New Mission, New Orbit, No Problem—Applying the Responsive Space Capability to Meet the ORS-6 Mission

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ABSTRACT

From a re-purposed Air Force bus, to a new reconfigurable NASA sensor, to the commercial ride-share launch service, the ORS-6 mission is a model of how flexible architecture, agile management, and creative engineering adjustments to heritage instruments can deliver first rate weather data with significant cost and schedule savings. The Compact Ocean Wind Vector Radiometer (COWVR) payload will measure ocean surface wind vectors at a comparable resolution and measurement accuracy to the WindSat radiometer on Coriolis, while using an order of magnitude lower power and mass. By adding polarimetric electronics and rotating capabilities to the Advanced Microwave Radiometer (AMR) flown on the Jason 1, 2, and 3 satellites, the COWVR instrument leverages years of heritage design, keeping non-recurring engineering costs down and reducing risk. Operationally Responsive Space will fly COWVR on a bus originally built for a mid-inclination, LEO, synthetic aperture radar mission. Because the bus was made with the Modular Space Vehicle architecture, a meld of both Space Plug-n-Play Avionics and Integrated System Engineering Team bus standards, it requires only a few moderate modifications to accommodate the new COWVR Payload in a higher altitude, high inclination, sun-synchronous orbit. Launching in the fall of 2017, ORS-6 will provide operational-like capabilities to the US Air Force weather program while space demonstrating the new bus and payload technology. This paper highlights how the modular construction of the bus allows for timely reconfiguration, assembly, and integration with the payload. Additionally, we present an overview of the COWVR instrument capabilities and how it will serve as a partial gap filler to the Air Force's Weather System Follow-On program. We emphasize how ORS-6 represents exciting possibilities for future space missions in terms of adaptability, cost savings management, and technological innovation.

INTRODUCTION

Cost overruns and schedule slips have become the norm in building and launching satellites. The cycle of the increase cost of space missions, leading to longer schedules and fewer missions, fueling demand for higher reliability, which then spirals back to higher cost, has begun to cripple both NASA and the DoD[1, 2]. Because launch costs for a CubeSat are so much less than they are for a large satellite needing to pay for a dedicated rocket, CubeSats have begun to break this cycle. The lower cost results in less demand for reliability, more room for innovation, and a greater access to space.

However, there is a limit to the CubeSat sphere of influence. There are payloads that simply cannot be shrunk down to CubeSat size. How can we positively affect the spiraling costs of the large, high dollar operational missions? The ORS-6 mission is a rare example of demonstrating technology that will directly influence the future acquisition of a high cost objective system: the Air Force's Weather System Follow-On (WSF), currently estimated to cost roughly $800 million[3] and launch in the early 2020s.

The ORS-6 spacecraft is being built for the US Air Force Space and Missile Command Weather System Follow-On (SMC-RSRW) by the Operationally Responsive Space office (SMC-ORS) under the Rapid Response Space Works contract. ORS-6 will launch in the fall of 2017 into a roughly 600km, sun-synch orbit. This is an orbit that neither the bus nor the payload were designed for, yet because of the flexible design of the bus, with the Modular Space Vehicle (MSV) architecture, ORS will reconfigure the bus and payload in a timely and cost efficient manner to meet the critical needs of the Air Force and weather community.

Weighing in at just over 300kg, ORS-6 is a small satellite in the historical context. Even though this mission represents an initial investment of Non-Recurring Engineering (NRE), the mission specific costs of the payload, with operational-like performance, the reconfiguration of the bus, the launch, and ground system are remarkably low. Furthermore, much of the technology investment in both the bus and payload design will serve as a template for future missions, once space qualified and demonstrated by this mission, thereby recouping much of the NRE costs. The ORS-6 spacecraft is an example of how small satellites can provide technology demonstrations that can enable, reduce the cost, and reduce the risk of large budget operational missions such as the Weather System Follow-On.

The ORS-6 spacecraft will launch as a commercial ride share. The commercial rideshare is among the first pursued by the Space and Missile Command and provides significant cost savings over the traditional dedicated launch service. Nonetheless, as a ride along the program has limited control over the launch window and the orbital parameters, placing extra constraints and necessitating additional bus and payload modifications as discussed below.

THE BUS

The ORS-6 bus was originally designed and built for ORS-2, a synthetic aperture radar mission intended for a mid-inclination, ~400km orbit[4]. ORS-6 will space demonstrate the MSV architecture, an architecture specifically created to allow for straightforward reconfiguration and seamless integration with any payload and any mission parameters as seen in Figure 1.

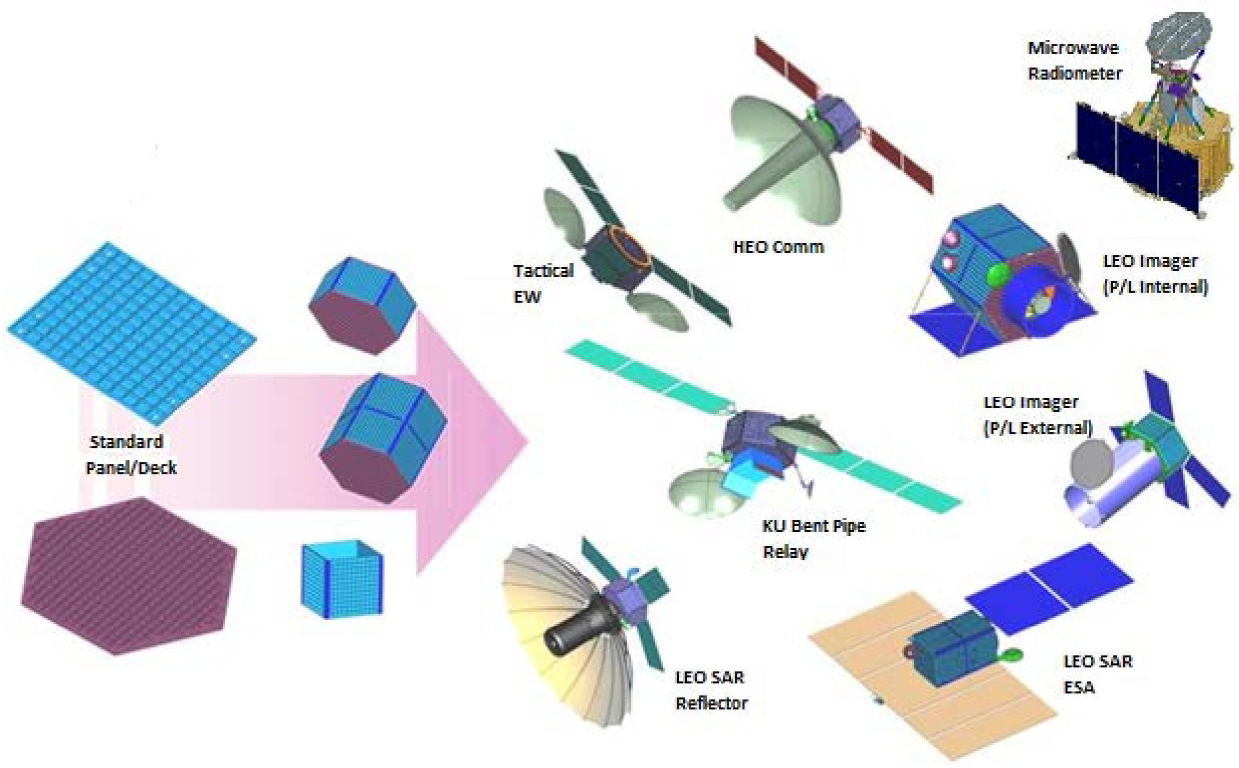

Figure 1: The many configurations of the MSV Architecture

MSV implements a Modular Open System Approach (MOSA) that uses the Space Plug-n-Play Avionics (SPA) standard, facilitating seamless payload integration by treating the payload as another subsystem endpoint with a standard communication interface.

Repurposing the ORS-2 bus for the ORS-6 mission will require only one major modification and three components to be made. The one reconfiguration is of the solar arrays, which were initially arranged in three sections (Figure 2) and will be joined together into one unit for optimizing power generation in the sun-synch orbit, as shown in Figure 3. The Payload Interface Unit (PIU) is a replacement of an ORS-2 designed but never built payload SPA interface for power control, communications and electrical interface between the bus and the payload. Lastly, the ORS-2 mission was de-scoped before a communications system was designed and built. Therefore, two new items are being manufactured for the ORS-6 communication subsystem; the radio and the radio SPA interface.

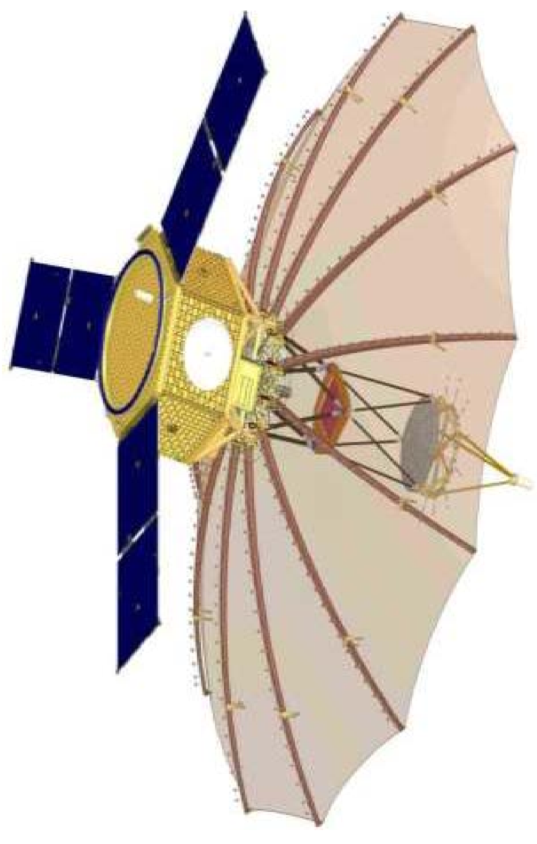

Figure 2: The ORS-2 bus configuration with the SAR payload

A common hurdle in the development of a spacecraft is the frequency allocation and approval process, which can easily take a year to complete. In going through this process the decision was made to use a Software Defined Radio that can dynamically change its receive and transmit frequencies and allow us to use both USB (Universal S-Band) and SGLS (Space Ground Link System, L-band) for data uplink. This has given the program the assurance that if our frequency is not approved after months of going through the frequency approval process, there will not be large schedule and cost hits to change the requested frequency. Furthermore, because the spacecraft can now uplink at two different bands, this gives the program the ability to use both the Air Force Satellite Control Network and the Universal Satellite Network ground stations.

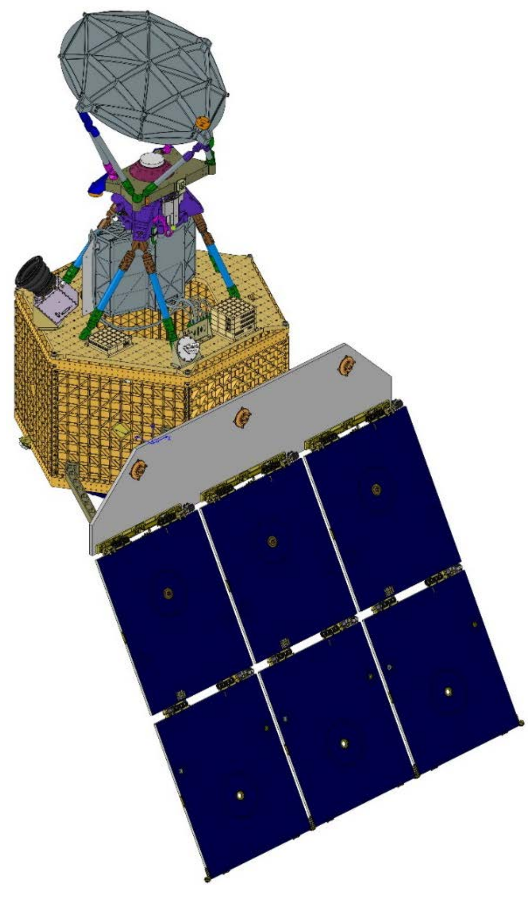

Figure 3: ORS-6 Configuration with the COWVR payload

In addition to the small modifications needed to change the bus from ORS-2 to ORS-6, there are a number of further realized successes stemming from the Modular Open System Approach spacecraft. The subsystems were designed for scalability: an additional battery, and an extra solar panel can be added to increase power storage, the ADCS system was simply scaled up to increase slew rates even before ORS-6, there are a number of empty network router ports that allow attachment of extra components or even additional routers, to name a few.

THE PAYLOAD

In recent years the Air Force has experienced a number of unsuccessful attempts in developing a weather system follow on program. NPOESS (National Polar-orbiting Operational Environment Satellite System) was canceled in 2010 due to schedule overruns and delays[5], DWSS (Defense Weather Satellite System) was canceled in 2011[6], and most recently the DMSP (Defense Meteorological Satellite Program) is at risk for termination. Following these setbacks, the Air Force decided to reduce risk, schedule, and cost to the operational follow on mission by seeking out new technology.

The Compact Ocean Wind Vector Radiometer (COWVR) payload was developed and built by NASA's Jet Propulsion Laboratory. COWVR leverages the heritage architecture of the Advanced Microwave Radiometers flown on the Jason satellites[7]. COWVR was built utilizing many of the same electronics designs as the AMR with small mission specific modifications, providing cost savings as well as the mission assurance of almost an accumulated decade of on-orbit use.

The innovative COWVR design advances the technology of conically imaging microwave radiometers providing nearly equal sensitivity and performance as operational radiometers such as WindSat[8] while being mechanically less complex and lower cost. The novel conception uses a single feedhorn for all 6 polarizations at three wavelengths, 18.7GHz, 23.8GHz, and 33.9GHz. This, coupled with internal noise calibration sources, implies that the feed horn and all back end electronics can be fixed with only the reflector needing to spin. The basis of the novel design is to perform functions electronically that were previously done mechanically, such as calibration, polarization rotation around the scan, and polarimetric channelization. This also enables the design to be flexible, such as having the ability to move the position in the scan where the instrument is calibrated (discussed further below).

Previous sensors rotated the polarization vector around the scan mechanically by co-rotating all the electronics with the antenna, resulting in significant spun momentum and a complex spin mechanism to pass power and data across the interface. Since COWVR does this electronically, the electronics remain stationary requiring only the light weight reflector to spin. The result is roughly a fivefold reduction in mass and power, and 50 times lower angular momentum than previous conically imaging microwave radiometers (see Table 1[7]). Another important benefit is that since all the electronics are on the stationary side, late modifications, such as those described in the next section, can be made without having to consider disturbing the spin balance of the system, which would not be the case in the heritage design.

Table 1: WindSat and COWVR Properties

Item	WindSat	COWVR
Channels [GHz]	6.8 (x2), 10.7 (x6), 18.7 (x6), 23.8 (x2), 36.5 (x6)	18.7 (x6), 23.8 (x6), 33.9 (x6)
Number of Feeds	11	1
Receivers	22 independent receivers	2 multi-frequency polarimetric receivers
Mass [kg]	330	69
Power [W]	350	90
Spun Momentum [N-m-s]	190	4

ADAPTATIONS TO THE NEW MISSION

Spacecraft buses, like almost every aspect of traditional space capabilities from stove pipe ground systems to dedicated launches, have historically been made as one-of-a-kind hardware specifically tailored to a given mission. While the development of CubeSats has helped to reduce the expensive one-off bus designs, this shift to reducing NRE has yet to be demonstrated in larger class satellites. To adapt the bus from a low inclination SAR mission to a sun-synch nadir pointing mission required a segmented bus with components that can easily be repositioned and are modifiable via software.

The hardware standards for the MSV architecture, including the Integrated System Engineering Team General Bus Standards[9], enables all bus components and subsystems to be moved anywhere on the inside or outside of the bus to within five linear cm. The goal of the MSV architecture is to have the essential bus components be building blocks with common interfaces that allow them to be located wherever needed on any of the bus panels. In the case of ORS-6, this enabled the star tracker to move a new location for easy alignment with the payload. The architecture also enabled ideal placement of course sun sensors and radio hardware, and simplified the mechanical design of the new payload and solar array interfaces.

Because the bus software was constructed with the SPA standard[10], every subsystem is treated in the same manner and uses the same software scheme, including the payload. Any subsystem that is not a native SPA endpoint is translated to SPA using an Applique SPA Interface Module[11] (ASIM). Since all bus components utilize the SPA standard, which includes a standard harness, it further eases relocation of those components. If the existing harness is too short, a new piece can be daisy chained to make it the proper length while maintaining any existing routing or staking. The complicated payload interface is addressed by the Payload Interface Unit ASIM that provides the full electrical and communication connection between all bus subsystems and the payload.

SPA utilizes AAIA standardized messages for communication between all components. All SPA components self-register on a universal network by subscribing to data sources and receiving commands through a standard query service in a Service Oriented Architecture. An eXtensible Transducer Electronic Datasheet (xTEDS) is used exclusively to convey component information, both the messages it produces as well as its subscription messages. To add an additional component to the system, an xTEDS must be written and the device must be SPA compliant. Compliance can be attained through the use of an ASIM for legacy components that do not have a SPA interface.

Using the SPA standard also enables the flight software to be modular. Usually flight software is built as a single monolithic system and often by a third party with proprietary code. This makes changes, troubleshooting, and the cost savings of competition difficult to implement. With SPA, each subsystem has its own flight software that, just like the USB interfaces on a computer, plugs into the network with seamless integration. For ORS-6 we are upgrading our attitude determination and control software, as well as the new software needed for the payload interface and communications subsystem.

The COWVR instrument was designed for a dawn-dusk orbit. This orbit follows the terminator and, as a result, provides a very thermally stable environment as well as continuous power charging opportunity. Therefore, the payload was designed to use passive thermal control, but included operational heaters and an oversized (and masked) radiator in the design for flexibility. Choosing the ride-share launch meant a different orbit where the vehicle would go in and out of eclipse, which resulted in a less stable thermal environment and necessitated adding a yaw maneuver for power optimization. Remarkably, only two small changes to the payload were needed to accommodate the orbit change, one jumper and one harness modification, with no effect on instrument performance. The first change resulted in the bus providing pulse-width modulated heating control of the three payload heater zones. The second alteration was for a bus timing adjustment to the instrument calibration to maintain it at the edge of the scan orthogonal to the velocity for any yaw position of the vehicle. It should be noted that on a traditional spinning microwave radiometer, where the calibration sources are mechanically fixed to the instrument frame, it would not be possible to modify when calibrations were taken resulting in a loss of data when the yaw movement placed the targets in the fore and aft swath positions. On the bus side, both of these modifications were easily added to the list of Payload Interface Unit functions.

The combination of hardware (Integrated System Engineering Team) and software (SPA) standards that make up the MSV architecture on the bus enabled a rapid and low cost reconfiguration of the ORS-2 bus for the ORS-6 mission. The reconfiguration effort has already demonstrated the multi-mission capability of this design.

The program could have decided to optimize the bus, or even create a new one for the ORS-6 mission. The ORS-6 bus reaction wheels are larger than they need to be, adding an extra solar array could have prevented the need for the yaw maneuver, or a new component could have been built to compensate for the payload spun mass. But better is the enemy of good enough. Making these changes or starting from scratch with one of a kind bus would have, in the end, resulted in higher cost. Instead the program has made smart trades, such as choosing a software defined radio, simple design changes, such as reconfiguring the solar arrays rather than reinventing them, and not wasted time over-designing and over-analyzing, while still meeting mission requirements.

RAPID RESPONSE WITH A FLEXIBLE APPROACH

The goal of the ORS office is to provide a rapid response to the joint-force commander’s needs. Our knowledge of ocean winds and weather is currently relying on the WindSat payload on the CORIOLIS spacecraft. CORIOLIS has been on orbit for 13 years and, while WindSat continues to supply excellent data, the aging spacecraft has already lost its other payload. With the cancelation of NPOESS and DWSS and with the Weather System Follow-on not scheduled for launch until 2021, there will likely be a need to fill the gap between CORIOLIS and the Weather System Follow-on missions. ORS-6 will not only demonstrate the novel technology of the COWVR payload, providing nearly equal precision and accuracy as WindSat, it also has the potential to serve as a partial gap-filler providing ocean wind vector measurements thereby delivering critical weather information for military services, the intelligence community, and civil agencies like the National Oceanographic and Atmospheric Administration.

In order to provide the COWVR instrument data in a timely manner, the ORS-6 mission is utilizing two leading-edge approaches to space. The first is the commercial rideshare launch. By using this launch service, the ORS-6 mission saved between 25-50% on launch costs and, assuming an on-schedule or minimally delayed launch, provided a faster ride into space than a traditional dedicated launch. Because ORS-6 is not a co-lead on the launch, and does not have the ability to dictate launch date, the ORS team is motivated to keep the bus reconfiguration, assembly, integration, and test on schedule in order to meet the launch date. Although rideshares are the standard for CubeSats, pursing a commercial rideshare for a larger mission is a big step for the Air Force. Despite the fact that the lack of control over the launch date adds risk to the program, the cost savings and the successful history of commercial rideshares have tipped the scales toward enabling the government to use this resource.

The second modern tactic that the ORS-6 mission is exercising is the Air Force's Enterprise Ground System (EGS) architecture. The EGS design seeks to disassociate space missions from pipeline ground system approaches and standardize ground system software, hardware, and interfaces. The result is yet another modular, integrated system that is flexible enough to be run from any Space Operations Center and work with the Air Force Satellite Control Network or Universal Space Network ground stations. While the EGS implementation is still in its infancy, the ORS-6 mission, along with a handful of others, it helping to solidify the EGS architecture so that future missions can easily, and cheaply, plug into a standard ground system solution.

Prior to actual integration, both the bus and the payload and ground system will have undergone extensive testing. With a test bypass system on the bus, the program is able to mimic on orbit scenarios by bypassing actual sensor component readings and injecting simulated data. Long before final end-to-end testing any issues on the bus will be discovered and fixed. Furthermore, within five days of delivery of the payload simulator the team was able to send commands with an emulated bus software on a beagle bone. Therefore, even before receipt of an engineering model of the PIU, we will be able to develop and troubleshoot the PIU flight software. Finally, with the ground control facility less than a mile from the assembly, integration, and test facility, the team will be able to fully exercise, and troubleshoot, satellite connections to the ground.

CONCLUSIONS

Between now and initial launch capability, ORS will integrate the bus and payload and conduct environmental and functional testing of the ORS-6 space vehicle. All major modifications and new components are on schedule for completion in early 2017 with space vehicle testing scheduled for spring 2017.

The careful design of the ORS-6 bus, the COWVR payload, the launch, and the ground system makes the ORS-6 mission a true demonstration not just of the novel bus and payload technology, but of a new approach by the US Air Force to provide a rapid, cost efficient response to an urgent need. In all but the most fortunate missions, change, whether it be budget fluctuations, leadership ebbs and flows, parts obsolescence, etc., is inevitable. In response to the near certainty of change, the ORS office decided to create a change-tolerant response construction that resulted in the MSV architecture. Leveraging a number of spacecraft standards such as SPA and EGS, the ORS-6 mission is a model of flexibility and adaptability and should serve as a template for future spacecraft, especially in situations where they may be uncertainty or ambiguity in defining the mission.

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