

# **The Johns Hopkins University Applied Physics Laboratory Space Sector Technology Transition: A Framework and Case Studies of Civilian and National Security Space**

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**The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has over 50 years of experience in the development of instruments, spacecraft and end-to-end missions for both Civilian and National Security Space applications. Over the course of this history, JHU/APL has evolved an organizational framework and processes for rapid transition of space technology from world-class civil science-driven missions to applications in National Security Space. This paper will present the elements of this framework within a historical context and discuss case studies of successful technology transition across the boundaries of Civilian Space and National Security Space application.**

## **I. Introduction**

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) is a research-oriented not-for-profit laboratory located in Laurel, Maryland. APL is structured as a University Affiliated Research Center (UARC) for the United States Department of Defense. As a UARC institution, APL is chartered with maintaining essential engineering and technology in a number of core areas including Space Science and Engineering. Over the course of its 69 year history, APL has evolved to be an essential National resource for both Civilian and National Security Space communities. This paper will discuss aspects of the organization and processes that enable a relatively small organization to make significant contributions in both communities and will highlight a few examples where successful cross-domain technology transition has occurred.

## **II. History of Space Technology at the Applied Physics Laboratory**

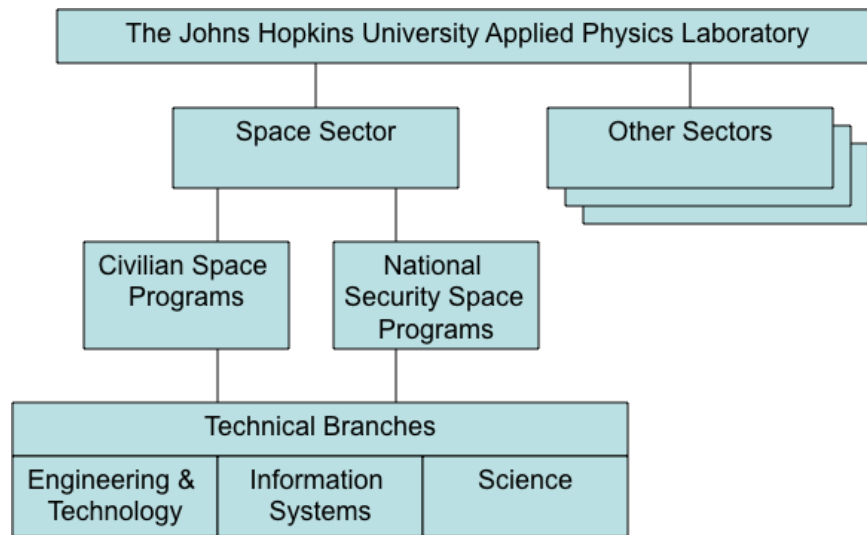
Since its inception in the 1940s, JHU/APL has designed, developed, and launched 63 spacecraft and more than 150 instruments in partnership with NASA and DoD. During that time, space has increasingly become a critical part of the nation's strategic posture; thus, JHU/APL continues to develop effective space-based solutions for the nation's challenges, including weather, reconnaissance, surveillance, space control, missile defense, and homeland security, while also providing enhanced space support for combat forces in navigation, communications, and targeting. Significant experience in both civilian and national security space programs allows JHU/APL to leverage capabilities and accomplishments from NASA programs to address national security space requirements – and vice versa. JHU/APL has chosen to take on these demanding technical and scientific challenges with the goal of enhancing national security through the application of space science and technology. In the early days of the space race, JHU/APL established a space science and engineering capability even before Sputnik was launched. As JHU/APL moves toward a new era of national security space initiatives, it will continue to provide nationally recognized capabilities: space weather, remote sensing from UV to near IR, and small, capable (CubeSat) spacecraft.

## **III. Current Space Sector Organization and Planning Processes**

The overall Johns Hopkins University Applied Physics Laboratory is organized into a subset of “Sectors”. Each of these Sectors has unifying aspects, such as common heritage, technologies, and sponsor bases. The exact number of Sectors has varied over the history of the Laboratory, primarily driven by on-going focus on the national critical

challenges that need to be addressed and solved. A Sector, furthermore, contains within it one or more Business Areas. A Business Area is the sponsor-facing organization that is responsible for a common set of programs and each can be thought of as a key Laboratory contribution area. A Business Area is therefore responsible for all phases of a program, including Program Formulation, Development, Execution, and Delivery.

For purposes of this paper, the Sector of particular interest within the overall Applied Physics Laboratory itself is the Space Sector. The Space Sector at JHU/APL is responsible for solving challenges within the entire space realm. This covers all low-earth, medium-earth, and geosynchronous orbiting platforms. Beyond that, the Space Sector includes all JHU/APL Deep Space Planetary missions. Additionally, the Space Sector is bifurcated into the Civilian Space Business Area (CSBA) and the National Security Space Business Area (NSSBA). The CSBA concentrates on civilian sponsors and challenges (such as NASA, NOAA, and NSF) whereas the NSSBA focuses on sponsors and challenges within defense and intelligence communities. So we have a Space Sector with two distinct yet complimentary Business Areas, garnered by a common set of underpinning technologies.

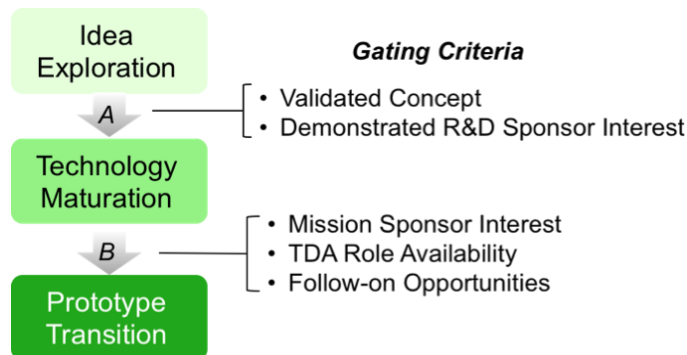


**Figure 1: Sector and Business Area Organizations**

### A. Technology Planning

Technology planning for both the Civilian and National Security Space Business Areas is an annual process that is driven by evolving sponsor needs and constraints. Both Business Areas work from a set of roadmaps that reflect established strategic priorities that are intended to frame technology needs over multiple planning cycles (years). These roadmaps are framed in terms of an abstract model for technology development and transition into operation (Figure 2). Although specific technology development scenarios may not flow in such a linear manner, perhaps depending more on uncontrollable environmental factors, this model provides a rough guide for planning purposes and that is the intent here.

As shown in Figure 2, the model specifies three phases of development for a particular technology initiative. Technology efforts in each of these phases are characterized by different objectives, constraints, and resource requirements. Thus, the roadmaps may be used to plan future Independent Research and Development (IR&D) and capital investment priorities.



**Figure 2: JHU/APL Technology Development Process**

In the first phase of technology development, “Idea Exploration”, the emphasis is on seedling levels of IR&D funding (< \$100K/yr) and in-depth investigation of competitive and collaborative resources. The emphasis is on vetting of initial ideas and concept demonstration. Two factors serve as gating criteria to move a development effort beyond this phase: validation of the initial concept through demonstration or analysis, and some indication of the potential for critical contribution as evidenced by interest from a relevant R&D sponsor.

Assuming that an effort has passed these initial gating criteria, the second phase of development, labeled “Technology Maturation”, may be pursued. The objective of this phase is the maturation of the initial idea beyond concept demonstration and into some form of prototype capability that can be used as a basis for transition to direct sponsorship. The emphasis in this phase will be on resources sufficient for moving a technology over the “mid-TRL” hump. Recognizing the challenges inherent in this process, larger levels of IR&D funding (\$200K+/yr) may be required and sponsor engagement activities will be focused on identifying and pursuing both R&D sponsors and potential stakeholder missions for future transition. Gating criteria for moving beyond this phase into transition include commitment from a transition sponsor, related TDA roles, or the possibility of follow-on technology development opportunities. In any of these cases, the need for IIP resources will dramatically decrease, but some internal support (e.g. capital resources) might still be required.

In the last phase, “Technology Transition”, it is assumed that technology development will be driven directly from the mission requirements of a transition sponsor. The emphasis in this phase will shift to collaborative activities that seek to broaden APL contribution and lay the foundation for follow-on seedling (i.e., Idea Exploration) activities.

## **B. Independent Research and Development Planning**

Independent Research and Development (IR&D) funding provides a key mechanism for coordinating and integrating Civilian and National Security Space technology development. The JHU/APL Space Sector IR&D process runs on an annual cycle, driven by fiscal year milestones. All projects are initially funded for one year and all project funds must be expended in that year. Multi-year efforts are re-evaluated each year and subject to both early termination and/or extension based on performance and continuing alignment with Space Sector strategic objectives. Management of the IR&D process is conducted by three individuals: technology coordinators for each of Civilian and National Security Space Business Areas and the Space Sector Chief Technologist. This structure allows IR&D program planning and execution to address domain-specific objectives while the Space Sector Chief Technologist remains responsive to potential technology overlap and transition opportunities.

The technology roadmaps described above provide a natural starting point for the annual IR&D process. Top level technology development needs as defined in the roadmaps are articulated in two Laboratory-wide solicitations (one for Civilian Space and one for National Security Space) that start the annual process cycle. These solicitations will typically contain 4-5 general areas for desired research and a request for both large scale integrated research efforts and smaller (“seedling”) ideas that might fall outside of the specific request areas. In general, the technology areas in the two solicitations are driven by differing strategic objectives and are therefore not coordinated at this level. All proposal response and decision dates are completely synchronized, however. Separate proposal evaluation committees are used for each business area, but there may be significant personnel overlap. Committees are co-chaired by the Space Sector Chief Technologist and the technology coordinator for the relevant Business Area. Proposal committee membership is made up of representatives from each technical organization in the Space Sector and selected representatives from other (non-Space) domains within JHU/APL. It is this membership that provides the critical overlap to facilitate technology coordination and transition between business areas in this early stage of technology development. Once IR&D awards have been made and a portfolio of projects selected for funding, it is this same committee that is responsible for regular review of progress and overall performance evaluation.

#### **IV. Case Studies**

The organizational structure of the JHU/APL Space Sector and integrated technology planning and development processes described above have resulted in several significant cases of technology transition between Civilian and National Security Space domains. The following sections will describe some particular examples.

##### **A. Space Weather Missions**

In the last five decades, JHU/APL has developed space-qualified instruments to measure the radiation environments near earth as well as at various locations in the Solar System. Radiation sensors have been part of every JHU/APL-developed space mission. These instruments, integrated on Civilian as well as National Security Satellites, have led to a much more in-depth understanding of what is known as Space Weather. Recently, JHU/APL developed charge particle instruments for the Jet Propulsion Laboratory mission to Jupiter and concurrently we are developing a Space Environmental Monitor for the Department of Defense’s mission known as the Defense Weather Satellite System. As an example of a Case Study for these types of missions, we will now take a closer look at a Civilian Space mission that shows specific examples of technology transition from Civilian Space to National Security Space.

The TIMED<sup>3</sup> (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) science mission is a NASA Earth Science mission that measures the dynamics of the earth’s atmosphere. First conceived in the early 1990s, the original premise of the mission was to place two twin spacecraft in the earth’s atmosphere in order to achieve a continuous stream of scientific measurements. JHU/APL, known for creative solutions to challenging problems, re-architected the system to meet the critical set of scientific requirements with a single spacecraft and overall mission costs at about ¼ of the original concept. In order to achieve these significant cost savings, JHU/APL introduced some foundational concepts that continue to be applied to both Civilian and National Security Space missions even today.

The first novel approach adopted by the TIMED science mission was related to the on-board navigation satellite system. In the early 1990s, the full GPS constellation was relatively new, with burgeoning consideration for non-DoD applications. JHU/APL, leveraging its foundational expertise in satellite-based navigation technologies, decided to become an early adopter and integrated a GPS receiver into the payload of the science spacecraft. If successful, this would have several inherent advantages. This approach would allow precise positional and time data to reside on board the TIMED spacecraft as the scientific measurements were made, including latitudinal and longitudinal position, altitude, and time-of-day. The precision of the position and time data, coupled with the scientific instrumentation data, would provide unparalleled accuracy for empirical data and analysis of the atmospheric measurements. By having real-time GPS data available on-board the spacecraft, it also greatly simplified the ground segment since the latitude/longitude/time data did not have to be reconstructed on the ground and later paired with the scientific data off-line. The on-board GPS also allowed another useful feature called Orbit Propagation. This complex algorithmic function, implemented on a spacecraft processor called the Integrated Electronics Module (IEM), utilizes the on-board GPS information to predict the exact orbital location of the

spacecraft at a time in the future. This is very advantageous for location-based activities, such as crossing over key markers, ground stations, poles, and other areas of interest (such as the South Atlantic anomaly). This also greatly reduced the amount of planning on the ground along with associated bandwidth to uplink plans since all of this is accomplished on-board the spacecraft. These techniques are being used in current JHU/APL National Security Space mission developments.



**Figure 3 Simplified block diagram of the Integrated Electronics Module of the TIMED spacecraft, showing the on-board GPS Navigation and Orbit Propagation capabilities**

Another approach highlighted from the TIMED science program relates to low-cost mission operations. In order to achieve drastic reductions in operational expenses, JHU/APL has pioneered and architected a lean approach to mission operations. Specifically for TIMED, the spacecraft design has been leveraged to allow for continuous instrument measurements while downloading the previously stored data to the ground segment. This ability, coupled with the on-board navigation, means much simpler ground commanding and processing as the spacecraft will automatically send the data to the ground when it is in the vicinity of a ground station. Furthermore, this allows for less staffing at the ground stations as the data downloads from the science spacecraft do not require human-in-the-loop activities and can be performed autonomously. Mission operators can also access the operations center through the Internet, which allows for remote status and health monitoring. All of these features add up to sizeable cost savings and help build upon JHU/APL’s institutional knowledge base, which has been applied to many space missions.

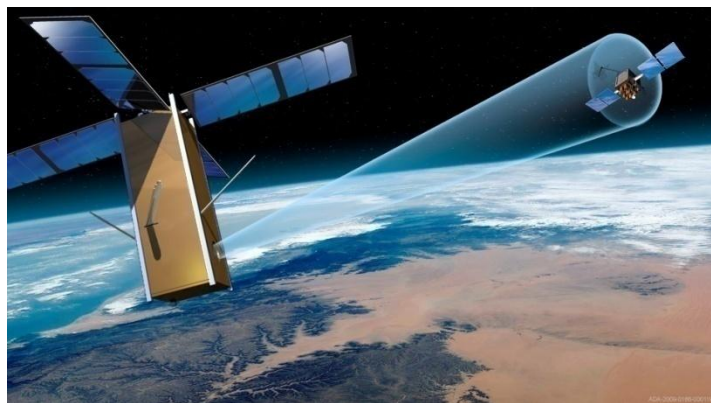
A final area where the TIMED mission has benefited National Security Space involves the actual science data that the spacecraft instruments collect, which is also of interest to the Space Weather community<sup>4</sup>. As such, the measured atmospheric data is regularly downloaded to the ground and then made available to other Federal agencies. These entities can then assimilate in the scientific data from TIMED to supplement their own models and measurements, particularly related to Space Weather. This information is especially useful for space weather forecasting, notification, and analysis.

The TIMED science mission was launched in 2001 and has been operational continuously for a decade. The success of this mission has allowed JHU/APL to achieve greater insight and expertise into several technical areas of Civilian Space with direct usage and impact on National Security Space. The on-board navigation capabilities, along with the low-cost operations have been a staple of many recent Civilian and National Security Space programs. Additionally, the direct usage of data from a scientific mission to lead to a better understanding of Space Weather, a key DOD area of active interest, also shows the synergy between Civilian Space to National Security Space programs at JHU/APL.

## **B. Small and Nanosat Systems**

In response to the requirements of National Security programs, JHU/APL recently developed smaller satellites known as CubeSats. These small spacecraft, which typically are about thirty centimeters in length and ten

centimeters in width, offer the capability to place smaller sensors and communication packages in space. Our Laboratories' approach was to design highly reliable CubeSats that actually could survive the challenges of the space environment; in particular, the charged-particle radiation environment. Our design incorporates the latest in micro-electronic and high-density packaging technologies offering integrated GPS receivers as well as momentum wheels and sun sensors. Designs of these CubeSats find their origins in IR&D funded work for which we developed an Integrated Electronics Module. Subsequently this technology was integrated for the TIMED Space Mission, as described previously. The CubeSat design takes this development to the next step: the present design offers significantly denser electronic packaging and at same time is EMC/EMI resilient. Furthermore, the current design of the CubeSAT IEM integrates the module in the Spacecraft housing, significantly reducing the weight of the CubeSats (<5 Kg).



**Figure 4: An artist concept of the CubeSats developed by JHU/APL. The total weight of these low-earth orbiting satellites is about 5 Kg**

The CubeSat program is another clear demonstration of how JHU/APL continues to adopt technologies developed for Civilian Space for National Security Space missions.

## V. Looking to the Future

As we look to the future, particularly a future of highly constrained budgets for both Civilian and National Security Space, the need for close coordination and technology transition becomes critical. Several areas seem to offer potential payoff in terms of new capabilities, or opportunities to advance existing capabilities. For example, JHU/APL is a leader in flight autonomy for deep space missions. This technology development has been driven by the hard requirement for spacecraft fault management in the absence of human contact on many Civilian Space missions. While NSS missions typically operate in close contact with ground controllers, spacecraft autonomy has the potential to provide important new capabilities for scalability and responsiveness in future mission scenarios. When such capabilities are needed, mature technology and operational understanding of its benefits and limitations will be readily available to leverage from the Civilian Space domain. This is but one example in an ongoing process of technical collaboration at JHU/APL that is facilitated by our size, organizational structure, and technology development processes as described in this paper.

## References

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<sup>4</sup> “A New Empirical Thermospheric Density Model JB2008 Using New Solar and Geomagnetic Indices”, B. Bowman, W. Tobiska, F. Marcos, C. Huang, C. Lin, W. Burke, AIAA/AAS Astrodynamics Specialist Conference, 18 Aug 2008