Effectively Integrating Laboratory, Government, and Industry to Develop and Acquire National Security Space Systems

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The Integrated Systems Engineering Team (ISET) is a pragmatic means to integrate government, industry, and laboratory/academic organizations to develop national security space (NSS) systems. To ensure that the government can be an intelligent buyer and industry can be an informed provider of future operational production, including an ISET as part of the technical approach is highly effective for acquisition programs that require concept definition and operational prototyping. A core challenge within the NSS community is developing complex operational systems with utility across various organizational entities; the ISET provides the ability to allocate organizational capability to manage risk during program development and acquisition. The ISET approach also allows technical interactions among participants, without conflict of interest, ensuring the efficacy of future competition for operational space, weapon, or intelligence system development. It is necessary to incorporate various institutional entities because typical operational systems require extensive risk reduction during development; typical systems also require infusing technology, demonstrating prototype capability, following acquisition processes, and evolving initial operating capability to a fully sustained operational system integrated with other supporting systems. The ISET is a means to leverage the strengths of the various entities during all phases of system development and acquisition by providing an open, technical forum for the exchange of knowledge, linking prior and current development efforts to reduce risks in future phases of system acquisition. The particular instantiation of the ISET described in this article was applied to a responsive, prototype operational system with tactical functionality.

INTRODUCTION

The national security space (NSS) community, encompassing the DoD and the intelligence community, continually faces the task of successfully developing complex systems to meet operational needs. It is difficult to mature a desired capability from concept and technology development, through demonstration, and into a successful acquisition that procures, deploys, operates, and sustains the desired capability in conjunction with other relevant systems. A critical underlying challenge in successfully completing such a system development effort can be posed as an essential question: How does a significant program manage government–industry interaction when considerable concept development, often best executed by laboratories and academia, must be completed before exercising the industrial base for a successful operational system acquisition and life cycle production?

NSS systems face aspects of this challenge to varying degrees across the development and acquisition cycle. Although mature capability needs, such as those for space-based navigation, may not require significant investment in high-risk technology development, extensive government–industry interfacing and technology infusion are still necessary to evolve the capability to meet current and future operational needs. Conversely, a new capability such as space-based missile tracking may require substantial development of the prototype by a laboratory with expertise in missile defense system integration before a knowledgeable industrial base can produce reliable, space-based operational elements. Underlying implications of the question include the need to effectively execute tasks over time and across organizations, including technical trades, program and concept formulation, development and iteration of requirements, as well as the need to support information sharing to provide a foundation for meaningful competition and procurement from a knowledgeable industrial base. The particular knowledge that is needed to realize a successful system acquisition is also necessary for industry providers to predict and meet the performance goals and cost and schedule constraints of the acquiring government entity.

An effective means to answer the system development question posed at the start of the *Introduction*, and to mitigate the risks inherent in system acquisition, is a construct implemented by APL based on more than five decades of system development and transition in partnership with government, industry, and academia: the Integrated Systems Engineering Team (ISET). This history from which the ISET was derived presents lessons drawn from programs that have explored the boundaries of complex system development, demonstration, and transition to operational status. This includes a spectrum of programs executed in partnership with government, industry, laboratory, and academic organizations. This includes operational space systems such as the Transit satellite navigation system, which spawned subsequent advances in geodesy, altimetry, and space-based navigation; the Area Air Defense Commander weapon system; and individual technologies at the subsystem, component, and integrated circuit levels.[1]

The ISET is a construct with processes and mechanisms that can be used to mitigate program risk by appropriately allocating organizational capability across the development and acquisition phases of a system. This assumes that the essential capabilities needed are available among the participating organizations—for example, government expertise in contracting, guiding operational need, and assessing utility; laboratory expertise in conceptual design and implementation, prototyping and technology development, system transition to industry, and sustained technical oversight; and industry expertise in production, economies of scale, and system sustainment and replenishment. Subsequent sections of this article will describe how these organizational capabilities are allocated and the benefits that can be achieved.

The ISET is initiated and managed by the program office or their designee and encourages collaboration so that preprocurement engineering activities can occur in an open forum that includes resources from government, industry, laboratories, and academia. As a managed environment under the direction of a program office, or partnerships across program offices, the ISET is most effectively executed with a focus on technical products rather than simply by being a forum for discussion or consensus building. Although the ISET provides processes to build technical understanding and consensus, it is best that it not act as a voting body; rather, the ISET should exercise empowered leadership and make recommendations to the program office for decision.

The remainder of this article details the attributes and execution of an ISET in a manner applicable to the development and acquisition of any complex system. After a description of the establishment, adjustment, and execution of the ISET, a recent implementation is described. This successful ISET example was implemented over multiple years to address the small-spacecraft development needs of the Operationally Responsive Space (ORS) community within NSS. The ORS ISET focused on developing a set of militarily useful, small-spacecraft standards applicable to a range of tactical NSS missions. As described in the following sections, it was executed during development of a parallel, Laboratory-led, tactical satellite experimental mission in a manner such that the ORS ISET technical products could form the basis for future production through procurement from industry.

The critical attributes that led to the success of the ORS ISET are described in general, followed by the specific description of the ORS ISET and its resulting technical products, thereby illustrating the applicability of the ISET to a broad range of programs. Subsequent sections detail the benefits to the program office that employs the ISET, the benefits to industry and participating organizations, the processes and mechanisms by which the ISET can be executed, use of an adjunct Integrated Business Management Team (IBMT) to allow industry to communicate with government regarding business-case issues, and experiential lessons learned.

ISET BENEFITS TO THE PROGRAM OFFICE

A number of critical attributes of the ISET result in significant benefits to the program office. These benefits are applicable to an ISET implementation that may be pursued by program office partnerships or leadership structures consisting of multiple stakeholder entities, assuming there are clear leadership responsibilities and streamlined decision-making by the stakeholder team. The overarching benefit is the ability to allocate organizational capability to phases of development where it is best suited; this is another means by which the program office can manage risk in developing and procuring highly complex systems. The other primary benefit to the program office is that the ISET provides a managed, controlled approach to fostering productive interaction among the government and the supporting industry and laboratory organizations.

With the goal of allocating organizational capability as a means to manage risk, the ISET allows the government program office to leverage participating organizations in a manner best suited to organizational strengths while realizing positive incentives under which participating organizations operate. This idea applies to the government program office itself, which is typically best suited to contracting, overseeing and managing independent assessment, guiding operational need, and assessing system utility in the operational context. Assuming that the program office is able to realize appropriate oversight and execution of the contract, the primary incentive to the government program office in the NSS arena is to acquire systems that are useful to the military or the intelligence community, that provide benefits that are commensurate with the cost, and that are delivered on schedule. Laboratory entities, however, are strongest in their technical ability to conceptualize operational need in terms of system implementations, to demonstrate prototype operations to reduce risk, to infuse enabling technology to enhance performance, and to transition the system to industry for production. Laboratories, and certain academic institutions, tend to be incentivized by developing new or gap-filling capabilities, exploiting and inventing new enabling technology, and maintaining essential research and development capability for the nation, often under conditions in which a business case does not yet exist. Conversely, industry is typically best suited to system production, system sustainment, and realizing economies of scale and operational efficiencies. Industry incentives are typically sustained profits and growth that result from proven capabilities.

Understanding the capabilities and incentives associated with engaging different organizations allows the program office to assign roles and responsibilities to the most effective organizations at appropriate phases in system development; whether that is conceptual design realization and technology infusion, which likely would leverage laboratories, or production, which is clearly a strength of industry. For particular ISET implementations, it is important to understand that for any given program situation, there will likely be overlaps and possible gaps in the range of capabilities and the driving incentives among participating entities; such overlaps or gaps must be taken into account for effective execution of the ISET. An underlying assumption in allocating organizational capability to manage risk is that a better understanding of the program goals and a solid basis for technical and programmatic trades can be achieved by exposing participants to all phases of development at some level of technical depth. This is an effective means to reduce risk as system development and acquisition evolves, at the cost of funding participation and sustained interaction through the ISET.

Broad but managed involvement by participating organizations across system development phases illustrates the second overarching benefit of the ISET construct to the government program office. Specifically, the ISET provides a controlled but technically meaningful manner by which the program office may engage industry and laboratories early in system development while maintaining a legally competitive environment for future procurements. It provides the program office with access to expertise in areas for which additional technical support is beneficial. In addition, by engaging laboratories with relevant experience and qualified industrial organizations in early systems engineering analyses and development, the program office minimizes unexpected results or situations in the implemented system.

This minimization of "solution surprise" reduces programmatic risk and gives the government a deeper understanding of the viable industry-driven solution space for production and its relationship to any prototype laboratory-based demonstration elements. Conversely, industry gains a deep and technical understanding of explicit and implicit goals of the program office, and this knowledge can serve to streamline or even eliminate aspects of an acquisition such as the common Request for Information interactions.

Further streamlining can be realized by the ISET because the technical products that are developed are synthesized within a performance/cost/risk/schedule trade space that has been explored to some level by all participating organizations. This is an essential element of effective systems engineering because it provides a means to address future trades and to adapt to modifications in requirements in a structured manner. Indeed, the ISET is a forum for vetting ideas, and executing critical technical trades and producing integrated products can serve to further streamline system development by directly supporting procurement documentation. Furthermore, no unfair or legally suspect competitive advantage is bestowed on future procurements because of the open manner in which trades are executed and technical products are produced.

ISET BENEFITS TO INDUSTRY, LABORATORIES, AND ACADEMIC PARTICIPANTS

The tasking of the ISET allows industry the opportunity to work with the laboratory and government teams in an integrated, technical manner. Thus, industry representatives have a means to put forth their good ideas during preproduction definition and prototyping of the system, and those ideas can be considered for future procurements. Conflict of interest is managed by executing the ISET in an open manner without proprietary barriers. Conversely, if an industry participant chooses to retain technical information for future competitive advantage, it is not considered in the predevelopment requirements definition and prototyping efforts. However, because the ISET allows industry to be involved at a critical technical level at the onset of a program, participants are well informed of the trades, decisions, and government needs for operational production. Thus, in a future competitive procurement, industry has the opportunity to propose the technical and risk cases for those ideas that were withheld during implementation of the prototype.

The ISET therefore provides a controlled, technical means by which to drive proof-of-concept prototyping. The products, including trades, development processes, and prototype systems, are the basis on which the government can establish the acquisition material for the competitive production procurement. Participation by industry is advantageous for companies or consortia that are viable candidates for operational production because the participants will gain a detailed understanding of the system and will have the opportunity to share critical aspects of the system with the government in a manner that is free of organizational conflict of interest. This is because the laboratory lead works with the ISET; however, technical decisions are made by the technical laboratory lead and become recommendations for government consideration. Furthermore, participation is encouraged by directly funding industry participation.

The resulting integrated interaction among industry, laboratory, and government participants provides a positive construct that mitigates the belief that industry has a conflict of interest (e.g., “fox in the henhouse”). This impression of conflict is often a result of recent approaches such as Total Integration System Performance Responsibility (TISPR) in which the government relied on industry both to develop system requirements and to implement the system.

ISET MECHANICS AND PROCESSES

ISET member organizations are competitively selected based on the technical focus of the prototype and operational system being acquired. Individuals are appointed by their organizations to support the ISET, and the team is typically led by a systems engineer from the laboratory that is leading prototype or preproduction efforts. Although the program office can chair the ISET, it is typically advantageous for a laboratory to lead the team so that it represents an independent technical body that openly recommends to the government products that can be considered in future production acquisitions. Figure 1 shows a typical ISET organizational structure, including a potential parallel development team focused

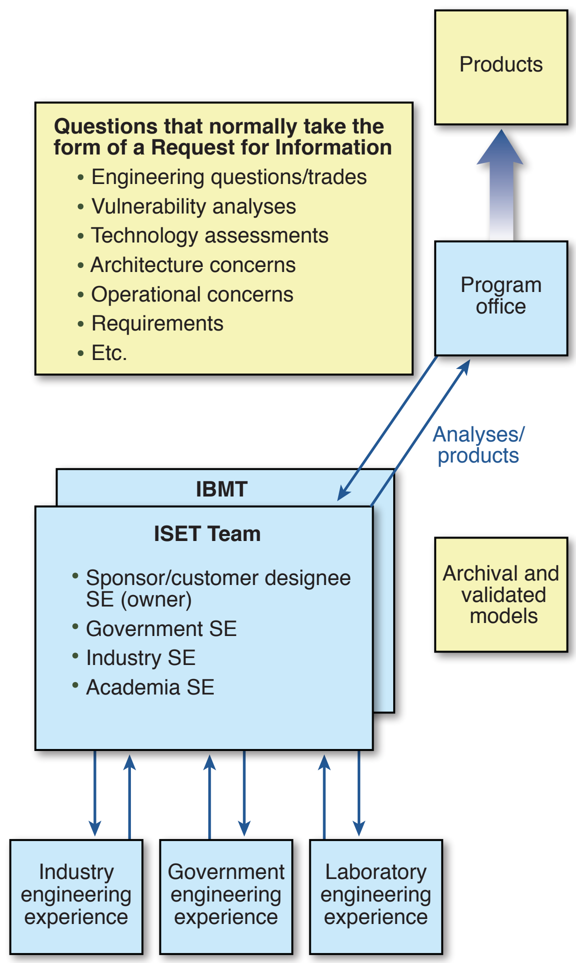

Figure 1. ISET structure. SE, systems engineer.

on business strategy, termed the Integrated Business Management Team (IBMT).

An essential element of the ISET approach is execution of the technical efforts across the team without proprietary barriers: succinctly put, nondisclosure agreements are unnecessary and are not accepted among ISET members. During conceptual analysis, technical trades, and system prototyping, industry participants, at their individual discretion, are free to share technologies or approaches to meeting the capability needs of the system. Material that is shared as part of a trade or analysis is considered in any prototyping work, whereas material that industry chooses to retain for future competitive advantage is not considered. Figure 2 shows details of the execution process for a typical ISET's technical efforts, including examples of technical tasking such as engineering trades, vulnerability analyses, and technology assessments. Specific tasking is established by the ISET lead, as is participation in individual efforts. All collected source material and synthesized results are shared fully among the ISET members, and full participation by all ISET members in outbriefings, reports, and technical reviews is encouraged.

Success of this approach hinges on the fact that the laboratory team leading the effort must be capable of filling any technical gaps in the preproduction ISET efforts, up to and including developing and operating prototype space or weapon systems. In this sense, as a credible developer of prototype systems for an operational environment in the best interest of the government, the lead laboratory team must execute the ISET. Because APL is typically prohibited from producing operational systems, a structure is established in which APL fills the traditional role of trusted technical advisor executing in the best interest of the government and is prohibited from competing with industry for future production contracts.

Although nondisclosure agreements are not executed among ISET members, controls are established to meet the government program office's need to manage information. This includes defining levels of material control to address public access, International Traffic in Arms Regulations restrictions, and classified material. An example of a data distribution relationship structure is shown in Fig. 3.

ADJUNCT IBMT

Whereas the ISET is specifically focused on technical development during system definition, requirements establishment, and prototyping, industry participants are driven by fundamental business-case issues. To minimize disruption to ISET efforts while still allowing industry

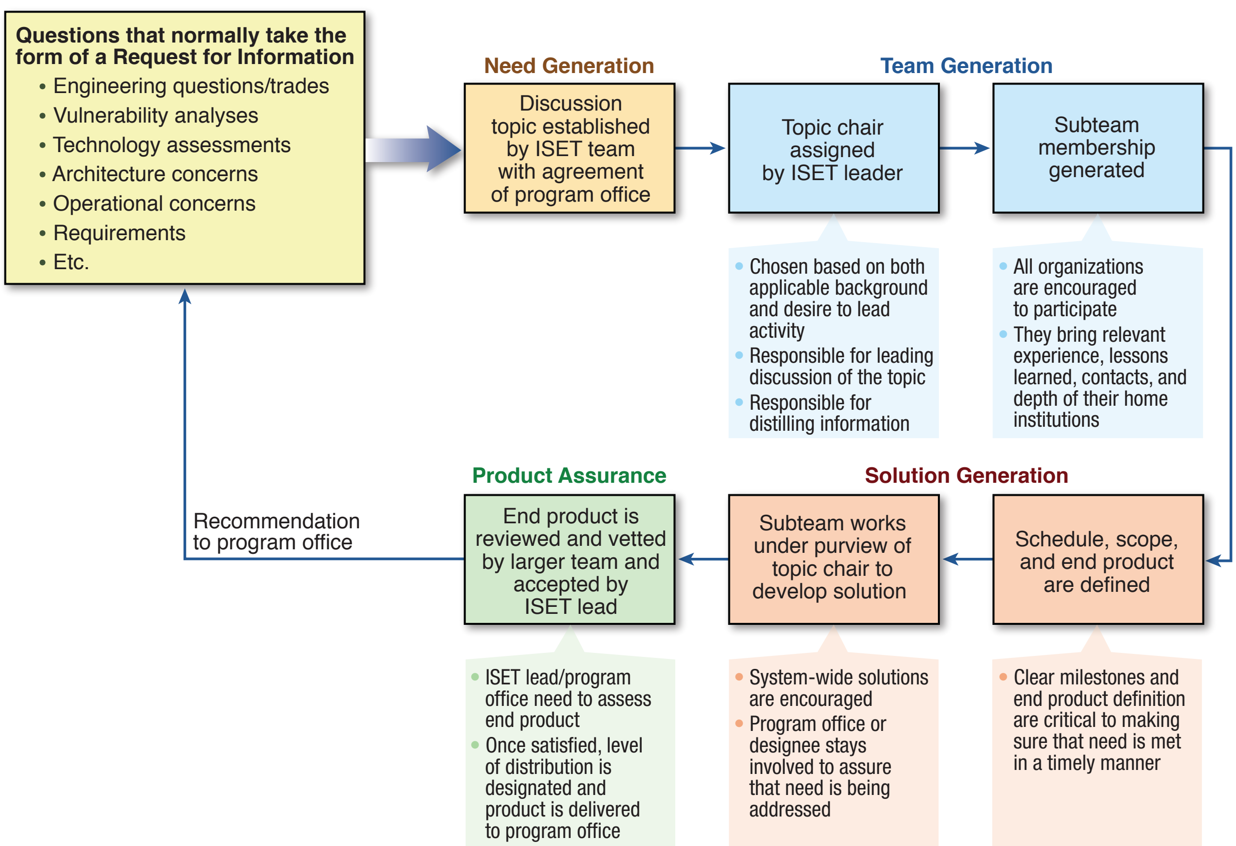

Figure 2. Typical ISET technical tasking process.

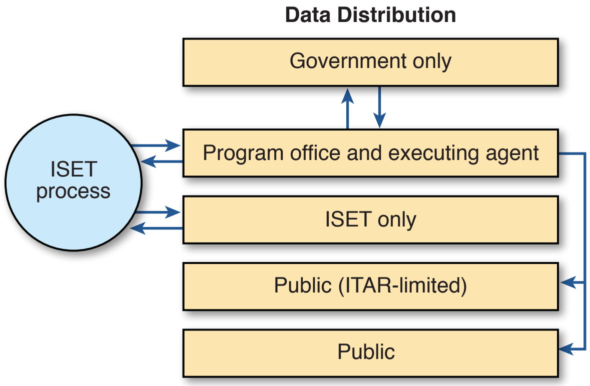

Figure 3. Example of ISET data control and distribution. ITAR, International Traffic in Arms Regulations.

open access to business development, an adjunct IBMT structure that parallels ISET efforts has been leveraged. Structured much like the ISET, although often funded only for specific tasks such as detailed cost estimates, the IBMT is an open, fair, and legal means by which to obtain industry feedback and suggestions on critical procurement considerations. The IBMT is a structured means by which industry may raise issues and suggest acquisition approaches before a production competition and without conflict of interest. Examples of IBMT tasking include integrating relevant business-case information into cost–benefit analyses and answering essential questions such as:

- What are the effects of multiple buys?
- What are the cost benefits of new technologies?
- What are the schedule implications associated with budget changes or program delays?
- What are the cost implications of a given sparing philosophy?
- What is involved in logistics and maintainability?
- How should procurements be structured?

ISET LESSONS LEARNED

Three primary challenges have presented themselves in recent ISET-like efforts during which industry, laboratory, and government personnel have engaged in integrated technical efforts. These challenges and the solutions that were successfully implemented are as follows.

- **Challenge:** Industry is unwilling to engage technically for fear of reducing its competitive advantage.
  - **Solution implemented:** Government/laboratory leadership must comprise a sufficient skill set to address technical areas that industry is hesitant to engage. Focus must be on a functional solution, not on a product-specific solution.
- **Challenge:** The industry business development team, rather than the technical experts, wants to engage.
  - **Solution implemented:** Force *participating individuals* to lead trades and to present detailed technical information to their peers. If necessary, provide business management opportunities, such as an adjunct IBMT, but do not allow government funds to be expended in support of efforts other than specific detailed tasks such as extensive cost estimating or analyzing the cost–risk effect of modifying existing production line processes.
- **Challenge:** The tendency for extensive debates, speechmaking, and unfocused discussions.
  - **Solution implemented:** Focus must be on well defined products [e.g., specification, standard, and interface definition; concept of operations (CONOPS); etc.]. All tasks are inputs to creating the product, and early in the process documentation is pulled together in draft form and is regularly reviewed and refined in detail by the technical team. This forces eyes on it, contributions to it, and dedication to necessary but deliberative progress. Government or laboratory leadership must make decisions and cut off debate: ISET is not a democracy, but a product-focused technical effort.

Key to successfully executing a program with integrated government, laboratory, and industry participation is allocating capability to more effectively manage risk. The government is responsible for contracting, oversight, providing structures for independent assessment, guiding operational need, and assessing utility. Incentives are acquiring systems that provide military utility and are within budget and on schedule. The laboratory is responsible for conceptualizing operational needs in terms of system implementations, demonstrations, technical risk reduction, prototyping, and transitioning the system to industry. Incentives are developing new or gap-filling capabilities, exploiting and inventing technology, and maintaining essential research and development capability; the laboratory can think strategically and do things that are essential or high-risk but do not have an efficacious business case associated with them.

CASE STUDY: ORS ISET

The ISET implemented from 2005 to 2008 to advance the DoD's ORS concept provides an end-to-end example of a typical ISET construct. The context for the ORS ISET as well as the ISET's focus and execution and its sample technical products serve as a realistic example that illustrates the utility of the construct for the generalized discussions that follow.

In 2007, the DoD established the jointly funded ORS office at Kirtland Air Force Base, New Mexico, in a continuing effort to develop and field cost-effective, novel systems to address NSS needs such as the reconstitution of space system capability, augmentation of existing capabilities under high-use (e.g., surge) conditions, and realization of new warfighter capabilities. As the ORS office was being established, APL was leading an ORS ISET to provide industry a technical forum with which to make recommendations to the ORS office for future system developments. The focus of the ORS ISET was the coordinated product development for a class of ORS systems that integrate into the broader U.S. NSS capability. Specific technical efforts addressed development challenges through the effective use of standards for a tactical class of spacecraft bus; the subsequent implementation of those standards was used as a validation exercise and also to provide a spacecraft bus for the TacSat-4 COMMx mission for communications-on-the-move applications.

ORS Phase III Bus Standards: Background and Objectives

APL, in partnership with the U.S. Naval Research Laboratory (NRL), was tasked to generate standards for the production of responsive spacecraft buses as Phase III of a multiphase ORS development effort initiated by the Office of the Secretary of Defense's Office of Force Transition in 2005. The final development phase, Phase IV, intended to be led by the U.S. Air Force (USAF) Space and Missile Systems Center, was to use these standards as an input to the procurement of spacecraft buses for ORS systems.[2–6] Phase IV was realized on 21 May 2007, with the establishment of the ORS program office in Albuquerque, New Mexico.

The ORS Phase III bus standards program was established to pursue the following primary objectives: (*i*) to establish a national systems engineering working group populated with representatives from U.S. laboratories, small-satellite industry, government, and academia to develop primary interface standards for a class of ORS spacecraft; and (*ii*) to validate or refine a subset of those standards by prototyping a flight system. This bus was to be used for the execution of a tactical space flight demonstration, eventually defined to be a communications mission, TacSat-4 COMMx.

ORS Bus Standards Development Task

Pursuit of the first objective is evidenced by the work of the ISET, with broad participation from industry small-spacecraft integrators and academia. The ISET defined a set of ORS bus standards, in an open environment, that are applicable to a significant set of militarily useful missions. The ISET was chaired by APL during the development phase, and its leadership transitioned to the USAF Space Development and Test Wing as planned as part of the transition to and maintenance of the ISET standards by the joint ORS office.

Development of the ISET bus standards was initially informed by efforts carried out during Phase I of the program, which consisted primarily of a utility analysis led by the Massachusetts Institute of Technology Lincoln Laboratory.[7] This initial analysis was intended to provide feasibility and guidance for determining a balance between cost and performance of ORS spacecraft to be militarily useful. The report had several findings: First, a tactical spacecraft bus, standardized across variety of NSS missions, can meet many, but not all, needs of a tactical commander. Second, small-sized tactical satellites can achieve large increases in mission utility if used in constellations to improve persistence. Lastly, there exist standard performance specifications for a small tactical satellite bus that satisfy a wide range of NSS missions.

Table 1 summarizes the various performance characteristics generated by the Phase I study for the type of spacecraft bus applicable to an ORS system considering a wide range of NSS missions. Each column presents the performance characteristic required for a spacecraft bus to meet the overall performance goal stated in the column heading; thus, actual ORS spacecraft characteristics should not be less than those presented or they will not be useful, and they also should not be much greater or they will break the low-cost and responsiveness model.

The primary conclusions of the study provided initial evidence that a tactical spacecraft bus developed to standard interfaces could meet a significant subset of needs for tactical applications; however, the details of an actual system depended on a number of undetermined modeling assumptions, as evidenced by the multiple columns in Table 1. This created the theoretical hypothesis; however, an experimental existence proof was required to ascertain whether a critical balance between capability and cost for military utility in real-world production was achievable.

ORS Phase III ISET Development Model

Participants in the ISET were assembled from a group of participants from each potential stakeholder and covered both the present development and future sustainment of the program (Fig. 4). The keys to the success of this team construct were the establishment of the leadership and the invitation of the participants. It was necessary to ensure that the leadership group was comprised of individuals who possessed both deep and practical knowledge of the environment and product under consideration in addition to an impartial and unbiased stake in the ultimate products developed. It was necessary to openly solicit participation from as many relevant gov-

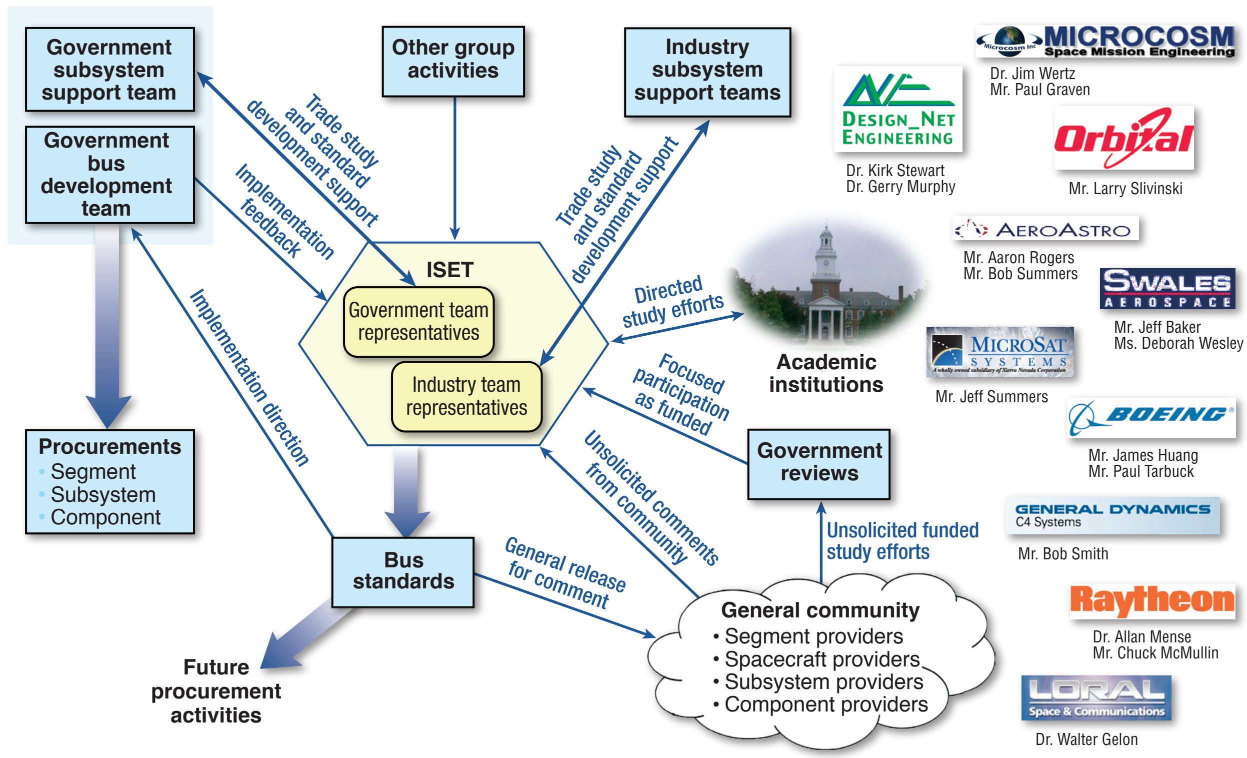

Figure 4. ORS ISET team construct.

ernment participants as well as to directly fund participation from all potential industrial partners. Through this active solicitation of industry, it was expected that both large and small companies would participate, unencumbered by the cost of volunteered contributions, and truly knowledgeable and practical experience would be provided, unfettered by marketing and business engagement interactions.

To solicit involvement, the ORS Phase III bus standards effort began with an industry day briefing on 31 March 2005. The half-day briefing was well attended by many aerospace companies. U.S. small-satellite integration companies were encouraged to submit proposals to participate in the ISET. Proposals were evaluated in early May. The proposal selection criteria focused on small-satellite companies that are established small-satellite integrators with experience building flight hardware within the last 10 years. Initially eight companies were awarded participation contracts, which increased to 10 companies by the end of the effort.

The first ISET meeting was held at APL on 3 June 2005. During this meeting, the results of the Phase I study were reviewed as a starting point for the effort. The remaining time was spent brainstorming on how to proceed for future deliberations. This activity was facilitated by requiring each of the participants to prepare a briefing using their own experience and company perspective on how the team should proceed. It was noted that many efforts of this nature had been tried in futility before and that if the charter of the ISET group was to design yet another standard bus, it was certainly destined to fail.

Instead, the ISET group adopted the following charter: "Generate a set of spacecraft bus standards, in sufficient detail to allow a space vehicle manufacturer to design, build, integrate, test, and deliver a low-cost spacecraft bus satisfying an enveloping set of mission requirements (launch vehicle, target orbit, payload, etc.) in support of a tactical ORS mission." This became the measure by which all activities were evaluated to ensure the effort stayed on track.

In response to the charter, the ISET identified four objectives and goals to achieve in support of tactical ORS missions. First, the team would extract from the Massachusetts Institute of Technology Lincoln Laboratory study and other resources a top-level set of mission requirements and CONOPS for ORS spacecraft. Second, the external interfaces of a standard spacecraft bus would be identified and standards established for each of those interfaces. As much as possible, the ISET would stay away from defining the internal interfaces within the spacecraft. This was a universal requirement from the industry participants such that individual spacecraft designers and manufacturers would be free to define those interfaces within their own specific spacecraft designs. Third, the functional and performance standards for the standard spacecraft bus needed to be established. Fourth, in specific support of Phase IV acquisition activities, the ISET needed to establish

Table 1. ORS spacecraft bus characteristics from Phase I study statistically envelop military utility for classes of small spacecraft.

	Maximum Utility, Low Cost	400-kg Limit	250-kg Limit	Maximum Utility/ Cost
Payload power (W)	250.0	200.0	100.0	250.0
Payload mass (kg)	200.0	150.0	100.0	100.0
Downlink rate (MB/sec)	50.0	50.0	50.0	10.0
Orbits (no./day)	12.0	8.0	3.0	12.0
Pointing knowledge (arcsec)	10.0	10.0	10.0	10.0
Pointing control (arcsec)	40.0	40.0	60.0	60.0
Slew rate (°/min)	10.0	10.0	10.0	10.0
Mission life (years)	2.0	2.0	2.0	2.0
Payload duty (fraction)	0.2	0.5	0.2	0.2
Downlink band (GHz)	7.5	7.5	7.5	7.5
Maximum ΔV (m/sec)	500.0	100.0	0.0	100.0
Total mass (kg)	566.8	378.1	238.4	264.7
Bus mass (kg)	366.8	228.1	138.4	164.7
Bus dry mass (kg)	288.7	216.2	137.8	156.4
Average power (W)	183.6	228.7	140.9	166.2
Peak power (W)	432.58	411.2	294.5	414.4
Array area (m^2)	1.1	1.4	0.9	1.0
Battery capacity (W·h)	306.2	381.1	234.1	276.9
Total volume (m^3)	0.4	0.3	0.2	0.3

programmatic mission-assurance and quality-assurance recommendations.

In keeping with the charter, it was also necessary to record the assumptions and constraints the ISET would accept before drafting any standards. First, to support tactical ORS, the system needed to consider tasking and data dissemination to the theater; however, access would be limited to the theater-command level. The second assumption stipulated that when "standard" spacecraft buses go into production, the *n*th-item goal for production costs should be less than $25 million, and the production volume requested by the government should be at least five spacecraft per year on a perpetual basis. The intent is to continuously launch ORS buses and payloads to respond to crises, to be used in experiments, and to maintain operational readiness. The third defining assumption mandated that the standard spacecraft buses, in addition to payloads, would be procured in advance of needs and stored in prepositioned integration facilities. Responsiveness would be achieved at the mission level. The timeline from payload/spacecraft bus integration to operational use, including payload integration, launch processing, and on-station checkout, would be less than 7 days. Lastly, the ORS standard spacecraft bus should have an operational lifetime of 1 year.

Subsequent meetings were conducted approximately every 3–4 weeks at each of the participating industrial partners' locations across the country. These "deliberation sessions" would become the central mechanism for achieving the success of the ISET effort. Typically, before these sessions each of the team members were directly tasked to research one or more areas and provide a briefing to be presented to the team at the next session. In addition, specific vendors and outside interfacing organizations, such as government stakeholders or members of the community that would use the system under development, were asked to come and present information to the team. Thus, these sessions facilitated information gathering and rigorous technical and programmatic discussion such that the ISET could build a technical basis to support the standards effort.

The detailed roundtable discussions during these sessions were an enjoyable part of the process, as each member weighed in with his or her expertise on the wide range of topics discussed.

To bring a quick focus to the deliberation sessions, the APL-led systems engineering team formulated a series of topics for initiating trade studies in support of the standards development activity. Topic chairs were chosen from within the ISET on the basis of their technical backgrounds and willingness. The basic requirements used to establish the topic areas were the external interfaces for the spacecraft bus and the ability for a single bus to support a wide variety of missions. In summary, the following initial discussion topics were established:

- **ISET focus, goals, and accomplishments:** The elements critical to the success of a bus standards development effort, the lessons learned from previous bus standards efforts, and the assumptions, goals, and products were the subject of this topic.

- **Mission-level requirements and CONOPS:** Given the limited and disparate definition of tactically ORS among the community, it was necessary for the ISET to define, to a sufficient level of detail, the scope of an entire ORS system to derive requirements for the spacecraft bus.
- **Design differences between highly elliptical orbit and low-Earth-orbit spacecraft:** The Massachusetts Institute of Technology Lincoln Laboratory Phase I analysis assumed that the standard spacecraft bus could support low-Earth-orbit and highly elliptical orbit missions. The group discussing this topic was tasked with understanding the potential commonalities and differences in spacecraft bus design between these mission types.
- **Payload support envelopes:** The group focused on this topic was tasked with defining a payload support envelope, on the basis of requirements breakpoints, that will satisfy a notional 80% of potential ORS missions.
- **Launch vehicle envelopes:** One key component of the ORS system as defined is the responsive launch with an underlying key requirement for the definition of a standard interface to be used across multiple potential launch vehicles.
- **Bus functional decomposition:** At the core of this debate was whether the bus standard should mandate a bus functional decomposition. It was expected that a general and objective analysis of the functional decomposition of the spacecraft bus, as applied to the ORS mission space, would inform the level and need for the spacecraft modularity.
- **Testing and verification approaches:** The group discussing this topic was tasked to develop a cost-effective testing and verification approach for multiple-spacecraft builds and to identify the means of minimizing the cycle time from call-up through on-orbit checkout.
- **Communications interfaces:** Another key external interface of the ORS standard bus would be RF communications with the ground. The group focused on this topic was tasked with investigating standardization for spacecraft command and control communications link and the tactical communication link.
- **Ground support checkout interface:** In support of the rapid call-up scenario, the group concentrating on this topic was tasked with developing standards for interfacing with the standard spacecraft bus and the future integration depot as well as interfacing the bus with the payload and processing the integrated space vehicle though launch. This requirement for rapid, automated interface verification between spacecraft and payload at the launch site is one of the unique activities under the ORS system design.
- **Operations center interface:** Although not always identified as a unique external interface with a space vehicle separate from the RF interface, the interface with the operations segment of ORS deserved specific consideration.

To ensure timely progress by the team and to open up the products of the team to much wider stakeholder review, a near-term systems requirements review was scheduled within 6 months of the start of team discussions. To ensure a satisfactory product from the ISET team members, participants for the review committee, in addition to membership from the sponsoring government entities, were solicited from the home organizations for each of the industrial members of the ISET.

Ultimately the ORS construct developed through the ISET model was distilled into four documents to establish the ORS Phase III bus standards:

- **Mission requirements and CONOPS document:** This document presents a top-level definition of the overall ORS mission, as defined by the ISET. It breaks down the system into system segments and defines the scope of the standards in each segment. It presents the basic CONOPS timelines for asset call-up, integration, launch, and on-orbit operations. It also discusses basic mission definitions, assumptions on which these standards are based, and the evolution from the Phase I efforts.
- **Launch vehicle interface document:** This document defines, in sufficient detail, the interface of the spacecraft bus to a generic ORS launch vehicle. It is expected that no additional launch vehicle information would be needed for a spacecraft manufacturer to build a spacecraft bus to fly in the ORS system. Thus, this document should be considered more than a guide; it is actually an interface control document from the launch vehicle perspective. It includes pre- and powered-flight environments and all interfaces (mechanical, electrical, thermal, etc.).
- **Payload developers' guide:** This document defines, in complete detail, the support accommodations for a generic payload by the spacecraft bus. The document defines the interface between the payload and the spacecraft bus (mechanical, electrical, data, thermal, etc.); the envelope of performance the spacecraft bus must provide for the payload; the constraints within which the payload must be designed; an envelope of operational capability for the payload; and all of the documentation requirements and integration, testing, and operational philosophies of the ORS systems as they pertain to the payload. It is expected that the designer of a payload would need

to use only this document to design, manufacture, and test a payload for the ORS system.

- **General bus standards document:** This document defines all the requirements for designing, manufacturing, and testing the ORS spacecraft bus that are not already defined within the three preceding documents described. Explicitly, this document contains general programmatic requirements for interactions of the vehicle manufacturer with the government, RF communications interfaces, interfaces with both the ground operators for the spacecraft command and control, bus functional and performance requirements, ground support equipment and depot integration facility requirements, and mission- and quality-assurance provisions.

ORS Phase III Prototype Bus Implementation Task

The second objective of the ORS Phase III bus standards program was to validate a subset of the bus interface standards developed by the ISET and provide a qualified bus for the TacSat-4 experimental mission. The prototype bus has been developed jointly by APL and NRL with subsystem leadership and technical support divided between the two organizations. The bus will be integrated and tested at NRL. The COMMx payload for the TacSat-4 mission is also being developed at NRL, and it will be used to verify and validate the critical bus/payload interface standards defined by the ISET.

The prototype bus implementation team consists of engineers from APL and NRL. To provide continuity with the ISET bus standards efforts and the critical feedback related to issues, challenges, and new ideas, the ISET members have acted as the design review panel at every major design review. Consistent with ISET deliberation sessions, all design reviews for the prototype bus build have been open to the ORS community with an extremely broad distribution of information for those who choose to attend or are interested in following developments by reviewing the material provided on the project website.

Milestone design reviews were implemented to provide additional oversight by the community, to share progress, and to improve both the prototype bus and the processes; all feedback received during the reviews was tracked and considered by the ISET for inclusion in the standards documents that have been produced.

A critical aspect of the relationship between the prototype bus implementation team and the ISET bus standards effort is the manner in which the process was managed; the manner was perhaps unique due to the nature of the program. Specifically, the bus implementation team baselined an early set of ISET standards and interfaces to provide a consistent means of comparison throughout the life of the program. It was known, however, that many issues were still unresolved at that particular time and that additional standards and interface development was in process. As the ISET continued to mature the standards, the prototype bus implementation team provided inputs and technical responses to ISET queries, but new or refined ISET standards were not imposed on the bus implementation team. Thus, the bus implementation team was able to inform the ISET efforts but was not required to react to a continuous flow of changes and considerations generated by the ISET. This resulted in the progression of the prototype bus implementation toward completion and at the same time produced a more complete and informed set of released ISET standards. This process is illustrated in Fig. 5.

Once integration and testing of the prototype bus is concluded, and no later than the preship review, the bus implementation team will compare the implemented bus to the ISET standards as a means of validating a subset of those standards.

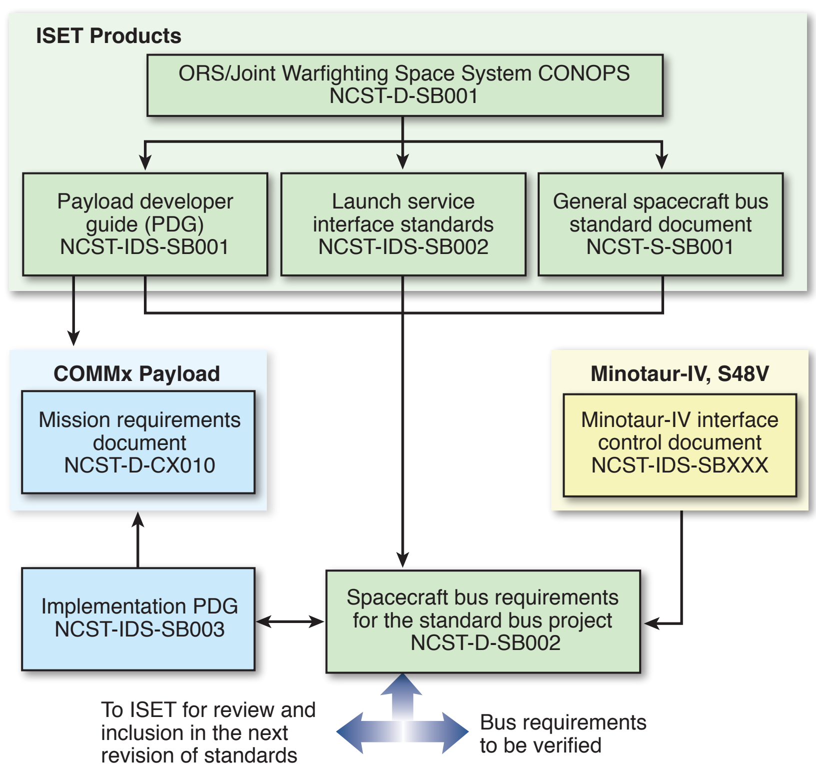

Figure 5. Prototype ORS bus implementation requirements flow showing ISET technical products and their relationship to the developmental phases of the TacSat-4 program.

CONCLUSIONS

The ISET construct improves the effectiveness of complex system acquisition by facilitating close collaboration among laboratory, government, and industry, without conflict of interest. The ISET approach provides a managed but open technique by which the government can develop a detailed understanding of what must be acquired to meet operational needs of NSS or weapon systems. Implementation of the ISET better defines for the government what is to be acquired, facilitates technical risk reduction before an operational procurement in a manner that allows laboratory innovation to be leveraged, and engages industry suppliers such that they can obtain a deep understanding of the government's future procurement needs. The effectiveness of the ISET is demonstrated in the sustained effort on behalf of the Office of the Secretary of Defense's development of ORS.

The prototype build of the ORS Phase III spacecraft bus to support the TacSat-4 mission was completed as scheduled in April 2008 and awaits launch on a Minotaur IV vehicle during FY2011. Through the efforts of the ISET, the program has successfully produced an extensive and well documented set of standards and interfaces for cost-effective spacecraft bus systems of the class of missions considered. Validation of a subset of these standards is proceeding through the development of the prototype bus in an open manner that allows government and industry insight into successful implementation approaches and challenges that have arisen. Because APL and NRL have led the development of the prototype bus, no proprietary claims have been exercised and any design aspects and techniques are available to the government sponsor for future consideration in industry-supplied operational builds.

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