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HOW ORS – Modular Space Vehicle on the T2E Mission

Charles J. Finley
Operationally Responsive Space Office
Kirtland AFB, NM 87117; 505-853-6663
Charles.Finley@kirtland.af.mil

Kimberly Richards, Jose C. Cabanillas, III, Denny Gudea, Phil Katz, Sarah Ray
Northrop Grumman Aerospace Systems
310-813-0348; Kimberly.Richards@ngc.com

George Moretti
Millennium Engineering and Integration
505-715-4101; GMoretti@meicompany.com

Demosthenes Tsairides
NASA Ames Research Center
650-604-2155; demosthenes.tsairides-1@nasa.gov

ABSTRACT

With their Modular Space Vehicle (MSV) and Rapid Response Spaceworks (RRSW) awards, the Operationally Responsive Space Office has clearly transitioned from their concept design and socialization phase to the development and implementation phase. The MSV and RRSW contracts, along with the Tier-2 Enabler (T2E) mission they will enable, are now ORS's top priority. With a clear directive from Congressional and military leadership, ORS will use the T2E mission to exercise their basic philosophy, to develop through contextual application, rather than studies or simulation. Central to the T2E mission will be a calculated gamble that the widely accepted Modular Open-System Approach (MOSA) is the right tool to change the paradigm of space and provide the DoD, as well as their civil, commercial, and international partners, a modular, scalable, and rapidly configurable architecture that can be employed to provide assured space power to the warfighter.

INTRODUCTION

The MSV and RRSW awards coupled with the emergence of the T2E mission as the Operationally Responsive Space (ORS) Office's top priority underscore ORS's commitment to "change the paradigm of space". Progress has quickly moved from conceptual design to development and implementation. This paper, like the ORS Office itself, will devote very little time in the future to the question of "Why ORS". Rather, it will detail, first in abstract form and then in the context of the T2E mission, "**How ORS**".

Though the majority of this paper is devoted to answering the very question of how the ORS Office and their larger contractor team are implementing the ORS vision, it's prudent to begin with a brief ORS history lesson. The need for a rapidly deployable space capability emerged from an acknowledgement that: a) the US is asymmetrically reliant on space capability when compared to our foes; and b) the US space capability is no longer invulnerable. Moreover, the Government Accounting Office (GAO) findings concluded, "There are about 10 major satellite systems under development by the DOD . . . All of these programs are over budget (way over, in some cases) and behind schedule or delayed."[1] Therefore, not only is our nation asymmetrically reliant on a vulnerable capability, but we have proven ourselves unable to replenish that capability within the cost and schedule constraints inherent to the modern state of our nation's resources.

That realization led to the following Presidential guidance, "Before 2010, the United States shall demonstrate an initial capability for operationally responsive access to and use of space to support national security requirements providing capacity to respond to unexpected loss or degradation of selected capabilities, and/or to provide timely availability of tailored or new capabilities."[2] This was followed by Congressional direction stating that the Mission of the ORS Office shall be: 1) to contribute to the development of low-cost, rapid reaction payloads, buses, space-lift, and launch control capabilities in order to fulfill the joint military operational requirements for on-demand space support and reconstitution; and 2) to coordinate and execute operationally responsive efforts across the Department of Defense with respect to planning, acquisition, and operations.[3] Finally, the Deputy Secretary of Defense introduced the ORS Office's dual roles of providing "assured space power focused on timely satisfaction of Joint Force Commander's needs" by: 1) Developing "end-to-end ORS enablers"; and 2) Executing rapid capability efforts to meet urgent operational needs of the JFCs".[4]

Ultimately, the ORS Office Director incorporated all of the above guidance into the following mission statement: The mission of the Office is to:

1. Enable a means for reconstitution to respond to an unexpected loss or degradation of space capability as well as providing timely availability of tailored or new capabilities
2. Develop low-cost, rapid reaction payloads, buses, space-lift, and launch control capabilities; allow the United States to recover quickly from attack
3. Provide affordable solutions: Space vehicle costs <$40M, launch vehicle and services cost <$20M (FY2007 $)
4. Prepare ORS enabling elements to meet USSTRATCOM responsiveness by 2015
5. Provide "Assured space power focused on timely satisfaction of Joint Force Commander's needs"

ORS APPROACH = MODULAR + SCALABLE + RAPIDLY CONFIGURABLE

Spacecraft have traditionally been too expensive to be allocated to any single customer. As a result, space programs have traditionally been developed to meet the needs of many stakeholders that impose many requirements, which inevitably evolve over time. Unfortunately, as the following graphics explain, the counterintuitive result of this cycle is to drive up the cost and extend the schedule of spacecraft development efforts, bringing us back to and amplifying the initial frightening reality – space programs are too expensive to be allocated to any single customer.

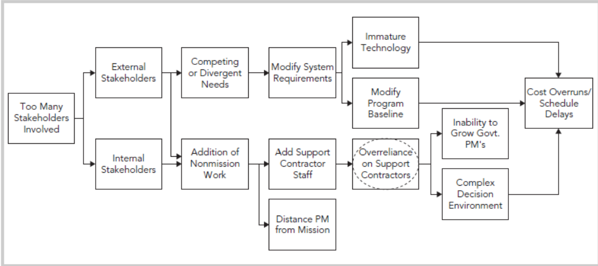

Figure 1: Formula for Cost Overruns and Schedule Delays

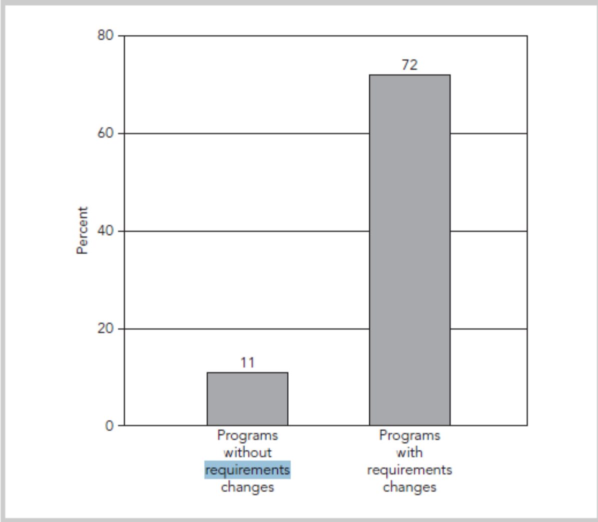

Figure 2: Cost Growth Due to Requirements Changes[5]

ORS is combating this cycle in two ways. First, it is setting a price point (and associated capability "ceiling") based on a one spacecraft/one customer mentality. A single space system will satisfy a single need for a single COCOM. However, since the very nature of ORS is to be "reactive" (or responsive), ORS must concede that this trend towards multiple stakeholders with multiple emerging requirements will continue. Therefore, the reasonable approach becomes to embrace this reality and build a flexible architecture that can be scaled with minimal non-recurring engineering (NRE), and the associated cost and schedule growth.

Moreover, one of the unspoken programmatic challenges to ORS that largely scopes their response trade space is the need to develop a capability to respond to COCOM space needs on unheard of timelines without maintaining large, expensive inventory of hardware and personnel. It is basically this requirement associated with currently forecasted missions, along with the need to remain scalable to unforecasted missions that drove ORS to a Modular Open-Systems Approach (MOSA) solution.

An open standard is a standard that is publicly available and has various rights to use associated with it. Some examples from the Information Technology industry are the World Wide Web Consortium (W3C) and the Google Open Handset Alliance, which is a group of 47 technology and mobile companies who have come together to accelerate innovation in mobile services. In a closer analogy, Unmanned Aerial Vehicles (UAV) are now actively employing a MOSA architecture so that added capability can be "componentized" with minimal additional non-recurring engineering or having a negative impact on the larger architecture. ORS's instantiation of MOSA is founded on two sets of standards. First, the Space Plug-and-Play Architecture (SPA) standards describe an appropriate set of interfaces for a modular, scalable, and rapidly configurable bus architecture. Building on that, the Integrated Systems Engineering Team (ISET) General Bus Standard (GBS) defines the interface between the bus and payload and the space vehicle and launch vehicle and ground system.

THE TIER-2 ENABLER MISSION

The "Reconnaissance Wing for Space" analogy is the long term End-State Vision for the ORS Office. ORS believes that it is most effective to develop the components of their "Reconnaissance Wing for Space" via an end-to-end mission that will graduate with an actual ORS Tier-2 (approximately 7-day) response to a relevant COCOM's operational need. T2E is that mission, so the approach must necessarily utilize/demonstrate steps towards this vision.

The T2E mission is an ORS "Enabler" mission, meaning it was not generated specifically to address a formal Combatant Command (COCOM) "Urgent Need" with an associated set of well-defined performance specifications and clearly defined operational goals. Rather, the T2E mission is internally driven within ORS to mature the processes, capabilities and technologies, i.e., the Enablers, which will allow the ORS Office to reach its End-State Vision. This mission will, for the first time, demonstrate a sustainable end-to-end (mission planning → bus/payload/ground system/LV AI&T → Ops Team training → launch campaign → on-orbit checkout, calibration, hand-off) response capability on a Tier-2 timeline. The payload for the T2E mission is a Synthetic Aperture Radar (SAR) imager providing regional capability.

In priority order, the goals of the T2E mission are:

1. Demonstrate an end-to-end RRSW Tier-2 Response.
2. Develop a standards based, modular, rapidly configurable, multi-mission bus architecture.
3. Develop an operationally relevant radar capability.
4. Develop a rapidly configurable, multi-mission RF payload architecture.

The T2E mission goals are tied directly to Task Orders (TOs) on the RRSW and Modular Space MSV contracts. Northrop Grumman Aerospace Systems (NGAS), as the prime for the MSV Bus TO, will develop the system described in objective 2. Sierra Nevada Corporation (SNC), as the prime for the MSV Payload TO, will develop the system described in objectives 3 and 4. Finally, Millennium Engineering and Integration (MEI), as the prime for the RRSW T2E TO, will integrate the T2E bus to the T2E payload, perform system level "first article" testing, disassemble the articles into a storable state, and execute an end-to-end Tier-2 response triggered by a notional time-critical JFC need, in accordance with objective 1.

On the programmatic side, the MSV bus and payloads are currently scheduled to arrive at the RRSW for integration in May 2013. The RRSW will spend six months performing system assembly, integration, and test (AI&T) and exercising their personnel, facilities, and hardware in performing a Tier-2 response prior to executing their "Graduation Exercise" described in mission objective 1.

NASA Ames Research Center (ARC) is executing all contracts, through a close partnership between ORS and ARC. It's worthwhile to elaborate on this unusual partnership. Just as responsive low cost satellites will allow the ORS Office to develop the capability to augment or replace space capabilities on very short timescales, it will also provide NASA the flexibility to meet science needs and build upon recent discoveries. If an orbiting Earth science satellite suffers instrument failure, the ORS paradigm offers the potential to rapidly fly a spare replacement instrument to provide continued temporal measurements. Open architecture, standard interfaces, and Plug-and-Play components can allow rapid configuration and launch to perform missions at lower cost, thus increasing scientific returns.

NASA not only brings a contracting capability that ORS does not have, but they bring technical expertise, facilities, and, perhaps most importantly, the critical high volume investment that might encourage industry to invest their resources in developing and employing the components of a MOSA space architecture. Ultimately, this collaboration will further drive down costs for both ORS and NASA missions, while increasing innovation and standardization by adding the creativity and expertise of both organizations.

THE MSV BUS ARCHITECTURE

Northrop Grumman is developing the standards based, rapidly configurable, multi-mission spacecraft bus architecture for the ORS MSV Program.

To meet future operational warfighter needs, the MSV bus development activity addresses the requirement of rapid manufacturing, integration and testing – within weeks to months – to meet the long term ORS vision.

These design attributes are ideal for users seeking an objective of an efficient, affordable platform for missions requiring quick capability on orbit, with a design life of one year.

The MSV bus is an essential element of the T2E mission and ORS's MOSA and networked avionics response architecture. The primary objective of the MSV spacecraft bus effort is the development of an open standards-based, modular, scalable, rapidly configurable and deployable, multi-mission architecture. The design is optimized for these primary objectives with mission performance being defined as "good enough" to meet warfighter needs. MSV is not a standard bus, but rather a bus architecture based on open standards. This is an essential discriminator since US government space has historically failed to accept the requirement compromises necessary to keep a bus "standard" over multiple builds. Modifications are expected and the reality is that modifying something that wasn't designed to be modified is a slow and expensive process. Modularity and scalability are key design elements of the MSV architecture. These open standards allow for a multitude of payloads that can be easily integrated and tested such as:

- Communications
- Intelligence, Surveillance and Reconnaissance
- Tactical Electronic Support
- Space Situational Awareness

This approach provides options that are affordable, innovative and expedient for customers, including the military services, intelligence community, and NASA. Bus subsystem details are described below.

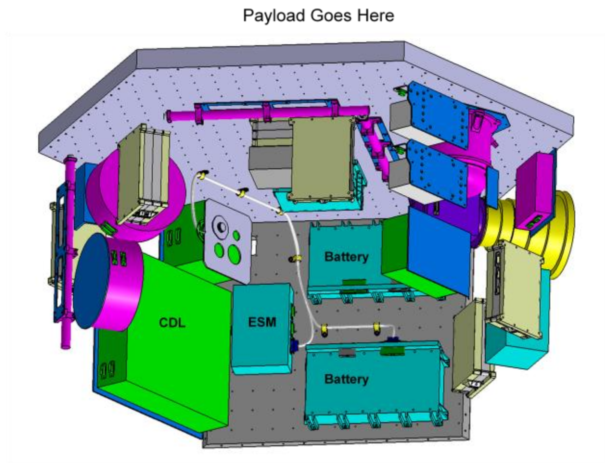

Figure 3: T2E Configuration of MSV Architecture

Structure and Mechanisms

The MSV structure is assembled from common, modular deck/panel "building blocks" with features that enable rapid I&T and optimization for numerous missions. The panels are sized by the ISET General Bus Standard (GBS) and made suitable for rapid integration by the SPA electrical/mechanical standards. The MSV reconfigurable bus structure allows a minimal number of structure "components" to be configured into multiple different vehicle configurations. Moreover, it accommodates scalability and rapid reconfigurability through the simple implementation of a SPA standards 5cm grid pattern.

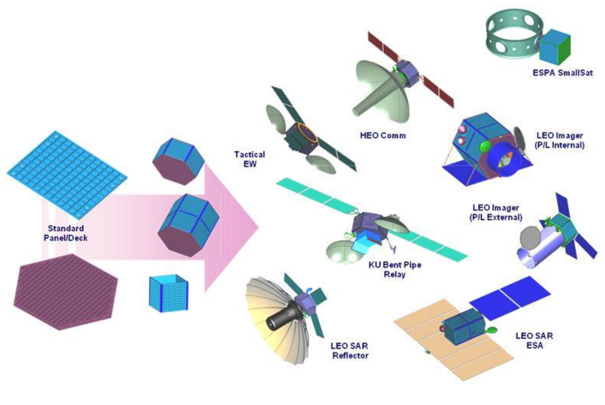

Figure 4: Reconfigurable Multi-Mission Structure

Command and Data Handling (C&DH)

One of the most groundbreaking innovations of MSV will be in the area of C&DH. For the first time, the Space Plug-and-Play Architecture (SPA) will leave a laboratory environment and be implemented on an operational space system. The following SPA Guiding Principles are tailor-made to support ORS's ideals of modularity, scalability, and rapid configurability:

1. Communication through AIAA standardized messages

2. SPA-X Databus Interfaces -- SPA components shall conform to an approved SPA-x interface (-U, -S, -1, -O, etc.) and shall employ well-defined hardware (electrical, mechanical, and signaling) standards to achieve an interface with connective integrity.

3. Self-describing components

4. Query Services -- SPA data sources and consumer needs shall be matched through a standard query service in a Service Oriented Architecture (SOA).

5. Self-Organizing Networks -- SPA components shall self-register on the network.

6. Mechanical Standards -- A SPA Device shall be physically mountable on a compliant SPA structure according to one of the applicable SPA mechanical standards.

From these "Guiding Principles" come several SPA Corollary Services:

1. Component Detection -- A SPA system shall automatically detect hardware or software components that are added to the system.

2. Component Self-Identification -- SPA components shall provide information about their functions and use to the system.

3. Command/Response Messages

4. Publish/Subscribe Messages -- A SPA component's Extensible Transducer Electronic Datasheet (xTEDS) details the command and response messages supported by the component.

5. System Monitoring of Component Status

6. System Common Time

7. Standard Mechanical and Electrical Interfaces

MSV features a SPA-Spacewire (SPA-S) compliant combined router and power distribution unit that provides standards-compliant power, data, and time distribution, a single-point ground, and test-bypass capability. All other SPA components are electrically connected to the C&DH architecture via a SPA-standard connector. This enables multiple standards-compliant configurations of components to accommodate multiple mission needs. All non-SPA COTS components (e.g., star trackers, GPS, reaction wheels, etc.), which constitute the vast majority of components, are fitted with an Appliqué Specific Interface Module (ASIM) to enable them to electrically connect to SPA-S and SPA avionics.

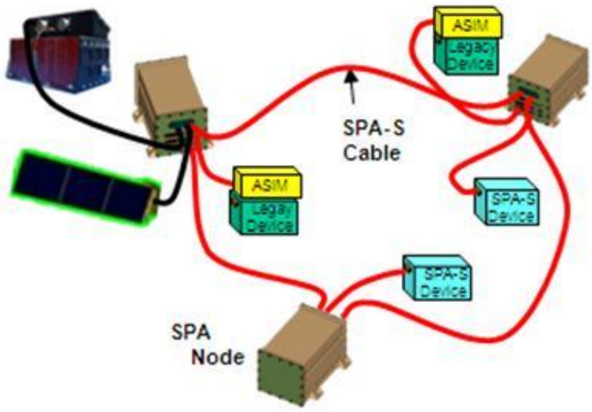

Figure 5: Scalable Avionics

MSV's SPA avionics are connected via standardized SPA-S harnesses. The SPA ASIM-adapted components can be rapidly reconfigured to accommodate varying missions. Components and their ASIMs are inventoried at call-up after the mission planning system determines the appropriate configuration to accommodate the time-critical ORS need.

Attitude Determination and Control Subsystem (ADCS) and Electrical Power Subsystem (EPS)

ADCS, in keeping with the SPA approach, is modular and scalable at the component level. ADCS components for MSV fit into three general categories – sensors, actuators, and FSW "components".

Like ADCS, the EPS follows the SPA approach and is modular and scalable at the component level. For EPS, these components also fit into three categories – power generation, energy storage, and power distribution. In the area of power generation, MSV has scalable solar panels, a scalable number of wings, and in extreme power cases, an articulated solar array option.

Thermal Control Subsystem (TCS)

A luxury afforded the "tactical" spacecraft is the ability to control thermal loading through CONOPS. Since ORS spacecraft are designed to serve regional interests, rather than worldwide interests as with our national assets, it is conceivable that operators will alleviate the need for active thermal control by simply turning high-load equipment off when the burden becomes too large. However, one innovation of the MSV architecture is the Thermal Control Interface Adaptor (TCIA), which implements the SPA approach and regulates thermal impact to the system at the component level, while providing a mechanical interface from the COTS unit to the SPA structure. Just as the ASIM allows electrical interface of non-SPA to SPA adaptation, the TCIA provides thermal and mechanical adaptation to the architecture.

Communications Subsystem

The communications subsystem includes both SGLS communications for command and control and a Common Data Link (CDL) radio that enables playback of mission data directly to deployed field terminals. For command and control link to fit within the ORS ground architecture, ORS is imposing the requirement that the space vehicle output encrypted Consultative Committee for Space Data Systems (CCSDS) formatted telemetry and accept encrypted CCSDS formatted commands. CCSDS is the guiding body for space to ground communications, so this ensures a space architecture that is rapidly integrable into existing ground architectures, but it also introduces some unique problems, since SPA messages are necessarily flowing throughout the vehicle and CCSDS messages must flow out of it. To that end, MSV is developing a software component to convert SPA messages into CCSDS messages, while trying to preserve the benefits of each to the maximum extent possible. This recurring theme of "adaptors" to accommodate standards is a conscious sacrifice ORS has made in the interest of scalability and rapid configurability, and the resulting overhead is tracked as a Technical Performance Parameter (TPM).

Flight Software (FSW)

MSV employs a modular, "componentized" FSW approach. The backbone of this approach is the Satellite Services Manager (SSM), which enables SPA messaging between hardware and software components. The following graphic depicts how SPA is used to direct subsystems in support of higher level Mode Agents associated with each nominal activity the spacecraft executes. The subsystem controllers provide an interface for standard subsystem tasks. When different missions arise, new mode agents can be placed into the spacecraft to utilize these subsystems in new or specialized ways.

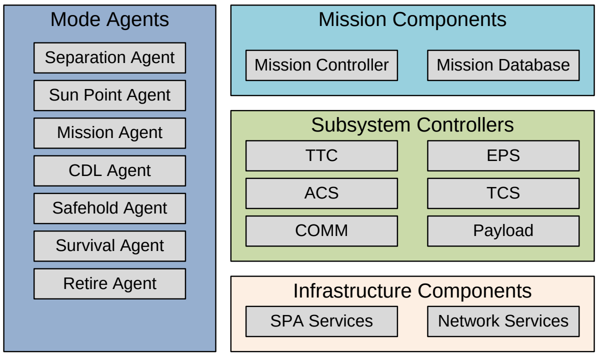

Figure 6: T2E "Component" SPA FSW

The ORS bus and payload software modular design effort enables similar treatment of other self-contained space vehicle components (e.g., star trackers) based on mission need. This approach maximizes reuse of software modules previously mission-validated, and provides low risk on future missions. Dependencies between modules are minimized and standardized using a Common Data Dictionary (CDD), allowing for configuration parameters that do not necessitate building and re-verifying the software. This approach, in turn, promotes rapid software checkout and common MOSA high level commands for multiple suppliers' of modular payload building blocks.

Propulsion

ORS is working with NASA Ames to develop a modular and scalable propulsion system and plans to demonstrate both an ESPA configuration and a T2E-compatible configuration in the near-term. Moreover, since legacy propulsion systems bring with them fueling campaigns that are incompatible with a Tier-2 response, ORS's system will be non-toxic (aka "Green") to eliminate the specialized facilities, personnel, and ground-support equipment (and the associated schedule and cost) of a traditional fueling effort.

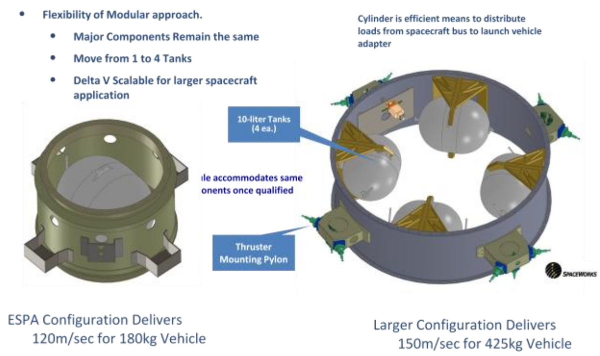

Figure 7: Modular, Scalable, "Green" Propulsion System

Test

A delivered test station supporting the Rapid Response Test Environment should:

- Provide test control, power and data interfaces
- Support any combination of actual Hardware, software and/or simulations, depending on the test need
- Support Subsystem to SV I&T level
- Ops testing and training support

The test environment should support rapid AI&T, initial satellite vehicle integration and test, be modular for easy support to environmental test, exercise support, launch vehicle integration, and on-orbit anomaly resolution.

The MSV architecture, as well as the ORS employment of that architecture, benefits from SPA's built-in test strategy – Test Bypass. As the system is incrementally built, Test Bypass allows system level tests and operator training campaigns to proceed in advance of a full set of hardware. Simulated component inputs are supplied by a hardware-in-the-loop rack and introduced at the ASIM, just as inputs from the actual component would be.

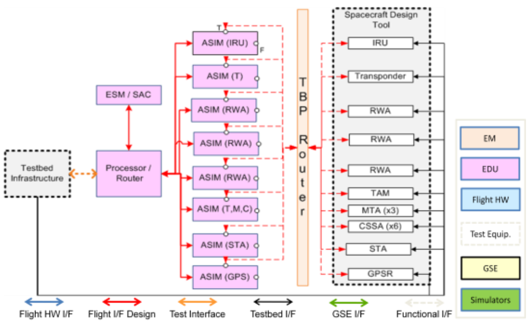

Figure 8: T2E MSV Test Bypass implementation

SUCCESSES AND CHALLENGES

If historical performance is any indicator, the T2E mission will have just the effect ORS planned when they resolved to develop their architecture in the context of an end-to-end mission. The mission has done a great deal to illuminate both the benefits and challenges of building a MOSA bus architecture and applying it to an Operational need.

Component Compatibility = *Success*

The emergence of MOSA as the new paradigm of space isn't as much of a revolution as a sequence of small victories. Recently ORS experienced one such victory. In 2008, the ORS Office purchased four "COTS" spacecraft components to employ in the MOSA spacecraft architecture they would feature on all of their upcoming missions. The only problem was that neither they, nor anyone else, had invented a MOSA spacecraft architecture. As a result, when they attempted to offer up a free Sodern SED-26 Star Tracker, Surrey SGR-07 GPS, and Ithaco IM-203 Magnetometer (a value of approximately $1M) to ATK for use on their ORS-1 spacecraft, ATK was able to use only the GPS, and they were only able to use that because it was the exact component they had designed into their ORS-1 spacecraft.

With the award of their MSV contracts, ORS is finally developing the kind of MOSA spacecraft architecture they envisioned since their inception. Their theory is that they can create an architecture that doesn't require redesign every time a component of that architecture is changed. This theory was recently put to test when ORS once again offered up their COTS components to NGAS for employment on MSV. NGAS and their MSV spacecraft architecture passed the test with flying colors. Though the COTS Star Tracker and Magnetometer were not the components NGAS had specified for the T2E configuration of their MSV spacecraft, NGAS enthusiastically agreed to employ them on T2E. They made this decision because they assessed that the new components provided the same class of service and, more importantly, because they had developed an architecture in which no single component forced an expensive redesign of the larger system. This marks a significant shift away from the point-design spacecraft towards ORS's envisioned MOSA spacecraft architecture.

Scalability** = **Success

T2E was categorized as an "Enabler" mission to relieve it of the burden of meeting a strictly defined COCOM-imposed requirement set. This had the unfortunate side effect of leaving the T2E with a lot of trade space in their determination of "good enough" on-orbit performance for this type of mission. Two primary trades were to determine how many spot images or how large a strip map area would be necessary for a single-ball asset to have a marketable impact on daily collection needs of a COCOM customer. Ground architecture limitations aside, the number of spot images collected on a single pass was largely driven by available slew rate. Therefore, a careful reaction wheel selection could be used to tailor performance in this area. NGAS developed the following trade matrix and the ORS Office ultimately decided to employ a unique asymmetric attitude control architecture to match their asymmetric satellite. Larger plug-and-play reaction wheels were aligned with the most challenging axes (in terms of moment of inertia) and a smaller reaction wheel was aligned with the less challenging axis to save mass and power. This is an ideal tangible example of how a configuration can be optimized without the NRE burden of optimizing the larger system to accommodate it.

Trade Parameters	Option-1	Option-2	Option-3
Configuration Description:	(Baseline) Goodrich 16B200	Goodrich 26E700	Goodrich 26E400
Performance Parameters			
(List applicable Key parameters here)			
Momentum Capacity (N-m-sec)	16.5 N-m-sec	26 N-m-sec	26 N-m-sec
Max Reaction Torque (N-m)	0.2 N-m	0.7 N-m	0.4 N-m
Speed Range (rpm)	+/-5100 rpm	+/-2020 rpm	+/-2020 rpm
Mass, single RWA (kg)	7.5 kg	14.5 kg total (10.4 kg for RWA, 4.1 kg for electronic box/driver)	12.4 kg
Total Mass, 3 RWAs	22.5 kg	43.5 kg	37.2 kg
Dimensions	26 cm RWA diameter, 13.5 cm RWA height	39.4 cm RWA diameter, 16.6 cm RWA height, 18cm x 18cm x 9cm driver box dimensions	39.4 cm RWA diameter, 18 cm RWA height
Peak Power Max (W)	250 W	380 W	250 W
Steady State Power at Max Speed (W)	28 W at 5100 rpm	28 W at 2020 rpm	28 W at 2020 rpm
*Max Estimated SV Rate at 75% RWA capacity**	X-axis: 2.11 deg/sec, Y-axis: 2.11 deg/sec, Z-axis: 3.28 deg/sec	X-axis: 3.33 deg/sec, Y-axis: 3.33 deg/sec, Z-axis: 5.17 deg/sec	X-axis: 3.33 deg/sec, Y-axis: 3.33 deg/sec, Z-axis: 5.17 deg/sec
*Max Estimated SV Acceleration**	X-axis: 0.034 deg/sec^2, Y-axis: 0.034 deg/sec^2, Z-axis: 0.053 deg/sec^2	X-axis: 0.119 deg/sec^2, Y-axis: 0.119 deg/sec^2, Z-axis: 0.185 deg/sec^2	X-axis: 0.068 deg/sec^2, Y-axis: 0.068 deg/sec^2, Z-axis: 0.106 deg/sec^2
Maneuver Time to Travel 90 deg (single axis maneuver)	X-axis: ~73 sec, Y-axis: ~73 sec, Z-axis: ~58 sec	X-axis: ~39 sec, Y-axis: ~39 sec, Z-axis: ~31 sec	X-axis: ~51 sec, Y-axis: ~51 sec, Z-axis: ~41 sec
Maneuver Time to Travel 180 deg (single axis maneuver)	X-axis: ~103 sec, Y-axis: ~103 sec, Z-axis: ~82 sec	X-axis: ~55 sec, Y-axis: ~55 sec, Z-axis: ~44 sec	X-axis: ~73 sec, Y-axis: ~73 sec, Z-axis: ~58 sec
Level	TRL 9	TRL 9	TRL 9
Cost (3 RWAs)			
Schedule			
Overall Risk Rating			

Figure 9: Scalable ADCS

As it turns out, increased strip map area collect capability is not a factor of slew rate as much as available power. Therefore the appropriate selection of power generation (solar array area) and power storage (batteries) capability could be used to tailor performance in this area. In similar fashion to the previous trade, NGAS put together the following set of configurations to give ORS the flexibility to match performance to requirements.

Trade Parameters	Option-1	Option-2	Option-3
Configuration Description:	Baseline 3 orbits in a for for: Eclipse + 10 min PL OPS + 10 min CDL Comm OPS + Slew	4 orbits in a row for: Eclipse + 10 min PL OPS + 10 min CDL Comm OPS + Slew	7 orbits in a row for: Eclipse + 10 min PL OPS + 10 min CDL Comm OPS + Slew
Performance Parameters			
Total SlewTime & Assumptions	Slew from/to sun point twice per orbit for a total slew time of 8 Minutes per orbit	Slew from/to sun point twice per orbit for a total slew time of 8 Minutes per orbit	Slew from/to sun point twice per orbit for a total slew time of 8 Minutes per orbit
SA Load	600 W	600 W	800 W
Battery	2 LCROSS	Add 2 LCROSS Batteries, 6,5 kg each (4 total)	Remove existing LCROSS batteries. Add two JWST Batteries, 19.8 kg each, W=37.7cm, L=26.5cm, H =17.7 cm
**SA Configuration (# of wings & Panels)*	3 wings, 6 panels	No change from baseline, 3 wings, 6 panels	Add one wing (4 wings total) Dimensions and weight are the same as for baseline wing
Electronics (ESM, SAC)	1 SAC, 1 ESM	No change from baseline, except possibly additional ESM (TBS)	Need to add one SAC module and one ESM
Dimensions	See MEL	See MEL	Each battery: W=37.7cm, L=26.5cm, H =17.7 cm
SA on SB Config	SRR pckg	See Attached Slides	Added one wing. Moved one wing 60 degrees to make layout symmetric
Mass (SB only)	244.95 kg	258.34 kg (8.34 kg above req)	276.27 kg (26.27 kg above req)
MOI (SB + Payload)	Ixx = 281 kg-m2 Iyy = 284 kg-m2 Izz = 187 kg-m2	Ixx = 286 kg-m2 Iyy = 286 kg-m2 Izz = 190 kg-m2	Ixx = 311 kg-m2 Iyy = 286 kg-m2 Izz = 198 kg-m2
Agility (Slew & Accel)	TBS	TBS	TBS
Mechanical Interface Accommodation	NA	No impact	No impact

Figure 10: Scalable EPS

These two preliminary trades offer great promise for ORS and their vision that the MSV architecture will be able to supply an optimized configuration of their scalable architecture to accommodate a wide range of specific mission needs. Moreover, when the situation warrants, they can adopt a "capability driven approach" and factor in bounding constraints, such as a requirement to fit in the launch envelope of a Minotaur 1, along with COCOM needs to converge on a solution, as in the case of T2E.

Uncontrollable Processes** = **Challenge

Technology (e.g., SPA) was a solution for many of the impediments to rapid configurability, but some of the most dramatic hurdles for a true ORS Tier-2 response are non-technical. ORS endeavors to build a reconfigurable architecture and employ it in response to time-critical COCOM needs. However, processes such as Information Assurance, Frequency Management, and Range Safety, as well as the personnel that implement them, don't share the same mandate for rapid configurability on ORS Tier-2 timelines. As a result, ORS will likely feature a rapidly configurable space and ground architecture on the T2E mission, but only be able to employ it in a simulated environment.

Eliminating NRE** = **Challenge

On the day of the ORS-1 launch an article on SpaceflightNow.com listed ORS-1 mission cost at

$226M. Wikipedia lists the TacSat-3 mission cost at $90M. In fact, each subsequent TacSat (1 through 4), and then ORS-1, have brought with the increasing cost. One of the largest selling points to the sole source award of ORS-1 to the team of Goodrich and ATK (who had previously built TacSat-3) was the NRE savings that would result from building what basically amounted to a second copy of TacSat-3, but with a different payload and added propulsion. Yet the mission sold on the "copycat" premise ultimately cost 2.5 times as much as the original.

One conclusion might be that the cost of modifying systems that weren't built to be modified is much higher than it seems they should be. However, the TacSat-3 to ORS-1 evolution is a perfect case study for ORS and it deserves a closer look to determine which factors resulted in the large cost differential. Candidates include: NRE associated with adding a propulsion system or changing the payload; cost of space-qualifying an airborne sensor; different cost of an IR sensor development compared to an HSI sensor; adding an "operational", rather than a lab flavor to a mission, bringing with it the associated requirements and lower risk posture; plugging into an established operational command and control (C2) and tasking/processing/exploitation/distribution (TPED) architecture, rather than using a "stovepipe" ground architecture; using the payload contractor for bus to payload integration, rather than a government integration.

It is not only the integrated missions that are consistently trending towards cost growth, but the components that are common to each mission seem to be following suit. Specifically, the CDL radio, implemented on ORS spacecraft to save costs by making the spacecraft compatible with existing ground architectures, are more expensive with each subsequent instantiation. Similarly, the cost of the Virtual Mission Operations Center, employed on the TacSat-2, TacSat-4, and ORS-1 missions, continues to grow. Breaking that patter of NRE dominating mission costs will be a major challenge for the MSV architecture and the T2E mission.

Non-Standard Compliant Components = Challenge

By design, the MSV awards required contractors to bid to a set of standards (rather than firm requirements), with the assumption that the mission component on the other side of the interface was bidding a system that met the other side of the standard. Much of the time leading up to Mission System Requirements Review (SRR) as spent addressing point design solutions to accommodate bus/payload interface challenges that resulted from non-standards compliant designs. These include: 1) space vehicle pointing; 2) lateral loads at the bus/payload interface; and 3) antenna accommodation by the payload on behalf of the bus Comm system. These point solutions are necessary for the T2E mission, but they are necessary only because ORS (knowingly) decided to fly a non-ISET compliant payload. If the payload: 1) Met the ISET Payload Developer's Guide (PDG) mass and CG requirements, an ISET compliant bus would be able to supply the ISET General Bus Standard (GBS) slew rates/acceleration at the interface and accommodate the lateral loads; and 2) Could accommodate a SGLS antenna with 2π steradian coverage, an ISET compliant bus would have omni-directional SGLS coverage.

The ORS lesson learned (which might fit into the "pretty obvious" category) is that when either side of an interface is unable to meet the standard, you are forced to work together on an Interface Control Document ICD) and a more traditional point design solution that becomes less readily extensible to the objective MOSA architecture. This approach commits you to future NRE when you try to apply the developed architecture to future urgent needs.

The T2E mission continues to struggle with this issue as they make plans to accommodate a developmental Ka-band Common Data Link (CDL) antenna. Requirements of this new antenna, both in terms of volume and data rate, make it inappropriate for SPA standards. Therefore, the mission is considering the introduction of a new "component" that combines a structural panel with the radio and antenna, making the RRSW logistics footprint that much more complicated.

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