

Development and Experimentation With a Small Satellite Bus Standard: Another Step Toward an Operationally Responsive Space System

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Abstract

The Office of Force Transformation and the A7 Space and Missile Command have joined together to sponsor a multi-phased effort to develop a standard bus for operationally responsive tactical applications. This effort involves multiple government, laboratory, and industry players, and the phases of the program are implemented to best spiral capability to support the warfighter.

This paper will focus on Phase III of the program, led by a Naval Research Laboratory (NRL)/Applied Physics Laboratory (APL) team, which will develop, with industry and academia, an ORS/JWS bus standard, and validate that standard by developing a flight-qualified prototype bus that refines and extends standards studied and advanced in the preceding phases. The research described focuses on the system engineering aspects of Phase III and describes linkage to Phase I analytical studies and Phase II advances in avionics standards and interfaces. Included is an overview of the approach that the NRL/APL team will use in leading the bus standards and prototype development and how key interfaces such as the payload and ground segment will be addressed to avoid cost shifting.

Since the standards will be ultimately used by industry, industry participation will be integrated throughout the program. The paper summarizes the overall standard bus development process and describes how the system engineering aspects will be executed with industry and academia involvement. One of the central objectives will be to ensure an open, level, and competitive marketplace while not stifling innovation. All design reviews and architecture decisions will be open to the domestic industry for further use. The paper will describe programmatic and systems engineering processes used to develop the standards and apply them through a hardware implementation.

BACKGROUND

The Department of Defense under the guidance of the Office of Force Transformation (OFT) is seeking to develop new revolutionary operational concepts and technologies for the conduct of military operations. Space is one venue “. . . where a new business strategy

combining new technology with new operational concepts can have a profound impact on how information energy can be applied on the battlefield. This may involve capabilities to generate very small payloads, very quickly on orbit.”¹

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This vision embraces two fundamental elements to provide responsive capabilities to the warfighter by leveraging space assets: (1) operational systems that can be quickly deployed to meet tactical warfighter needs, and (2) science and technology (S&T) systems that use rapidly developed, cost-effective standard systems to develop new technologies through experimentation. To date much of the focus of individual programs has been on developing S&T systems and coupling experimentation with COCOMs to provide a spiral development capability towards operational systems that would be components of an Operational Responsive Space (ORS) acquisition. Specifically, in May of 2003 an initial TacSat-1 experiment was begun and is currently launch ready. Subsequent S&T missions of the TacSat series, including TacSat-2, TacSat-3, and TacSat-4 are in various program phases from planning through integration and test. Each experiment has had joint participation for implementation, and in particular, the TacSat-3 experiment also took the important step of creating a joint process for mission selection by the end users, not the space communities. Each experiment tests key elements needed for a deployable operationally responsive space (ORS) system, emerging as the Joint Warfighting Space (JWS) system. Thus the DoD vision hopes to bridge the gap between S&T systems and operational systems by using aspects of the S&T experiments as inputs to future operational systems.

It should be noted that a critical element of the ORS/JWS concept, responsive launch, is also the focus of several efforts, including the DARPA/AF FALCON program and privately funded launch vehicle development efforts. The success of a cost-effective and responsive launch system is essential to the success of any ORS/JWS system. Such a cost-effective, responsive launch system may, be a new "low cost" system or an existing system tailored to provide ORS capabilities.

As with any new and rapidly growing effort, processes are in the early development stages both in terms of organization and implementation. Broadly there are currently three main areas being worked for ORS. First, the architecture and operations concept have been started by the National Security Space Office (NSSO) and by the U.S. Air Forces's (AF) Space and Missile Command (SMC). The NSSO study is called Responsive Space Operations and the AF concept is Joint Warfighting Space. JWS will also be entered into a joint process for requirements and concept development. Second, the S&T/R&D community continues joint TacSat selection and experimentation to incrementally develop and test various aspects of an ORS/JWS system as discussed earlier. The third area is the ORS/JWS Standard Bus Initiative organized by OFT and SMC. The Standard Bus Initiative is the focus of this paper.

Coordination among these efforts is beginning to align the organizations involved. Coordination will improve significantly once JWS goes through the joint development process and SMC Detachment-12 stands up the JWS office—targeted for FY08. Also of note, in 2004 Mr. Teets and Dr. Sega made Responsive Space one of the DoD's four S&T thrust vectors.

OFT ORS/JWS PROGRAM SUMMARY

As the several disparate ORS/JWS-related efforts have begun to better coordinate efforts toward the common goal of providing new capabilities to the tactical warfighter and disadvantaged user, one common need that has emerged is a desire to move towards more standardized systems. A fundamental reason for this is the drive for a successful acquisition of both operational and S&T systems – standardization at a system level, developed in partnership among government, industry, and academia, allows for broader, more competitive acquisitions and would provide a healthier industrial base should that acquisition be pursued in a robust manner.

In particular the need for effective spacecraft bus standards has been identified as a necessary condition for a successful ORS system, as noted by OFT and the Naval Research Laboratory (NRL) at the onset of OFT's operationally responsive space initiative. Organizations such as SMC, the Air Force Research Laboratory (AFRL) and The Johns Hopkins University Applied Physics Laboratory (APL) have independently identified the importance of a spacecraft bus standard to varying degrees. In addition, industry has used several forums, such as the AIAA Responsive Space Conference, to raise the topic of more standard spacecraft bus approaches within the context of a robust acquisition program.

The OFT and SMC have therefore undertaken a four phase initiative to develop and test bus standards and subsequently transition them in support of a significant acquisition. This effort involves multiple government laboratories, industry partners, and academic institutions. The four phases of this initiative provide steady, tangible steps to spiral capability and receive operational feedback while moving toward the final goal of a successful DoD acquisition for both operational and S&T systems. In a general sense, Phase I provides initial analysis of a technical framework for ORS/JWS systems and the business case and related elements of these systems. In particular, the latter encompasses the potential of a broader user community than just the DoD, including civilian uses such as the National Aeronautics and Space Administration's (NASA) scientific needs. Phase II is an AFRL led effort that focuses

on the rapid development of a specific bus to meet the TacSat-3/JWS Demonstration-2 mission while advancing, within programmatic constraints, avionics standards between the bus and the payload. The Phase III effort, as detailed herein, is a joint NRL/APL led initiative, with significant industry and academic participation, to develop a sustainable spacecraft bus standard that will serve elements of future acquisitions (e.g., one of several classes of ORS/JWS buses) and to prototype a standard bus to vet that developed standard. Phase IV of the Initiative, represents the fundamental goal of all parties – the acquisition of operational ORS/JWS systems to provide new tactical capabilities to the warfighter and disadvantaged users.

A more detailed description of the various phases follows in the remainder of this section, including the linkages among them.

Phase I – Analysis and Business Case

Phase I of the Standard Bus Initiative consists of two focused studies to analyze the technical and business aspects of a standard bus within the ORS/JWS System concept. The business case aspects have been recently initiated under the leadership of the MITRE Corporation as directed by OFT. Results of this study will be deferred for future publication pending completion; however, the thrust of the effort is to consider the broader user community of bus standards and the potential for overall acquisition from industry of a standard bus of the classes under consideration for ORS.

The second element of the Phase I effort was led by MIT/Lincoln Laboratory (MIT/LL) and has focused on developing a technical framework for classes of ORS standard buses in an effort to assess their utility within the identified mission context. The research sought to determine whether meaningful military utility could be derived from relatively small spacecraft. While this fact may be taken for granted by the small satellite community, it is far less accepted by military personnel accustomed to working with much larger spacecraft. This phase provides an analytical departure point to determine at least one proper class of ORS/JWS spacecraft needed to be militarily useful. This utility analysis drew on experienced users and system developers to generate measures of utility mapping system characteristics (e.g., geolocation accuracy, imaging resolution, dwell time, etc.) to mission capability across a broad set of identified ORS/JWS mission areas. Missions considered included RF collection, visible imaging, spectral imaging, navigation, communications, etc.

Baseline results and a final report are currently available. The results identified a number of missions opera-

tionally responsive small spacecraft might satisfy. The study team, together with participants from the other program phases, identified the key mission performance parameters. The study team then interviewed representatives from the user community to determine the relative utility of increasing capability for each of the performance parameters. Similarly, the study team identified the key spacecraft performance parameters. Using internally-developed models, the MIT/LL team varied spacecraft performance parameters to produce more than 120,000 designs, deriving mission utility and relative cost for each design. From this large trade space, the team selected optimal spacecraft performance capabilities based on different measures of performance and levying different overall constraints on the system.

The study concluded that although a single spacecraft design could not satisfy all needs for all missions, a single small spacecraft design could provide meaningful military utility across all missions. A secondary conclusion was that higher utility can be achieved by adding more spacecraft or by tailoring the spacecraft capabilities to target specific mission types.

The Phase III Bus Standards development team will use this report, and the data gathered within as “initial conditions” for the analysis and determination of spacecraft design and development bus standards.

Phase II - TacSat-3/JWS-D2 Bus Development

The Phase II bus effort is led by AFRL. This phase has two required objectives: provide avionics standards between the bus and the payload and provide a spacecraft bus for the TacSat-3 hyperspectral payload within approximately 14 months. In addition, many other approaches to internal bus modularity and plug-and-play bus standards are being explored in this phase.

The contracting approach is to use a BAA to award four (4) contracts with authorization to proceed to Preliminary Design Review (PDR). At PDR one contractor will be down-selected to provide a Phase II bus for the target S&T mission.

It is expected that some of the external interfaces with the spacecraft will be brought to maturity by the Phase II development effort and will subsequently be captured within the Phase III Bus Standards development effort and thus leverage the NRE spent between the two programs.

Phase III – Spacecraft Bus Standards Development and Verification

The NRL and APL are leading Phase III of the standard bus initiative, which will establish bus standards with industry and academic participation. A prototype a flight bus will result to validate the defined standards and provide lessons learned for Phase IV. The first objective of Phase III is to bridge the gap between an S&T and an operational bus capability. This will be accomplished by prototyping a bus with ORS/JWS system-level standards to retire select nonrecurring engineering (NRE) with government investment and provide a credible baseline for the Phase IV acquisition. The second objective is to establish a national system engineering working group with the US small satellite industry to develop and maintain ORS/JWS bus standards. The third objective is to work towards consensus and buy-in by maturing standards in an open environment with broad government, industry, and academia participation. This open approach should also have the effect of increasing the number of possible vendors for any future Phase IV acquisitions. Most recently, a fourth objective has been added; to further develop the business case for the acquisition of spacecraft buses, expanding the Phase I efforts by the MITRE Corporation. It was realized early on in the Phase III effort that the setting of standards for a spacecraft bus is inseparable from the needed/expected procurement volume and rate. Phase III will ramp-up business case efforts with the ISET industry companies post SRR.

Phase III implements a government-industry team development approach, which has been highly successful many times in the past. Some examples include the U.S. Navy's SBSS system for submarine security, the Transit navigation satellite system which proved the viability satellite navigation, and the Timation/NTS satellite series, which transitioned to the Global Positioning System as the follow-on to the Transit system. Broad participation is encouraged from both industry and academia. Several methods of participation and several contracting mechanisms are being used to facilitate this participation. For US small satellite integration companies, funded participation on the system engineering working group was solicited. Eight companies were awarded contracts via the GSA 871 schedule for system engineering. For any unique and innovative subsystems, components, standards/interfaces studies, or other related approaches/solutions a "spacecraft technologies" proposal can be submitted under an existing NRL BAA. Finally, subsystems, components, and services will be procured throughout the program as usual. To facilitate meaningful contributions to the bus standards efforts, a white paper can be submitted directly to the Phase III government program management and system engineering team for feedback if there is uncertainty about an idea or about how a company would participate prior to the formal submission under the BAA for contract

award. Additional information documents about Phase III, as well as links to the various contract vehicles described above can be found at <https://projects.nrl.navy.mil/StandardBus/>.

Phase IV – Spacecraft Acquisition Program

The Phase IV bus acquisition is led by SMC. Primary Phase III transition is to the SMC Detachment-12 with critical support from SMC's Technology Directorate. An initial JWS procurement is planned to start with JWS office POM funding in FY08. If successful, the results of Phase III will form the basis for standards and provide a credible baseline for this procurement.

Specifically, the Phase III effort will produce a Payloads User's Guide, which will support the Phase IV team by providing guidance to payload developers that wish to take advantage of the ORS/JWS Standard Bus – this can serve as a "requirements document" to vendors developing payloads for flight within the JWS program. In addition Phase III will develop a set of "Bus Standards" either as a single document or multiple documents that will be used as a "requirements document" to vendors developing spacecraft for flight within the ORS/JWS program.

Relative to industrial and production aspects of the ORS/JWS program, the Phase III team, in conjunction with the Phase IV team will develop a Transition Plan that will map Phase III results into SMC's procurement of satellites for the JWS program. This plan will provide basic definition of the roles and responsibilities of each of the constituents of the JWS program, basic criteria for planning, solicitation and selection of spacecraft for the JWS program as well as initial plans for payload-spacecraft integration, launch vehicle-spacecraft integration, the launch campaign and on-orbit operations.

Finally from a practical perspective, the Phase III effort provides a Prototype Validation Vehicle that will be used to vet the process and the standards. It is expected that the lessons learned throughout the duration of the Phase III effort will be used to improve and update the bus standards and processes used during Phase IV. Specifically, it is expected that lessons will be observed through the proper use and tracking of Phase III analysis, waivers, deviations and root cause assessment. Furthermore, it is expected that the Phase III prototype vehicle will be properly instrumented to validate the design, testing and environments such that future vehicles built using the standards can reduce verification activities. Though beyond the immediate scope of Phase III, it is anticipated that the prototype bus developed under this effort will be integrated with a future

ORS/JWS payload and deployed for an appropriate S&T mission with an operational leave-behind focus. The likely mission for this prototype bus is TacSat-4, which will be jointly selected in September 2005.

In the near-term, the Space Test Program (STP) Standard Interface Vehicle (SIV) acquisition may provide an immediate opportunity for select results from the Phase III efforts, provided the standards apply to the defined STP ESPA class spacecraft. Depending on the ultimate time phase between the two programs, the Phase III effort may be in sufficient advance of the STP-SIV program to allow some level of standards to be leveraged and transitioned.

PHASE III SUMMARY AND OBJECTIVES

The standards a ORS/JWS bus requires include a set of overall performance characteristics coupled with interfaces to the payload, launch vehicle, ground, and likely to an optional propulsion module. All ORS/JWS current concepts show the need for this system-level modularity. Additionally standards and modularity internal to the bus may be useful. The value of internal bus standards will be determined based on their ability to reduce cost in spacecraft production, integration time, or provide useful flexibility. This value will be assessed by each subsystem and decisions made on a case-by-case basis. Two fundamental approaches have been identified, with AFRL pursuing a “plug-and-play” approach that would allow for designing spacecraft on the fly. The Phase III team will pursue a variation on that approach, leveraging payload “plug and play” while preparing for a near-term SMC operational procurement expected to implement an inventory concept for ORS/JWS. Currently this approach is viewed by AF/SMC as a more near-term approach to support immediate results as the technology and processes of the “plug-and-play” mature. The inventory model is likely to be more realizable for rapid response in the near-term, with internal modularly increasing over time with volume.

The Phase III will produce several products. A Payload User’s Guide will be provided, allowing payload designers to design to the ORS/JWS standard bus similar to how they design a payload for a Predator UAV. This guide, combined with some volume procurement in Phase IV, could begin a fundamental change in bus-payload user interactions and approach. A bus “design specification” will be a provided product and will contain the developed standards, interfaces, and overall performance level (slew rate, power, mass, etc.). Alternatively, this collection of items could be considered the bus “standard”. This is specifically not a spacecraft point-design, nor does it represent a design that it im-

posed on industry; rather it is a system level performance and interface specification that will enable multiple developers and integrators to support future AF acquisitions. Phase III will also produce a transition plan developed in concert with SMC. Finally, a prototype bus for flight experimentation will be produced. While Phase III will provide a single bus for flight experimentation, success will be determined by the transition to SMC for quantity procurements. A success metric will be if industry accepts and feels they helped create and approve, the standards/interfaces/performance levels SMC uses for their procurement.

The proper incentives and environment for the team to design and test in an R&D environment, which inherently lacks a well defined set of requirements is a necessary element for success. In this environment government funds the NRE directly, thereby removing the risk from industry (for example, by using time and material contracts versus firm fixed price contracts). This approach allows higher risk and rapid changes in design direction if necessary without the overhead of rescoping and contracting. This approach also provides a more open environment, keeping the system level intellectual-property open via government “ownership”. This environment and increased openness allow systems to be experimented with and understood, so good requirements can be developed by the acquisition community. Fundamentally, this environment allows for an open standard that is detailed enough to provide an effective way-ahead, while providing great latitude to allow for innovation and competition among bus integrators and component suppliers based on their ability to innovate at the subsystem and component levels, retain IP at these levels, and put forth more effective and efficient processes.

Both NRL and APL have an appreciation for the great challenge this ORS/JWS bus presents, and look forward to the opportunity to working with an integrated government, industry and academic team to address this challenge. Phase III kicked off on March 31, 2005 and has a 30 month schedule. SRR is scheduled for September 2005. Chris Garner (NRL) and Patrick A. Stadter (APL) are the program managers for Phase III.

PHASE III PHILOSOPHY AND ASSUMPTIONS

The Phase III Bus effort has made certain assumptions that underpin the program and affect the available design trade space. First, any bus standards resulting from the Phase III effort must be based upon technologies available now or available within the very near term. This is necessitated by two factors: (1) the Phase III effort involves a prototype bus build, and the Phase III

budget and schedule will not support significant technology development and (2) the bus standards resulting from Phase III will lead to an industrial procurement for Phase IV, and therefore transition to industry is of fundamental importance.

A second critical assumption is that, for the time being, the military will implement an inventory model for operationally responsive space. In this scenario, the military will build and store spacecraft busses. These spacecraft will then be called up as needed, joined with a payload, tested, mated with a launch vehicle, launched and operated on-orbit. This approach has several important implications. First, the rapid response time envisioned—several days to weeks—applies only to the process flow from mating the payload and the bus through on-orbit checkout. However, the process of designing, building, and testing the bus can proceed in a typical fashion. Of course, the military would benefit from technology developments that could significantly reduce this cycle since they could provide lower cost, faster replenishment of used inventory, and more rapid injection of new technology. Design and manufacturing flexibility are expected to mature and increasingly shift the model closer to real-time building versus inventory for ORS procurements in the longer-term.

Second, using an inventory model limits the number of bus classes and versions of each bus class that can be procured. Common sense suggests—and the Phase I study validates—that higher utility can be achieved by tailoring the bus to the unique needs of each mission. A simple example is to build versions of the bus with and without propulsion. However, the military cannot afford to build a vast inventory of all versions of all bus classes included in the overall operationally responsive space concept. However, with careful functional decomposition of the spacecraft bus relative to mission function it should be possible to employ limited modularity of the bus design such that the majority/core of a spacecraft bus is common to all missions with selective modules added across well defined standard interfaces to change performance or capacity based on mission needs.

Finally, the Phase III bus standards definition process does not exist in a vacuum. In addition to Phase II, numerous bodies and organizations are developing standards. Preeminent in this thrust is the Air Force Research Laboratory (AFRL), with the establishment of working groups and initiatives in the areas of spacecraft avionics interfaces, a Plug-n-Play working group, and spacecraft mechanical design and spacecraft thermal design concepts with a working group to investigate each area. Furthermore, the AFRL has established a testbed laboratory to investigate the future goals of a

complete assembly line approach to a custom tailored spacecraft bus on a rapid n -day schedule. In addition, groups at NASA have started to discuss power subsystem design (Glenn Research Center), flight software design with the working design of operating system abstraction layers (Goddard Space Flight Center (GSFC))) and ground software design with the establishment of GSFC Mission Services Evolution Center interface standards.

The Phase III implementation team will review all applicable on-going standards definition efforts and consider them for inclusion in the Phase III bus standards. Phase III does not represent a one-time, static definition process. Rather, it is the initiation of an on-going living standard. Therefore, technologies that are not sufficiently matured to be included in the bus standards during the Phase III effort and Phase IV initial buy can be considered for the standard of future buys.

THE TEAM - INDUSTRY SYSTEMS ENGINEERING TEAM (ISET)

Recognizing that the government can not properly construct a set of standards that govern the design, manufacturing, assembly, test and integration of a high utility bus, with out significant buy-in from the industry that will be called upon to produce them, the concept of an Integrated Systems Engineering Team (ISET) was established. The basic charter of this team is to develop a set of specific standards that allow industry to produce spacecraft buses for the government at moderate volume for low cost that satisfy, on average, the 80% mission utility across a number of mission types.

To establish the team, the government solicited responses from credible domestic small satellite integrators to supply full-time or near-full time senior systems engineering support conversant in both high level system design and detailed subsystem design with demonstrated hands on experience in the design, development, manufacturing, integration and test of satellites, preferably small satellites and/or volume production of satellites. In addition to the industry participation, it was essential to have participation from both the potential user community of these assets as well as the operators of these assets. Thus an initial body of approximately 12 members was established to deliberate of the standards, where the chairman of the body is the NRL/APL members of the team.

In the initial phases of the program, the team gathers at deliberation meetings, a face-to-face conference for 1-2 days, approximately once a month. In addition, the team conducts weekly teleconferences. It is expected that frequency of these meetings will reduce as the

Phase III effort progresses from the initial requirements/conceptual stage of development to a detailed design stage, where the focus of the ISET team will slowly shift from a standards generating board to a standards advisory board to verify that the standard as envisioned is being implemented. This later focus include design reviews, manufacturing recommendation, integration and testing involvement, and to provide technical assistance in re-working the standard base on prototype experiences and lessons learned.

To provide additional sources of input to the team, both solicited and unsolicited proposals in specific areas of interest to the standards board (e.g., tactical communications, interface protocols, etc.) will be continuously evaluated in an effort to bring the standards board as much information as possible with which to set the standards. In general, these solicitations can start out as a “white paper” submitted to the ISET chair for consideration. In some cases the chair may request some further clarification and focus. Once the chair is satisfied with the scope of work, a formal submission for funding of the effort will be requested under a standard BAA contract agreement.

THE STANDARDS — WHAT DOES IT COVER

The terminology “standard” is used here in the most generic sense as an establishment of a common understanding for a design such that regardless of time, location and facility of manufacture, the design is common/interchangeable to the extent specified within. In general, the standards will be a combination of system requirements (i.e., establish functional and/or performance levels for **what** a particular design must satisfy) and system specifications (i.e., establish functional and/or performance definition for **how** a particular design must be produced), depending on the depth with which the ISET determines is necessary in each area of consideration.

Although still under consideration, the bus standards are envisioned to cover a broad area of considerations from programmatic, to quality/mission assurance, to the technical external and internal interfaces to the spacecraft. From the programmatic point, the standards should consider the type and level of required oversight by the sponsor, the level of documentation required both delivered as well as internal to the manufacture, etc. From the quality/mission assurance perspective, the standard needs to employ value added QA/MA **not** added employment; areas such as traceability, parts programs and workmanship processes will be evaluated. In addition, explicit statements on the risk tolerance of the spacecraft will be established.

On the technical side, all of the expected external interfaces to the spacecraft will be considered, including the interface with the payload, the launch vehicle, communications links (both for the command and control of the spacecraft as well as the command, control and data flow of the payload down to the tactical user), the ground checkout equipment and the operations center (both for the spacecraft bus and the payload).

Lastly, the detailed technical requirements on the spacecraft bus need to specify standards for total mass, operational modes, lifetime, fault protection philosophy, electrical systems concepts (e.g., grounding), pointing performance, orbit and attitude knowledge, payload I&T time, on-orbit checkout time, scheduling, etc.

The specific documented form of the standards has not been completely established, but at a minimum it is expected that a Payload Users Guide will be developed so that potential users of the bus will know the design constraints of the system. In addition a “Bus Standards” document will be developed to capture all of the other programmatic, quality, technical as well as external and internal interface requirements/specifications generated by the ISET team. It is possible that the team may ultimately decide to separate the information in this one single document into multiple documents in the future.

Finally, the terminology “Bus Standards” is used specifically to convey the thought that the combined set of requirements and specifications written down provide direction and constraints to manufactures in the design, development, assembly and testing of spacecraft bus to be utilized for the scope and missions considered by the ISET, but should not be considered the definition of a single “Standard Bus”.

DEVELOPING BUS STANDARDS—AREAS OF INVESTIGATION

Using the ORS Phase I report as initial conditions, the ISET team started out with the establishment of some basic topics of discussion, the products of which will be used directly to generate the bus standards, the prime products from this body. Using the results from Phase I as “bounding initial conditions” and somewhat of an existence proof, the following probing areas of discussion were established to further refine the details necessary to generate the standards.

With any activity involving a group of people engaged in a collaborate effort, it is essential to establish high level goals, expected accomplishments and specific focus of the group. In particular for this effort, the government team did not want to pre-suppose these efforts

with out engaging industry. Thus the “ISET Team Focus of Goals and Accomplishments” topic of discussion was established. Predominate in this discussion will be the limited amount of resources and time that is available under the ORS/Phase III contract.

In order to generate a set of standards in a general category such as a spacecraft bus, it is essential to capture all of the relevant mission level requirements and concept of operations over the broad set of missions the spacecraft bus is expected to support. Once these are known, it will be necessary to distill them down to a common set of requirements and operations concepts that provide for the 80% utility support across all of the missions. Thus the “Mission Level Requirements and CONOPS Development” topic of discussion was established.

There are a number of potential external interfaces with the spacecraft bus, but two of the more significant design drivers to any spacecraft bus are the payload to be supported and the launch vehicle. Thus, the topics “Payload Envelopes” and “Launch Vehicle Envelopes” were established. The focus of these topics is to gather information of potential realistic payloads, based defined mission sets and launch vehicles that the spacecraft bus would need to interface. In the case of the payload, it will be necessary to discuss with some of the potential payload providers the true performance limitations, if the envelope is constrained in ways that a traditional “build-to-payload-requirements” is not. This should establish a usable envelope, captured in a Payload Users Guide that payload providers can realistically build to and produce measurements of value. In the case of the launch vehicle envelope, the team must consider both the currently available launch vehicle/service fleet as well as the future fleet that is under development, particularly those geared toward ORS. This approach precludes, at least at the technical level, the chicken and egg argument of small responsive spacecraft and small responsive launch service.

In addition to considering the design implications of the various missions on the external interfaces to a spacecraft, it was recognized that some consideration should be paid to the potential internal layout and functionality of the spacecraft to determine if some level of standardization within the spacecraft should be considered. The theory for providing standardization within the spacecraft bus architecture is that some level of common interfaces and architectures facilitates lower overall costs of manufacture, increased ability of technology updates, and the potential ability to modularize for performance and capacity. Thus the “Bus System Functional Decomposition” topic of discussion was established. As an adjunct to this area of discussion, the

design implications on the spacecraft bus due to the on-orbit environment are also considered. From the initial studies, it is recognized that there are two rather distinctive regimes of orbits that the spacecraft bus would need to consider if it were to provide utility across all expected missions. Thus the “Design Differences between LEO and HEO Missions” topic of discussion was established. This topic will investigate the true impacts on spacecraft design, from subsystem to subsystem, between the LEO and HEO on-orbit flight environments and potential mission profiles. In particular, distinct similarities and differences will be drawn in an attempt to determine if some modularity of a core spacecraft design can be established as well as determine the “penalty” in designing for the combined environment would be for the design for any single individual environment.

The last of the initial topics of discussion to be established was the “Test and Verification Approaches” topic. The basic focus of this area is to consider how to streamline the testing and verification of the spacecraft bus, considering some volume production and possible reduction in individual vehicle reliability by eliminating redundant verification activities, moving verification activities to either a higher or lower level of integration, replacing test verification by analysis with sufficient margin and removal of unnecessary test verification activities.

SUMMARY

The U.S. military has embarked on an ambitious set of activities aimed at transforming the application of space to warfighter needs. Combined, these efforts represent a disciplined approach to the many facets and means of achieving operationally responsive space goals. Within this broader context, OFT has established a coordinated, phased implementation plan to develop standards for one class of operationally responsive spacecraft bus. Phase III, the bus standards definition and prototyping phase is now underway, with the support of a broad industry and academic team. Although the development and implementation of bus standards is a daunting challenge, both the OFT ORS initiatives and the wider ORS effort have been structured to maximize the probability of success. The OFT ORS team looks forward to reporting continued progress in the coming years.

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ACRONYMS

AFRL	Air Force Research Laboratory
APL	Applied Physics Laboratory
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
ISET	Industry systems Engineering Team
JHU	The Johns Hopkins University
NASA	National Aeronautics and Space Administration
NRL	Naval Research Laboratory
OFT	Office of Force Transformation
ORS	Operationally Responsive Space
SIV	Standard Interface Vehicle
STP	Space Test Program

REFERENCES

1. "What Is Transformation?" Vice Admiral (ret.) Arthur K. Cebrowski, Director, Office of Force Transformation, October 2002
2. www.scienceblog.com/community/article2416.html, posted 8 Mar 2004.
3. Ibid.