into a set of blocks from which a system or multiple system concepts can be formulated. Figure 3 presents a notional configuration of blocks that represents a concept. The goal in describing the activities in each block is not to achieve overwhelming detail but to understand the relationship of blocks to one another. As the relations of activities across the blocks are all achieved through codes, the correction and optimization of relationships through systems formation are feasible and could be critical to acquisition success. Four methods of systems analysis, using this reference frame, can support the organization of acquisition activities.

Method 1: Forming Multiple Systems or Reduced Systems Based on Decomposition of the Mapped Concept

The relationships between blocks from a mapped concept may have natural weak points where forced integration yields acquisition risks. These weak points may merit the breakup of the materiel solution concept into separate systems for acquisition. Weak points could be places where there will be: (a) high risks or low benefits for integration in terms of schedule, cost, and performance, (b) high stress in sustaining integration because of varying pace in technology advancement, and/or (c) extreme challenges in achieving

FIGURE 3. NOTIONAL EXAMPLE OF BLOCK CONFIGURATION MAPPED FROM SOLUTION CONCEPT



integration due to technology scaling and new technology requirements. The breakup can be along any of the three dimensions and can follow a complex path of weak points. Some attempts at creating an integrated software environment may be better pursued as the development of separate applications. Some attempts at trying to provide capability to the society or enterprise may be better pursued by providing separate capabilities to smaller sets of key organizations. In addition, some attempts at delivering services through the Internet may be better pursued as a delivery of more controlled services through secure networks and portals. The objective is an end state characterized by a stable configuration of blocks to create system concepts before the start of the acquisition process.

Method 2: Forming a Single System or Reduced Set of Systems Based on Integration of Multiple Mapped Concepts

The configuration of blocks from a mapped concept may lend itself to being integrated with configurations of blocks associated with other materiel solution concepts. If so, an opportunity may exist to develop a single system that can satisfy multiple sets of requirements. Factors to consider when studying the opportunity for integration include: (a) the ability to consolidate the integrated configuration to reduce schedule and cost, (b) the ability to enhance performance through cross-leveraging of activities, (c) the challenges in achieving integration, and (d) the risks in integration. The simplest way to integrate is to identify all the overlapping block definitions along the three dimensions and create the hybrid configuration based on the overlaps. Alternatively, one can study the definitions of the blocks on all sides to see whether a redefined set of blocks can satisfy all the configurations to be integrated.

Method 3: Establishing Co-Development Activities Between Multiple Mapped Concepts

Some blocks in a mapped concept may exhibit common characteristics with blocks in other materiel concepts even though the separate configurations will not be integrated. Such commonalities suggest that co-development or technology sharing opportunities are still available. Given the complexity of software structures, commonalities at the lower levels, scopes, and sources may not always be obvious when comparing overarching concepts. Therefore, comparing blocks along each of the three dimensions is important. A commonality of software elements at any level clearly encourages coordination between systems acquisitions. However, even a commonality of users at any scope suggests a coupling of funding priorities. Also, a commonality of delivery mechanisms from any source suggests a coupling of infrastructure and supporting hardware.

Method 4: Forming New Systems Based on Reorganization or Redefinition of Activities for Mapped Concepts

The most optimal sequencing and timing of developmental activities for the blocks may not be that suggested by the initially mapped concept. Optimal timing may require grouping the blocks into evolutionary increments or iterations within one major release. Optimal sequencing may require some blocks to be redefined and others to be eliminated to facilitate the efficiency of acquisition.

The ability to organize IT acquisition activities into all manner of partial product releases under the spiral development concept is a two-edged sword. When done effectively, the timing of partial releases can take advantage of technology maturation stages, availability of supporting commercial products, user feedback for product refinement, and early mission support opportunities. However, identifying the right pieces for release, timing of release, and extent of release can be difficult. Too many releases may eat away the time periods for refining products. Too few releases may lead to greater adjustment of developmental activities. Further, poorly timed releases may result in less beneficial user feedback, missed opportunity of mission impact, and wasting of test and certification resources.

Understanding the natural breakpoints in a system concept could reduce the level of error in sequencing acquisition activities and determine conditions for partial product release. The proposed reference frame could aid in this understanding throughout the acquisition process.

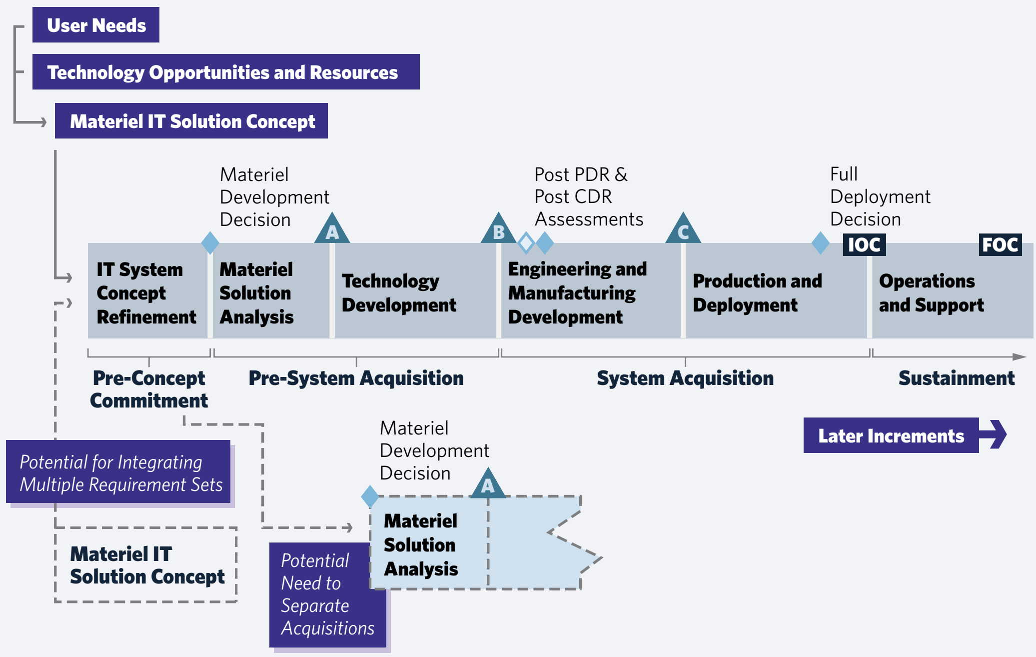
Conclusions

The systems acquisition process in DoDI 5000.02 and the tailored IT systems acquisition process proposed by the DSB both have a hard starting point in the form of the MDD. Our research suggests that the IT systems acquisition process can benefit from a soft start period where the acquisition community can negotiate with the user community regarding system concepts that can satisfy the materiel solution concept resulting from JCIDS. This period also allows the proposed acquisition to be considered within the context of all acquisitions, paralleling the user community effort to ensure that the materiel solution concepts fit within the total concept of joint warfighting. An MDD Review can then be held after the system concept has been appropriately established.

The risk in committing to materiel development without an accurately defined system concept is that the acquisition process can quickly advance to focusing on the user materiel solution concept as the default path to a system concept. Although the Analysis of Alternatives process could, and maybe should, question the materiel solution concept, the analyses in many cases have been directed toward comparing different acquisition approaches instead of questioning what is to be acquired. Even with the alternatives of "maintaining the status quo capability" or "do nothing about achieving capability," the requirements and associated materiel concept are still typically used as the measurement baseline. If the concept of what is to be acquired has not been optimized for efficient system acquisition by the MDD point, the resulting challenges could continue uncorrected throughout the acquisition life cycle.

The drive to satisfy user requirements may push the acquisition community along paths of overwhelming integration, overly ambitious expectations for use, and overestimation of commercial capabilities. When the complexity of acquisition activities exceeds the government's ability to understand, some program offices may

FIGURE 4. UTILITY OF THE SOFT START PHASE FOR IT SYSTEMS ACQUISITION



attempt to acquire the capability as a service, anticipating that commercial entities will assume the risks of development. The shifting of risks through a Service Level Agreement (SLA) does not eliminate the risks. If commercial entities cannot master the nature of government system needs, then all an SLA can do is to reduce the government's financial risks through nonpayment for an undelivered service. However, the lack of service capability to support missions will remain a problem.

Soft starts in the acquisition process are already occurring to reduce technology risks. In many cases, technology projects such as Joint Capability Technology Demonstrators are used to accelerate program execution to capture technology opportunities or delay program initiation to manage technology risks (Department of Defense, 2009b). The IT soft start period proposed through this research (Figure 4) will require far less resources than technology projects. Further, the resources should come from a general pool of existing funds to: (a) permit early acquisition community involvement, (b) allow integrated examination of concepts across multiple materiel solution needs, and (c) delay the first obligation of funds for a specific system acquisition until after MDD. Through the soft start, the risks in achieving a full-deployment decision 5 years after the first obligation of funds, as measured by Congress, is dramatically reduced.

In DoDI 5000.02 (DoD, 2008), the Concept Refinement Phase was redefined and renamed the Materiel Solution Analysis Phase. This change may more accurately reflect the activities of the acquisition community after MDD. However, the notion of concept refinement may still be valid. Our proposed soft start period can be named the IT System Concept Refinement Phase, which leads to a development decision and the analysis of the adopted concept. Once IT acquisition activities have been more accurately initiated, perhaps the debate regarding which tailored acquisition process is best suited for a specific system acquisition will not be as critical because all processes can be more easily refined.

Author Biographies

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A FRAMEWORK FOR SYSTEM OF SYSTEMS EVALUATION WITHIN AN AIRBORNE INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE ENVIRONMENT

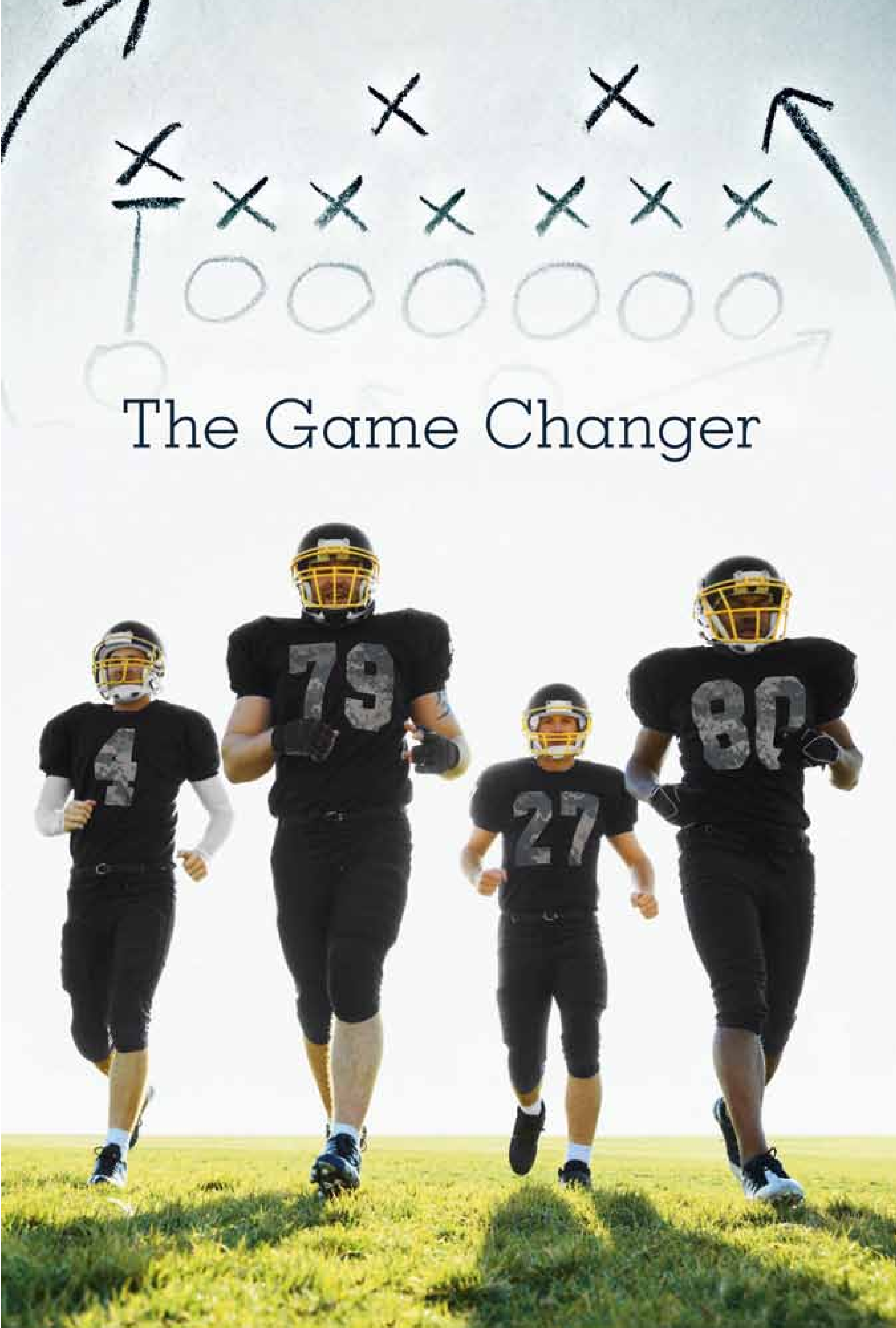
Rick S. Thomas, N. Clark Capshaw, and Paul M. Franken

Federal *test and evaluation* agencies, particularly those associated with the U.S. military, are grappling with the challenge of evaluating *system of systems (SoS)* or a *family of systems (FoS)*—in short, developing methods whereby the contribution of *individual systems* can be evaluated *when operating in combination with other systems,* and determining the effectiveness when various subcomponents are added or removed from the overall SoS. In this article, the authors present a proposed framework for conducting such evaluations through integrating developmental testing, operational testing, and operational performance data into the evaluations. A recent example of the evaluation of a suite of aerial *intelligence, surveillance, and reconnaissance (ISR)* systems is also discussed, relating the aerial ISR evaluation to the proposed framework.

Keywords: *System of Systems (SoS); Family of Systems (FoS); Test and Evaluation; Developmental Testing (DT); Operational Testing (OT); Intelligence, Surveillance, and Reconnaissance (ISR)*

image designed by Nina Costine »

The Game Changer



Federal test and evaluation agencies, particularly those associated with the U.S. military, are grappling with the challenge of evaluating system of systems (SoS) or a family of systems (FoS)—in short, developing methods by which the contribution of *individual systems* can be evaluated *when operating in combination with other systems*, and determining the effectiveness when various subcomponents are added or removed from the overall SoS.

This is particularly challenging when trying to assess airborne intelligence, surveillance, and reconnaissance (ISR) sensors employed as an SoS, due not only to the abundance of sensors (Imagery Intelligence [IMINT], Signals Intelligence [SIGINT], Measurement and Signals Intelligence [MASINT], etc.), but also the myriad ways in which these sensors can be used in combination with one another to achieve mission effects. Further complicating such an evaluation is the notion that ISR sensors are employed at different levels, both in the sense of mission focus—national, strategic, operational, and tactical (N, S, O, T)—and physical altitude.

The aim of this article is to develop and present a framework for how an SoS evaluation might be realized. It begins by noting the special challenges of evaluating an SoS, introduces an analogy to aid in further discussion, and concludes by relating this analogy to a recent U.S. Army Test and Evaluation Command (ATEC) SoS evaluation of a suite of aerial ISR systems. The article also relates this framework to other recently published evaluation frameworks.

In the examples discussed in this article, ATEC used a systems-level methodology that concentrated on an effects-based approach of layers of sensors distributed across multiple aircraft. In focusing on multiple individual systems, ATEC focused on the effects of the systems and not the overall element or family; accordingly, this article will reference SoS versus FoS.

A Conceptual Model for an Airborne ISR SoS

Consider the model for airborne ISR assets presented in the Table. Note that each level presents different mission sets and capability gaps that must be addressed.

As illustrated in the Table, not only are there many kinds of airborne ISR sensor types (IMINT, SIGINT, and MASINT, etc.), but also many different mission sets, instantiations (satellites, manned aircraft, unmanned aerial vehicles), and levels of focus characterize the individual sensors. The Table is misleading in one respect; it shows an apparent clear demarcation from a mission set at one level (e.g., tactical) to the next (e.g., operational). In practice, these clear lines

TABLE. A TAXONOMY OF AIRBORNE ISR SENSORS

Level	Focus	Examples of Mission Sets	Instantiation	Sensor Type
National	Very wide	Monitor nuclear weapons development and testing	Satellites	IMINT still photography, experimental/ advanced and esoteric sensors
Strategic	Wide	Monitor troop massing at border areas for potential attack	High-altitude aircraft	IMINT, SIGINT, MASINT
Operational	Medium	Monitor troop movements in an existing theater of operations; monitor activities of personnel associated with enemy networks	Medium-to-low altitude aircraft and unmanned aerial vehicles (UAVs)	IMINT-wide area focus, full-motion video, aerial photography
Tactical	Narrow	Observe specific enemy attacks and activities, such as emplacement of improvised explosive devices, ambushes, etc.	Low-altitude aircraft and UAVs	IMINT full motion video

are at best fuzzy, and often nonexistent. Increasingly, the national level wants to know every bit of intelligence gained, even down to the tactical level; in turn, tactical operations incorporate as much national-level intelligence as possible. Trying to determine what asset contributes most effectively and its position within the Table is a tough problem—one which a rigorous SoS evaluation should address—but how?

Evaluating the Sum of the Parts or the Capability of the Whole?

By definition, an SoS is an amalgam of individual systems, each of which is designed to perform a specific function. When individual systems are combined into a greater whole, this can conceivably change their character and function.

Testers often find it much easier to conduct evaluations of individual systems because the parameters, threats, and variables that are part of the individual system's tests are not complicated or influenced by other systems that could either augment or degrade the individual system's inherent capability.

In contrast, when evaluating an SoS, multiple additional challenges surface that evaluators need to consider. These challenges could be mitigated during an individual system test, so long as the evaluation teams are aware of force structuring of the SoS before conducting the individual test. The discussion that follows addresses some of the considerations that increase the complexity of effective SoS testing.

Optimization of Systems When Integrated With Complementary Systems

When individual systems are integrated as part of a larger SoS, an evaluation strategy must account for how the individual systems work to the complement or to the detriment of the other systems. To effectively evaluate these relationships, systems should be tested in an iterative fashion, first evaluating effectiveness of individual systems through isolated tests, and then determining the capability of the entire SoS while looking for synergistic benefits that may present themselves. Compatibilities can be determined by identifying all of the potential relationships the individual systems have with one another, distinguishing which relationships are most critical to the SoS, weighting the importance of these relationships, and then building these relationships into the SoS evaluation strategy. Duplicative capabilities or gaps in a particular capability must also be identified and factored into the overall assessment.

Force Structure for an SoS

The nature of SoS employment requires that certain force structure characteristics, which are not inherently part of the existing units, be in place to synergize the SoS. An operational unit is more readily capable of integrating an individual system into its structure because managing the capabilities and limitations of one system is a skill and discipline that soldiers, down to the individual level, are trained to do. However, integrating multiple systems with multiple capabilities and limitations, and the complex relationships between them, is significantly more challenging for a soldier in an operational environment to assimilate. Additionally, battle command training and leader development for the employment of individual systems, as compared to an SoS, is significantly different. With SoS employment, all stakeholders must be trained to understand the often-complex relationships that exist between the systems' sensors to ensure that each system sensor is employed as efficiently and effectively as possible. For example, a specific SoS includes assets that support all echelons of battle command, yet would be employed at the tactical level, thus requiring units to have a mechanism in place to maximize the capabilities, understand the echeloning of the capability, and synergize the entire SoS.

SoS In-Theater Evaluation Versus Domestic Test Range Evaluation

The logistics required to create a test event for an individual system are relatively simple compared to the logistics for an SoS test event. Coordinating the presence of an individual system at a test range with its respective personnel is a feasible task, even during a time of war. Conversely, coordinating the presence of multiple systems and their respective personnel at a domestic test range, all at the same time, for a test event during a time of war is extremely difficult, if not impossible. Quite often, the systems that comprise the SoS have been evaluated individually and are already deployed in theater.

The foregoing constraints limit SoS evaluation using traditional, domestic test range operational test and evaluation procedures, thus making in-theater evaluation a more attractive alternative. Yet, when conducting an in-theater evaluation, additional factors must be considered. The following discussion presents two factors that surfaced during ATEC's most recent in-theater SoS evaluation.

RED FORCE CONSIDERATIONS

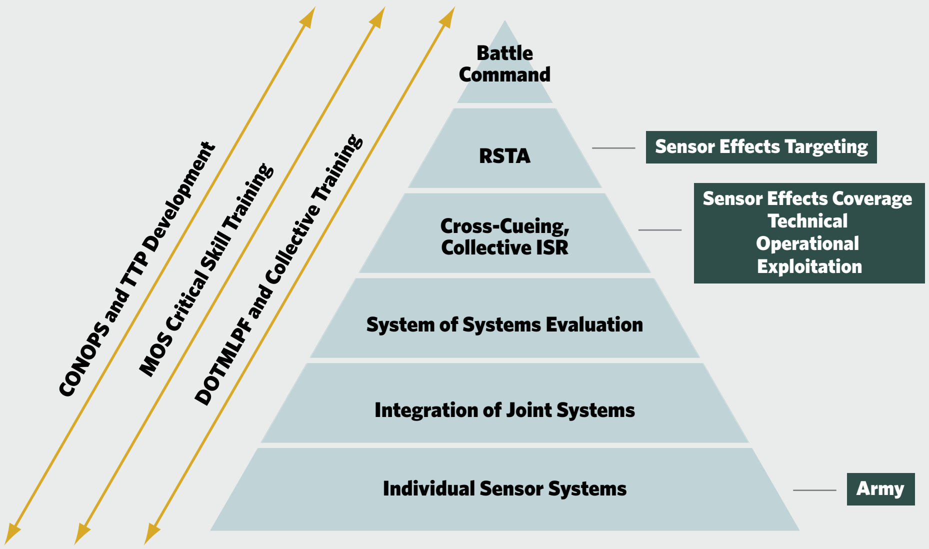
The red force component that would be used in a domestic operational test would be based upon the intelligence community's best assessment of the tactics and capabilities of the enemy. Notwithstanding the best efforts of the intelligence community, assessments based on recent intelligence may not accurately represent activity of the enemy at that particular time. An in-theater assessment, however, measures the SoS against the true red force, and thus provides the most accurate assessment of the SoS capabilities and limitations. Unfortunately, knowledge of red force activities in an actual theater of war is limited—a situation that equates to SoS evaluation under uncertainty. For example, consider an SoS designed to find enemy improvised explosive devices (IEDs). If the SoS finds five IEDs, did it perform well or poorly? How does the evaluator know how many IEDs were emplaced by the red force? Evaluators can count the number of IED explosions that were documented and the number of IEDs found and cleared, but they have no idea how many IEDs remain undiscovered and undetonated, or how many exploded without documentation.

CONCEPT OF OPERATIONS/TACTICS, TECHNIQUES, AND PROCEDURES (CONOPS/TTP) CONSIDERATIONS

Blue force CONOPS and TTP are defined for individual systems, but are often informal and evolutionary for the employment of the SoS. This presents an enormous challenge for the evaluator, who must develop measures of effectiveness for the SoS based upon CONOPS and TTP that are still under development. In addition, TTP are consistently modified based on enemy response to blue force actions. This constant operational dynamism makes it difficult to formalize measures that are relevant to the environment where the SoS is employed.

Beyond the limitations inherent in range testing or in-theater evaluation, the hierarchical relationship that exists between the employment of individual systems and the supporting tasks that enable effective operational SoS-level deployment must also be considered by the test community (Figure 1). SoS evaluation should examine the entirety of factors involved in SoS employment, applying a multidisciplined methodology to achieve a multidisciplined measure of operational effect. But, doing this in practice can quickly become

FIGURE 1. SYSTEM OF SYSTEMS PARADIGM



Note. DOTMLPF = Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities; MOS = Military Occupational Specialty; RSTA = Reconnaissance, Surveillance, and Target Acquisition.

an intractable problem, considering the number of variables involved and the difficulty in altering those variables one at a time.

The capabilities gained through modeling and simulation (M&S) and associated software packages, focused on insurgency operations, are essential to the overall evaluation of an SoS. M&S is needed that can ingest all of the relevant data from the system, assess the environment associated with insurgency operations, assess the immediate threat, and then fuse and maximize inputs from other systems operating under the same parameters to identify the best mix of assets at the strategic, operational, and tactical levels. The results from SoS evaluation should inform the community of not only the capability of the enterprise to engage and be successful, but how best to distribute the capabilities for the greatest overall operational effect.

The following hypothetical example taken from the world of sports may best illustrate the concept of SoS evaluation.

An Analogy for SoS Evaluation

Consider an analogy. A professional football coach is facing a decision: a first-round draft pick for a new player. This opportunity to draft a new player forces the coach to thoroughly evaluate the array of available players and their potential contributions to the team. Does he go for an offensive player or a defensive player? Does he go for a quarterback, a lineman, or a running back? If he chooses a quarterback, does he choose one from a college that has an aggressive passing game, or one from a school that has a run-based offense?

Now consider the data that the coach has for making his decision. Undoubtedly, he has accumulated data on the draft choice's speed, weight, strength, and performance in a college environment. If he is thorough, he also has some information about how the player performs in a high-stakes environment such as a championship game, his injury record, and how he fits in as part of a team. Though the coach should optimally consider individual players' skills (*system level*) in making a draft decision, his decision should be ultimately based on his evaluation of the player's potential to improve the overall performance of the team (*SoS level*).

Finally, the coach makes his decision and drafts a player. But, he doesn't put the new player in as a starter automatically. Instead, he uses training camp, pre-season games, and regular season substitutions to determine whether the new player merits a starting position with the team.

Let's suppose the coach has done all of this throughout the new player's first season, and at the end of the season the team's record is 11–5—a substantial improvement from a lackluster 8–8 performance the previous year. Does the coach attribute the entirety of the improvement to the new player? Probably not, considering the team gained a number of new players—some from the draft, others from trades, and several through free agency. These new players, as well as factors beyond the coach's control such as schedule difficulty, have affected the team's performance. So, how does the coach determine what mixture of variables contributed to the team's improved record? How does he decide which players to retain and which ones to shed for the next season?

Each of the coach's inquiries and decisions represents a stage in the evaluation of an SoS, and it is instructive to the development of the framework to now extend this analogy to the evaluation of an SoS.

Relationship of Sports Analogy to an Airborne ISR SoS Evaluation

The sports analogy presented earlier illustrates some of the challenges of conducting an airborne ISR SoS valuation. First of all, are the capability gaps clear? Do decision makers know for what "positions" they are recruiting? Is there a gap in N, S, O, T mission coverage, or perhaps all four? Is there a reason to believe that an airborne ISR asset can fulfill one or more of these gaps?

Second, what is known about the "players"—the specific airborne ISR assets that might be added to an SoS? Much of this type of information is gleaned from *developmental testing (DT)*. DT enables evaluators to gain knowledge of the *technical* capabilities of the ISR asset (analogous to a player's weight, strength, and speed), but little or no knowledge on how the asset will perform when integrated with the "team."

Integration into the "team" begins with operational testing (or OT), which is often performed in an artificial environment, such as one of the Army's proving grounds. Use of such a test center allows evaluators to gain a better understanding of how the system undergoing testing will perform when used in an operational environment. A true operational environment will also enable evaluation of the system not only with its actual "teammates" (the Blue Force), but also in the presence of the opposing team (the Red Force).

Finally, the system is deployed and integrated with other ISR assets, all of which are dedicated to fulfilling a mission, but this mission may have components or effects at each of the N, S, O, T levels. Certain mission-related effects are measured, and things seem to be improving; coalition causalities, for example, have declined.

Now, the real dilemma begins! How is it possible to determine whether one particular combination of assets (a "team") is responsible for the improvement, or whether the improvement was due to exogenous factors (such as a troop surge or intelligence from an enemy defector)? How is it possible to determine whether certain assets (the "players") are performing well at their positions, or whether it would be better if certain of the ISR assets were "traded" for other assets?

Example of a Recent ATEC SoS Evaluation

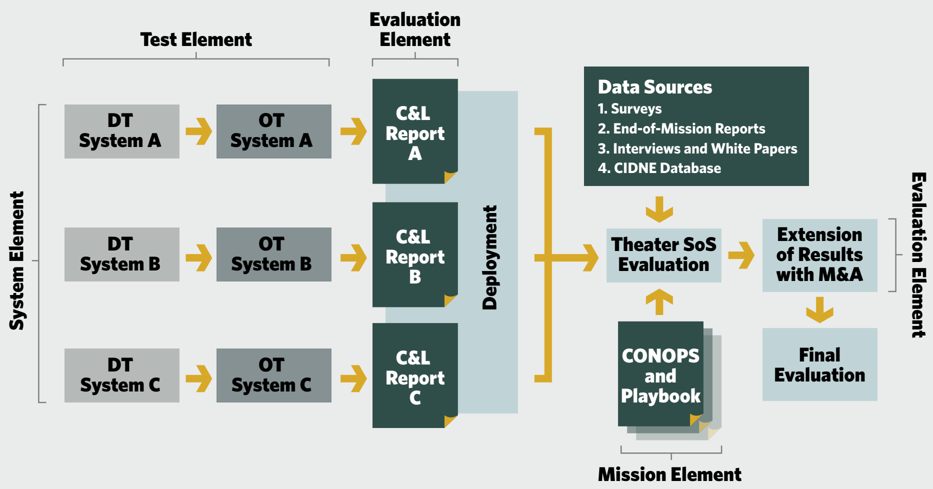
ATEC has rich experience conducting SoS evaluations, including the recent evaluation of an Army suite of aerial ISR systems (an SoS). Figure 2 also shows how the *system, mission, test, and evaluation elements* were integrated into ATEC's recent evaluation.

A general discussion to demonstrate how the framework previously described can be applied to similar SoS evaluations follows.

ATEC began its SoS evaluation by performing thorough DT on each individual aerial ISR component of the SoS. Through DT, ATEC was able to examine the *technical* capabilities of each of the sensors. In this case, all of the sensors were IMINT sensors, though each was employed in a different way and was expected to add a unique capability to the final product.

Then, in a series of OT scenarios conducted at Yuma Proving Ground, ATEC was able to extend the *technical* results of the DT to gain a better understanding of these aerial ISR systems and how each might perform as part of an overall SoS. Although data were limited due to the operational conditions in theater, ATEC used scientific methods to complete the initial study of the SoS. In addition, ATEC developed test and threat protocols to ensure like testing across a

FIGURE 2. ATEC TFO SoS EVALUATION FLOWCHART



Note. C&L = Capabilities & Limitations; CIDNE = Combined Information Data Network Exchange; TFO = Transport Flow Optimization.

series of systems, and then supplemented this information with a forward operational assessment (FOA) team that collected data while systems were deployed in operational conditions.

ATEC's FOA team collected performance data from several sources: end-of-mission reports, user surveys, commander surveys, stakeholder interviews, white papers, and reports of enemy activities. Further, ATEC developed and used the Common IED Exploitation Target Set ontology and application to define conditions and standards, and model results for OT (Franken et al., 2009).

ATEC extended the results of this SoS evaluation by using modeling and analysis (M&A) methods. M&A methods were utilized to explore the possible mission effects of employing the SoS differently and in different combinations with a focus on insurgent methods, timing, and location of attack. The use of M&A created a virtual test environment for this SoS evaluation, and helped reveal a more operationally effective way (i.e., system composition, user tactics, flight schedules, etc.) to employ this SoS. The data from tests, operational assessment, and threat integration were used to conduct first-order validation of the insurgent model. More detailed verification and validation will be executed as data become available.

Relationship to Other Frameworks

The framework presented in this article is not intended to be used in isolation, but in combination with other frameworks that can help lend clarity to the evaluation of SoS. Two of these are addressed in the following discussion.

Simmons and Wilcox (2007) introduced the notion of a four-element framework for test and evaluation, encompassing system, mission, test, and evaluation elements in an integrated whole.

> The four-element framework provides a systematic approach to developing a T&E plan that evaluates mission capabilities, system effectiveness, and system suitability. The mission and system elements define what is to be evaluated. The mission-to-system interface links the elements together and ensures that the development of the evaluation and test elements always remain focused on the unit's ability to execute the mission when using the system. This provides a defined guideline for developing the evaluation measures and a roadmap for how the tests support the evaluation. (p. 66)

A National Research Council (2006) report cited "continuous process" as the framework upon which to meet the challenge of testing in an evolutionary acquisition environment.

> In evolutionary acquisition, *the entire spectrum of testing activities should be viewed as a continuous process of gathering, analyzing, and combining information in order to make effective decisions* [emphasis added]. The primary goal of test programs should be to experiment, learn about the strengths and weaknesses of newly added capabilities or (sub)systems, and use the results to improve overall system performance. Furthermore, data from previous stages of development, including field data, should be used in design, development, and testing at future stages. (p. 3)

The ATEC aerial ISR SoS evaluation example described earlier followed these lessons learned. The aerial ISR SoS was an evolutionary system, and all testing and evaluation activities were integrated into the overall evaluation. Additionally, M&A was used to extend the evaluation to examine and explore the other possible employment combinations and methods for this SoS in an asymmetric insurgent environment.

Conclusions

The importance and implementation of thorough SoS evaluation—distributing and measuring the effects of individual systems as they are integrated across the entirety of the SoS—poses a challenge to the test community. This challenge can be met by incorporating the lessons learned and data from multiple events, using M&A and scientific methodology to integrate and optimize the testing and providing relevant feedback to affected communities—typically soldiers employing the SoS or planners executing acquisition strategy. With the continued interdependence of SoS deployed and relied upon in operational environments, SoS evaluation must be capable of using all available assets to ensure operational realism is met in all test events, and relevant quantitative measures are applied in evaluating the SoS, ensuring a legitimate SoS evaluation, not merely an evaluation of a system within a system.

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PERFORMANCE-BASED LIFE CYCLE PRODUCT SUPPORT STRATEGIES: ENABLERS FOR MORE EFFECTIVE GOVERNMENT PARTICIPATION

Steve Geary, Scott Koster, Wesley S. Randall, and Jeffrey J. Haynie

Organic government-owned and -managed *product support* organizations are often viewed as less capable than their commercial counterparts. In fact, highly effective government organization participants in product support do exist, supported by a host of success enablers in use at government-owned and -managed organizations across the Services. These enablers can stimulate best-value participation by government organizations in performance-based life cycle support strategies. More effective government participation results in increased synergy and collaboration for the warfighter, the organic structure, and the taxpayer. This article documents and describes some of the success enablers used to catalyze more effective integration of the government-managed support structure into the industrial base.

Keywords: *Product Support, Product Support Strategy, Life Cycle Product Support Strategies, Performance-Based Logistics (PBL), Product Support Assessment, Sustainment Support, Contractor Logistics Support, Award Fee, Contract Incentives, Interorganizational Success*

image designed by Tia Gray »


DEPARTMENT OF DEFENSE
BLENDED DoD-INDUSTRIAL
PRODUCT SUPPORT STRATEGY

In 2009 the Department of Defense (DoD) published a report on *Product Support Assessment* (DoD, 2009), with particular emphasis on DoD's vision for improving the integration of government-owned and -managed capabilities into performance-based product support strategies. Rather than treating the government share of the industrial base as distinct from the commercial base, the report develops and posits the notion of a single industrial base, partially managed by the government and partially managed by the commercial sector; and that the government participants can be best-value participants. The vision for industrial integration strategy uses this foundation to speak to the opportunity for synergy from a more collaborative organic and commercial industrial base.

Effective product support requires contributions from both the public and private sectors. A significant challenge over the course of the next decade, particularly in today's acquisition environment of declining financial resources combined with projected deficits and undiminished operational demands, is creating a more effective, unified, and fiscally prudent industrial integration strategy for product support. More than 60 years after World War II (WWII), when the standing commercial industry (still seen today) originally spurred the post-World War II economic boom, the DoD has yet to fully leverage and blend the knowledge, skills, and capabilities of the complete defense industrial base through a considered and deliberate integration strategy.

As a part of the continuing efforts to achieve acquisition reform, Congress has passed legislation better defining the role of government entities involved in executing product support strategies. The government has always been fully responsible and accountable for product support delivered to the warfighter. That principle has been reinforced with the passage of the National Defense Authorization Act of FY 2010 (NDAA, 2009). Section 805 of the NDAA adds clarity to and elaborates on this principle.

The provisions of Section 805 require that the Secretary of Defense issue guidance on life cycle management and the implementation of product support strategies for major weapon systems. Additionally, each major weapon system shall have a product support manager to develop, implement, and validate the *product support strategy* (e.g., Performance-Based Logistics [PBL], *sustainment support*, *contractor logistics support*, life cycle product support, or weapon system product support).

The responsibility for the product support strategy is clearly in the hands of the government. In addition, most government participation in product support is more expansive than oversight. Some product support *must* be performed by the government. To cite two common examples, either statutory requirements or operational requirements in forward-deployed environments dictate execution of certain tasks by the military. Other examples demonstrate that government organizations are best-practice contributors to product support because their role and participation are driven by best value, not statutory requirement.

Across the landscape of performance outcome-based product support strategies, numerous examples illustrate the adoption of best practices that allows government-owned and -managed capabilities to participate in product support strategies as best-value contributors. These examples demonstrate an ability to overcome commonly cited obstacles to participation by government elements and execute a more successful integration of the organic assets into a unified industrial base. Although it is true that government organizations are not *profit-making* businesses, they are businesses, nonetheless, and can successfully compete and win in PBL using best-in-class practices.

In this article, we will examine four distinct case studies that demonstrate a spectrum of viable practices available to government organizations to allow them to compete on merit for business as product support integrators and product support providers. A description of the four case studies follows:

> Case Study No. 1: An Environment of Success, Huntsville
>
> Case Study No. 2: From Source of Repair to Business Partner, Jacksonville
>
> Case Study No. 3: The Joint STARS Contract–A Decade of Success
>
> Case Study No. 4: The Upstarts–Naval Surface Warfare Center, Crane Division

The foundational development of core competencies through the incubation of best-practice capabilities, as envisioned in 10 U.S.C., Section 2474, makes this possible (Armed Forces, 2004):

> The Secretary of Defense shall establish a policy to encourage the Secretary of each military department and the head of each Defense Agency to reengineer industrial processes and adopt best-business practices at their Centers of Industrial and Technical Excellence in connection with their core competency requirements, so as to serve as recognized leaders

in their core competencies throughout the Department of Defense and in the national technology and industrial base.

From a financial standpoint, effective, efficient, and best-value use of government-owned resources is a victory. The U.S. taxpayers have a huge, long-standing investment in government-owned support capabilities, particularly in inventory control, distribution, and maintenance depots. At the same time, although the government-owned and -managed base contributes significantly, it cannot do all of DoD's product support work. American industry provides a source of innovation, and flexible and productive capacity for the defense industrial base. The way ahead for more cost-effective product support lies in effective blending of these complementary capability sets where the best use is made of the entire industrial base, facilitated by the continuing expansion of best business practices in both the commercial and government sectors.

We should not lose sight of the fact that more effective government participation in DoD's product support strategies will result in better collaboration and synergy among the warfighters, the organic structure, and U.S. taxpayers.

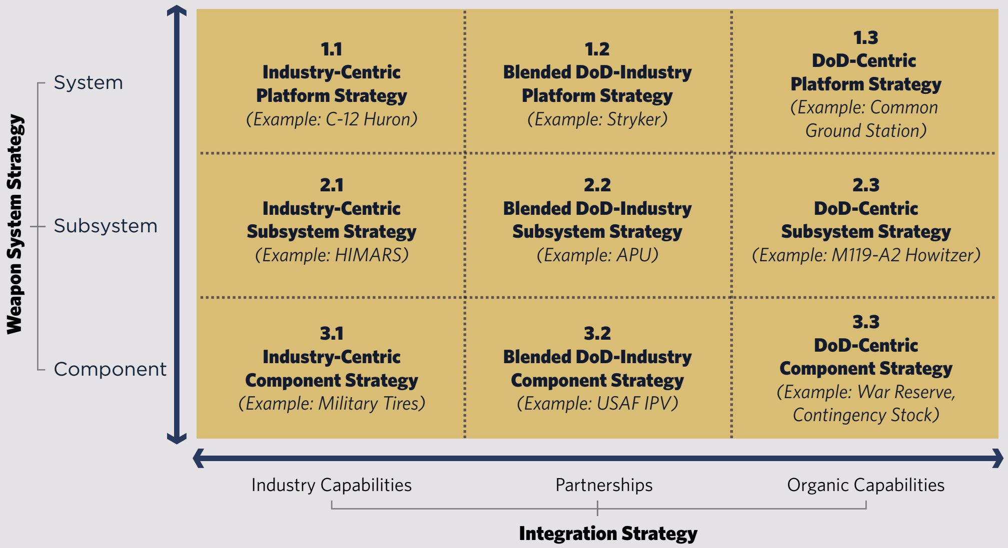
Method

The study team followed a simple three-step process to produce the resultant case studies. The first step consisted of identifying candidate programs with characteristics that were germane to the research objectives. The second step was researching and interviewing representatives from the candidate programs. The final step included analyzing and writing the study findings that form the basis of this article.

To identify and select potential candidate programs for this study, the team used two primary criteria and one limiting factor. The primary criteria are the location in the Decision Matrix for Product Support, or DMPS (Figure 1) and distinctive performance. In selecting the programs to review, the limiting factor was the availability of program sustainment teams to support the inquiry. The team looked across the Services and at end-item operating environments (land, sea, air, and space) as a consideration in the selection of candidate programs to include.

Understanding how the candidate programs populate the DMPS in Figure 1 enabled the team to base the selection decision on the characteristics of the product support strategies from an objective perspective. In short, the DMPS was designed to help program man-

FIGURE 1. DECISION MATRIX FOR PRODUCT SUPPORT



Note. Adapted from *DoD Weapon Systems Acquisition Reform Product Support Assessment*, Department of Defense, 2009, p. 46. Retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=328610. HIMARS = High Mobility Artillery Rocket System; APU = Auxiliary Power Unit; USAF IPV = U.S. Air Force Industrial Prime Vendor.

agers identify their product support strategy. A program's location in the matrix will influence decisions relative to the Product Support Integrator (PSI) composition, metrics, incentives, Performance Based Agreement (PBA), and analytical tools. The matrix is based on a framework that outlines nine product support options as defined by the intersection of two key strategic system characteristics that drive the appropriate support strategy. The key strategic system characteristics are weapon system strategy and integration strategy (DoD, 2009). The two characteristics are useful mechanisms to categorize programs so that the team can focus on only those programs that are in line with the study objectives.

Figure 1 is also used to identify those programs with "blended" integration strategies. From the population of programs with a "blended" integration strategy, the team looked for programs from each of the weapon system strategies. With the limiting factor of program availability, the study team was able to identify candidate programs in two of the three weapon system strategy categories of subsystem and system.

From this list of candidate programs, the study team next looked for discriminating factors to identify five or six programs that formed

Figure 2. A U.S. sailor assigned to the aviation intermediate maintenance department's jet shop watches during a jet engine test cell on an F404-GE-400 jet engine for an F/A-18C Hornet aircraft on the fantail of aircraft carrier *USS Nimitz* (CVN 68), October 14, 2009, in the Indian Ocean. The F404 engine has twice won the Department of Defense Performance-Based Logistics Award. U.S. Navy photo by MC3 John Phillip Wagner Jr.

the target programs to review. Discriminating factors included recognition of excellence (DoD PBL submission packages), duration of current "blended" product support strategy, "commerciality" of the materiel, and ongoing research efforts at Redstone Arsenal, Alabama.

The selection process, in conjunction with program availability, resulted in the selection of three programs for the research and interview step. The study team gathered information on the programs and traveled to the program offices, depot business offices, and remanufacturing facilities to interview the managers and artisans involved in each project. The team also incorporated organizational team climate, based upon related research between Auburn University and U.S. Army Air and Missile Command (AMCOM) in Huntsville, Alabama.

With the time available, the team was able to perform a "deep dive" on the F404 engine, which has twice won the DoD PBL award (Figure 2). Product support awards are a result of the remanufacturing activity at the Fleet Readiness Center, Southeast (FRCSE), and subsystem inventory management at the Defense Logistics Agency.

Case Study No. 1: An Environment for Success, Huntsville

The U.S. Army AMCOM has created an environment of high-performing, award-winning product support teams. Huntsville organizations have earned recognition for their performance-based product support initiatives. Specifically, a number of Huntsville programs have won the annual Secretary of Defense Award for Excellence in PBL, as follows:

2005 Shadow 200 Tactical Unmanned Aircraft System

2006 High Mobility Artillery Rocket System

2007 Improved Target Acquisition System

2008 Tactical Airspace Integration System

2009 High Mobility Artillery Rocket System

In fact, this is the complete list of PBL Award winners for the Army, and every one of these award winners is at Huntsville. No Army competitor for the PBL Award has ever won the competition from any location other than Huntsville. According to the 2009 PBL Award memo:

> *Performance-Based Logistics (PBL)* is the Department of Defense's strategy to improve weapon system readiness by obtaining life cycle product support of weapon systems, subsystems, and components as an integrated package based on output measures, such as materiel availability, materiel reliability, and reduced ownership cost.
>
> The Secretary of Defense PBL Awards recognize government and industry teams that have demonstrated outstanding achievements in providing our warfighters with exceptional operational capability through PBL agreements. (Carter, 2009)

What makes Huntsville distinctive? How can it so completely dominate as the Army's leader in PBL? What special enablers are present in the Huntsville environment? Why is Huntsville so successful in driving outcome-based product support strategies that maximize contributions from across the industrial base (Haynie, Randall, Armenakis, & Geary, 2009).

In this phase of the research, we sought to understand and identify the practices that contribute to this high performance. Accordingly, we interviewed team members from many of the high-performing product support teams from AMCOM, including many of the award winners. These interviews included personnel from both government and industry who were involved with post-production support of U.S. and allied defense systems. We ensured that our interviews included strong government participation by conducting interviews with personnel from Apache, Letterkenny Army Depot, Close Combat Weapon Systems, Corpus Christi Army Depot, Unmanned Aerial Systems Logistics Division, the Integrated Materiel Management Center, and the Precision Fires Project Office.

Through discussion during site visits, we attempted to understand what behaviors and perceptions led to success. Those we interviewed gave us a rich perspective of the inter and intraorganizational behaviors that appear to foster PBL success.

We found individual behaviors and organizational processes were consistent with suggestions in supply chain research on how to improve collaborative performance. What we found was that AMCOM appears to have fostered a PBL culture that aligned and oriented those behaviors and processes. The orientation created through a proactive PBL strategy appears to positively influence cost control and performance improvement in the eyes of the managers. The strength of performance-based support strategies seems to be their ability to strategically align cross-functional and interorganizational processes of multiple firms, customers, and bill payers; and focus them on a long-term performance goal in a manner that creates consistent and measurable success. The review of the environment at Huntsville was not intended to validate the efficacy of their performance-based approach. Rather, given the numerous PBL Award winners from Huntsville, the research uncovered eight factors critical to enabling an environment for success.

Eight Critical PBL-Driven Interorganizational Success Factors

In effect, adoption of a performance-based product support approach represents a strategic change in interfirm practice. By analyzing teams that implemented this new strategy of outcome-based product support, we found key enabling factors present in the environment that contributed to the successful participation in, and often leadership of, outcome-based programs by government organizations.

The eight factors identified at Huntsville include:

FACTOR NO. 1

Cooperative Interdependence. Cooperative interdependence is an understanding that goal attainment is dependent upon other team members reaching their goals (Deutsch, 1973).

FACTOR NO. 2

Transformational Leadership. Transformational leaders transcend short-term goals (Eisenbeiss, Van Knippenberg, & Boerner, 2008) and focus their attention on the higher order intrinsic needs of subordinates, inducing them to transcend their own self-interests for the benefit of the organization or team.

FACTOR NO. 3

Team Climate for Innovation. Team vision, participative safety, climate for excellence, and support for innovation are components in the creative process, leading to greater team innovation (Deutsch, 1973).

FACTOR NO. 4

Team Innovation. Team innovation is the combination of the quality and quantity of creative ideas that have been implemented within an organization. These innovations represent changes and can be either administrative or technological in nature (West, 2002).

FACTOR NO. 5

Team Learning. Team learning is the process by which teams discuss and solve problems. Collectively, the team engages in information seeking and reflective decision-making processes that positively impact the degree of knowledge and information for other members (Hirst, Van Knippenberg, & Zhou, 2009).

FACTOR NO. 6

Team Performance. Objective performance represents the outcomes of the team's activities that are valued by one or more of its constituencies, such as reductions in operating costs, greater efficiency, and increases in profits (Mathieu, Maynard, Rapp, & Gilson, 2008).

FACTOR NO. 7

Change Appropriateness. Innovations can produce desired outcomes such as increased product quality and reduced support costs. However, it is important that the appropriateness of the innovation be taken into account; unbridled innovation can be counter-productive (Armenakis, Harris, Cole, Fillmer, & Self, 2007).

FACTOR NO. 8

Means Efficacy Climate. Means efficacy climate is the shared attitude concerning the degree of organizational support supplied to the team through policies, processes, and procedures (Eden, 2001).

These enablers are not new. They are described and validated in the more generalized academic literature related to management and change management. What is new is the manner in which these factors interrelate under a PBL strategy to create an environment whose whole is greater than the sum of its parts. Our findings demonstrate how a proactive PBL strategy provides a benchmark of management best practices.

To close the loop, the research team conducted validation sessions with senior executives, senior managers, engineers, program managers, and logisticians familiar with performance-based strategies. The subject matter experts confirmed that, from their perspective, the data, analysis, and identified factors fit with their environments.

Implications for Outcome-Focused Product Support Success

The AMCOM has a culture of demonstrating innovation and leadership when it comes to post-production support. Our research suggests that an organization-wide understanding of the eight factors that interrelate to create a winning culture drives success. These factors have evolved and emerged at Huntsville largely because they have been able to create a collaborative partnership approach. This partnership extends across the organization and into partners in the industrial base and is less adversarial in style, based on a mutual understanding of where the motivations and interests of each party lie. By acknowledging and managing areas of divergence and tension, and supported by a willingness to share information in a spirit of openness and transparency at all levels, the partnership philosophy becomes a key competency. Creation of that environment must take place within the government post-production support infrastructure, culture, and resources in order to drive PBL. The AMCOM in Huntsville identifies and demonstrates the elements that are best practices.

Expanding the role of DoD's government-run sustainment infrastructure (e.g., depots) presents challenges in the planning for, and delivery of, integrated, affordable, outcome-focused product support. What Huntsville demonstrates is that, regardless of the obstacles, critical success factors are known and are within the control of those leaders responsible for the government's post-production support infrastructure. Good management drives performance-based success; this, in turn, leads to a win for the warfighter, the organic structure, and the taxpayer.

Case Study No. 2: From Source of Repair to Business Partner, Jacksonville

Jacksonville's Journey

"We provide aviation maintenance solutions that satisfy Navy warfighter's demands," according to the FRCSE mission statement. Actually, from a review of two product support efforts, the FRCSE, located in Jacksonville, Florida, is evolving by leveraging its robust manufacturing capability and forward-leaning business practices that help position existing capacity for use in partnerships. The new development is the extent that FRCSE and its private-sector business partners have aligned their respective business models to create a blended and compelling value proposition for the warfighter.

Like Huntsville, Jacksonville has created an innovative environment where the adoption and application of best commercial business practices have been embraced. The discovery work at Huntsville included a detailed validation of the elements required to develop a working environment, receptive to the adoption of best practices in support of performance-based life cycle product support. Rather than replicating Huntsville, the review in Jacksonville focused on the implementation of specific best practices themselves.

High-visibility, performance-based product support strategies are currently in use by several programs in Jacksonville. The two product families that participated in the research are the F404 and F414 engines, used on the F-18 aircraft; and the Forward Looking Infrared family of sensors, used on a variety of platforms. Meetings took place with the FRCSE business office, as well as company representatives from General Electric Aircraft Engines (GEAE) and Raytheon, the respective Original Equipment Manufacturer (OEM) and business partner on these programs.

Foundation

For both of these programs, the following four solid foundational elements of performance-based product support set down in the public-private partnership fully align with the description offered in the Product Support Assessment (DoD, 2009).

ELEMENT NO. 1

Long-term committed relationships executed with flexibility and integrated across organizational boundaries, with complementary skill sets and abilities, are both essential and possible.

ELEMENT NO. 2

Shared partnership vision and objectives with the right metrics and incentives drive alignment and are especially effective when supported by a clear delineation of complementary roles and responsibilities.

ELEMENT NO. 3

Full coordination with all stakeholders supported by transparency, open communication, and the flexibility to change partnership scope is an essential ingredient to success.

ELEMENT NO. 4

Clearly documented objectives support alignment and fuel the success of the partnership. This can be achieved through incentives that drive desired outcomes and are supported by sound economic analysis.

Nothing new or particularly innovative is embodied in these foundational elements of performance-based product support. The Government Accountability Office (GAO, 2003) first documented the essential elements. What is interesting at Jacksonville is the distinctive degree of integration and coordination they have established on top of this foundation.

Beyond Transactional Approaches to Maintenance, Repair, and Overhaul: Moving From Wrench Turning to an Integrated Business Model

One of the recommendations of the Product Support Assessment (DoD, 2009) speaks to the vision of leveraging government-managed, post-production support capabilities outside of the traditional, program-centric events:

> ...Expand partnering 'beyond maintenance,' drive standardization across Services, and promote proactive establishment of single-source repair capability. (p. 43)

At Jacksonville, we see in execution a prototype defense industrial base of the future. Here, a government-run depot support operation has moved beyond a job-shop maintenance operation, becoming a fully capable industrial partner that is deeply integrated with commercial partners. The partnerships that are being created provide the government customer with a unified government and industry post-production support effort. The individual activities in large part are not distinctive, but the degree of integration and coordination is.

In the engine shop, under one roof, the Jacksonville support operation maintains engines from two different OEMs. Integrated processes and shared capacities support both OEM families, managed by a unified staff. Through this Navy capability set, it also maintains engines for the A-10 aircraft—an Air Force platform. The Jacksonville operation is moving inexorably down the path of managing its engine maintenance capability in a standardized fashion across product families, and indeed across Services.

Its success has led to the capture of additional work from GEAE, formerly performed at the GEAE facilities north of Boston. This is the typical pattern of success in the maintenance arena for depot partnerships. Yet, in Jacksonville, this accretion of additional work has created an opportunity to move beyond legacy maintenance functions. The facility is now being audited by GEAE to become, in addition to the current role as a source of repair for the 404 and 414 engines, a new module manufacturing site for the 414 engine.

The FLIR team, including both Raytheon and the FRCSE, also demonstrates highly evolved thought beyond the traditional maintenance partnership roles. In discussions, they clearly draw a distinction between maintenance partnerships and business partnerships; for the FLIR sensors, the team maintains that they are in a business partnership and that they have moved beyond wrench turning a long time ago.

The original PBL in the FLIR family was for the device on the H-60 helicopter. Rather than viewing this as a unique opportunity, first Raytheon, and then Raytheon in partnership with the FRCSE, saw this as a competitive opportunity to capture more work. Over time, capacities and equipment were upgraded in Jacksonville. With Raytheon as the prime and the FRCSE as a teammate and subcontractor, the team competed for and earned additional work. Today, a single set of equipment in one government building services a diverse set of FLIR devices.

A breakthrough took place in 2009. The capacities in Jacksonville were purposely designed to be able to accommodate the FLIRs installed on the Air Force's Predator and Reaper Unmanned Aerial Vehicle platforms. The ability to maintain these FLIRs is a core requirement, meaning that the DoD is statutorily required to maintain government post-production support capability. The Navy's FRCSE was selected by the Air Force as the Depot Source of Repair for the Predator and Reaper FLIRs. The complete set of FLIRs that are now slotted to use this capacity are AAS-44V (older H-60 series), AAS-44(C)V (MTS-A for H-60R/S), AAS-52 (MTS-A for Predator), DAS-1 (MTS-B for Reaper), AAQ-27 (MV-22), and the AAQ-29 (CH-53E).

By viewing themselves as an integrated capability set, the FRCSE and various industry teams have been able to step beyond traditional program-centric maintenance relationships. They are now integrating horizontally across the portfolio, and they are integrating across the Services. The government's post-production support capabilities, developed under the umbrella of Section 2474 and nurtured by their industry partners, are stepping into higher level activities like new module assembly. Private industry has been instrumental in directly assisting the incorporation of these best practices into this public facility, and together the team is reaping the benefit. They are bootstrapping themselves through an evolutionary process toward becoming a single-source capability for specific technologies used across the Services.

Enabling Best Practices

The FRCSE has demonstrated an ability to deploy a broader approach to partnership that is not the typical public-private partnership based on arms-length arrangements. This, in turn, has allowed industry to look to the government post-production support infrastructure for a capability that is sought by the industrial base. With the jet engine, that means the FRCSE can provide jet engine fabrication and assembly expertise, not just artisan labor. For the FLIR, it means the FRCSE has off-the-shelf, one-stop capacity and capability to perform maintenance, repair, and overhaul on a technology that is becoming more and more ubiquitous and sophisticated across military weapon systems.

This evolution did not happen overnight. According to the research participants familiar with the progression, the team built a foundation of business partnerships based upon a common strategic vision. Each party identified their revenue streams and began working toward a "business" relationship that addressed the needs of each participant. This developmental process spanned years.

These needs are different from the point of view of Jacksonville and the industrial partners. For the industrial partners, the definition of need is simple: profit. Real dollars flowing to the bottom line matter to commercial organizations. On the other hand, the government depots, and other post-production support organizations, are "break even" operations. The FRCSE looks at sustaining or increasing labor hours, avoiding Base Realignment and Closure recommendations, satisfying statutory requirements (core, 50/50, etc.), and improving support of the fleet as "profit."

Rather than clashing over the differing needs, the FRCSE has found common ground that allows it to operate in understandable "swim lanes" with its industrial partners. The FRCSE lauds industry's superior ability to manage component supply more effectively, and unhesitatingly turns to industry to contribute. Other areas where the FRCSE accepts help are: technical data, information systems, test, training, technical assistance, transportation, packaging, engineering analysis, inventory management, quality support, logistical services, materiel movements, and engineering on the shop floors. Although the FRCSE and its industrial partners are grappling with a complicated set of best-value decisions, none of them retreat from making the hard business decisions.

Motivated by self-interest, FRCSE and its partners have maneuvered themselves into a position where they focus together on the joint opportunities and seek to grow the business and consequential benefits to each party. This is an extremely sophisticated, strategic approach to business. Or, as one industrial partner described the process, they worked diligently to "put the depot in a position that they would have to make a bad business decision by not forming a true business partnership."

In conjunction with the development of a shared strategic vision, the government post-production support activities implicitly adopt a mindset that drives alignment to the desired outcomes. The introduction of performance into the equation encourages the OEMs to competitively seek to meet the benchmarks, and to find partners who can help them do it. This, in turn, encourages the government post-production support organizations to improve in areas where they have competency, thereby making them more attractive to the OEMs. This creates a positive, perpetual cycle that drives best practices into the government post-production support organizations, all resulting from the embrace of a shared strategic vision.

Highly visible indicators are evidence of the depth of alignment and integration between commercial partners and the government post-production support industrial base. Technical employees of the commercial partners are embedded within the government post-production support operation, including on-site offices and free access to the workspaces of the artisans. The FRCSE has embraced Lean and Six Sigma approaches to continuous improvement. Bulletin boards are prominently displayed with objective performance measures so all employees can see what they are being measured against.

Further, contrary to conventional wisdom, artisans can earn incentive payments based on their performance. In the contemporary financial environment, cost reduction is an imperative in any PBA. So, although the FRCSE works on a cost-reimbursable basis, it has put in place a very aggressive gainsharing program with the artisans—in a union environment no less. A "controllable" hourly labor cost is defined for each work center, and 40 percent of any achieved cost reduction against that rate is paid to the employees. For reimbursement purposes, the depot can still invoice for the incentives paid, because the bonuses are considered labor cost, but the achieved hourly cost reduction rolls into the controllable hourly rate for the next reporting period.

Open Issues

The FRCSE follows conventional government business practices, which rely on cost-reimbursable contracts. However, it can become more completely integrated into a singular industrial base by acting like its partners and using a contract vehicle called firm fixed price (FFP). The definition of an FFP is derived from the Federal Acquisition Regulation (FAR, 2005):

> A firm-fixed-price contract provides for a price that is not subject to any adjustment based on the contractor's cost experience in performing the contract...It provides maximum incentive for the contractor to control costs and perform effectively and imposes a minimum administrative burden upon the contracting parties. The contracting officer may use a firm-fixed-price contract in conjunction with an award-fee incentive (see 16.404) and performance or delivery incentives (see 16.402-2 and 16.402-3) when the *award fee* or incentive is based solely on factors other than cost. The contract type remains firm-fixed-price when used with these incentives.

This contract type can be a contentious issue. Although an FFP may align depot incentives with performance objectives, similar to FFP use with a contractor, an FFP contract with the depot would shift a burden of risk to the depots. Historically, this is not an area of risk that the depots have had to assume. On the other hand, an FFP could open up opportunities for the government operation to leverage incentives and reduce costs.

According to the Office of the Naval Air Systems Command (NAVAIR) Comptroller, "Sales of DoD goods and services to private-sector entities on a fixed-price basis are authorized when the work is well defined and there is a reasonable basis upon which to predict costs" (DoD, 2005). This is analogous with private-sector practices, improves the ability of private-sector partners to predict production costs, and serves to constrain unit cost by more fully utilizing the production capacity of DoD maintenance depots. Cost-reimbursable pricing is appropriate when future production costs cannot be reasonably predicted (Camacho, 2008).

Through participation in an FFP, the government post-production support organizations would create an opportunity to positively influence Net Operating Result over the life of the contract; this is the other side of the risk coin. However, if success under an FFP occurred, the FRCSE would "earn" funds to invest in capital equipment: variances can be reinvested in the depot. This could create a funding source to facilitate earlier standup of depot capabilities and

Figure 3. A U.S. Air Force E-8C Joint Surveillance Target Attack Radar System (Joint STARS) aircraft assigned to the 128th Expeditionary Air Command and Control Squadron. The Joint STARS is a battle management and command and control aircraft that tracks ground vehicles and some aircraft, collects imagery, and relays tactical pictures to ground and air theater commanders. U.S. Air Force photo by SSgt Aaron D. Allmon II.

facilitate the establishment of a single authoritative source of depot repair for the programs.

Finally, no single business office spans the Navy post-production support capabilities, or even the depots themselves. Each depot maintains its own business office, using policies and practices in line with the commander's intent for that installation. While this maximizes flexibility at the operating level, it complicates efforts to deliver needed standardization and reforms.

The existence of open issues serves to illustrate that more effective collaboration across the industrial base, spanning government and industry resources, is a continuing work in progress. Partnership at the strategic level is possible, and Jacksonville, just like Huntsville, is building an organizational climate that drives success. And, as we continue to see across our case studies, more effective government participation is mutually beneficial for the warfighter, the organic structure, and the taxpayer.

Case Study No. 3: The Joint STARS Contract—A Decade of Success

The E-8 Joint Surveillance Target Attack Radar System (Joint STARS) is a U.S. Air Force airborne battle management command and control, intelligence, surveillance, and reconnaissance platform (Figure 3) that conducts ground surveillance to develop an understanding of the enemy situation, and supports attack operations and targeting that contribute to the delay, disruption, and destruction of enemy forces.

Product support is provided through a Total Systems Support Responsibility (TSSR) contract, with Northrop Grumman Corporation designated as the PSI. From its inception, the Joint STARS TSSR contract—first awarded September 15, 2000—has been recognized as a pathfinder in the Air Force. The Under Secretary of Defense for Acquisition, Technology, and Logistics selected the Joint STARS Future Support Team to receive the David Packard Excellence in Acquisition Award. At the time, a Defense Contract Management Agency spokesman said, "This innovation sets a benchmark for partnering with industry and leverages that relationship to increase weapons system availability while reducing operating costs."

The Joint STARS TSSR Program Management Team, located at the Warner Robins Air Logistics Center (WR-ALC), provides program oversight. Northrop Grumman has the responsibility, authority, and accountability for the majority of day-to-day sustainment. Specifically, Northrop Grumman is fully accountable for OEM and vendor tasks, depot performance under a workshare agreement, and management of platform-unique items. The government manages and executes product support for the engine, common repairables, common consumables, and common support equipment.

Depot and depot-level repair work is executed via partnership between the government depot at WR-ALC and Northrop Grumman. Northrop Grumman performs periodic depot maintenance and modifications on Joint STARS and all software integration. Some software support is performed at WR-ALC under partnership, and Northrop Grumman executes some software support. Likewise, some prime mission equipment repair is performed by WR-ALC under partnership, while other prime mission equipment repair is handled by Northrop Grumman. The engine is managed and maintained at the Oklahoma City Air Logistics Center.

Rather than the traditional approach to TSSR, which tended to be a platform-level agreement with broad scope provided to the PSI, the government program structure maintains an active and visible role in directing, managing, and executing the product support strategy, while at the same time empowering a commercial entity as the PSI. It is an integrated approach, bringing together core competencies across the breadth of the industrial base, and tailoring the portfolio to meet the requirements of this strategic weapon system.

The net effect is an active and valuable role for the depots.

Enduring Performance

The Joint STARS is a complex suite of technology riding on an antiquated airframe, the Boeing 707. Yet despite these challenges, the integrated performance of the PSI has consistently met all requirements, even though, for example, the PSI has no direct authority over depot support. Northrop Grumman, over the past 6 years, in every 6-month award period has always earned within a few percentage points of the maximum award fee available under the contract. And, in an attempt to address a common criticism of award-fee approaches, the program has defined objective criteria for setting an award fee. Since 80 percent of the award-fee recommendation is driven by specific and defined performance outcomes, clearly, the Joint STARS platform is performing to expectations.

A defined protocol for making award-term decisions also exists. Initially awarded with a 6-year base period, the Joint STARS contract was configured to allow up to an additional 2 years of contract performance, based solely on performance, during each year. As of the end of 2009, Northrop Grumman had already earned contract extensions through 2017.

Enabling Best Practices

The complexity of integrating a product support strategy as complex as Joint STARS into a functioning, integrated whole is considerable. To keep the program aligned, the team has brought together a tapestry of interwoven checks, balances, and incentives to drive desired outcomes. Although each of these approaches is a best practice, the integration of all of these practices into a single strategy is truly best in class.

By any benchmark in the world of product support, a base period of 6 years is long. To provide a secure umbrella under which the business partnership could flourish, the Air Force elected to look to a longer horizon. Instead of only rewarding a contractor for excellent performance with additional award fee, it rewards the contractor by extending the contract period of performance without a new competition. Under an award-term incentive, the government monitors and evaluates the contractor's performance, and if specific criteria are met, additional contract length is automatically awarded.

For Joint STARS, the base period, coupled with the opportunity for the contractor to earn an award-term incentive, leads to a total potential opportunity of 22 years to perform. The Joint STARS PSI has a powerful incentive to both perform and make life cycle decisions across a long horizon. This is yet another example of a successful best practice that could be more generally used; however, not all of the Services choose to recognize award-term contracts as an available enabler to drive performance.

It is possible, during 1 year of performance, to earn an additional 2 years of term. However, the award-term provisions cut both ways; if the PSI performs poorly, it can lose performance period. This clearly encourages consistent and reliable performance.

In many circles, private industry is reluctant to embrace workshare arrangements with depot resources, because industry has neither contractual control over the resource, nor the opportunity to earn revenue/profit on the work at the depots. At WR-ALC, a workshare arrangement is in place, but a business model has also been put in place to incentivize the PSI to influence, and hopefully drive, performance at the depots. Simply put, the PSI can earn award fee based on depot performance. This simple step makes the PSI a stakeholder, deeply invested in making the depots successful.

Deep implications are also inherent to the award-fee approach with Joint STARS. Typically, award fee is distributed based on subjective judgment. Instead of the conventional approach, the program has defined objective criteria for determining award fee. By defining specific and objective measures and using those to determine the distribution of award fee, the Air Force has driven alignment to specific outcome criteria across the program. This is a key principle of performance-based product support.

Tools have been developed to allow the PSI to augment government organizational performance when necessary. The PSI is authorized, when requested to do so by the government, to provide common item(s) when the government item manager's estimated delivery date does not meet the warfighters' need date. The PSI is also authorized to handle surge workload and shortfalls when the capacities at WR-ALC handling repair of mission systems are unable to meet the requirement.

Open Issues

One of the most difficult issues in establishing long-term, performance-based contracts is the establishment of objective performance outcome measures that remain relevant, challenging, and attainable over the life cycle. Today, almost 10 years into the Joint STARS TSSR, the PSI and the Air Force are revisiting the measures used to develop award-fee recommendations. Past attempts to modify the targets have stalled because the targets are contractual terms, and any modification requires mutual consent.

The grinding requirements of ongoing operations have caused a shift in perspective. Today, warfighters express a greater interest in aircraft availability and sortie effectiveness. Consequently, the program team is working to rearrange the weights of certain governing metrics. Today, 17 metrics roll up into a final weighted score. Ideally, one of these metrics—Depot Possessed Aircraft—can be moved from 12 percent of the total to 20 percent; and Introductory Flight Training sortie effectiveness can be increased from a mere 2 percent to 10 percent. This 10-percentage-point weight shift would come by reducing the relative weight of cost measures.

The determination of what the right weights should be is a discussion best left to the team most familiar with the weapon system; and the number of measures tracked as top-level outcomes is open to debate. This process, however, highlights the need to build reset and calibration mechanisms into measurement schemes to allow outcome definitions over time.

As with the previous cases, Joint STARS has opportunities to continue with its improvement journey and deliver more effective performance. That said, the innovations we see at WR-ALC, proven over the last decade, demonstrate that enablers are available to drive best-value participation across a breadth of government resources. And, once again, we see that more effective government participation promotes increased synergy and collaboration for the warfighter, the organic structure, and the taxpayer.

Figure 4. An HH-60G-Pave Hawk helicopter from the 33rd Rescue Squadron (RQS) receives fuel from a KC-130J during a 3-day intensive air refueling course at Kadena Air Base, Japan. The KC-130J, which performs air-refueling missions, is a specialized version of the C-130J, a medium-range, tactical aircraft and the newest upgrade to the C-130 fleet. U.S. Air Force photo by SSgt Chrissy Best.

Case Study No. 4: The Upstarts—Naval Surface Warfare Center, Crane Division

The C-130J is a modification of the C-130H, undertaken by Lockheed Martin Aeronautics Corporation (LMAC) as a private venture, with intended sales to the United States and various foreign markets. The C-130J aircraft is a medium-range, tactical aircraft and is the newest upgrade to the C-130 fleet. Specialized versions of the aircraft include the C-130J Stretch, which has an increased cargo floor length of 15 feet; the WC-130J, which performs weather reconnaissance missions; the EC-130J, which performs electronic warfare missions; the KC-130J, which performs air-refueling missions (Figure 4); and the HC-130J, which performs search and rescue missions.

Currently, the U.S. Government operates approximately 100 airframes, with 65 in the U.S. Air Force, 29 in the U.S. Marine Corps, and 6 in the U.S. Coast Guard; another 60 are owned by foreign governments. Historical practice would suggest that since the C-130J was built using private investment, the military would rely on a system-level, performance-based product support acquisition strategy, with the OEM as either the integrator or playing an active role in the integration. That is not the case in the Navy.

The NAVAIR–NSWC Crane Partnership

The Air Force supports the C-130J under a long-term, PBL partnership among LMAC, the C-130 Program Office, and the 330th Air Combat Support Group at WR-ALC. Initially, the NAVAIR followed the U.S. Air Force product support strategy and relied on LMAC as the source of supply for KC-130J platform-unique components. However, as operational requirements and ongoing commitments grew without proportionate additions to budgets, the Navy found itself under financial pressure. Seeking alternatives, and unable to afford the pricing available through LMAC, the NAVAIR program office opened up a dialogue with the Naval Surface Warfare Center (NSWC), Crane Division.

In collaboration with the program office, NSWC Crane began seeking alternative repair item sourcing strategies for the KC-130J. Since the C-130J is a complex weapon system, subcontractors produce many items on behalf of LMAC. Additionally, the government owned technical data for many of the components. The solution Crane offered was simple: It would replace LMAC as a supply chain integrator at the component level for the program office, and reach out directly to the supplier community. This arrangement offered the additional benefit of swift implementation without the need for a Business Case Analysis: NSWC Crane is within the same Service and can readily accept Military Interdepartmental Purchase Requests.

According to the program office, NSWC Crane has been extremely successful as an agent, driving dramatic cost reductions in costs per flight hour, and in many cases obtaining warranty coverage superior to that available from LMAC. Further, NSWC Crane is behaving entrepreneurially and, in conjunction with the program office, has identified a way to apply the next-generation business model described in the Product Support Assessment (DoD, 2009) to its advantage.

As reported by the NSWC Public Affairs Office, logistically reengineering the sustainment program and re-baselining “by the flight hour” has been successful (Camacho, 2008). NSWC Crane receives a fixed rate for each KC-130J flight hour flown and promises a specific minimum level of performance. The project team employs continuous improvement Lean tools in keeping with NSWC Crane's continual efforts to provide timely, affordable, and quality solutions to the warfighter. This approach helped increase the desired efficiencies that ultimately benefited flight-hour costing and mission capability. The minimum level of performance was set at 85 percent mission capability due to supply issues, but successfully executed in excess of 95 percent since support moved to NSWC Crane. In 2007, NSWC Crane's role in KC-130J sustainment had saved the government $42 million by reducing the cost per flight hour by nearly 75 percent from 2005 to 2007 (Camacho, 2008). More recently, according to PMA-207’s APML, the relationship with NSWC Crane has yielded more reductions in operating costs. If NAVAIR had stayed with LMAC, estimates of the current cost are more than $1,000 per flight hour. At times, the

KC-130J has operated under $300 per flight hour for unique repair of KC-130J repairables.

The government post-production support element at NSWC Crane has leveraged its skill and operates as a viable competitor to the commercial OEM as a PSI on an FFP basis.

Open Issues

While the strategy employed on the KC-130J is innovative and successful, there are risks. Bypassing LMAC moves NAVAIR and NSWC Crane's PBL out from under the umbrella of LMAC. To mitigate, NAVAIR contracts for technical support from LMAC through another arrangement that is managed as a part of the program portfolio. The program office has elected to retain more responsibility—and more risk—by accepting a more active and central role in the execution of the support strategy.

To illustrate the potential risks of the approach, consider the life cycle. The KC-130J is a maturing platform, and obsolescence challenges as well as diminishing manufacturing sources of supply can be anticipated. Will the program office and NSWC Crane be able to manage transitions as effectively as LMAC? Or would NAVAIR be better off by involving the OEM more directly in the PBL strategy through some sort of integrated accountability for performance and outcomes, instead of acquiring technical support in a fee-for-service arrangement? There are trade-offs, and costs to date have clearly been positively impacted by the arrangement, but as the platform matures, a strategy review may be appropriate to ensure continuing success.

As NAVAIR and the U.S. Air Force have charted independent courses, they have disaggregated the support strategy for the platform itself. The U.S. Air Force maintains a separate program office at WR-ALC, with its own strategy and portfolio of contracts. Against the imperatives of the individual Services, reasonable managers have made reasonable decisions. However, opportunities for cross-Service standardization and cross-pollination may exist.

All things considered, in a climate of increasing financial challenges the program office has answered the call for innovation and creativity. More effective government participation is possible, and it is mutually beneficial for the warfighter, the organic structure, and the taxpayer.

Findings and Recommendations

The next-generation product support strategy will not deliver unless the whole community, including both government and commercial industry, is able to make the necessary changes in behaviors, organizations, and business processes. The necessary changes, as we have shown in the case studies, include the following 10 strategies:

STRATEGY NO. 1

Integrating of government post-production support capabilities as best-value partners into a unified industrial base.

STRATEGY NO. 2

Creating the correct blend of government and industry partnership based on best value capabilities, not statutory entitlement.

STRATEGY NO. 3

Defining the PSI role based upon program requirements and not dogma.

STRATEGY NO. 4

Leveraging incentive strategies in the government-owned and -managed resources to drive down life cycle cost.

STRATEGY NO. 5

Capitalizing on the government post-production support organizations' ability to perform at affordable prices.

STRATEGY NO. 6

Creating a culture of high-performing, innovation-driven government-industry teams.

STRATEGY NO. 7

Sharing vision and tying that vision to objectives, metrics, and incentives.

STRATEGY NO. 8

Understanding all stakeholder interests and striving for win-win.

STRATEGY NO. 9

Seeking common ground, with a shared view of a common end customer; what unites government and industry should be stronger than what divides.

STRATEGY NO. 10

Understanding incentives (FFP, award term, incentive fee, etc.).

What we have seen in a crosscutting sample of government post-production support organizations' participation in performance-based *life cycle product support strategies* is that government organizations can effectively and aggressively participate and compete.

We have included examples of government post-production support organizations from each of the Services, and have taken care to include programs from a spectrum of commercial companies, including General Electric, Raytheon, Northrop Grumman, and Lockheed Martin. The examples presented demonstrate that, regardless of the perceived obstacles, determined and motivated government post-production support organizations can identify opportunities and compete effectively and successfully. What we are now seeing in the government is the emergence of competitive organizations, fully capable of participation, not as a matter of entitlement, but as a matter of competence.

Adoption of partnership approaches on a broader scope necessarily provides impetus to the cross-fertilization of best practices between industry and the government post-production support base. At the same time, there exists considerable core competency in the government community, particularly in human capital and infrastructure, which means that there should be cross-fertilization from the government post-production support base to industry. In the General Electric example, we have seen the Jacksonville FRCSE moving into a new line of business—OEM—because General Electric views the government capabilities as more cost effective than its own.

The Product Support Assessment (DoD, 2009) describes a visionary agenda for structural change to facilitate a more integrated industrial base. In fact, it recommends that DoD "Propose modifications to Title 10 to enable maximum implementation of industrial integration." The report then elaborates:

> A rethinking of the nature of partnership includes statutory requirements and issues which may impede effective and

affordable implementation of a warfighter-based product support strategy. A more consistent approach to financial rules and incentives, putting government and commercial organizations on equal footing, will inevitably lead to results that are more predictable. Revised or new statutory requirements should do three things:

1. Propose a strategy for enabling, requiring, and monitoring the ability of the Department of Defense supply chain offices and industrial activities to produce performance-driven outcomes and meet materiel readiness goals with respect to availability, reliability, total ownership cost, and repair cycle time.

2. Enable industry investment in DoD's industrial and other product support activities by submitting a legislative change to modify the government ownership requirement of depot and other support equipment and facilities used in support of core capabilities.

3. Establish reporting constructs to stimulate financial and cost reporting equivalency (i.e., comparable) between industry and the government, and require cost transparency to the greatest extent possible while respecting the need to protect competition-sensitive information. (p. 45)

As we have illustrated through the case studies in this article, an active and vibrant community across the defense industrial base is already bringing the vision of the Product Support Assessment (DoD, 2009) to life. The initiatives proposed in the report, as time has proven, eventually served as a catalyst to the community's current success.

As previously cited in the Jacksonville case study, the report also recommends, "Establish policy and training to expand partnering 'beyond maintenance,' drive standardization across Services, and promote proactive establishment of single-source repair capability." As we have seen in this report, ample opportunity and proven best practices are available to fuel this effort in the government post-production support structure.

How to interpret and apply the examples presented in this report is subjective, but within the context of establishing policy and training, driving standardization, and promoting single-source repair capability, specific actions are possible.

ACTION NO. 1

The Defense Acquisition University (DAU) should train leadership levels within the government post-production support organizations on how to apply the critical success factors uncovered at Huntsville and demonstrate their linkage to PBL. Leverage academic and practical expertise to provide managers, senior managers, and executives with an understanding and ability to create a team climate for innovation.

ACTION NO. 2

Highlight the ability of the government post-production support organizations to make use of incentives paid to hourly workers, and demonstrate how to align that with outcome-based product support strategies.

ACTION NO. 3

Make visible the proven utility and legality of FFP contract approaches at the depots.

ACTION NO. 4

Train the government post-production support organizations in identifying their core competencies, and establish business plans to grow, manage, and market these capabilities across programs and Services.

ACTION NO. 5

Develop case studies on taking a portfolio approach to depot standup, and build single-source repair capability from the ground up, incrementally.

ACTION NO. 6

Promote the long-term success of the Joint STARS program to demonstrate that hybrid approaches utilizing long-term contracts can be successful.

ACTION NO. 7

Provide guidelines and training to appropriate government post-production support organizations on the business opportunities available if core capabilities as a PSI for supply chain integration are developed and marketed.

ACTION NO. 8

Support the development of training materials and case studies at DAU based on the government post-production support organization successes documented in this report.

ACTION NO. 9

Create virtual business offices for each Service and a mechanism to promote standardization while leaving the resources resident in the individual commands.

ACTION NO. 10

Continue to drive for the adoption of performance-based product support across the enterprise, and use the examples in the report to demonstrate the opportunity that this approach provides for the government post-production support base.

Success enablers are abundant for government post-production support organizations to participate in performance-based life cycle product support strategies. It's time to spread the knowledge.

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A NEW PROCESS FOR THE ACCELERATION TEST AND EVALUATION OF AEROMEDICAL EQUIPMENT FOR U.S. AIR FORCE SAFE-TO-FLY CERTIFICATION

Ismail Cicek and Capt Gary S. Beisner, USAF

Aeromedical flight equipment must meet airworthiness criteria according to Department of Defense Handbook MIL-HDBK-516, *Airworthiness Certification Criteria*, MIL-STD-810G, and MIL-STD-1791, which requires restraint of any item that may potentially cause injury to personnel during emergency landings, an over-water ditching, or crash loads. Several government standards provide adequate descriptions of *acceleration test* methods; however, none formally documents a non-destructive test method to qualify equipment as safe-to-fly (STF). Using the USAF fixed-wing aircraft STF test criteria, this article presents a structured process developed by the Aeromedical Test Branch, 77th Aeronautical Systems Group, to assess equipment as STF. Further, it demonstrates the application of this process to meet the acceleration requirements for *aeromedical evacuation* equipment.

Keywords: *Acceleration Test, Aeromedical Equipment, Safe-to-Fly Process, Test and Evaluation, Aeromedical Evacuation, USAF Aircraft*

image designed by Miracle Riese »

MILITARY, CIVILIAN AND PROFESSIONAL

Evaluation of AE

Generally speaking, medical devices are designed to function in environmentally controlled locations, such as stationary hospitals, and not within the harsh, dynamic aircraft environment. Yet, the same medical devices used to care for patients in a hospital environment are often the most capable devices for patient care during transport from one facility to another. These missions are called aeromedical evacuations (AE) missions, and they provide life-sustaining care for a vast array of patients. However, because the devices are designed for a controlled environment, concerns they may adversely affect the operation of aircraft systems must be addressed. Conversely, the aircraft may adversely affect the proper operation and efficacy of the medical equipment.

USAF STF Test Process for AE Equipment

Failure of medical devices during in-flight medical care may result in exposing patients and aircrew to hazardous situations. All medical equipment identified for use on U.S. Air Force AE fixed-wing aircraft must undergo a STF test process in accordance with Section 2.5.1.7 of Air Force Instruction 11-202 (Department of Air Force, 2006), before the STF certification can be issued by the authorizing aircraft system organizations. Military standards, civilian regulations, and professional experience and expertise are all part of the STF evaluation package.

A typical STF evaluation features three phases.

Phase I: Baseline Assessment

The purpose of the baseline assessment is to verify that the equipment under test (EUT) operates in accordance with the manufacturer's specifications and the operator's manual. The EUT is evaluated for adherence to optimum human factors referenced in MIL-STD-1472F (Department of Defense, 1999) and basic electrical safety requirements. The test team becomes familiar with the equipment to select the appropriate tests based on the U.S. Air Force AE equipment test requirements. From there, the team identifies the tie-down configuration, aircraft interfaces, and operational use of the equipment during the baseline assessment. The test plan is then developed and submitted to the aircraft system organizations for review prior to starting the laboratory tests.

Phase II: Laboratory Tests

The purpose of the laboratory testing phase is to simulate the operational in-flight environment through testing, which is modeled after a series of worst-case event scenarios, such as a rapid decompression event or other aircraft incidences or mishaps. Military and industrial standards are used as guidance to select the tests and establish the test criteria. Typical laboratory tests include vibrations, electromagnetic interference (EMI), hot and cold temperature extremes for operational use and storage, humidity, explosive atmosphere, altitude, rapid decompression, and acceleration.

Prior to 2006, specific types of aircraft were dedicated almost exclusively to AE missions. The use of medical devices during flight was a routine part of the daily mission, and acceleration testing was not a solid STF test requirement. Since then, refinements in the employment of cargo aircraft have enabled a broader array of assets for AE and other transport missions. This change allows any available cargo aircraft, or "opportune aircraft," to be quickly designated and configured as an AE transport aircraft. While this fundamental shift in operations greatly benefited the overall AE mission, more exhaustive testing procedures were implemented to assess medical devices prior to in-flight use to ensure safety across the numerous aircraft fleets. These devices were now expected to conform to typical airlift standards just as any other cargo brought on board. The most notable change to the testing procedures was the addition of more robust acceleration testing requirements. After the AE test article completes the laboratory phase, an In-Flight Assessment (IFA) may begin.

Phase III: IFA

The purpose of conducting an IFA for AE equipment is to perform functional checks on board the aircraft during an aeromedical readiness mission. The controls, visual and audible alarms, and display screen of the AE equipment are observed and evaluated during the flight. Test personnel interact with and solicit feedback from AE crewmembers regarding the device's form, fit, and function. These data are used to identify any remaining issue with the use of the device that may not arise during the simulated laboratory test scenarios. Further, this final phase also assists in evaluating and solidifying the intended concept of operations for the device.

Acceleration Testing

AE equipment must meet airworthiness criteria according to MIL-HDBK-516B (Department of Defense, 2008). The criteria require items that could cause injury to personnel during emergency landings, ditching, and crash loads to be restrained. Since aeromedical devices are not mission-critical equipment and are typically considered carry-on equipment, the main thrust for acceleration testing hinges on the inertial loads where safety is paramount. Successful completion of acceleration testing ensures AE equipment can sustain acceleration loads found in aviation mishaps and, more importantly, ensures the safety of the aircraft's occupants. Ultimately, testing is used to ensure medical devices or any cargo does not adversely impact any chance of survival or impede or prohibit passengers' egress. Additionally, high levels of acceleration may have detrimental effects on the AE equipment, leading to broken fasteners, supports, and mounting components. Failures such as these may result in insufficent restraint of the device or its components, ultimately allowing it to become a projectile during a typical crash scenario. Therefore, the equipment's mounting and/or restraint methods must be tested to verify that they will not fail and subelements can be properly contained within the system during an acceleration event.

Acceleration, as addressed in MIL-STD-810G Method 513.6 (Department of Defense, 2009), is a load factor (inertial load or "g" load) that is applied slowly enough and held steady for a period of time such that the materiel has sufficient time to fully distribute the resulting internal loads to all critical joints and components. The common methods used to expose equipment to a sustained acceleration load are centrifuge and track/rocket-powered-sled testing. However, both methods impose limitations on AE equipment testing. For example, the costs required and the scheduling, planning, and coordination phases associated with the use of these types of test facilities are often prohibitive. In some cases, centrifuges and track/rocket sleds may limit the orientations at which the test article can be mounted for testing. To maintain validity, all AE devices are tested under the same mounting configuration as intended for operational use. Finally, due to the often expensive and delicate nature of medical devices, insufficient inventories often prevent the use of these tests due to their somewhat destructive nature.

Because of the difficulties associated with physical dynamic testing, the ATB team initially turned to Finite Element Analysis (FEA) as the method of choice for meeting acceleration test requirements. Recent technological advances in microcomputing and higher resolution graphics capabilities allowed complex systems to be modeled and simulated for both static and dynamic tests.

The FEA techniques were already used by others for various aircraft structures and devices. For example, Foster and Sarwade (2005) performed an FEA of a structure that attached medical devices to a litter. This structure was later approved as STF. Continuing on the same theme, Lawrence, Fasanella, Tabiei, Brinkley, and Shemwell (2008) studied a crash test dummy model for NASA's Orion crew module landings using FEA. Viisoreanu, Rutman, and Cassatt

(1999) reported their findings for the analysis of the aircraft cargo net barrier using FEA. Furthermore, Motevalli and Noureddine (1998) used an FEA model of a fuselage section to simulate the aircraft cabin environment in air turbulence. These and similar studies demonstrated the successful use of the FEA method to verify requirements by analysis for an acceleration test.

Given the costs associated with dynamic testing, the ATB originally envisioned using the FEA method to alleviate budget and inventory concerns. To test this theory, the ATB employed FEA for testing various AE structures to meet the acceleration requirements and found some aspects of this method to be cost- and time-prohibitive. Lessons learned from these studies are provided in the case-studies section.

The various types of analysis and test methods raise questions as to what the correct decision process is for selecting the most appropriate method for STF testing of AE equipment. The authors of this article describe the process developed and employed by the ATB for the acceleration testing of AE equipment since June 2008. The ATB's process has proven to be well suited for identifying the most appropriate test method—one that not only represents the most appropriate and effective test method, but also minimizes the use of available resources. This process includes testing both structurally simple and complex equipment and successfully introducing the use of the Equivalent Load Testing (ELT) method, which permits the use of alternative testing approaches, such as pull testing and tensile testing.

ATB's Acceleration Test and Evaluation Process

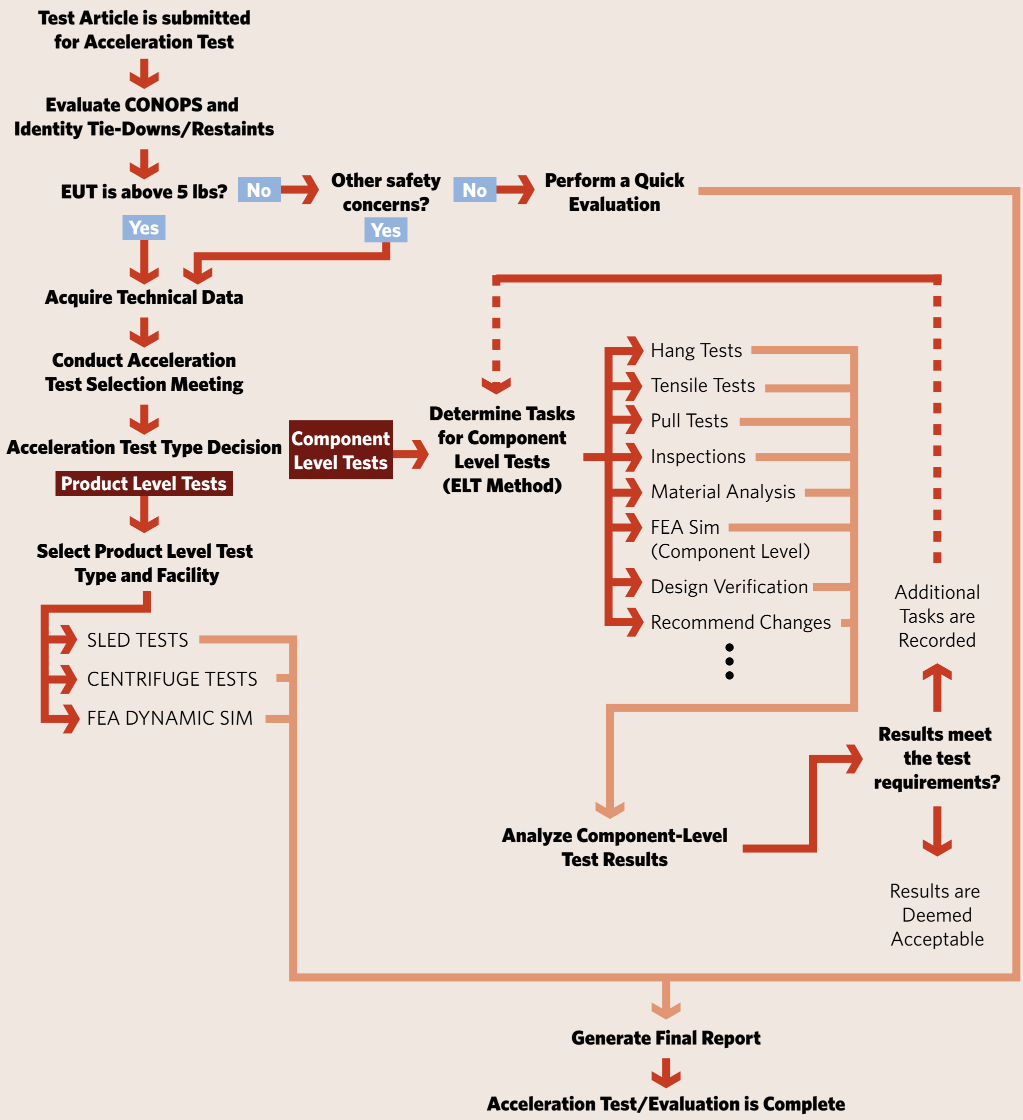
Process Description

An integrated team approach remains the cornerstone for the acceleration *test and evaluation* process for AE STF certifications. The team members, each having different skill sets, become part of an acceleration test assessment meeting where the subject test item is evaluated against the acceleration test requirements and the type of test is identified. The team also identifies the intended operational and tie-down configuration, assesses the means in which components and subcomponents are mounted to the system, and all other concerns related to acceleration requirements. The overall process is depicted in Figure 1.

The initial task of the integrated team is to evaluate the test article for any inherent safety concerns. For example, the ATB team identified that AE devices weighing less than five pounds are usually perceived to pose no substantial risks due to acceleration; therefore, a quick assessment and description of the equipment tie-down were found satisfactory. Generally, the team conducts a test selection meeting for the items weighing more than 5 pounds.

When the test team finds product-level tests are required, the article is tested in a physical environment, namely sled tracks or cen-

FIGURE 1. ACCELERATION TEST AND EVALUATION PROCESS DIAGRAM



Note. CONOPS = Concept of Operations; SIM = Simulation.

trifuges, or a model representing the product can be developed and analyzed using FEA simulation. The component-level tests refer to the tests specific to a subcomponent or a structural member of the equipment, i.e., mounting brackets, screws, beams, straps, etc. When the decision is a component-level test type, the ATB team applies the ELT method by conducting an in-depth evaluation of the test article, identifying the critical areas within the item, and noting any potential safety concerns within the environment. The outcome of this evaluation is a list of tasks that includes a series of tests, analysis, inspections, and evaluations. The component-level test requires a final assessment meeting where the ATB team analyzes and deems acceptable the component-level test results or determines whether additional tasks are required.

Prior to 2008, acceleration tests were typically conducted at the product level. However, the case studies presented in this article highlight a multitude of alternative test options for component-level testing as well. When selecting between product or component-level testing, the ATB carefully considers many different aspects of the overall design of the equipment, its intended use, and any unique safety concerns. For example, component-level testing would most likely not be adequate for a system containing compressed gas cylinders because this form of testing would only target the key structural features of the system, such as the handles on the outer case. Rather, a product-level test, such as a sled test, would be more appropriate as it would test the whole system including the connections between the cylinders and the system where dangerous leaks could occur.

The component-level test was recently added to the acceleration test process and has saved a significant amount of time and money since 2008; therefore, the ATB places emphasis on the component-level test, unless the product must be tested in a physical environment. The component-level test uses the ELT method, which is detailed in the following section.

The ELT Method

The ELT terminology used in this article refers to the constant, or approximately constant, loading that is applied to the test item for a finite duration. The magnitude, point of application, and the direction of the load are equivalent to the properties of inertial loads and moments generated in an acceleration event under the g-levels shown in Table 1. The levels represented in this table are some of the common test requirements for AE equipment as outlined by the aircraft system organizations. The magnitudes shown in this table are consistent with Title 14 Federal Aviation Administration regulations, like Special Federal Aviation Regulation 23.787, which dictates that the equipment tie-downs and restraints must sustain a 9g inertial load factor (Aeronautics & Space, 2010).

The magnitude of the equivalent load is determined using the magnitude of the sustained acceleration load that would be exerted on a tie-down component, a critical part, or a joint of the equipment in a physical test. For example, 9g of acceleration introduces 90 pounds inertial load on a device with 10 pounds of weight; and the critical areas, such as tie-downs and restraints, must be tested to verify they are capable of restraining the inertial loads and moments.

TABLE 1. TEST G-LEVELS USED FOR ACCELERATION TESTING

Forward (G)	Aft (G)	Up (G)	Down (G)	Lateral (G)
9	1.5	4	8	4

The authors reviewed the definition of static load and compared it to the definition of the sustained acceleration described in MIL-STD-810G Method 513.6 (Department of Defense, 2009). Shigley and Mitchell (1983) define a static load as "a stationary force or moment acting on a member" and identified the following attributes:

- Unchanging magnitude
- Unchanging point or points of application
- Unchanging direction

The following statements are also true for an acceleration test per the definition of acceleration found in MIL-STD-810G (Department of Defense, 2009):

- The magnitude of acceleration loading introduced to the EUT is sustained. In other words, a test is conducted for a certain period of time with a constant acceleration.
- Acceleration loading is applied to each axis independently; therefore, the point of application does not change during a test.
- Each direction of loading is applied independently; therefore, the direction of loading does not change.

Table 2 summarizes these definitions for identifying the attributes for a test load to use in the ELT method. This comparison helped determine the properties of the appropriate test loads used in ELT methodologies. For example, when a carrying handle is the key component used to restrain an EUT, the handle becomes the primary

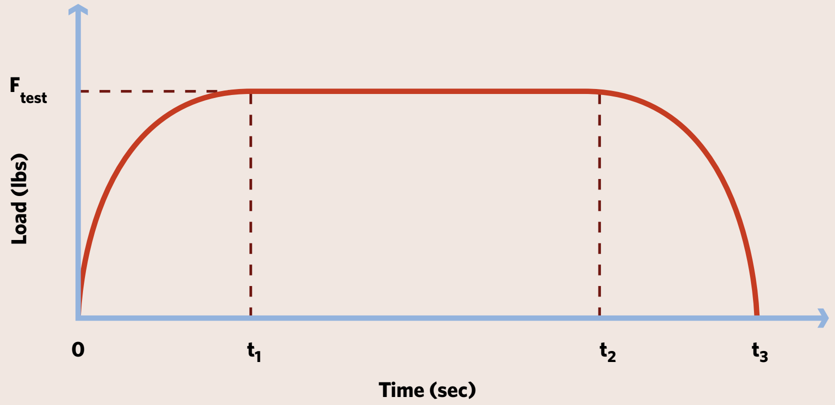
TABLE 2. ATTRIBUTES OF STATIC LOADING VS. EQUIVALENT G-LOAD FOR TESTING PER MIL-STD-810G

Attribute	Static Loading	Acceleration G-Load in Testing (MIL-STD-810G, Method 513.6)	Test Load to use in the ELT Method
Load Magnitude	Constant	Sustained acceleration (Constant for a period of time)	Sustained loading for a period of time
Point or Points of Application	Unchanging	Tests are conducted at each direction independently	Unchanging
Direction	Unchanging	Tests are conducted at each direction independently	Unchanging

area of concern for the acceleration tests. As such, the handle may be tested using the ELT method. The test load would be sustained for a period of time, such as t_2-t_1 as shown in Figure 2. The magnitude of the test load shown in Figure 2 (F_{test}), would be equivalent to the magnitude of the inertial forces generated by the acceleration g-levels, as illustrated in Table 1. The test load would be applied to a specific component or components previously identified as critical areas during the acceleration test assessment meeting.

The following sections describe both the acceleration test and evaluation process and ELT method using real case studies. The ATB decided to apply the test load for 6 seconds of duration after reviewing the military standards that describe the static tests. For example, MIL-STD-209K (Department of Defense, 2005) states the

FIGURE 2. CONCEPTUAL LOAD CURVE FOR EQUIVALENT LOAD



"loads applied in the vertical, longitudinal, and lateral directions shall be applied statically and independently for not less than 6.0 seconds." This duration became an ATB standard test parameter after gaining concurrence from the various aircraft system organizations. It was consistently used when the ELT method was selected for an acceleration test.

Case Studies

Table 3 shows some of the acceleration test and evaluation projects implemented since May 2008 using the new test process, as well as the ELT method described earlier. This section discusses some of the selected projects in the next subsections. As listed in Table 3, the ATB team applied the new process to a total of 14 projects and successfully used the ELT method in eight of those projects.

Case Study No. 1: ELT Approach for Testing a Lightweight Device (EUT No. 1)

EUT No. 1 is a lightweight medical device mounted in a small ruggedized case. The item weighs 6.23 pounds, and all components of the system are confined inside the case. In terms of acceleration testing, the only key feature of this equipment was its handle when secured to a patient litter as shown in Figure 3. The team decided to employ a tensile test on the handle and the handle mounting pins to evaluate the EUT under the previously stated acceleration criteria.

Figure 4 shows the ELT setup for a 9g acceleration test under the two worst-case loading scenarios assuming that the equipment may potentially slide out from between the strap and litter. Figure 5 shows the configuration of the EUT No. 1 on a tensile tester for two orientations. These are consistent with the identified test orientations shown

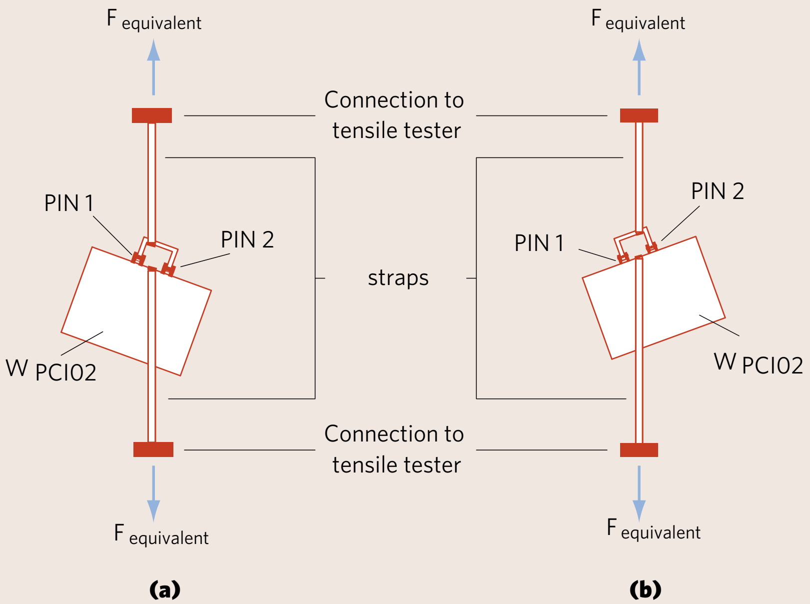
FIGURE 3. EUT NO. 1—TIE-DOWN ON A LITTER


FIRE

TABLE 3. EXAMPLE ATB ACCELERATION TEST AND EVALUATION PROJECTS

Project Number	AE Equipment Description	Case Study in this Article	Test Method
ATB-08-01	Lightweight device housed in a small, ruggedized container	EUT No. 1	ELT
ATB-08-02	Portable oxygen system in a protective cover	Not covered	ELT
ATB-08-03	Patient litter for accomodating patients up to 250 pounds	EUT No. 3	FEA (Product-Level Test)
ATB-08-04	Patient litter for accomodating oversize patients	EUT No. 3	FEA & ELT
ATB-08-05	Mechanical structure to attach AE devices to patient litters	EUT No. 3	FEA (Product-Level Test)
ATB-09-01	High-pressure oxygen system in a large, ruggedized container	EUT No. 4	Sled Testing
ATB-09-02	Electrical cables, plugs, and converters in a medium-sized, ruggedized container	Not covered	ELT
ATB-09-03	Patient monitor/ defibrillator with about 16 pounds of weight	EUT No. 2	ELT
ATB-09-04	Neonatal transport system with heart and lung support	SUT No. 1	ELT
ATB-09-05	Smaller neonatal transport system structure	SUT No. 2	ELT
ATB-09-06	Mannequin with a control system	Not covered	ELT
ATB-09-07	Mannequin with a control computer	Not covered	ELT
ATB-09-08	Stacking litter structure	Not covered	ELT (in plan)
ATB-09-09	Small, portable electrical generation system in a carrying case	Not covered	Centrifuge Test (in plan)

FIGURE 4. EUT NO. 1—TEST CONFIGURATION ON A TENSILE TESTER

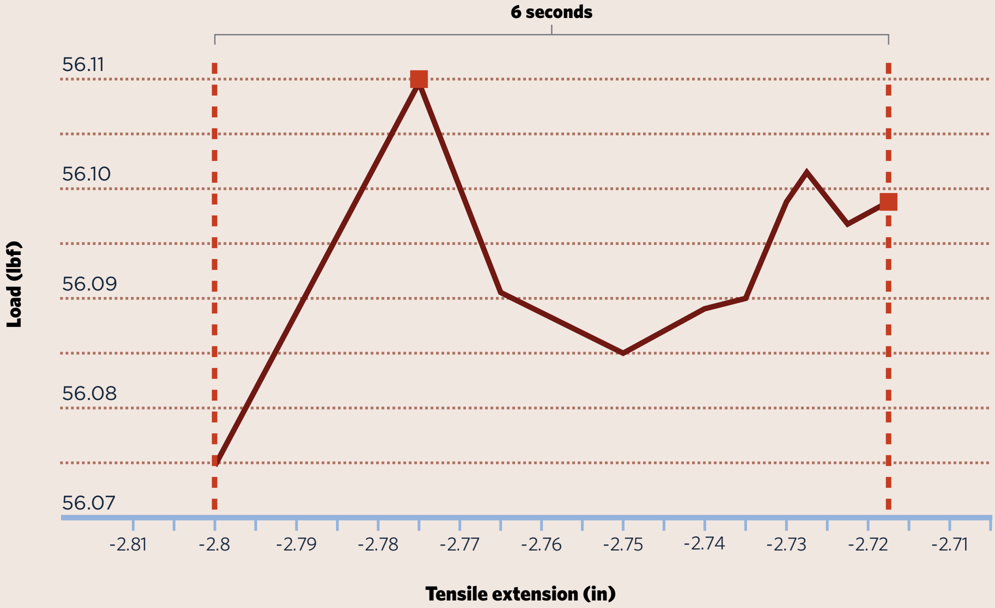


Note. (a) = Orientation 1; (b) = Orientation 2.

FIGURE 5. EUT NO. 1—ACTUAL TEST CONFIGURATIONS

Note. The image on the left coincides with Figure 4 (a), Orientation 1; the image on the right coincides with Figure 4 (b), Orientation 2.

FIGURE 6. EUT NO. 1—LOAD CURVE MEASURED DURING TENSILE TESTING, ORIENTATION NO. 2



in Figure 4. Figure 6 shows the actual record of the load applied for the Orientation No. 2. The test load was held at approximately 56 pounds-force for a 6-second duration.

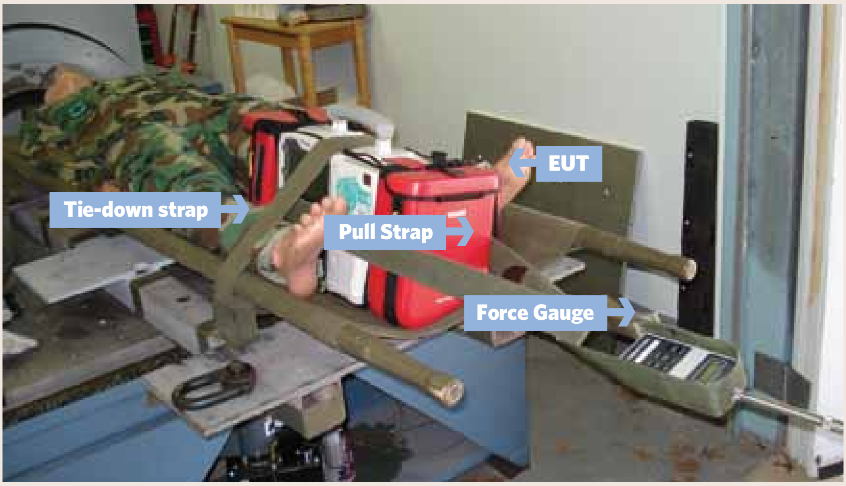
When considering a physical test for EUT No. 1, the ATB estimated a substantially higher cost for the use of appropriate facilities, fixtures to hold the device during testing, and any expendable materials used during the test. In addition, a physical test would have required additional planning and coordination time, thus driving schedule delays and adding additional costs for manpower spent during planning. In this case, much of these cost and schedule risks were mitigated by using in-house tensile test stands.

Case Study No. 2: ELT Approach Used in Testing of a Portable Monitor (EUT No. 2)

EUT No. 2 was a lightweight, portable, patient monitor/defibrillator weighing 16.2 pounds. The team's main priority was to verify the item could be properly restrained such that it would not become a projectile during an acceleration event. To do so, the team came up with a tie-down method using litter straps to restrain the EUT's movement in all directions. If successful, this tie-down method would become the approved method for restraining the device in the aircraft during operational missions. As shown in Figure 7, the litter strap passes through the handle of the EUT and the stirrup of the litter.

FIGURE 7. EUT NO. 2—TIE-DOWN ON A LITTER

FIGURE 8. EUT NO. 2—TEST SETUP



The team also noted that when the EUT is exposed to forward acceleration loads, it may potentially slide out from between the strap and litter. Under this scenario, the handle of the EUT would be required to bear the full 9g inertial load of the device. Therefore, the team conducted a pull test to verify this configuration restrains the EUT. This test would also verify the ultimate stresses of the handle were not exceeded if 146 pounds of equivalent load corresponding to 9g inertial load factor were applied through the EUT's CG in the forward direction.

The team conducted a pull test in the configuration shown in Figure 8 using a calibrated force gauge for a 6-second duration. By using this in-house test method, the team was able to properly test the EUT under its operation configuration in less than 1 hour. Further, this test method only required the purchase of a new force gauge and accessories totaling $1,250. If an FEA or sled tests were used on this

FIGURE 9. AE PATIENT TRANSPORT SYSTEM

device, estimated costs would start around $30,000 and would take several weeks to plan and conduct the test.

Case Study No. 3: FEA Used in Testing of Patient Litters (EUT No. 3)

The team recently evaluated three AE articles used to move patients: two patient litters and a special structure used to attach medical devices onto the litter during transport. In this case, the team decided to perform an FEA using the ALGOR static stress and mechanical event simulator packages. The FEA results successfully identified components that may fail under the required acceleration loading on all three AE equipment items. Despite the successful use of FEA to identify potential safety risks, the time and money spent to evaluate these three devices were substantially higher than the methods discussed in the first two case studies. More than $200,000 was spent on the FEA analyses over a one-and-a-half-year period. The decision to conduct an FEA on these three items was made prior to the development of the ELT method.

Case Study No. 4: ELT Approach Used for Test and Evaluation of a Complex Transport System Structure (System Under Test [SUT] No. 1)

The ATB team evaluated a structure of a complex system used to transport neonatal and pediatric patients in critical condition. The SUT, shown in Figure 9, contains 13 medical devices and weighs about 820 pounds. Due to the system's one-of-a-kind nature, as well as the cost and lead time associated with procuring the advanced medical devices mounted within it, the team consulted with several of the aircraft systems organizations and decided on using the ELT

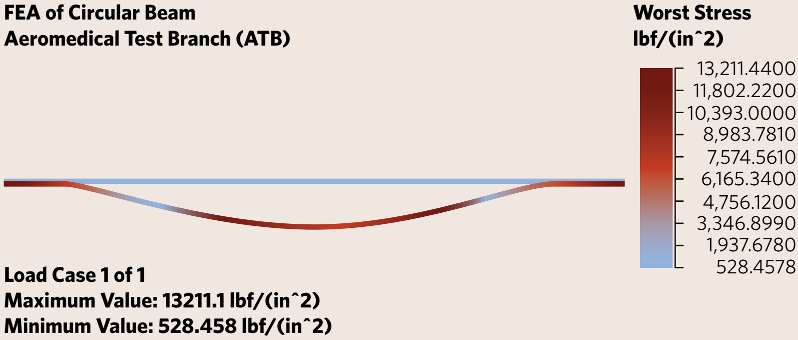
TABLE 4. SAMPLE TASKS IDENTIFIED FOR THE ACCELERATION TEST AND EVALUATION OF SUT NO. 1

Task ID	Component	Task	Method
ATB-SUT1-001	D-rings	Perform a load test to verify that each tie-down ring is capable of holding 1 g of acceleration load.	Hang Test for D-rings; duration: 6 seconds Load analysis using the 12 cargo straps.
ATB- SUT1-002	Casters	Determine the load capacity of the casters. Identify the maximum payload. Determine the load and pressure distributions on the aircraft floor. Determine shoring requirements.	Manufacturing data CG calculation and analysis for finding the reaction loads and pressures. Finite Element Analysis (FEA) of the columns and top plate members.
ATB- SUT1-003	Locking Rod	Perform structural analysis on the locking rod and side bracket mounting screws used to secure the locking rod.	Finite Element Analysis
ATB- SUT1-004	Locking Rod	Verify proper alignment of the UPS units locking rod side brackets.	Instruction/Inspection
ATB- SUT1-005	Writing Table	Include requirement that the writing table is locked/stowed during takeoff, landing, and emergency situations.	Instruction/Limitation
ATB- SUT1-006	Padding	Ensure foam padding installed underneath the compressed gas cylinders.	Instruction/Inspection
ATB- SUT1-007	Straps	Verify the use of straps to restrain the handle of Medical Device No. 3 to the back housing bracket.	Analyze strap strength Instruction/Inspection
ATB- SUT1-008	Sliding Shelf Assemblies	Perform a pull test on all sliding shelf assemblies to demonstrate their ability to restrain the designated device under 4g lateral acceleration force.	Pull tests, 4g, each sliding shelf assembly; duration: 6 seconds

Note. CG = Center of Gravity; UPS = Uninterruptible Power Supply

FIGURE 10. VIEW OF SUT NO. 1 DURING HANG TEST

FIGURE 11. WORST STRESS FOR SUT NO. 1 LOCKING ROD



method. Employing this method, the team used a combination of analysis, inspection, and supporting tests to satisfy the acceleration test requirements. Therefore, this case study is covered in more detail than the previous case studies.

The acceleration test and evaluation team completed an in-depth structural analysis on the SUT during which 23 tasks were identified. These tasks included the test, inspection, and analysis of the structural members, restraint mechanisms, and tie-downs of SUT No. 1. For a description of the process, a sample of eight of the tasks is provided in Table 4.

The acceleration test team successfully conducted tests and performed analysis for each of the tasks identified in the assessment meeting. For example, the eight D-rings and four additional structural members were hang-tested, and the team subsequently verified that each tie-down location was capable of withstanding 1g acceleration load. Figure 10 shows a view of the SUT captured during one of the hang tests. When each tie-down location is used, the restraint capability for the system can sustain at least a 9g forward acceleration load.

Figure 11 shows the analysis results for the FEA of the locking rod, which demonstrated the locking mechanism is able to sustain 1.5g lateral loading. Additionally, the shoring was recommended based on the FEA results and in conjunction with sample calculations provided in MIL-STD-1791(2) (Department of Defense, 1997).

It is important to note that the ATB team previously considered using FEA for the acceleration testing of this SUT. However, projected cost and schedule figures similar to those noted in Case Study No. 3 discussed earlier negated the use of FEA on this system and required a new approach to meeting the acceleration requirement. In fact, initial estimates for the FEA started around $474,000 and were scheduled to take an estimated 2 years to complete. The ATB is currently planning to apply the same approach for the test and evaluation of two similar transport structures, saving an estimated $169,000 and 2 years of analysis time.

Case Study No. 5: Sled Testing of a High-Pressure Oxygen System in a Large, Ruggedized Container (EUT No. 4)

This EUT was a bulky, high-pressure mechanical system used to store large volumes of medical grade oxygen for patient use during transport. Weighing nearly 200 pounds, the system is housed in a ruggedized container and contains two large compressed gas cylinders. As mentioned earlier, applying an ELT test method would save substantial time and money; however, using this method would not adequately test the interaction of all components within the system.

More specifically, the ELT method would not test the reaction of the cylinders to the imposed acceleration load and how that reaction could affect the gauges, valves, and associated plumbing. Based on this rationale, the ATB team determined the accuracy and validity of the test data generated from a physical test far outweighed its cost and schedule risks, and the team began planning a sled test for the EUT. To further improve the relevance of the test and most accurately mirror its operational configuration, the team elected to test the EUT in its pressurized state, thus requiring the tests to be conducted at an outdoor facility.

The selection of this test method proved successful in assessing the safety of this EUT. Although the tests cost roughly $30,000, required the construction of a containment structure and two special fixtures to hold the device, and took over 5 months to complete, the data generated from this sled test presented a very detailed prediction of how this EUT would perform during and after an acceleration event. This test also confirmed the intended tie-down configuration was capable of restraining the EUT during the g-loads shown in Table 1.

Conclusions

In the ever-changing world of acquisitions and the increasingly limited amount of money and time for testing activities, the ATB began exploring new test methods to satisfy acceleration testing requirements on AE equipment. The structured process described in this article continues to provide a methodical procedure for evaluating the safety of medical devices and determining the best method or combination of methods for conducting acceleration tests.

While this article discusses only certain aspects, much of this testing process is founded on a wealth of operational and technical experience. Additionally, each test article features unique characteristics that do not allow for standardization in the decision process. Because of these factors, the ATB team depends on the integrated team construct to help balance the decision process for each project.

Applying this process has already saved the ATB over $900,000 in testing and analysis and cut more than 4 years from its busy test schedule. This process, including its dependence on an integrated team approach, has the ATB poised to continue to meet the demands of the constantly evolving acquisition environment in which today's acquisition practitioners must execute their programs.

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THE P-51 MUSTANG: A CASE STUDY IN DEFENSE ACQUISITION

Alan Haggerty and Roy Wood

In the rapidly changing global situation, defense acquisition needs to be equally agile and innovative. We must look to every source—government, industry, and academia—for ideas to make warfighter systems more capable and affordable. This article presents a historical case study of the World War II *P-51 Mustang* fighter plane development that illustrates ways the aircraft designers embraced the challenge to build a world-class fighter aircraft in the face of a challenging enemy, entrenched bureaucracy, and immature industrial capability. Enduring lessons are presented for today's acquisition professional.

Keywords: *P-51 Mustang, P-40 Warhawk, North American Aviation, Curtiss-Wright Corporation, Risk, Aircraft Manufacturers*

image designed by Tia Gray»


INNOVATIVE ··· FLEXIBLE ··· INTERDISCIPLINARY

The world is an unpredictable and dangerous place. In 1919, a group of men gathered to sign an armistice to close the "war to end all wars." A short two decades later, the world was fighting an even broader and bloodier war. In the mid-1970s, Iran, a staunch U.S. ally, was the strongest regional power in the Gulf. Five years later, the Shah had been deposed, Iran was in the midst of an anti-western revolution, and U.S. citizens were being held hostage. In 1989, the Berlin Wall separated East from West, and at Dick Cheney's confirmation as Secretary of Defense, no one even mentioned Iraq ("Background Briefing," 2001). One year later, the Berlin Wall was down and American forces were toe-to-toe with an 800,000-man Iraqi army. On September 10, 2001, the greatest national concern was the health of the stock market and which dot.com company would be the next to go under. On September 11, everything changed. Global instability, nuclear proliferation, and ongoing armed conflicts around the world threaten U.S. security. More ominously, such instability and global warfare appear to be growing at an alarming pace.

Defense Acquisition and the Changing Environment

Yet, defense acquisition appears to be ill prepared to respond to many of the rapidly emerging challenges. As a poignant example, improvised explosive devices were killing soldiers and Marines in Iraq, but the solution—a heavily armored Mine Resistant Ambush Protected vehicle—remained bogged down in a peacetime acquisition system until heroic, high-level efforts broke through the bureaucratic obstacles (DeCamp, 2007; Feickert, 2008). On April 6, 2009, Secretary of Defense Robert Gates refused to buy additional lots of F-22 fighter jets, designed for the Cold War and stuck in a 20-year development-to-delivery cycle (Gates, 2009). At some point, the question arises as to whether our defense acquisition process can ever be as responsive as necessary to rapidly changing global threats, or whether, after all is said and done, its application to today's acquisition environment is largely irrelevant and perhaps itself a danger.

Has defense acquisition always been this problematic, or are we in a particularly difficult transition period? Certainly, defense acquisition has always been hard. The first ship procurements for the U.S. Navy in the 1790s experienced cost and schedule overruns, congressional lobbying, and technology overreach (Toll, 2006). But, the nation rebounded to produce resounding achievements such as the nuclear powered submarine, the intercontinental ballistic missile, and, of course, the Manhattan Project. These programs all were begun in response to significant global changes and dangerous emerging threats. Defense acquisition has shown tremendous responsiveness, when the need arises, to provide game-changing innovations that transform the trajectory of warfare.

The Case Study Approach

What enduring lessons, then, can we learn from events in history that required the system to respond quickly and effectively to deliver these transformational systems? This article develops one case study to explore the acquisition challenges brought about by severe environmental changes and synthesizes lessons from the case that could have applicability to our current acquisition system. This is but one case, albeit an interesting one, and *risk* is always inherent in generalizing findings (Yin, 2003). Nevertheless, in the acquisition business scholar-practitioners can gain valuable and perhaps far-reaching insights through studying successful developments and attempting to draw lessons from them; comparing and contrasting best practices; and discovering better ways of plying the trade today.

Case of the P-51 Mustang

The P-51 Mustang remains a highly recognizable, legendary World War II fighter aircraft that was the pride of both the United Kingdom and the United States. Development of this innovative aircraft was fraught with challenges—technical, political, and programmatic. The development story takes place in a world on the brink of a second global war, where allied forces were largely unprepared to face an enemy with better technology, war tactics, and wartime organization. In the United States, neither the military, having retreated to a peacetime pace after World War I, nor industry, recovering from the Great Depression, was prepared for another butter-to-guns transformation (Baumol, Nelson, & Wolff, 1994).

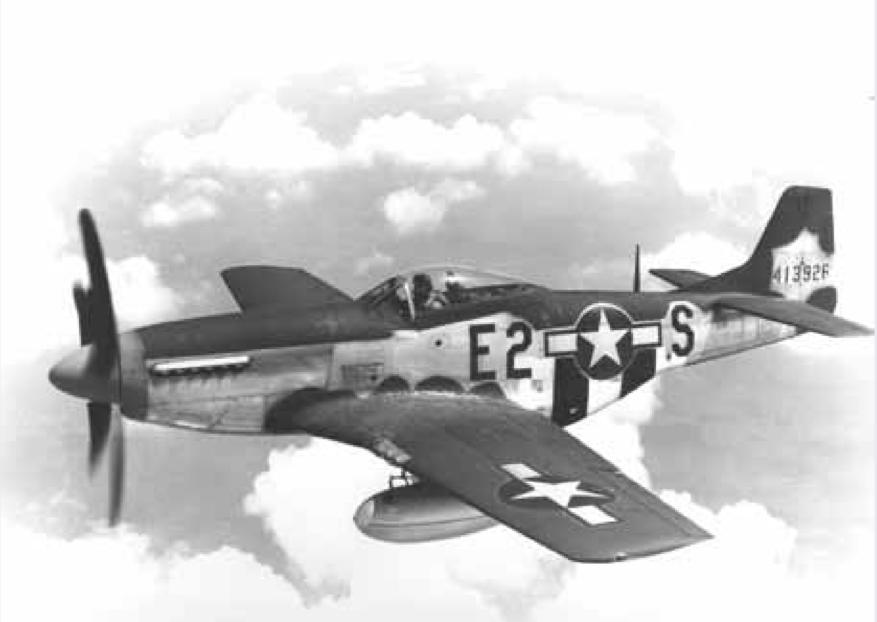
The year was 1940. World War II was raging, and Europe was in a desperate situation. In the United States, memories of the horrors of World War I were still fresh, and public sentiment had turned decidedly isolationist. Despite early warnings from many experts, the United States and its military were not well prepared for another global conflagration.

With the blitzkrieg, Germany had quickly rolled up much of continental Europe under the Nazi flag. The Battle of Britain was at hand, and the Royal Air Force (RAF) was critically short of fighter aircraft to respond to the coming German onslaught. British industry was clearly unable to meet the RAF's production needs, so a Purchasing Commission was sent to the United States in the hope of finding long-range fighter aircraft suppliers for its bomber escort missions.

The RAF agents initially approached the dominant U.S. aircraft supplier, the *Curtiss-Wright Corporation*, with a request to place an order for more than 300 of their best fighters—the *P-40 Warhawk*—which was also the main fighter in U.S. Army Air Corps service. Curtiss-Wright turned the order down due to lack of factory capacity.

The desperate British then turned to a small California company, *North American Aviation*, which specialized in building training aircraft. The British asked North American to consider a licensed production deal with Curtiss to build the Warhawk in their factory. The company's president, "Dutch" Kindelberger, asked for time to consider the offer. He knew that the P-40 Warhawk was a relatively old design that was tough and heavily armed, but slow and lacking the maneuverability and combat performance to go against the German Luftwaffe in air-to-air combat.

After some discussion, the young company president and his small design staff made an astonishing counter-proposal to the British. They offered to design and deliver a new airplane, using the latest in aviation technology. In doing so, they promised the British a



P-51 Mustang courtesy of the U.S. Air Force fighter of far greater capability, while at the same time leapfrogging Curtiss-Wright and establishing their tiny company at the forefront of the international aviation industry.

The desperate British were taken aback. North American had never designed a combat aircraft before. They would have to build an entirely new factory and invent new processes to manufacture the airplane. And to fulfill the contract, they would have to produce a world-class fighter that could outperform the German Air Force. Their company's future, not to mention the survival of the United Kingdom and possibly that of the entire free world, was riding on their abilities.

Amazingly, the British agreed, with two provisos. First, North American should use the same engine as the P-40—the American Allison V-12. This engine had a simple, one-stage supercharger rated for low-altitude flight, since American doctrine at the time called for fighters to operate in direct support of ground troops at low level. Second, they had to design and produce the first prototype in less than 120 days! The company agreed to the British conditions and went to work on what would become the NA-73 Mustang.

North American's goal was to build the fastest aircraft they could make given the limits of the Allison engine. Their designers decided to use two cutting-edge technologies that had never been included in a production fighter aircraft before.

The first was the *laminar-flow wing*. The laminar-flow airfoil was the product of massive investments in the 1920s and 1930s by the U.S. government, specifically the National Advisory Committee on Aeronautics (NACA), the forerunner of the National Aeronautics and Space Administration. This design "smoothed" the otherwise turbulent airflow across the wing surfaces, reduced drag, and increased aircraft speed and efficiency ("Laminer Flow Airfoil," 2010).

The second was an untried cooling radiator design called the *Meredith effect duct*. The Meredith duct was essentially a divergent-convergent duct with a radiator at its widest part. The theory was that the engine's waste heat would accelerate the flow of air through the duct, producing a ramjet effect to reduce engine cooling drag at high speeds. The design had never been used before, and, in fact, had only been proposed as a theoretical possibility in an academic paper in Britain between the World Wars (Meredith, 1936).

Exactly 117 days later, on borrowed wheels, the prototype Mustang rolled out of the North American factory (Bowman & Laurier, 2007, p. 7). The British immediately placed a large production order, and the RAF Mustang was soon in front-line service as a low-altitude attack and close-support fighter.

A few months later, the United States entered the war. The U.S. Army Air Corps had several new fighters coming online, but they lacked a first-rate ground attack and tactical reconnaissance plane; therefore, the Corps ordered the Mustang under the U.S. designation A-36 Apache. The British Mustang and U.S. A-36 Apache served in several theaters with great success, and if the story had ended there it would have been a superb historic case study of the technology and defense industry communities working together in a time of great need.

But, of course, the story didn't end there. The American tactic of low-altitude fighter combat proved to be flawed—aerial dogfights were high-altitude affairs in the European theater. The Allison engine was not up to the task because its supercharger lost power at high altitude. The British, however, had developed the Rolls Royce Merlin, with a superlative high-altitude supercharger. This innovative two-speed, two-stage supercharger had been designed by a young Cambridge University mathematician, Stanley Hooker, and it allowed the Merlin to operate at high power to altitudes above 40,000 feet (Hooker, 1984).

The new P-51 Mustang, with the improved Merlin engine and larger fuel tanks, went on to dominate the air war over Europe, and later the Pacific. The German Air Force commander said after the war that he knew the war was lost when he looked up and saw Mustangs in the skies over Berlin (Rickard, 2007). In the opinion of many historians, the P-51 turned the tide of the war in Western Europe and was crucial in gaining the final victory there.

Case Analysis

The P-51 Mustang may have been one of the greatest success stories in the history of defense acquisition and a triumph of innovative technology insertion. Note that the Mustang did not spring wholly formed from a highly structured requirements generation process or from the pages of some early edition of DoD Instruction 5000.02 (DoD, 2008). The Mustang succeeded because its makers were driven by a combination of urgent warfighting need, intense industry competition, and the freedom to draw on the intellectual forces of government, industry, and academia to help them succeed.

This story may hold additional critical lessons. First, consider the source of the technologies used to give the Mustang its superb performance.

LAMINAR FLOW WING

The laminar flow wing came from a government research and development agency, funded by the U.S. Congress. Experiments and trials were conducted in massive wind tunnels at NACA labs in Langley, Virginia, and at Moffett Field in California. NACA was solving an interesting physics problem, but the solution had not made its way into any application toward the war effort until the North American team took the concept and applied it to the Mustang. Similarly, the Meredith Effect radiator duct was the product of basic academic research published in a scholarly journal.

Lessons. The U.S. government continues to spend substantial sums on basic and applied research at laboratories and universities across the country and with our allies. Harvesting that technology has been, and continues to be, devilishly difficult and unpredictable. Historically, that seems to be the nature of innovation. When the right programs in need of technology solutions bump into the right technologists who have been working on similar problems, magic happens. Rather than a stepwise, rational process to solve difficult problems, this is a perfect illustration of the classic "garbage can" model of organizational problem solving (Cohen, March, & Olsen, 1972). Here, a seeker with a problem is rummaging around and happens to find another with a potential solution, but who is unaware that the problem exists.

To facilitate this form of "accidental" problem solving, there needs to be very proactive networking between programs-of-record actively seeking solutions, with the technology community who may have solutions to problems of which they are unaware. The aim must be to more intentionally force these innovation "collisions" to happen more frequently. All too often, promising solutions lie dormant waiting on someone to pick them up, dust them off, and look at using them in new and fresh ways.

SUPERCHARGER CONCEPT

Stanley Hooker's supercharger concept enabled the Mustang to outperform the German Luftwaffe in high-altitude dogfights. The technology was not originally envisioned, however, as a military improvement. Rather, it was developed, tested, and matured in the highly competitive environment of civil aircraft racing competitions.

Lessons. Today's downsized defense industry, similar to that of the United States and United Kingdom between World Wars I and II, lacks robust competition. Indeed, without a daunting enemy threat, not even a clear vision or pressing need exists for innovation in defense systems. However, a vigorous commercial sector working in an unforgiving global competitive environment continues to develop new and innovative products, many with defense-application potential. These need to be identified and encouraged. Too often, when a potential military or dual-use item emerges from a commercial source, it becomes subject to oppressive import and export restrictions. This practice has a chilling effect on commercial innovation, makes U.S. industry less competitive globally, and needs to be changed. The Defense Department also needs to help foster greater competition among second- and third-tier defense and commercial subcontractors, as well as buy and use as much unaltered off-the-shelf technology as possible from non-defense businesses. To facilitate transitioning commercial technology to defense use, there must be a healthy market scanning ability within the DoD to identify those promising products and vendors that add competitive value to our programs. As seen in Iraq and Afghanistan, innovative insurgents and terrorists will require U.S. defense, in order to succeed, to also exercise the cutthroat entrepreneurialism for which Americans have become famous.

SUCCESS OF THE UNDERDOG

Finally, "Dutch" Kindelberger, the legendary head of North American Aviation, had the technical savvy, gambler's instinct, and almost insane confidence in his company to go head-to-head with the best *aircraft manufacturers* in the world—and win.

Lessons. The aviation industry of the 1930s was in its heyday, similar to this era's dot.com and information technology industries, with allure that attracted smart, aggressive entrepreneurs. Aviation pioneers of the 1930s hired bright young designers and engineers, and gained confidence by cutting their professional teeth in the great commercial air races of the 1930s. Today, we need to attract and reward similar entrepreneurial risk taking in defense and defense-related commercial industry. Thousands of Kindelbergers are out there anxious to change the world. The challenge is to find and enlist them in the effort to maintain the strongest military on the globe.

The Secret Sauce

None of these insights are original, and many might argue that these lessons are already being incorporated into the policies and processes of defense acquisition. If the recipe is so simple, then why are current defense projects so fraught with challenges? Why can't defense acquisition seem to tackle a modern-day project like the Mustang and be just as successful?

The authors believe we can, but, over the past 40 years, we have allowed ourselves to grow accustomed to 10-year missile developments and 20-year fighter aircraft acquisitions. We've built a risk-averse bureaucracy that favors innovation-stifling oversight and rigid, failure-intolerant policies to responsible program risk taking and a sense of urgency in fielding weapons systems. The current acquisition system has become so unwieldy that any sense of urgency or spark of innovation is often lost or frustrated.

Recommendations

The way ahead will be challenging. We have to move from a system that imposes sweeping requirements to one where simpler is better, and good enough is, well, good enough. The first Mustang wasn't a war-winning pony, but had sufficient design margin to be adapted to evolving threats and changing operational assumptions. Today's systems should be designed and managed this way too.

We cannot allow our acquisition system to continue to be so rigid and risk-averse that we lose the opportunity to adopt new technologies when they come along. The magic can happen if we allow it, but we must be aware that technologies can emerge from unexpected places. These are often the real game-changers. History is replete with examples—the Internet (originally a nuclear attack-resistant government network), stealth (first proposed in a Russian academic paper), and unmanned aerial vehicles (emerging from radio-controlled scale models for hobby enthusiasts). We should embrace the garbage can model and begin actively networking challenged programs with technologists who might have solutions.

Finally, we need to reenergize the sense of urgency that we should be feeling as our troops fight in a prolonged counterinsurgency war in southwest Asia. While our national survival is not yet imminently at stake as Britain's was in 1940, we must work to streamline our processes to deliver needed battlefield equipment much sooner. We cannot be satisfied with the current system, and we can never become complacent or resigned to the status quo.

We should study and learn from the lessons of history, like the Mustang story. From it, we can remind ourselves that Americans are, by nature, innovative and entrepreneurial. We must restore our self-confidence in our ability to do remarkable things, remain steadfast in our resolve to improve our system, become intolerant of bureaucratic obstacles to innovation, and rededicate ourselves to the task of making our nation safer for ourselves and our children. The next acquisition success story is out there if we can muster the courage to succeed.

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Mr. Alan Haggerty served as an officer in the U.S. Navy for 27 years, including 15 years as an engineer and acquisition professional. His final assignment was as major program manager of Above Water Sensor acquisition programs in the Naval Sea Systems Command's Program Executive Office for Integrated Warfare Systems. After retirement from the Navy, he served as Deputy Under Secretary of Defense for International Technology Security from 2006 to 2009.

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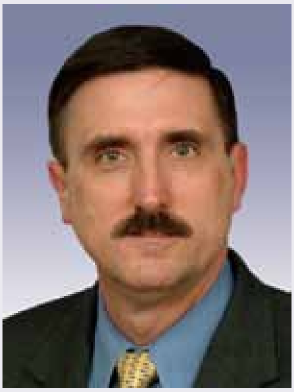

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