Operationally Responsive Space – The Way Forward

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ABSTRACT

The Operationally Responsive Space Office was created by the U.S. Congress in 2007 partly in recognition that space acquisition took too long and cost too much. The primary role of ORS as stated in the 2007 National Defense Acquisition Act (NDAA) is to contribute to the development of low cost, rapid reaction payloads, busses, launch, and launch control capabilities in order to fulfill joint military operational requirements for on-demand space support and reconstitution; and to coordinate and execute operationally responsive space efforts across the Department of Defense with respect to planning, acquisition, and operations. The ORS Office pursues critical or enabling technology development within the disciplines of launch and range, ground systems, and/or modular bus/payload systems to reduce time and cost for JFC solution delivery. The ORS Office successfully demonstrated a responsive capability to an urgent need with the ORS-1 mission. In this budget constrained environment, the Department is pursuing the principles of the ORS Office and leveraging the lessons learned through its current missions on other space acquisition programs. ORS-5, the newest ORS mission, will demonstrate the tenets of ORS and address the guiding principles outlined in congressional language.

INTRODUCTION

VADM Arthur K. Cebrowski, USN (retired) conceived the ORS concept as a new business model for space while serving as Director of the Office of Secretary of Defense's (OSD) Office of Force Transformation (OFT). As a 2006 Government Accountability Office report notes, "Operationally Responsive Space (ORS) is the term used to describe this new, complementary business model. Rather than teasing operational capabilities from systems designed and paced for larger national security capabilities, the full spectrum of critical capabilities are created from the bottom up. So, the new model is about defining a joint military demand function and providing joint military capabilities for operational- and tactical-level commanders. Finally, the model emphasizes short cycle times and accelerated learning, providing high-speed iterative advancement in operational capabilities."[1]

The Operationally Responsive Space Office was created by the U.S. Congress in 2007 by Section 2273a of Title 10, United States Code. This legislation defined the ORS mission as to contribute to the development of low cost, rapid reaction payloads, busses, launch, and launch control capabilities in order to fulfill joint military operational requirements for on-demand space support and reconstitution and to coordinate and execute operationally responsive space efforts across the DoD with respect to planning, acquisition, and operations. The primary objectives for ORS are to develop End-to-End Enabling Capabilities and respond to Joint Force Commanders' needs. While not changing the ORS mission, the reporting structure through the Air Force Program Executive Officer for Space directed by the 2013 NDAA provides a streamlined approach to satisfying identified warfighter needs. The 2014 NDAA reaffirmed the ORS mission to demonstrate, acquire, and deploy an effective capability for operationally responsive space to support military users and operations from space. [2]

The office has had rocky existence since its inception. Although it quickly achieved a number of early successes including the delivery of the ORS-1 satellite in less than 33 months, due to budgetary constraints it was slated for closure in 2013. With strong support from the U.S. Congress, Air Force leadership reversed the decision and now strongly advocates the ORS mission and its streamlined acquisition approach. The newest ORS mission was selected by the DoD Executive Agent for Space to address space situational awareness capabilities. ORS-5 will demonstrate the tenets of ORS and address the guiding principles outlined in congressional language. This mission should enable ORS to step down from the $200M missions toward the congressional cost goal of $60M. Other objectives include moving toward smaller and more cost-effective launch alternatives, use of commercial practices, and incorporation of commercially mass-manufactured components to lower cost, shorten delivery time and strengthen the industrial base. The ORS Office often says, "ORS is not new, it's just bringing new approaches to space." The ORS Office is adapting concepts and principles that have a proven history of success in commercial and military as well as international and domestic for both space and non-space applications.[3]

Figure1. ORS-1 Launch from Wallops Island

OPERATIONALLY RESPONSIVE SPACE

The DoD defines Operationally Responsive Space as, "Assured space power focused on timely satisfaction of Joint Force Commanders' needs." [4]

—Department of Defense

On May 21, 2007 the Deputy Secretary of Defense and Executive Agent for Space established the Operationally Responsive Space (ORS) Office as a proactive step to adapt space capabilities to changing national security requirements and to be an agent for change across the community. Operationally Responsive Space contains two key elements: assurance of capabilities and timely delivery. ORS can increase resiliency of space capabilities by responsive reconstitution, and rapidly deploy new technical/operational innovations. The ORS Office is taking a new approach to risk and mission assurance to rapidly deploy capabilities that are good enough to satisfy warfighter needs across the entire spectrum of operations, from peacetime through conflict. The warfighting capabilities needed for Operationally Responsive Space include reconstitution of lost capabilities, augmentation of existing capabilities, filling unanticipated gaps in capabilities, exploiting new technical or operational innovations, and enhancing survivability of space systems. In this context, two essential tasks must be accomplished to achieve ORS. First, we must develop and mature end-to-end ORS enablers that will be required to deliver highly responsive capabilities. The second essential task is to execute rapid end-to-end capability efforts to meet urgent operational needs.

Additionally Congress directed the ORS Office to demonstrate, acquire, and deploy an effective capability for operationally responsive space to support military users and operations from space, which shall consist to include responsive satellite payloads and busses built to common technical standards; low-cost space launch vehicles and supporting range operations that facilitate the timely launch and on-orbit operations of satellites; responsive command and control capabilities; and concepts of operations, tactics, techniques, and procedures that permit the use of responsive space assets for combat and military operations other than war."[5]

The ORS office has pursued the dual nature of its Title 10 mission, as stated above, under two broad categories. One of those categories is pursuing enabling capabilities designated as "enablers" and the other is offering solutions to identified "urgent needs". Enablers are those activities that build capabilities across the range of disciplines required to advance responsiveness of the space enterprise as a whole. These are the "pillars" of ORS and are largely drawn from the elements called out in both the first part of the Title 10 mission statement and in the policy statements from the FY07 and FY14 NDAAs.

The ORS Office is working with the broader space community to provide "assured space power focused on timely satisfaction of Joint Force Commanders' needs." The objective of the ORS concept is the ability to address emerging, persistent, and/or unanticipated needs through timely augmentation, reconstitution, and exploitation of space force enhancement, space control, and space support capabilities. The ORS Office is implementing a rapid innovation process using a Modular Open Systems Architecture (MOSA) to facilitate rapid assembly, integration, and test (AI&T), deployment, and operations of space assets into the current space architecture in operationally relevant timelines. The ORS Office focuses on material (spacecraft, launch, range, payloads) and non-material solutions (business model, acquisition, policy, industrial base, training, command and control, tasking, exploitation, processing, & dissemination, concept of operations), and collaborates with national and international agencies to leverage existing investments and develop long-term partnerships.

One of two primary ORS mission is support to identified urgent needs. This is tied to immediate warfighting requirements and is in direct response to the second part of the Title 10 mission statement. Procedurally, action on urgent needs is triggered by a direct request from the Commander, USSTRATCOM. Due to the short-notice nature of these requests as well as the accelerated timelines, funding can present challenges. Unlike the normal flexibility of the Director of the ORS Office to execute a broad effort on enablers under the Air Force Program Executive Officer for Space (AFPEO SP), consideration to proceed forward with an urgent need necessitates review at the ORS EXCOM level and prioritization by the DoD Executive Agent (EA) for Space. Ultimately the decision to move forward requires prioritization of urgent needs among the existing enabling activities – an action identified in Title 10 under the role for the DoD EA for Space. Joint Force Commanders continually submit Joint urgent Operational Need Statements identifying communications, surveillance, reconnaissance, and early warning capability gaps. Operationally responsive Space (ORS) concepts and capabilities have emerged as a potential solution for filling Joint Commander's needs. The ORS office is responsible for developing low-cost, rapid reaction payloads, buses, space lift, and launch control capabilities in order to fulfill joint military operational requirements for on-demand space support and reconstitution. ORS and USATRATCOM have developed a request and solutions process to employ responsive space capabilities. [6]

The ORS Office pursues critical or enabling technology development within the disciplines of launch and range, ground systems, and/or modular bus/payload systems to reduce time and cost for Joint Force Commander (JFC) solution delivery. Some examples include the Modular Open System Architecture (MOSA), Super Strypi launch vehicle, open manufacturing, and Autonomous Flight Safety System (AFSS). Enabler projects are often executed by teaming with other national security stakeholders such as DARPA, National or Service Laboratories, and often use Small Business Innovation Research (SBIR) contracts.

As part of the Enabler mission, ORS conducts S&T development for responsive space needs, however, with the ORS Office Director now reporting to the Air Force Program Executive Officer Space (AFPEO/SP), the Office will change to better leverage available service processes. The ORS Office will participate in the Air Force Program Executive Officer /Technology Executive Officer review process to identify technical needs and requirements for responsive space capabilities. The S&T community responds to the PEO with S&T guidance and solutions, and tech roadmaps then AFSPC/A8 briefs final guidance to S&T community. Because the Office now is integrated into SMC, this process will be used to address responsive space needs as a specific category of requirements.

A more recent option now exists as an additional means to accomplish the second part of the ORS mission statement. The reporting structure through the AFPEO/SP attributed to the FY13 NDAA provides a streamlined approach to satisfying identified warfighter needs. This approach targets documented needs that are of immediate concern and appropriate for ORS solutions. Under the authority of the AFPEO/SP, the ORS office is well-positioned to assist other program offices in developing solutions beyond the more formal urgent needs efforts triggered solely by a memorandum from CDUSSTRATCOM. Selected projects will be accomplished using ORS authorities for operationally responsive acquisition to advance capabilities under other program elements and often within an established program of record. This is consistent with the intent to further ORS concepts outside of just the ORS office. Implementation of this initiative represents a major step for ORS tenets and authorities becoming more integrated into program offices within Space and Missile Systems Center (SMC) and other product centers.

DOD IMPLEMENTATION PLAN FOR OPERATIONALLY RESPONSIVE SPACE

As part of the implementation of the Operationally Responsive Space Office, the Under Secretary of Defense issued an implementation plan in April 2008. It defined the ORS mission and roles and responsibilities. The ORS Office provides the means necessary to space capabilities in order to meet Joint Force Commanders' urgent needs for on-demand space support, augmentation or reconstitution. ORS projects are executed on highly accelerated timelines, require close and creative relationships with industry, and leverage interactions across a broad range of government partners in the United States and with our allies.[7]

The ORS Office operating principles are based on highly streamlined and expedited processes across all phases of the program from concept through fielding activities to support the urgent space needs of the JFCs as directed by the DoD EA for Space. Other factors such as technical feasibility and value are also considered, but meeting the JFCs' timeliness requirements is paramount. ORS is complementary to current space capabilities and is a means to implement new capabilities designed to provide the timely application of space power in a theater of operations. Perhaps most important, ORS provides a conceptual framework and new way of thinking across the full spectrum of doctrine, organization, training, materiel, leadership and education, personnel, and facilities to attain more agile, resilient, and "tailorable" space capabilities.

The key ORS operating principles include a short, narrow chain of command, centralized control, decentralized execution. "best athlete" execution, Funding Stability, and a Small, Handpicked Team. The entire ORS effort will be based on small, streamlined government and industry teams, empowered to execute a difficult mission. The ORS Office will leverage existing acquisition organizations contracts/developments to the greatest extent possible. The chain of command for "best athletes" will put the necessary tools in place to ensure ORS acquisition and contracting are streamlined to the maximum degree possible.

The ORS Office links established ORS needs and Science and Technology to develop capabilities, with acquisition support, to fill operational needs and gaps by working to identify and present options for concepts/solutions and experimentation, conduct concepts development, solutions assessment, rapid evaluation of alternatives, experimentation, and modeling and simulation support, plan for operational experimentation and Military Utility Analyses, and develop budgetary recommendations for ORS solutions.

The ORS Office has authorities that allow the rapid acquisition and contracting required to meet USSTRATCOM identified timelines. Existing authorities in the FAR and DoDI 5000.02 are utilized and tailored as applicable. The objective of ORS acquisition processes is to streamline system development bringing capabilities to bear quickly and effectively and to minimize oversight and bureaucracy, as appropriate, at all stages of the acquisition process in response to urgent need requests. ORS acquisition process must work within the constraints of a small office. Desired attributes for ORS acquisition are timely — fast, agile, and flexible, "best athlete" approach in selection of executing agents, processes that are tailored and disciplined in execution, networked, integrated, and comprehensive across the ORS community, authority that is clear, delegated, and direct, and oversight that is appropriate and risk tolerant.

ORS SUCCESS STORIES

The Operationally Responsive Space Office has had a number of significant achievements since its inception in 2007. To date ORS has responded to five USSTRATCOM directed urgent needs which resulted into two ORS programs, ORS-1 and ORS-5. The office has advanced nine pillars of enabling capabilities including launch, ranges, busses, payloads, C2, TPED, CONOPS, authorities. Progress across all pillars to achieve open-systems, rapidly-configurable, multi-mission, modular space vehicle architecture. The ORS Office demonstrated performance with 5 launches in 4 years: (July 2008) JUMPSTART: Rapid transport & integration – *6-day call-up demonstrated;* (May 2009) AFRL's TacSat-3: Hyperspectral imager – *Transitioned to Operations in June 2010;* (June 2011) ORS-1: Dedicated battlespace awareness – *CENTCOM employed*; (September 2011) NRL's TacSat-4: Comm-on-the-Move – *JMUA completed*; (April 2012) Spaceloft-6: Sub-orbital test bed demos -- *Proof-of-concepts realized*; and (November 2013) ORS-3: Multiple CubeSats on Minotaur 1 – *31 payloads and experiment.* ORS is continuing to deliver new and enduring capabilities to the warfighter.

ORS-1: First ORS Office Operational Mission

ORS-1 was initiated at the direction of the Commander, U.S. Strategic Command and the DoD Executive Agent for Space to address a U.S. Central Command (USCENTCOM) need for enhanced battlefield awareness. ORS-1 is the first and only dedicated space intelligence capability for USCENTCOM, introducing Operationally Responsive Space as a new paradigm for the Department of Defense. The fielding of the first Operationally Responsive Space (ORS) satellite, ORS-1, was tremendous accomplishment for our Department of Defense (DOD) and Air Force. ORS-1 is proving that significant military surveillance capability can be provided using a small satellite fielded in about two years for about $200 million, including space vehicle, launch, and all associated ground infrastructure and operations costs. The satellite, originally designed to operate for a year, reached orbit in June 2011 and continues to provide support. In January 2012, AFSPC/CC approved ORS-1 Operations Acceptance and Initial/Final Operational Capability and was fully accepted for mission operations. On 1 July 2015, ORS-1 completed its fourth year in space supporting USCENTCOM and other COCOMs. ORS-1's development, launch and operations demonstrated the possibilities to meet the Joint Force Commander's (JFC) emerging needs for responsive, resilient space capabilities. The rapid development and deployment of the ORS-1 spacecraft reinforces the potential of low-cost, tactically focused satellites that can augment existing ISR capability for the warfighter. ORS-1 provides USCENTCOM an assured ISR capability that cannot be preempted by support to other users. It is an enabler for sustaining operations and objectives in a highly volatile region and is laying the path for future rapid reaction space systems. The team doggedly adhered to a "good enough to win" approach to deliver a capability that was affordable, rapid, and risk tolerant.

Figure 2. ORS-1 SYERS2 Payload and Bus

ORS-1 demonstrated Rapid Acquisition: Contract awarded in less than 3 weeks; maximized use of existing systems and architecture including AFSPC's Multi-Mission Space Operations Center Ground Support Architecture for command and control; utilized a U2 derived payload and the space qualified TacSat-3 bus. It featured standardized spacecraft to ground interfaces for payload, tasking, and scheduling using the NRL developed Virtual Mission Operations Center. ORS-1 demonstrated rapid development and deployment in 32 months after program approval. Designed as a quick--response and low--cost alternative to traditional satellite systems, ORS--1 differs in several ways, but its primary distinction stems from its birth. It took approximately three years to develop from concept to launch and on--orbit operations, compared to seven years or longer for traditional systems. Its payload technology was gleaned from a camera first developed for use aboard U2 spy planes decades ago. Contractors attached a larger telescope to the Senior Year Electro--Optical Reconnaissance System--2 camera to give it adequate resolution from orbit. Although originally dedicated to USCENTCOM support, ORS-1 capabilities have been extended beyond a single combatant commander. The vehicle was designed to support CENTCOM, but the ORS-1 team recognized it could do so much more. We sent word out to U.S. Pacific and U.S Africa Commands, and reached out through the Joint Functional Component Command directly to combatant commander staffs to let them know we could support their taskings too. As a result, ORS--1 now provides effects for PACOM on a regular basis and does so occasionally with AFRICOM and Special Forces commands. ORS-1 earned early combatant command acceptance in less than 90 days after liftoff and was named one of nation's top new technologies by C4ISR magazine.[8]

Recognizing the innovation of the ORS-1 mission and its success, the ORS-1 team captured a number of "Lessons Learned" which will be incorporated into future ORS missions. These include: TacSat-3, TacSat-4, and ORS-1 demonstrated that small satellites have military utility; refining requirements directly with warfighter results in out-of-the-box solutions that work; key stakeholders understand the acquisition, and operational requirements and manage to a "good enough" mindset; a small, agile team – key to executing at a fast pace; adequate and stable funding absolute necessity – senior leadership buy-in and advocacy required; operational prototype capability costs significantly more than S&T demonstration; don't use "Urgent Need" for technology development; and ORS-1 program constantly re-evaluated schedules, approaches, and objectives to explore all acceleration and recovery options.

ORS-1 is going into its fourth year on orbit. One of the neat things about ORS-1 is that it was originally set up just for USCENTCOM and certainly supported them during the conflicts in the Mideast. But because of the responsiveness of the system, we've been able to expand that to support several combatant commanders. It's now three years beyond its design life. It's the kind of system that ORS was set out to do: rapidly delivered, responsive capability, flex to support a variety of different contingencies. We expect ORS-1 to continue for at least a couple more years. How has ORS-1 been a pathfinder for other programs? One of the most important lessons of ORS-1 was the ground system.

That was the first operational system flown on the Multi-Mission Space Operations Center. It's now one of five satellites that have flown on that system. As a matter of fact, the next system we're building, ORS-5, is going to fly on that system as well because we learned the lesson of open architecture and flexibility built in up front. That benefit has been huge across a lot of Space and Missile Systems Center programs and it's turning into a look at how we do ground systems across the board.[9]

ORS-3: Enabler Mission

The ORS-3 Enabler Mission launched the Air Force's Space Test Program Satellite-3 and 28 CubeSats on an Integrated Payload Stack on November 19, 2013. These enablers not only focus on the ability to execute a rapid call-up mission, they automate engineering tasks that once took months and reduce those timelines to days or hours, resulting in decreased mission costs. ORS-3 launched on November 19, 2013; SMC/AD's

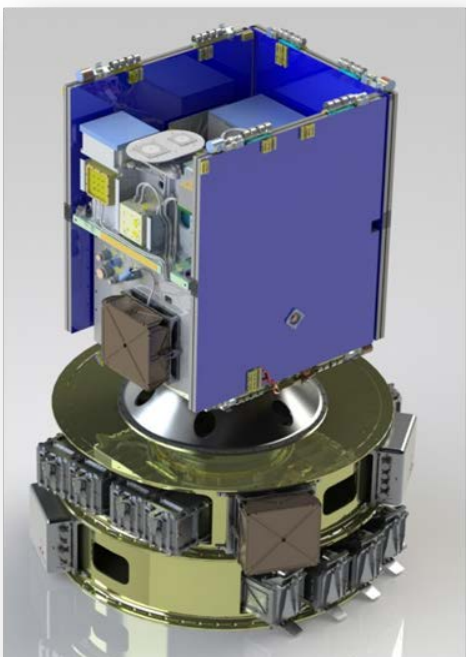

Figure 3. CubeStack Secondary Payload Adapter

STPSat-3 launched along with numerous CubeSats as part of the overall ORS-3 mission. Spacecraft separation occurred shortly after lift-off and all 29 payloads were successfully delivered to the desired orbit. The ORS-3 mission demonstrated several ORS objectives in making access to space more efficient and cost effective. First, this mission demonstrated the use of an FAA Licensing approach of a Government launch system to take advantage of a more commercial like process. This allowed the launch service contractor, Orbital Sciences Corporation, to take advantage of commercial practices that will potentially drive the overall launch costs and timelines lower. Additionally, the mission demonstrated a secondary payload adapter designed to dispense multiple CubeSats known as CubeStack. This adapter allowed for up to eight 3U CubeSats (or equivalence of) to be manifested. This allowed for the additional launch capacity to be used and increases access to space for CubeSat programs that are executing science mission or demonstrating new technologies. The ORS Office has been working on several enablers that focus on automating time consuming and thus costly processes. Two new tools have been developed, the first focuses on automating the launch service contractor's mission trajectory development. As a result of the ORS investment in this area, a 3 to 4 month process has been automated and produces a validated flight trajectory and the necessary data to complete the mission specific software data load in just under 48 hours. A second process that has been automated is focused on the flight safety development of the mission rules and graphical user interfaces the flight safety officer's use. Again the ORS investment has taken a multi month process and reduced that to five days. In both cases that not only represents a responsive solution, it also reduces the engineering hours which leads to lower cost. Finally, the ORS Office has partnered with the Government safety offices at the Air Force and NASA ranges to develop an Autonomous Flight Safety System (AFSS). An AFSS box was flown on ORS-3 in a demonstration mode which will also serve as one of three certification flights. AFSS has the potential to significantly reduce the cost of range operation and maintenance cost by eliminating the aging flight safety infrastructure that is currently used.

The Joint Space Operations Center (JSpOC) orbital analysts at Vandenberg AFB tracked all of the 28 small spacecraft "CubeSats" and the larger STPSAT-3 deployed during the ORS-3 launch. The intensive planning effort and advanced coordination with our space surveillance units in the 21st Space Wing, MIT Lincoln Labs, and the ORS Office played a very significant role in ensuring our success and continued safety of flight in the space domain." The ORS-3 Mission, also known as the Enabler Mission, demonstrated launch and range improvements to include: automated vehicle trajectory targeting, range safety planning, and flight termination; a commercial-like procurement and Federal Aviation Administration licensing of the Minotaur I rocket; and the Integrated Payload Stack consisting of 29 spacecraft.[10]

ORS ENABLERS INITIATIVES

ORS pursues critical or enabling technology development within the disciplines of launch and range, ground systems, and/or modular bus/payload systems to reduce time and cost for JFC solution delivery." Enablers are those activities that build capabilities across the range of disciplines required to advance responsiveness of the space enterprise as a whole.

ORS Open Manufacturing Initiative

Reducing the cost of space access is an important part of Operationally Responsive Space. Guidance provided to the ORS Office at its inception clearly and purposefully imposed unprecedented cost and schedule goals to drive the family of solutions they considered appropriate and sustainable for ORS. The 2007 National Defense Authorization Act highlights that launch vehicles should be less than $20 million a copy and integrated satellites should be less than $40 million. ORS is using novel manufacturing techniques to reduce costs and improve the defense industrial base. Technology life cycles are getting shorter, and satellites are no exception. A decade ago it was not uncommon for satellites to take almost ten years to design, build, and launch, with many costing almost $1 billion per spacecraft. Today, many small commercial satellites can be manufactured in months for a mere fraction of the cost. Capabilities of large satellites generally outclass small satellites in functions related to SWAP (Size, Weight, and Power), and, greater investment per spacecraft can support extensive additional R&D. However, cycles of innovation for large satellites lag dramatically by comparison and risks per spacecraft are profoundly increased. In government, continual cost reduction is far more difficult to achieve because systems are not designed to take advantage of a rapidly changing environment. The acquisition cycle of many government spacecraft often outlives the actual tactical requirement. Disproportionate management overhead has been created by costs related to procurement, standards, and processes, all designed to preserve integrity of government investments. As costs continue to drop and satellite life cycles grow shorter, associated government business processes designed for expensive longer life cycle satellites need to be redesigned for a new world of tactical satellites, without discarding best practices that have led to U.S. space success and superiority.

MicroSat (spacecraft weighing less than 100Kg) will become the larger part of the global satellite market by 2025. Government processes for space qualification and mission assurance must catch up to ever faster moving evolutions in the space industry. Today's satellite space process involves a cumbersome collection of manufacturing quality control measures that are fundamentally mismatched to ever-shortening satellite life cycles. These processes have been in place to ensure the success of multi-billion dollar satellite programs over multiple decades, and to guarantee that billion dollar satellites perform as expected. Traditional paradigms of mission assurance and risk management are antiquated for easily replaceable satellites. Legacy procedures for management of risk and mission assurance are wholly born out of the legacy space era and analog methods. While this approach worked well for exquisite satellites, it has proven to be overly restrictive and antiquated in the face of the digital revolution, particularly in light of the ready availability of advanced analytics in today's environment. Quality Assurance, heavily weighted in personnel overhead costs, can add more than 50% to the total cost of a satellite due to legacy processes. This is prohibitively inefficient in the new world of short-lived tactical satellites. Until recently, labor intensive processes applied to manufacturing and quality control by seasoned subject matter experts have been some of the prime underlying drivers of very high satellite costs.

The ORS Office has pioneered new manufacturing techniques and is leading the way in reducing space costs and initiating innovation breakthroughs. Open Manufacturing now reduces costs and improves quality. Costs are driven down significantly through standardization, use of off the shelf components, and making many more "one size fits many" satellites. These cost declines are principally achieved through reuse of change tolerant systems, reducing exquisite space qualification requirements, automating testing and fabrication, and reducing labor costs related to manual assembly and legacy mission assurance approaches. Advanced robotics combines the creative diversity of human ingenuity with highly repeatable processes. The best of natural and artificial intelligence, hardware, and software is being increasingly leveraged to build satellites with the aid of robotics. Advanced robotics used in Open Manufacturing allows computerized robots to perform processes requiring exact measurements (such as satellite Assembly, Integration and Test (AI&T)), delivering a lower error rate through controlled repeatable processes that also drive down space costs and reduce time to launch delays. ORS uses autonomous manufacturing techniques and digital assurance to produce operationally-relevant "canesterized" spacecraft (6U CubeSats).

Leveraging the strength of the U.S. manufacturing process has allowed ORS to take advantage of revolutionary advances that have occurred over the last decade. These dynamic leaps forward have created advanced automation, process quality improvements, and have lessened the physical labor intensity of humans, which represents a significant portion of manufacturing costs. "Digital Assurance" drives down costs of quality control by using cameras, sensors, and software to monitor quality in the satellite building process real-time. By capturing the build process and mission assurance data real-time during fabrication, the data can easily be manipulated, analyzed and presented to appropriate decision makers in a much more streamlined approach. Defense Industrial Base (DIB) assurance is accomplished by updating aging spacecraft manufacturing facilities with modern digital approaches, such as are already being employed in almost all other manufacturing sectors.

Autonomous Flight Safety System (AFSS)

A collaborative effort was established between the ORS Office and its partners to develop an AFSS that uses on-board tracking and processing to terminate an errant launch vehicle. Traditional Flight Termination Systems rely on a man-in-the-loop to make decisions on the state of the vehicle based on radar tracking and sensory data sent from onboard the vehicle via telemetry. The AFSS brings the decision process onboard the vehicle via digital high speed processing of primarily positional data coming from an onboard Global Position System (GPS) and/or Inertial Navigational System (INS) sensors. AFSS continuously determines the instantaneous impact point (IIP) of the vehicle based on real-time sensor data, and makes the decision to terminate the flight when the vehicle becomes hazardous with respect to its predicted IIP being in violation of Range Safety Boundary allowances. AFSS payoffs include full qualification and range safety approval, reduces permanent range infrastructure, supports over-the-horizon operations, provides remote launch capability where no ranges exists, enables quick call up to launch systems and automated launch planning and operations, provides cost savings on a per mission basis, and reduces overall operating costs (launch vehicle providers, range safety, maintenance and ground support). The successful launch of a Minotaur 1 rocket from NASA's Wallops Flight Facility in Virginia marked the first flight test of a new on-board safety system aimed at preventing errant rockets from causing damage or bodily harm on the ground. The GPS-aided Autonomous Range Safety System (AFSS) uses tracking data independent from on-board vehicle instruments to calculate whether a rocket is on course after leaving the launch pad. The system determines whether and when it is necessary to destroy a rocket that has strayed from its planned flight path. Currently a destruct signal is sent to the rocket from the ground by a range safety officer, but the AFSS could create an option to automate that process. Eventually we could take the man out of the loop once it proves itself. A final test could be done at the Pacific Missile Range Facility on Kauai, Hawaii, in fall 2014 during the ORS-4 launch aboard a brand new, rail-launched rocket called the Super Strypi.[11]

CURRENT ORS MISSIONS

The ORS Office continues to support enabler initiatives and USSTRATCOM urgent needs with several upcoming programs.

ORS-4: "Super Strypi – Responsive Small Launch"

ORS-4 will launch in October 2015 to demonstrate a new, low-cost launcher to Low Earth Orbit. It will be the first demonstration of a small rail-launched vehicle to launch satellites, called the Super Strypi. The primary payload is a hyperspectral imager built by the University of Hawaii. The ORS-4 Mission is a first flight demonstration of the experimental, low cost, Super Strypi small launch system. The ORS Office is managing development of Super Strypi in partnership with the University of Hawaii, Sandia National Laboratories, the Pacific Missile Range Facility (PMRF) and the Aerojet Rocketdyne Corporation. The goal is to deliver payloads in the range of 300kg to Low Earth Orbit (LEO). This effort includes the development of three new solid rocket motors and installation of a new rail launcher at PMRF. The Super Strypi launch system is designed to reduce cost using established sounding rocket technologies, methods and practices, including rail launch, spin stabilization, low parts count, and rail launch. The University of Hawaii's HiakaSat will fly as the primary payload with an additional 12 CubeSats flying as secondary payloads. An Autonomous Flight Safety System (AFSS) will also fly as a non-separating secondary payload. The ORS-4 mission will launch at a medium technical risk, higher than normally acceptable for operational missions, but acceptable for a first flight mission to meet program and mission partner objectives. Specific mission objectives are to develop responsive, low cost launch system capable of 300kg/475km/45 degree inclination, a cost of $15M in production ($12M desired), to exploit 21st century range technologies with a reduced infrastructure, Autonomous Flight Safety System (AFSS), GPS metric tracking, space-based TM relay, and automated flight planning.

The first flight of a new rail-guided satellite launch system from a military missile range in Hawaii has been delayed until late October 2015 due to problems with the rocket's first stage motor, according to a U.S. Air Force official. Launch delays of the new launch system were driven primarily by technical development challenges on the first stage motor including design and delivery of the rocket motor case and the integrated rocket motor. This motor is now complete along with the rest of the launch vehicle, and the launch is on track for late October from a new launch pad on Kauai. The mission aims to demonstrate a concept to accelerate launch preparations, cutting processing time from months to weeks and slashing the cost of launching small satellites into orbit. The missile range on Kauai is also used for missile defense testing and other military activities. The Super Strypi is powered by three solid-fueled rocket motors based on technology originally developed for suborbital sounding rockets. The launcher will be spin-stabilized and launch on a tilted truss-mounted rail system to point it in the right direction at liftoff, eliminating the need for a complex and costly guidance system. The Super Strypi also carries fins for added stability, and a cold gas attitude control system on the second and third stages will maneuver the rocket in space.

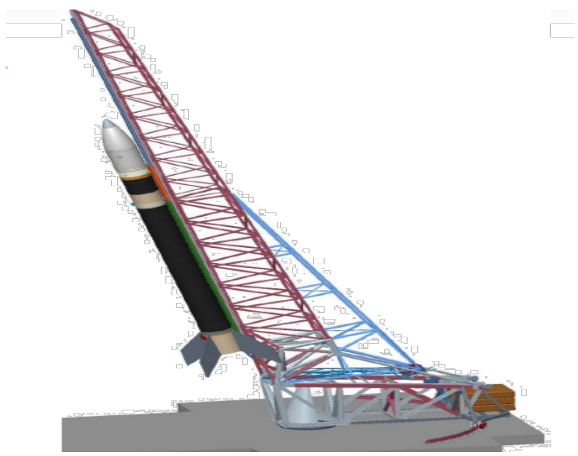

Figure 4. ORS-4 Super Strypi on Rail Launcher

The spin-stabilized, rail-launched Super Strypi launcher is capable of placing as much as 300 kilograms of payload into low Earth orbit. Based on designs developed by Sandia as part of nuclear testing programs dating back to the 1960s, the Super Strypi is ultimately expected to cost about $15 million per mission. ORS hopes the new launcher, essentially a souped-up sounding rocket, will provide a low-cost launch option for small satellites, including CubeSats, which are becoming increasingly popular with universities and government agencies. U.S. defense organizations including the Army, the Air Force and even the National Reconnaissance Office, which is known for building billion-dollar satellites that launch on heavy-lift rockets, have been investing in CubeSats in recent years. The Super Strypi was designed by engineers at Sandia National Laboratories, building on the Strypi sounding rocket developed in the 1960s for nuclear weapons tests in space. Aerojet Rocketdyne is supplying the Super Strypi rocket's three rocket motors. The first stage motor, called the LEO-46, generates nearly 300,000 pounds of thrust. The LEO-46 motor measures 52 inches in diameter and 40 feet long. Aerojet Rocketdyne completed a ground test firing of the Super Strypi's first stage rocket motor in August at Edwards Air Force Base, California. Engineers completed test firings of the LEO-7 second stage and LEO-1 third stage motors in 2012 and 2013. Standing about six stories tall, the Super Strypi can place up to 606 pounds (275 kilograms) into a 248-mile-high (400-kilometer) orbit from the Hawaii launch base, according to Aerojet Rocketdyne. Operationally Responsive Space Office, other Government and industry officials hope the Super Strypi has applications in the commercial industry as a dedicated small satellite launcher. The Air Force estimates the Super Strypi launch system will cost about $15 million per flight once in production, with a goal of cutting the unit cost to $12 million.[12]

ORS-5: Operational Demonstration for SSA

The Air Force is assessing future space situational awareness (SSA) opportunities to continue the SBSS satellite program's mission to detect, track, and identify objects in deep space. These capabilities are needed to give satellite operators actionable knowledge and the ability to leverage U.S. and allied space capabilities to protect space assets and counter any potential hostile space activities. On February 25, 2014 the Defense Space Council and ORS Executive Committee approved a new mission for the ORS Office located at Kirtland AFB, NM. The ORS Office, in partnership with the Space and Missile Systems Center, Space Superiority Systems Directorate (SMC/SY) and Advanced Systems and Development Directorate (SMC/AD), is developing a mission to answer a Joint Force Commander (JFC) need for Space Situational Awareness of the geosynchronous (GEO) belt. The ORS-5 program tasked Massachusetts Institute of Technology-Lincoln Laboratory (MIT/LL) to design and build an operational demonstration of the SensorSat satellite, which continuously scans the GEO from a low earth orbit. The ORS-5 program will demonstrate a low cost small satellite launch capability and autonomous operations via the existing Multi-Mission Space Operations Center ground architecture. The overall objectives of the ORS-5 program are, in priority order are to demonstrate technologies that could prove "good enough" for geosynchronous SSA, create risk reduction opportunities to a future program of record, and develop and demonstrate ORS enablers and principles. In addition, the ORS-5 mission will act as a pathfinder for technologies to be used in a follow-on to the current Space Based Space Surveillance satellite. ORS-5 provides risk reduction for cutting-edge technologies to be transitioned to Space-Based Space Surveillance

(SBSS) system Follow-On program. ORS will execute a technology transfer strategy, seeking opportunities for early industry involvement through requests for information and a near-term industry day. The Operationally Responsive Space (ORS) program is to fly a single demo vehicle to become familiar with its strengths and capabilities and can maximize them in the follow-on.

A 2014 Space News article announced that "The U.S. Air Force is hoping to bridge a potential gap in on-orbit space surveillance capabilities with a small satellite launching as soon as 2017 that would be developed by the Operationally Responsive Space Office. General William Shelton, commander of Air Force Space Command, told the House Armed Services strategic forces subcommittee that the Operationally Responsive Space (ORS)-5 mission also would act as a pathfinder for technologies to be used in a follow-on to the current Space Based Space Surveillance (SBSS) satellite. Perhaps it'll provide us a little bit of operational capability in the interim," Shelton told Space News after the hearing. "This will be a trailblazer so the development process here will be as quick as we can make it." The technologies demonstrated aboard ORS-5 could be applied to SBSS follow-on, Shelton added. The Air Force's 2015 budget request describes the ORS-5 mission as addressing "rapidly evolving threats and to serve as a pathfinder in this vital mission area."[13] ORS-5 is planned for a mid-2017 launch using an innovative commercial launch services contract.

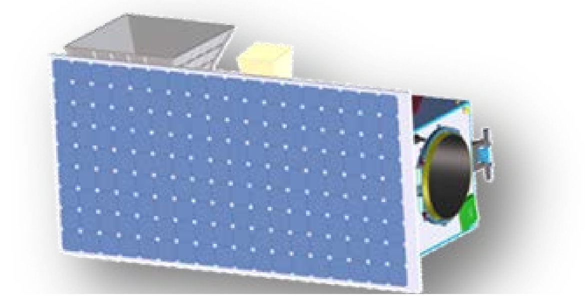

Figure 5. MITLL SensorSat

Modular Space Vehicle Bus (MSV)

The ORS Office is fully invested in producing an ORS architecture that is redefining the space enterprise. The end state vision of the ORS Concept consists of reconfigurable, modular systems with standard interfaces that are interoperable with the existing ground systems architecture. This concept will be demonstrated in the MSV Enabler Mission. The program consists of a bus called Modular Space Vehicle (MSV) that employs a Modular Open System Architecture, using Plug-n-Play technology to allow for rapid manufacturing, integration and testing. The MSV spacecraft bus, developed by a team led by Northrop Grumman, was delivered to the Department of Defense's (DoD's) Operationally Responsive Space (ORS) Office at Kirtland Air Force Base, New Mexico, in February 2014. Objectives of the ORS-2 initiative are to develop multi-mission bus architecture: Standards-based, modular, and rapidly configurable; develop multi-mission payload architecture; develop end-to-end modular satellite vehicle processing, and demonstrate End-to-End architecture to include satellite system, ground systems architecture and innovative processes.

The MSV program was launched as part of the larger ORS-2 enabler mission which aims to develop, assemble, integrate, launch and operate small satellite systems rapidly and cost-efficiently. The preliminary design review (PDR) of the MSV was completed in November 2011, the Critical Design Review (CDR) was completed in June 2012 and the assembly, integration and functional testing of the MSV bus hardware were completed by Applied Technology Associates (ATA) in July 2013. The MSV implements a Modular Open System Approach (MOSA) using Space Plug-n-Play Avionics (SPA) to enable rapid manufacturing, integration and testing. The spacecraft bus can be assembled and integrated with the payload in a matter of days. Fitted with modular radio frequency (RF) and electro-optical payloads, the MSV bus possesses multi-mission capabilities in communications, tactical persistent intelligence, surveillance and reconnaissance, tactical electronic support and space situational awareness. The MSV is capable of operating in low earth, medium earth and geosynchronous orbits, accommodates payloads for a vast range of missions including radar imaging, missile warning, military communications and weather, and has a life expectancy of one to more than seven years.[13]

It can be launched from launch vehicles such as the Minotaur I and IV, Evolved Expendable Launch Vehicles (EELV) and the Falcon 9. The MSV is also compatible with the EELV Secondary Payload Adapter (ESPA). The standard plug-and-play interfaces enable the checking of the payloads prior to integration and the spacecraft can use common test equipment for all missions, the flexible power subsystem can be configured for multiple missions by adding or reducing batteries and solar arrays, and the MSV system can accommodate last-minute payload and bus component changes with minimal impact to cost and schedule. The equipment's of the MSV are assembled on a common payload deck, and the components are all plug-and-play objects that can be freely interconnected. The MSV features a command and data handling (C&DH) subsystem which is comprised of nine flight Applique Sensor Interface Modules (ASIM) and one SPA

Spacewire Network router with flight software incorporating a BroadReach processor.

The Space Plug-N-Play Avionics (SPA)-Spacewire (SPA-S) central router and power distribution unit provides a central networking of all units, and the SPA components are connected to the C&DH subsystem through a standard SPA connector or cable. "The MSV is capable of operating in low earth, medium earth and geosynchronous orbits." Other non-SPA components including star trackers, coarse sun sensors, inertial reference unit (IRU), global positioning system (GPS) and reaction wheels are fitted with an ASIM to electrically connect them to the SPA-S and SPA components. Batteries are fitted on the payload deck for multi-mission power storage and power is generated by solar panels mounted on its wings. Communications subsystem includes both space-ground link system (SGLS) for command and control and a common data link radio that enables playback of mission data directly to deployed field terminals. SPA messaging between hardware and software components is enabled through Satellite Services Manager (SSM).[14]

The program was originally planned as a radar mission but the program was re-structured following budget constraints. Plans are now being formulated to fly the MSV bus with the JPL developed COWVR payload. The Compact Ocean Wind Vector Radiometer (COWVR) which is being designed, built and tested by the Jet Propulsion Laboratory for an Air Force proof-of-concept technology demonstration mission. COWVR is a low-cost, low-mass, low-power fully-polarimetric imaging radiometer system operating at 18.7, 23.8 and 34.5 GHz and based on the Jason-2/3 Advanced Microwave Radiometer (AMR) design. The fully-polarimetric observations enable retrieval of ocean surface wind vector, as well as other key environmental parameters such as perceptible water vapor, cloud liquid water, precipitation rate and sea ice. A compact highly integrated MMIC polarimetric combining receiver implementation, lowering the system mass and power which in turn makes the system well suited for deployment on smaller class, lower cost satellites. If approved, MSV/COWVR would be launched in 2017 using a “ride share” concept.

ORS WAY FORWARD

The ORS Office was given a strong endorsement by Air Force leadership through the 2014 Report to Congress. Air Force Space Command is committed to Operationally Responsive Space and taking advantage of lessons learned from the ORS program to look at building smaller satellites, some of which represent disaggregated capabilities and others which would merely take advantage of the smaller sensor packages. Resilient space systems are a major area of emphasis for the ORS Office. Without assured access to space we cannot replenish our constellations as they age or worst case if we lose one to an attack, debris event or system failure. Therefore, assured access to space is one of the cornerstones for resiliency. We need a resilient space architecture that can fight through any threat and come out the other side. “Building and fielding resilient space systems is fundamentally important to sustain critical missions in an era of increasingly sophisticated counter-space threats. Resilience means we can provide space capabilities to our forces around the world, even in a congested, contested, and competitive environment. Factors influencing resiliency are assured access to space through timely launch, the number and type of satellites we have in orbit, and the strength and type of signals the satellites transmit. Disaggregation can increase resilience by dispersing capability across smaller, less complex satellites to avoid single-point failures that could cause a catastrophic outage over the battlefield. In addition, we can use commercially hosted payloads, lease commercial capabilities, or leverage our allies’ satellites to round out our capabilities. And we have to be resilient to be able to operate through that warfighting domain. And so resilience is made up of a number of things. Disaggregation could be a big piece of that, because right now we have a very small number of satellites on orbit and our adversaries know exactly where they are. If you know exactly where they are, then it's fairly easy to figure out how to deny the capabilities that comes off those satellites.”[14]

General John Hyten, AFSPC Commander said, “Now we have that perfect marriage of the ORS office under SMC with the right authorities, the right kind of thought process…I think we can actually go very fast, deliver those capabilities, and fulfill the warfighter needs in the timeframe that we need whereas if we went through the longer, more traditional big program office it'd be a couple of years before we get started. And Congress told us to do that; I think there are a number of congressional leaders [who] really want us to go after real programs under the ORS construct, not just experiments.” “We're making a huge push this year to take full advantage of the operational response of space authorities that are in the law. We have two requirements that looked like they meet the description that you just made for ORS. One is the space-based space surveillance system follow-on. The ORS office is already building a pathfinder towards the next generation. It just seems logical to us to take that work they're doing on the pathfinder and follow right along with the operational capability to do that. It is operationally responsive space. The authority should allow us to go faster and come up with a capability to do that for a cheaper price as well, and I think we can do it faster and cheaper. "[15]

ORS is supporting the approved development of ORS-5, a Space Situational Awareness mission on the geosynchronous (GEO) belt. While not finalized, planning is underway for potential future ORS missions. In April 2015, ORS Executive Committee approved the ORS program to mitigate gaps in space based environmental monitoring. The ORS Office and SMC Remote Sensing Directorate will jointly execute the program. Funding will come from the AFSPC Weather Mission program element supported by the ORS Office staff as funded by the ORS program element. The program will address two JROC validated capability gaps: the 2015 gap for "Ocean Surface Vector Winds" and the 2021 gap for "Tropical Cyclone Intensity." "ORS Next - Weather System Gap Filler addresses emerging gaps in space based environmental monitoring provides ocean surface vector wind and tropical cyclone intensity data. The prioritized mission objectives are "Good Enough" solution for Joint staff JROCM Need; ocean surface wind vector requirements: refresh rate, resolution, speed and direction uncertainty; and utilize ORS principles to streamline acquisition process The ORS Office will pursue the most responsive option to minimize the impending gaps which is expected to be a passive space based microwave solution as the operational gap filler.[16] Due to the joint nature of the program and this being the first application of ORS principles in a program of record, the Under Secretary of Defense (AT&L) requested the program team work with AT&L staff, Joint Staff, Navy, and AF to develop an acquisition strategy.

In summary, the Operationally Responsive Space Office will continue to move forward retaining capability for Rapid Capabilities Office-like office to address Urgent Needs, integrate ORS into SMC Processes for efficiencies leveraging support functions to allow ORS staff to focus on innovative acquisition and technical solution, and integrate ORS processes into the SMC Acquisition systems.

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