7th Responsive Space Conference
RS7-2009-4001

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7th Responsive Space Conference
April 27–30, 2009
Los Angeles, CA

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ABSTRACT

The Operationally Responsive Space (ORS) mission depends on innovative ways to acquire components, satellites, and launch vehicles, assemble and test space systems; and perform launch and mission operations. Many US allies are already focused on developing and exploiting small satellites and streamlined mission operation strategies for civil and defense applications. From the beginning, the ORS Office and AFRL have had the goal of collaborating with our allies to develop a single set of responsive space standards and enlisting their abilities and expertise in realizing the ORS vision. Toward that end, AFRL has initiated the "Globalize and Internationalize [ORS] Standards and Technology" or GIST program to develop and document the legal foundation and establish an international team to participate in the development of ORS standards. GIST has developed a strategy that will establish a collaborative environment to allow government, industry, and academic entities in the US and multiple ally countries to work together and forge the set of standards necessary to enable the responsive spacecraft assembly and test that is a keystone of the ORS vision. The strategy incorporates two different approaches, one that addresses DoD requirements for international technology development activities, and one that authorizes the exchange of so-called "export-controlled technical data" between US non-defense entities and their foreign counterparts (industry, academia, and civil space organizations). The full paper describes how this international approach aligns with the ORS Office plans for further standards development; how the GIST approach ensures ITAR-compliance by employing existing treaties, export licensing processes, and defense international project agreements; and how the program will increase opportunities for international collaboration in developing ORS components and provide export opportunities for the US space industry.

KEYWORDS: ORS Standards, ORS Technology, International Collaboration

INTRODUCTION

The Responsive Space Community has been keenly interested in the Operationally Responsive Space Program since its inception in 2007. Even before 2007, AFRL engineers had developed and presented briefings on both Space Plug-and-Play Avionics (SPA) technology, and why SPA standards are important to realize the vision for ORS operations. After describing the ORS vision and why standards are important to that vision, this paper will describe the "Globalize and Internationalize ORS Standards and Technology" (GIST) Program. The purpose of GIST is to establish the processes and procedures required to authorize Department of Defense (DoD) and non-defense entities (e.g., industry) to collaborate with our allies in developing and codifying SPA and other ORS standards (Internationalize) and to publish publicly-releasable or "open" standards (Globalize) and to establish a world-wide community to evaluate and extend the concept of responsive space standards.

BACKGROUND

The ORS program is focused on developing and fielding approaches that allow US forces to rapidly develop and, in some cases, rapidly deploy quick-turn solutions to US defense needs. There are three tiers to the ORS program.[1] Tier 1 focuses on using or adapting existing assets rather than using materiel solutions. Tier 2 uses system components that are in storage and available for rapid launch (within 6 days) while Tier 3 develops an entirely new capability with 12 months. Tiers 2 and 3 include the requirement that payloads and busses can be rapidly assembled from components that are stockpiled or delivered just-in-time. The ability to rapidly assemble a satellite from components produced by a variety of manufacturers is essential to realize the ORS vision. Similarly, to enable that rapid assembly it is necessary to have standardized functions, interfaces, and protocols for all the components.

There have been a number of presentations and publications by ORS and other personnel that articulate the importance of a modular approach and ORS Standards as integral parts of the Modular Open System Architecture (MOSA) for ORS Tier-2 and Tier-3 systems.[2,1] MOSAs are seen as key to rapid innovation and responsiveness for ORS.[2] For example, Figure 1 evokes the "Plug-and-Fight" concept where a modular bus and pre-existing or real-time-assembled payload modules enable a mission design tool to quickly guide the assembly of a satellite tailored to meet the needs of a Joint Forces Commander.[1] Again, the MOSA approach depends on modular designs of components and assemblies, and widely-supported standards.[2]

Several "tailored"[†] standards have been developed in support of the ORS program. An NRL-led team developed the Integrated System Engineering Team (ISET) General Bus Standards. ISET Standards are a set of standards that address overall bus performance characteristics and key interfaces. In addition, a total of five Space Plug-and-Play Avionics (SPA) Standards have been developed thus far. The purpose of SPA and the SPA Standards is to use modular components and standardized interfaces, protocols, etc., to reduce the design and integration time and cost for ORS spacecraft. Through the remainder of this document when discussing tailored standards, the SPA Standards will be used as examples.

Besides the tailored standards described above, the Open Standards Team (OST) is a group of government, contractor, and volunteer industry personnel that is focused on developing a collection of completely releasable (i.e., open) ORS Standards. There are a multitude of reasons that open standards are seen as important to ORS, not the least of which is that the MOSA approach depends on using open standards whenever possible.[2]

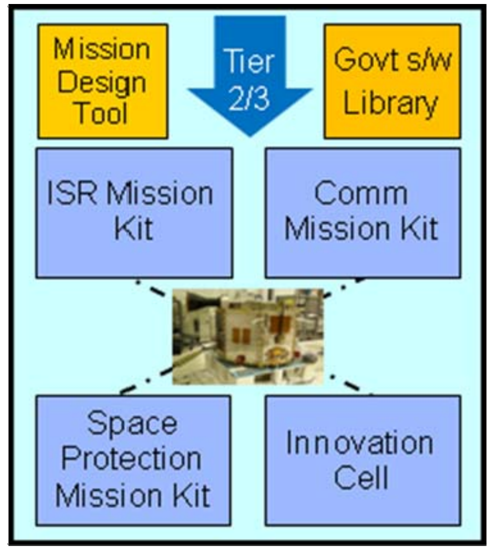

Figure 1: Plug-and-Fight Spacecraft assembled rapidly due to Modular Open System Architectures [1]

Taken together these two standards development activities will prepare a comprehensive set of ORS Standards that, when combined with the modular design of the ORS bus and payload components, will enable the extremely short ORS timelines for satellite design, assembly, and checkout. As described in more detail below, the tailored standards will be reviewed and revised to permit the public release of those standards; however, there will probably always be some ORS Standards that must include details that keep them from being released publicly. Thus, the two sets of standards are an expeditious way to get standards in place, but will probably persist to meet a complex set of needs.

Since before the ORS Office was established, thought-leaders in Responsive Space believed that technical, national security and foreign policy interest would best be served by collaborating with key international partners in developing certain aspects of the ORS program. In particular, standards development has long been seen as an important area for international collaboration, even in the case of export-controlled standards, wherever possible. One of the purposes of the GIST program is to provide an approved mechanism for US and foreign entities to collaborate in developing ORS Standards.

[†] The term "tailored" is used here to distinguish between ORS-specific standards and existing open standards that may be adopted by ORS

SPA STANDARDS DEVELOPMENT

The Space Plug-and-Play Avionics (SPA) Vision is to employ machine-negotiated interfaces to permit the elements of a complex system to transparently perform and accelerate the integration process, thereby reducing or eliminating error-prone human integration.[3] Adaptive avionic interfaces, through processes of electronic self-organization, can enable rapid space vehicle construction. The Space PnP Avionics (SPA) approach fully supports an à la carte method of constructing complex arrangements of virtually any sensor or actuator. This capability enables a network that is easy to expand and modify, and also makes it robust to system failures that result from either natural causes or from deliberate attack.

The objective of the SPA Standards is to provide normative references for constructing hardware and software capable of interfacing with a SPA satellite system.[3] SPA seeks the ease-of-use model promoted by USB in the PC industry, but it is not simply a matter of transplanting consumer Plug-and-Play (PnP) into aerospace devices. SPA exploits existing standards for physical and logical transport layers, but it accommodates special space-system constraints not faced by commodity PnP products: the environment (i.e., radiation, temperature, and vibration), size, weight, and power limitations, fault tolerance, synchronization requirements, and on-orbit testing.[3] SPA also differs from terrestrial PnP by including self-identifying and self-enumerating functions to support scalability and a broader range of devices and power demands.

According to the SPA Guidebook, "SPA Standards are defined as an interface-driven set of standards, encompassing hardware, software, and protocols, intended to promote the rapid development and integration of spacecraft busses and payloads."[3] One of the key objectives of the SPA Standards is to enable the rapid design and assembly of ORS satellites by technicians rather than highly-trained satellite assembly crews.

Over the past five years there has been a continuous process focused on developing a complete set of standards for SPA. The work was initially started by the AFRL and contractor personnel involved in developing the proto-devices that originally demonstrated space plug-and-play capabilities. Subsequently, AFRL, with support from defense contractors, the commercial space industry, the National Aeronautics and Space Administration, academia, and other DoD organizations, has continued to develop SPA standards. Between June of 2004 and today there have been over seven workshops that focused on SPA and the SPA Standards.

The Plug-and-Play Satellite, aka PnPSat (see Figure 2), was developed to demonstrate that the quick-turn modular satellite bus concept has been realized—a SPA proof-of-concept. There is a widely-seen movie that shows technicians rapidly assembling the PnPSat in less than four hours. That four-hour process would not be possible without pre-defined standards for interconnects, power, data formats, protocols, mount designs, etc., and the reduced system complexity that SPA provides.

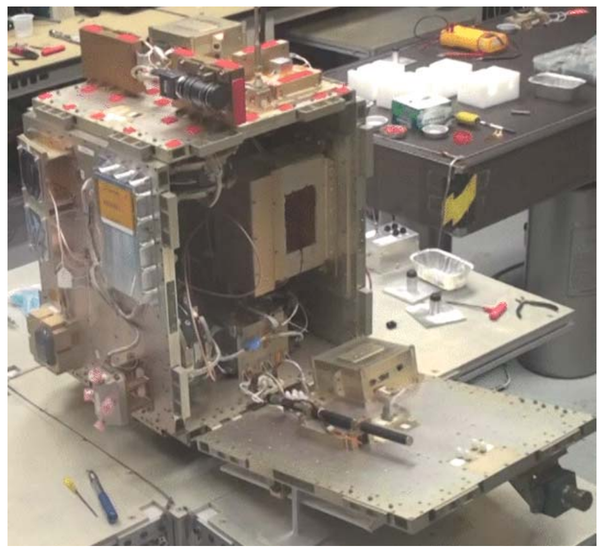

Figure 2: The Plug-and-Play Satellite (PnPSat)[x]

Currently there are five SPA standards documents in draft form. The first of those documents is the "SPA Guidebook." The Guidebook provides a general description of the SPA architecture and each of the SPA Standards. The Guidebook also provides a top-level description of the Spacecraft Data Model that is used to form and manage the on-board SPA network. A common ontology is described that was used to produce a Common Data Dictionary (CDD) that defines a stable set of terms that are used across the SPA network to integrate hardware and software components into the network. Interfaces between bus components, the PnP protocols currently in-use and the adaptations needed for space application are also described.

The next draft document is the Satellite Data Model (SDM) Standard. This standard provides the requirements for interfacing applications and hardware with the existing SDM and the SDM Messaging Protocol to construct a SPA satellite system.

The third document is the draft standard that defines the SPA-S capability. This standard provides the requirements for adapting the European Cooperation for Space Standardization (ECSS) SpaceWire Standard, ECSS-E-50-12A, as complimented by the pending ECSS-E-50-11 SpaceWire Protocol ID standard. The fourth is the draft SPA-U Standard. It is based on the USB data transport standard. The SPA-U standard specifies the required physical interface, with signal characteristics, for a SPA-U device and the Appliqué Sensor Interface (ASI) data transfer protocol developed for low-data-rate devices.

The final document is the draft SPA XML Transducer Electronic Data Sheet (xTEDS) Standard, which establishes the format and allowable terminology for the electronic data sheet required for each component of a SPA satellite system to define the specific data interfaces to the component. Every device and every software application must have an xTEDS to function in the SPA network.

As mentioned in the previous section, from the early days of the AFRL Responsive Space program there has been an interest in exploiting the small satellite developments and expertise in foreign countries. One challenge, the largest challenge when considering international collaboration, is the US export-control regulations. DoD Directive 5230.25 states, "…the Secretary of Defense may withhold…technical data with military or space application…if such data may not be exported lawfully without an approval, authorization, or license…"[4] and the International Traffic in Arms Regulations identifies "technical data directly related" to "specifically designed or modified [space] systems or subsystems, components, parts…"[5] as part of the US Munitions List and, therefore, requiring a license for export. In order to work with foreign partners in developing ORS Standards, an approach will have to be developed that obtains Department of State (DoS) and DoD approval for the desired collaboration.

OPEN STANDARDS DEVELOPMENT

In addition to the Tailored Standards Teams that are developing the ISET and SPA Standards, there is an Open Standards Team (OST) that is developing ORS Standards. The OST is a group of government, contractor, and volunteer industry personnel that is focused on developing a collection of ORS Standards that are completely releasable (i.e., open). The OST identifies needed standards across the spectrum of ORS activities, for example, bus standards, payload standards, and launch-vehicle/spacecraft integration standards. The OST's mantra is, "Adopt, Adapt, and only as a last resort Develop."

The initial focus of the OST is on payload and bus standards, with the intent of shifting their efforts to C2 and TPED standards in FY10. For each area the OST is working (e.g., payload standards), it simultaneously performs three tasks. First, the team identifies what standards are required by ORS in that area of interest. At the same time, the team reviews existing open standards for spacecraft and other systems to determine what existing standards can be adapted to satisfy identified ORS needs. Finally, and in addition to the need/solution identification process, the team reviews drafts of tailored standards for multiple reasons. The primary reason is to see if it is reasonable to create an open standard by removing sensitive material from the tailored standard. If so, the OST undertakes re-writing the tailored standard into an open one. In addition, the OST reviews the tailored standards related to the area of interest they are working to possibly give them additional insight to ORS standards requirements.

Through this dual-track approach, developing tailored and open standards, most tailored ORS Standards developed with our international partners will be adopted into open standards. The open standards will then be published in the public domain to seek recommended improvements, encourage adoption or adaptation for other space system developments, and facilitate a global discussion of the open standards and spacecraft standards, in general. By keeping these two teams coordinated, the ORS Office ensures there is a sound approach that strikes the appropriate balance between optimization and openness.

PURPOSE OF GIST

Responsive Space program leaders realized early on that there were great benefits to leveraging our allies' interests and expertise in small satellite technologies, systems, and standards. At the same time, it is clear from Department of State (DoS) and Department of Defense (DoD) policy and regulatory documents that technologies that are developed for defense applications are only exported when that export supports national defense and foreign relations objectives.[4]

The purpose of GIST is to develop and implement a DoS and DoD approved approach for international collaboration to develop SPA and other ORS standards and, in parallel, develop publicly-releasable standards. This approach will allow (i) US defense, civil, and industry entities to collaborate with their counterparts in approved allied countries to develop ORS standards and technology and (ii) publicly release approved information that will give everyone insight to how these standards enable responsive system development and thereby engender open discussion and research.

One minor complication is that there are two different processes that must be used for defense and commercial entities to establish approved international collaboration. For US defense entities (e.g., the ORS Office), government-to-government agreements are required. Since the 1950s, DoD Components have collaborated with the defense components of allied and friendly nations to exchange scientific and technical information in areas of mutual interest.[6] The simplest way to be authorized to collaborate with a foreign partner is to develop or use an existing Memorandum of Understanding (MOU), for example, the Trilateral Technology Research and Development Program (TTRDP).[7] These MOUs are government-to-government agreements on specific joint projects. The nature of the activities and the ability to share the results of the projects are determined by the terms of the MOU. Any particular joint project often requires the establishment of a Project Agreement (PA) under the auspices of the MOU. The PA defines an even more restricted scope of activities as well as the objective, responsibilities, and expected outcomes of the project. An example of such a PA is the Small Satellite Utility PA which is pursuant to the TTRDP MOU.[8] There are a number of other ways for defense organizations to enter into international collaborations. Most of those programs that are related to Research, Development, Testing and Evaluation are described in the International Armaments Cooperation Handbook.[6] The bottom line here is there are procedures that must be followed for a defense organization like the ORS Office to participate in an international collaboration, and those procedures are significantly different that those that must be followed by a commercial organization.

Commercial organizations must comply with Department of State regulations to collaborate with foreign entities. In particular, for the type of technical data sharing we are interested in for SPA Standards development, we must seek approval to perform "defense services," which includes, "…furnishing to foreign persons of any technical data…"[9] For the purpose of the GIST program, we will use a Technical Assistance Agreement (TAA).[10]

MECHANICS OF GIST

The purpose of GIST is quite rational and obvious; however, the way to accomplish it may not be so obvious to everyone. Figure 3 provides an overview of the top-level approach that will be used to Globalize and Internationalize ORS Standards and Technology.

Working initially within the US we will identify the required standards and prepare a draft outline or terms of reference for each standard or set of standards. Much of this has been completed for the SPA Standards, as described previously. These initial documents, when necessary, will be identified as containing export-controlled information and will be distributed according to AFI 61-204[11] to "US Persons"[†] involved in the standards development or related processes. The next step is to develop the approved approach that will allow international collaboration.

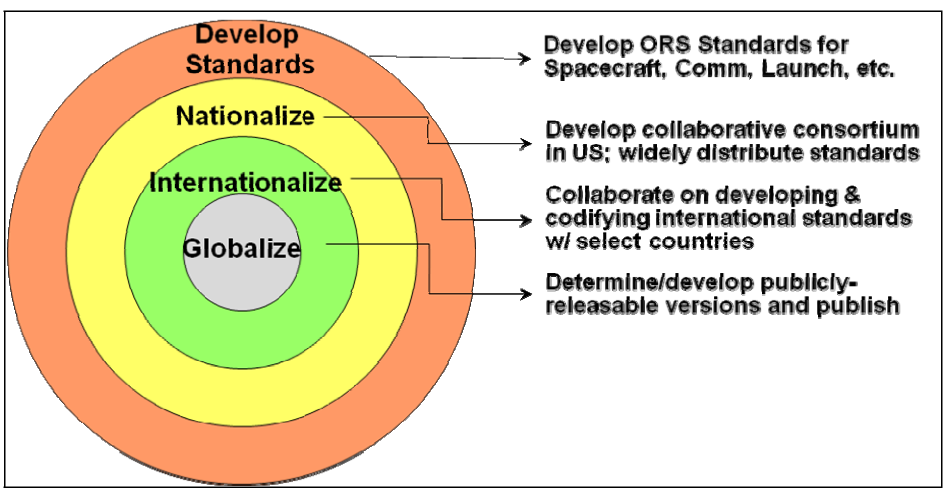

Figure 3: Overview of GIST Approach

[†] In common terms, a US Person is a US citizen by birth or naturalization, a Permanent Resident (Green Card holder), someone that has been granted exile or asylum status by the US government, or any company or other entity that has been incorporated to do business in the US (see 22 CFR 120.15).

Allies will be involved in the standards development process by establishing a Technology Assistance Agreement (TAA) that authorizes, in the beginning, one US company, two foreign companies, and ORS/AFRL to exchange export-controlled technical data (i.e., the ORS standards). Each of the organizations described in the previous sentence is called a licensee, except the government organizations which are advisors. In a TAA, each licensee can have any number of sublicensees with which the licensee can share the technical data, thereby allowing the sublicensees to participate in the standards development, too. The reason this arrangement was selected is because it is reasonably fast to get approved. If the initial set had been decided to be ten licensees, for example, the approval process would have been much longer. A pictorial description of the initial TAA is shown in the top half of Figure 4.

In a TAA, the only authorized communication or information transfer between teams (here a team is a licensee and its sublicensees) is through the licensees. The disadvantage to having a small number of licensees is the resulting communication challenges. For example, for one sublicensee (sublicensee-1 or s-1) to communicate with sublicensee-2 (s-2), s-1 must pass the information to its licensee who then transfers the information to s-2's licensee who transfers it to s-2. These communication restrictions are required by the Department of State before they will approve the TAA. Discussion between ORS, AFRL, and their support contractors determined that the benefits of getting the TAA in place quickly outweighed the challenges of the complicated communication channels.

The TAA will authorize specific companies (the licensees and sublicensees) to exchange export-controlled information and work together to develop and publish the export-controlled ORS Standards. Once the TAA is approved, the authorized participants (the licensees and sublicensees) will participate in the entire standards development process, including identifying and drafting new standards as described in the first paragraph of this section.

There are several reasons for working with international partners in developing standards. First, several foreign countries have robust small satellite programs and have extensive expertise in developing small sats. The approach will bring that expertise to the standards development process, thereby improving the quality of the standards. Furthermore, the standards developed in this manner will be used by the involved countries in their own modular small-satellite programs, thus

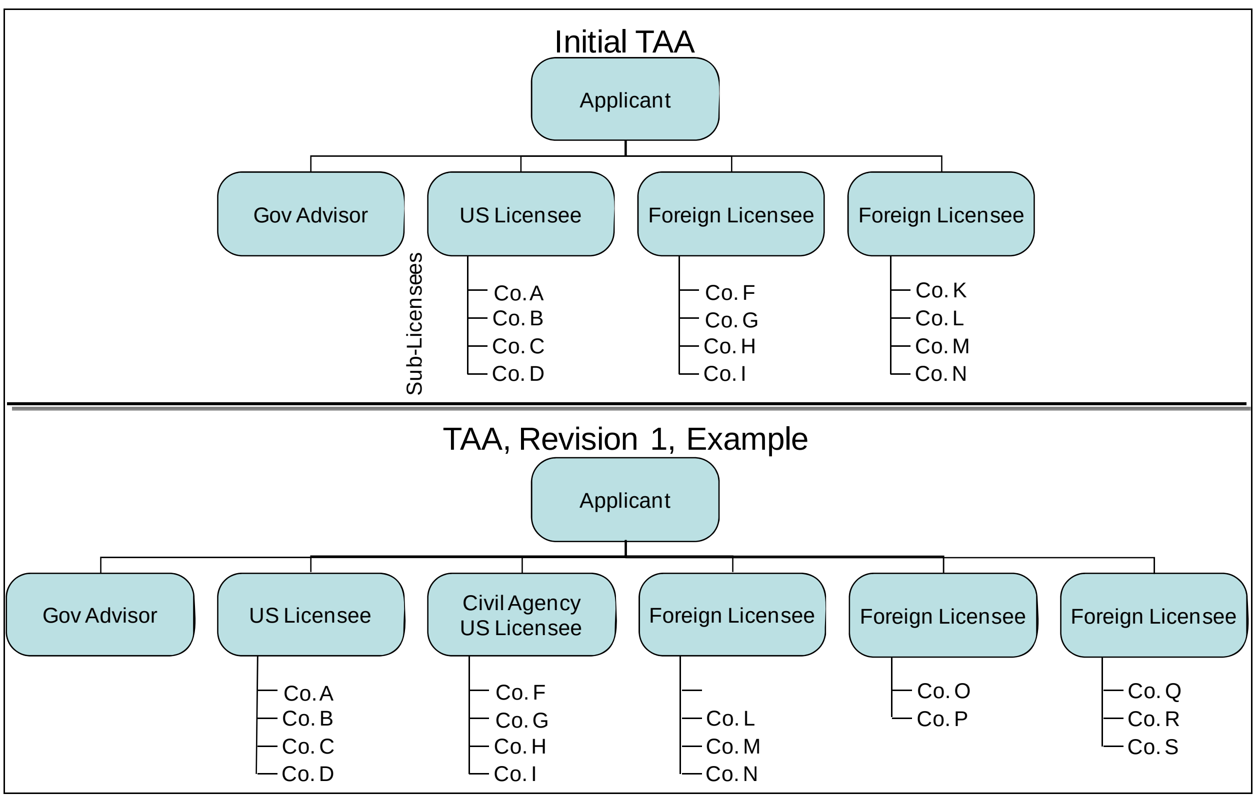

Figure 4: Conceptual Diagrams of the Initial TAA and Rev 1

multiple countries will be using identical standards for small satellite components. This approach increases the number of sources for small satellite components and also increases the size of the market that is accessible to component developers. If a US company develops an ORS component, there will be foreign markets for that component, too. The company will need to license the export of the component, but the special small-satellite relationship between the US and the participating countries will simplify that process in most cases.

The disadvantage to having a small number of licensees in the initial TAA was mentioned above. Specifically that disadvantage is complicated communication channels. There is, however, a plan for streamlining those communication channels. Once the TAA is in-place (i.e., approved by the DoS Directorate of Defense Trade Controls), it can be modified. While the modified TAA is being prepared and approved, the original TAA is in effect. Therefore, immediately after the initial ORS Standards TAA is approved and operating, a revision will be initiated (see the bottom half of Figure 4) to create new licensees, often by moving sublicensees up to the licensee level, but also by adding new industry or civil entities as licensees. At the same time, new foreign sublicensees can be added to the TAA. There will be a continual process of TAA revisions to increase the number of licensees to simplify the communication processes and to add or change the participants as some standards become mature or as new standards, such as structures or thermal management standards, are initiated.

SUMMARY

The ORS program is focused on developing and fielding approaches that allow US forces to rapidly develop and, in some cases, rapidly deploy quick-turn solutions to US defense needs. The ability to rapidly assemble a satellite from components produced by a variety of manufacturers is essential to realize the ORS vision. Similarly, to enable rapid assembly it is essential to have standardized functions, interfaces, and protocols for all of those components.

Since early in the AFRL Responsive Space Program, several thought-leaders proposed an international collaboration on standards and technology. The GIST program is developing and implementing a DoS and DoD approved approach for international collaboration to develop SPA and other ORS standards and, in parallel, develop publicly-releasable standards.

To authorize the desired international collaboration, the GIST program will establish a TAA that allows specific US and foreign entities to collaborate on developing and codifying the ORS Standards.

ACKNOWLEDGEMENTS

The authors thank the Operationally Responsive Space Office and the AFRL Space Electronics Branch for their support and assistance in preparing the plan for the GIST program and in creating/reviewing this paper.

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