

4th Responsive Space Conference 2006

Paper Summaries

SESSION I — ARCHITECTURE

(4/25/06, 1:30 pm – 3:15 pm, Chair: Dr. Richard Van Allen, SSTC, Microcosm)

1001 “System Architecting Challenges of Changing Missions for a Flexible Mission Spacecraft”

John Bystroff, University of Southern California, Leesburg, VA

Air Force Space Command has been a strong advocate of an operational responsive space (ORS) capability. Operationally responsive space, as described by Arthur Cebrowski, Director of Force Transformation, Office of the Secretary of Defense, involves establishing a mission need “driven by adaptive contingency planning cycles rather than predictive futures or scripted acquisition periods.” In practical terms, this means for a space system to be considered operationally responsive, identified mission needs require fulfillment within days or weeks, not the years the current acquisition process requires.

One concept to fulfill responsive space requirements involves placing a flexible mission spacecraft (FMS) on-orbit. An FMS would have the capability to re-configure its bus and payload hardware and software to meet emerging mission requirements. Various new technologies, such as Software Defined Radio (SDR) and micro electro mechanical systems (MEMS) enable considering how to create a satellite with a malleable architecture.

However, an FMS presents a significant system architecting challenge by its malleability. The challenge is not merely in its initial deployment, but in changing missions. To successfully support new mission requirements, an FMS must not only be able to change its own architecture, but it must be integrated with a mission architecture on the ground. It must support interfaces for the new mission along the entire stack of layered protocols from physical to application.

The purpose of this paper is to highlight the system architectural challenges associated with an FMS in transitioning from supporting one mission to supporting a different one within the time-frame demanded of an “operationally responsive space system.” The challenges are first addressed with respect to satellite design concerns. The interface challenges with the ground mission infrastructures are then described with reference to the Open System Interconnect (OSI) model.

Finally, it is proposed that the traditional waterfall spacecraft architecting approach is not suited to supporting an FMS mission change within the constraints demanded by ORS. Rather, the characteristics of the architecting environment for changing an on-orbit satellite design match closely with the situation faced in software development. Therefore, it is proposed that a spiral software development process provides a more viable architecting approach when changing an FMS mission.

1002 “Fractionated Space Architectures: A Vision for Responsive Space”

O. Brown, Defense Advanced Research Projects Agency; Paul Eremenko, Booz Allen Hamilton

The advent of the integrated circuit some four decades ago set off mankind’s insatiable thirst for computational power. The quest to quench this desire led to the development of increasingly more sophisticated computers. Microchips sprouted ever greater numbers of transistors, choking buses, and forcing memory banks to struggle to keep up. The novelty of micro- and minicomputers was quickly trumped by the sheer computational prowess of supercomputers.

And so the trend continued. In a matter of two decades, however, this drive towards greater processing power culminated in mammoth mainframes whose rapidly increasing complexity, fragility, and cost quickly outpaced the capability gains. A scant few years into the second decade of the era of the integrated circuit, the availability of inexpensive, mass-produced microcomputers, and the advent of fast, seamless internetworking ensured the relegation of the large monolithic mainframes to obsolescence and obscurity. Spacecraft have followed a trajectory that is uncannily parallel (and, of course, technologically intertwined) to the history of high-end computing. Borrowing the historical analogy, we posit that the era of distributed space architectures has likewise arrived. The gargantuan monolithic systems deployed to orbit today have grown too large, too complex, too fragile, and consequently much too expensive; furthermore, these trends have not been offset by commensurately rapid growth in capability.

We propose a fractionated architecture for space systems, whereby a satellite is decomposed into a heterogeneous set of components which interact wirelessly. In the extremum, the fundamental functionality of most space systems is the reflection of photons back to earth.

Thus, assuming that the requisite photon collection, processing, and re-radiation can be accomplished, the spacecraft need be nothing more than a collection of free-floating “pixie dust.” In the realm of the foreseeable technological future, however, there are a handful of schema for severing and distributing the functionality of a monolithic spacecraft. Perhaps the most basic is fractionating the spacecraft along its data channels, resulting in a loose cluster of networked spacecraft modules. Somewhat more challenging is also fractionating the power system and disseminating power wirelessly among the modules. At the technological horizon is also fractionating the propulsion and stationkeeping functionality, also necessitating the wireless transmission of forces and torques.

The fractionated architecture is likely to incur an aggregate mass impact versus its monolithic counterpart (although it is noteworthy that at least one massive component may shrink – the flywheels necessary to ensure payload pointing accuracy need only be responsible for stabilizing and pointing the payload module, not the entire spacecraft). The impact on overall system cost is ambiguous since the cost impact due to greater system mass is at least partially offset by learning curve and mass production effects across the multitude of modules. For a constant required level of functionality, however, the fractionated architecture dramatically outperforms its monolithic counterparts in its value proposition. It affords its user/operator greater flexibility in the form of system scalability, reconfigurability, and adaptability (including multi-payload functionality). It dramatically increases robustness and survivability. It allows the isolation of the payload for both improved security and increased pointing accuracy. It lowers possible increases in lifecycle cost and decreases schedule risk by decorrelating failure probabilities of the various component subsystems and multiple payloads. It improves responsiveness by allowing incremental capability deployment, by enabling the utilization of small launch vehicles for the emplacement of massive orbital capabilities, and by shifting the deployment decision chain from the strategic to the tactical level. Perhaps most importantly – and much like the internetworked microcomputer – it commoditizes the space industry and transforms it from an exotic boutique to a customer-driven, cost-competitive enterprise.

The technologies needed to make fractionated space systems a reality are well within reach. They potentially include responsive and inexpensive small launch vehicles, highly secure ultra wideband inter-module data links (which may also provide relative navigation capabilities for the spacecraft modules), efficient radio frequency power transmission, passively stable Keplerian cluster orbits, and mass-produced, inexpensive, space-qualified satellite components (many with their legacy in the newly-emergent field of unmanned aerial vehicles). More esoteric technology options include very high frequency power beams, laser power transmission, and remote force and torque transmission through electromagnetic induction.

The Defense Advanced Research Projects Agency (DARPA) has been studying the fractionated architecture concept and is poised to commence an initiative entitled F6 – short for Future Fast, Flexible, Fractionated Formation-Flying Spacecraft utilizing Information eXchange, and incidentally a tornado of unimaginable strength on the Fujitsu scale – that will mature the associated technological, architectural, and organizational advancements necessary for an onorbit demonstration of a fractionated spacecraft. A brief discussion of the vision for F6 concludes.

**1003 “National Security Space Office Responsive Space Operations Architecture – Final Report Presentation”
Ed Kneller, U.S. Navy**

The National Security Space (NSS) Enterprise is facing a significant transformation as it moves from a Cold War posture to one capable of maintaining pre-eminence in a new environment of rapidly changing and unpredictable threats. Concurrent with this strategic transformation, the Partnership between the U.S. Government and the Industrial Base is increasingly challenged in its effort to deliver cost effective NSS systems.

The NSSO Responsive Space Operations Architecture views Responsiveness as a critical attribute throughout the NSS Enterprise that must be greatly improved in order to surmount these challenges. The RSO Architecture Study assessed responsiveness across representative sectors of the enterprise and will recommend a set of capabilities for layered responsiveness as well as implementation vectors to effect the transformation. These capabilities can be broadly categorized into a First Response capability from pre-deployed systems; a Call-Up Response capability for the deployment of space, terrestrial and atmospheric systems; and a Government/Industrial Base Response to rapidly adapt to new strategic requirements and technological advances.

**1004 “Aggressive Surveillance as a Key Application Area for Responsive Space”
James R. Wertz, Richard Van Allen, Christopher J. Shelner, Microcosm, Inc.**

Traditional space-based surveillance is fundamentally strategic. Systems are expensive and take a long time to develop. Thus, they are intended primarily for global coverage and launched on a schedule largely unrelated to world events. Opponents may be aware of the broad system parameters, such as the orbit, and hide from the system when it is overhead.

The goal of aggressive surveillance is to go after the opponent by being able to act or react quickly, at low cost, and in ways that cannot be predicted. In addition, aggressive surveillance allows us to take advantage of technology advances in the shortest possible time, thus significantly magnifying technological superiority.

This paper describes key elements of aggressive surveillance and estimates the time and cost required for an initial implementation. These include, but are not limited to:

- Low cost, responsive, scalable launch systems
- Responsive communications and operations
- Responsive orbits
- Low cost surveillance payloads, such as visible or IR observation systems, wind lidar, and other potential detection systems
- Agile spacecraft for responsive, on-orbit operations
- Autonomous, on-board orbit control for the construction of virtual constellations and coordinated observations
- Plug and play spacecraft and payload systems for rapid changes or insertion of new technology

Initial systems can be developed with a total recurring cost per spacecraft (launch, spacecraft bus, payload, and 1 year of operations) between \$15 and \$20 million. After the process is initiated, the potential exists to truly change the way business is done in space – in defense, science, education, and commercial applications. In addition, the process and system are inherently scalable, such that savings in both cost and schedule can be rapidly extended to larger systems at a small fraction of the non-recurring cost and time normally associated with traditional, large space systems.

1006 “Using Proven Aircraft Avionics Principles to Support a Responsive Space Infrastructure”
Randy Black, Honeywell Space Applications

Creating an engineering environment that supports responsive space involves a variety of interrelated disciplines. Included within these disciplines is the ability to quickly re-configure systems through plug-and-play hardware and software. Plug-and-play hardware as a concept has been progressing well throughout the electronics industry. Plug-and-play software has been somewhat more challenging. While some advances have been made through object-oriented architectures and model-based autocoding, software lags behind hardware in this area. Honeywell has experienced significant success for the past ten years fielding plug-and-play software at the application level. Using a combination of time and space partitioning, table-driven operations, and robust off-line development tools, Honeywell’s Integrated Modular Avionics (IMA) has produced significant savings in development cost and schedule. More importantly, modifications to either hardware or software are quickly and easily integrated into the overall system with minimal re-certification required. During the past decade, Honeywell has produced multiple implementations of this advanced avionics technology. One lesson learned is that specific implementation details are not as important as designing to key architectural principles. This paper describes several of those principles that have a proven track record of enabling rapid reconfiguration of system architectures. Architectural principles that support plug-and-play software applications, as well as minimizing the impact of hardware modifications, provide the core of a system design that is integral to an overall responsive space infrastructure.

SESSION II — LAUNCH
(4/25/06, 3:45 pm – 5:30 pm, Chair: Anthony Straw, SSTC, Boeing)

2001 “Responsive Air Launch Using F-15 Global Strike Eagle”
Timothy T. Chen, Preston W. Ferguson, David A. Deamer, John Hensley, The Boeing Company

A near term military need exists for a capability to execute global strike, responsive spacelift and space control missions. This paper presents an innovative concept based on integrating off-the-shelf components to provide this capability, while avoiding technology development risk. The concept would utilize an F-15E with minimal modifications to provide a reusable first stage for the F-15GSE (Global Strike Eagle). The upper stages of the F-15GSE would consist of currently available solid rocket motors packaged to meet the mission requirements. The F-15GSE concept could provide an “all azimuth” capability from a single CONUS base while reducing the Delta-V required for orbital insertion by 5000 fps versus a ground launch rocket system. Advantages of an F-15GSE system include: increased mission flexibility, rapid response time without deployment of assets, multiple basing options and covert launches. Operational missions could be completed within two hours while on alert status with minimal infrastructure from CONUS or remote bases. Initially this concept could provide a low-cost demonstration of global strike, while military operational capability could be met with an expansion of fleet size. The F-15GSE would be capable of global reach with delivery of munitions including the Common Aero Vehicle (CAV) and also provide a LEO launch capability for microsats. Planned future upgrades are available to enhance capability for delivering heavier ballistic and orbital payloads.

2002 “Systems Engineering for Responsive Launch”
Thomas P. Bauer, Shyama Chakroborty, Robert Conger, James R. Wertz, Microcosm, Inc.

In the Microcosm Responsive Launch Systems model, a key requirement is that the launch vehicle be essentially a commodity, built to inventory, and ready to go whenever needed, much like cruise missiles or rental cars. This, in turn, implies the need for low vehicle cost and minimum ground infrastructure in order to hold down the capital cost of maintaining systems in inventory, as well as minimizing the actual launch operations time. Thus, one way to achieve responsive launch is to design a low-cost system which provides a ready inventory and necessitates a brief launch operation to keep operations cost low.

This paper addresses 5 key system engineering trades in the implementation of low cost, responsive launch systems:

- Propellant selection
- Pressure-fed system
- 3-stages to orbit
- Common technology in all stage
- All-weather launch

Virtually all American launch vehicles use 3 stages to get to usable low earth orbits or they employ high performance features, e.g., hydrogen/oxygen engines, very high chamber pressure (RD-180), or exotic structures (balloon tanks). This is a direct result of the rocket equation. High performance features drive up life cycle cost because of both high developmental costs and high manufacturing and operating (recurring) costs.

The Scorpius® design seeks to substantially lower the time and cost of payload delivery to usable low Earth orbits. The design strategy is to use technologies of moderate performance so as to keep developmental and recurring costs to a minimum. Minimizing cost using “conventional” propellants, e.g., LOX/kerosene, and structures and other systems that are easily manufactured and handled, i.e., of moderate weight, necessitates the use of 3 stages for the low Earth orbit mission.

Since the Scorpius® design seeks to exploit pressure-fed systems because of their extremely low life cycle costs, which tend to be heavier than moderately performing pump-fed systems, three stages are required for cost efficacy. The third stage enables a substantially lower gross weight and higher margins in the quest for low cost, especially for the pressure-fed technology. The use of three stages has the added benefit of the design’s being less sensitive to growth in dry mass.

The relatively short, squat design and pressure-fed system provides other features that drive down cost and directly impact responsiveness. Specifically, the use of 7 nearly identical pods per vehicle allows a significant cost reduction due to learning curve even when only a small number of vehicles are built per year. The short, robust mechanical configuration allows the system to be designed for all-weather launch, the lack of which is typically a major impediment to responsive launch.

The net result of these trades is the Sprite Small Launch Vehicle, capable of putting 810 lbs into LEO for \$4.2 million with a small number of launches per year. Launch can be within 8 hours from the storage condition (not on alert), within 2 hours from alert on the launch pad (indefinite hold period), and within 5 minutes when the system is on alert and fueled.

2003 “QuickReach™ Responsive Launch System” Gary C. Hudson, AirLaunch

The QuickReach air-launched SLV will be described and progress in Phase 2A and 2B of the DARPA Falcon program noted.

QuickReach is a small, two-stage Space Launch Vehicle that is air-launched from a cargo transport aircraft. Designed to be highly responsive, it will provide a call-up time of 24 hours or less, and will be able to place a 1,000 lbs spacecraft in the reference orbit. The SLV will be able to meet a cost goal of \$5M or under at a launch rate of 20/yr.

To date, drop tests have been conducted, along with Stage Two engine firings and other component development. Progress towards a first demonstration launch will be discussed.

2005 “Responsive Range Operations” David Seo, Lockheed Martin

While Operationally Responsive Space requires responsive launch vehicles and responsive payloads, it also requires responsive launch ranges. Several functions, including planning, scheduling, range safety (ground safety, flight safety analysis, flight safety), and range configuration must be accomplished quickly if a launch range is to be responsive.

After taking a high-level look at each of these launch range functions and describing how they could be made more responsive, this paper addresses, in much greater detail, launch range configuration. It identifies the many elements of a range that must be configured and the timelines required to meet Operationally Responsive Space objectives. This paper then discusses techniques and processes for accomplishing range configuration within the required timelines.

To provide additional support for the conclusions drawn in this paper, examples are provided where these techniques and processes have been used successfully in similar applications.

This paper concludes with a look at the pros and cons of standing up a new, responsive launch range versus making an existing range more responsive.

3002 “Responsive Tactical Space Using Micro-Satellites and Aerial Launching: The Perspective of a Small Nation” Col. (Res.) Yoram Ilan-Lipovsky, Head, Space and UAV Center, Tal Inbar – Space Research Center of the Fisher Institute for Air & Space Strategic Studies, Israel

During recent years, a growing interest in the world space community has awakened, regarding a new approach in the field of space technology. This approach is based on a new and revolutionary look at the needs of small nations in space and on technological innovations as well. The importance of responsive space for civilian purposes and for defense use – at the tactical level will be presented in detail in the article and presentation.

Our Vision calls for many satellites working together in constellations on low earth orbit, providing continuous target coverage. Some of the satellites would be launched on demand from military or civilian aircrafts and will be placed in optimal and focused orbits. The platforms will be Micro Satellites. Among other aspects, the paper will deal with civil and defense needs and the relevancy of emerging technologies such as miniaturization, ion driven thrusters, Nano-technologies, laser communication, data fusion and advanced imaging, to the realization of this vision.

The article will describe the unique status of a small nation, such as the state of Israel, and the benefits it could gain from responsive space guidelines, especially in the fields of aerial launch and micro satellites.

The paper will address all aspects of the Responsive tactical micro satellites vision, applicable for a small nation, such as:

- Analysis of the needs – military and civilian
- Defining future missions for TMS (Tactical Micro Satellites)
- A comprehensive study of the Launch On Demand (LOD) concept and focused orbits idea
- Technical and financial aspects
- Aerial Launching – detailed analysis of 2 main alternatives – launch from a fighter plane (such as the F-15) and from an airliner (such as 747 or 767)
- Micro Satellites – architecture, basic design, the bus, payloads, propulsion and orbits
- Constellations and satellite formations flying
- The very low Earth orbit environment

2006 alt “Responsive Low-Cost Launchers Available Today, Orbital Launching While Others are Talking”
Keith Emerson, Scott Schoneman, Orbital Science Corporation

Operationally Responsive Spacelift (ORS) is a topic that has been gaining increasing emphasis in support of Military Space operations. There are a variety of new concepts in various stages of development that are specifically focused on this requirement. However, most of them require a significant amount of investment to achieve the ultimate objective of low cost responsive launch. Moreover, as development programs they have little to no actual launch history and are subject to schedule and cost growth risks that are not unusual with new launch vehicle developments. As an alternative, Orbital programs such as the Orbital Suborbital Program (OSP) Minotaur family, Pegasus, and Taurus launch vehicles are fully capable now of meeting most of the ORS objectives with a relatively small amount of additional investment and at much lower risk. While we have heard much discussion of savings in the launch industry in the last couple of years we have seen one unsuccessful launch and many PowerPoint presentations on the transformation that is yet on the horizon. Orbital stands ready to provide responsive space launch capabilities that are far down the learning curve, continue to prove launch success, and have the benefit of launching while the alternative discussions continue.

SESSION III — SPACECRAFT
(4/26/06, 10:30 am – 12:15 pm, Chair: Mark Webster, SSTC, Ball Aerospace)

3001 “Analysis of Modular Spacecraft Bus Design for Rapid Response Missions”
Lucy E. Cohan, Richard-Duane Chambers, Rachel K. Lee, Col. John Keese, Massachusetts Institute of Tech.

Rapid Response spacecraft are becoming more essential due to current affairs. The long development and testing times of typical satellites necessitate a change of paradigm to accommodate responsive space timeline requirements. One necessary component of this paradigm shift is a standardized bus. A standardized bus allows for a minimal amount of bus redesign and testing for each mission. Instead of forcing the bus to conform to the payload, the payload must conform to a set of predetermined requirements imposed by the bus. By reducing the need for satellite redesign and test, standardized buses allow for mission readiness in a matter of weeks rather than years.

However, using standardized buses reduces payload flexibility and leads to buses that are oversized, overdesigned, or otherwise inappropriate for a particular payload. This study proposes that a modular bus might provide standardized interfaces for responsiveness, yet still provide some flexibility to match the needs of the payload. However, modularity comes at a price, introducing inefficiencies and testing cost.

This paper presents a quantitative analysis of the cost and efficiency of two competing standardized bus options: a traditional monolithic design and an emerging modular architecture. The study further attempts to quantify this tradeoff and determine the optimal degree of modularity for a responsive satellite bus. The degree of modularity is determined by specifying which, if any, subsystems should be considered as separate modules that can be upgraded or replaced, and which subsystems should be a part of an integrated bus common to every mission.

The study has been undertaken using MATLAB[®] simulations. The individual simulation components represent various satellite subsystems, as well as satellite demand, cost, testing time, and inventory size. The codes are run to determine the efficiency, cost, reliability, response time, and inventory of each configuration of modular and integrated subsystems across a range of payloads. Specifically, this study explores payloads of the following three types: a communications payload in low earth orbit, a communications payload in highly elliptical orbit, and an optics payload in low earth orbit. The efficiency is defined as being the excess mass, power, and volume capacity created by utilizing the standardized bus that is designed to work with many payloads as opposed to a monolithic bus designed specifically for the given payload. The response time is defined as the time from the mission call to the time that the satellite is ready for launch. Additionally, there is an efficiency associated with the amount of inventory required to maintain mission readiness. The study establishes the optimal combination of modular and integrated subsystems, as well as testing strategy and inventory for responsive space missions of these types.

3003 “Low-Cost Responsive Exploitation of Space by HAUSAT-2 Nano Satellite”
Young-Keun Chang, Suk-Jin Kang, Byoung-Young Moon, Byung-Hun Lee,
Hankuk Aviation University, South Korea

This paper addresses the development and design of the HAUSAT-2 (Hankuk Aviation University SATellite-2), being developed by SSRL (Space System Research Lab.) of Hankuk Aviation University. This is the second satellite system development program executed at the university level in Korea. The HAUSAT-1, a next generation 1kg class picosatellite, has already been developed by SSRL as the first ultra-small satellite and is planned to be launched in the first quarter of 2006 by a Russian “Dnepr” launch vehicle. The development of ultra-small satellite such as HAUSAT-1 and HAUSAT-2 project offers graduate and undergraduate students great opportunities to understand the satellite design process, analysis, manufacturing, assembly, integration, test, launch and operation, as well as providing practical experience working as a team member. In addition, these ultra-small satellites can also be utilized as a space technology test bed.

Main mission objectives of the HAUSAT-2 are to study the scope of activities and ecology of animals using Animal Tracking System (ATS) and collect space environment data of mission orbit from Electric Plasma Probe (EPP) as a space science payload.

The secondary mission objectives are to provide the following space technology verifications: performance verification of a star tracker manufactured by SaTReC-i and a spaceborne GPS receiver manufactured by NAVICOM.

The HAUSAT-2 is a nano-satellite, having a mass of 25kg with 30cm x 30cm x 39cm hexahedron configuration. It is being designed to operate in LEO with 650 ~ 800km altitude sun synchronous orbit. The three-axis stabilization is being implemented with pitch bias momentum method. The electrical power subsystem includes 8 cell Li-Ion batteries, 5, 12, and 28 volt regulators, and 5 gallium arsenide (GaAs) solar panels capable of generating more than 21.7 watts average solar power at end-of-life (EOL). Link budget analysis results allow the HAUSAT-2 communication subsystem to implement the amateur bands for uplink (VHF) & downlink (UHF) communications and 2 watt radio radiation power. The command & data handling subsystem(C&DH) includes an OBC (On-Board Computer) consisting of a MPC860T microprocessor operated by VxWorks O/S and a TCA (Telemetry & Command Assembly) with 89C50 microcontroller. The design mission life of the HAUSAT-2 satellite is expected to be 2 years.

The HAUSAT-2 incorporates five types of operation modes; Initial, Normal, Science (Mission Mode), Communication, and Safe. The power requirements at individual modes are different and calculated by considering average and maximum power consumption.

The critical design of the HAUSAT-2 has been completed. The STM (Structural-Thermal Model) was developed as the first system model used for verifying structural and thermal design margin. The qualification level vibration and thermal tests have been conducted on the STM. Detailed circuit design and parts selections were carried out at the module level and EM (Engineering Model) units and payloads have been manufactured in which Integrated system performance and flight software algorithm were verified through the ETB (Electrical Test Bed) tests. Box-level qualification tests were achieved to ensure required performance in launch and space environments.

3004 “Bandit: A Platform for Responsive Educational and Research Activities”
Michael Swartwout, Washington University in St. Louis

There are many potential paths to improving the responsiveness of space systems. At Washington University, we are investigating three: drastically-reduced spacecraft size, drastically-reduced mission lifetime, and pre-placement of assets on-orbit. Extremely small spacecraft (under 10kg) are believed to be more responsive due to their low part count (reducing cost / time of fabrication and assembly), ease of handling/integration and increased ability to fit in the unused corners of payload fairings (i.e., as lastminute additions to already-manifested launches). Missions that last days or hours have significantly less risk of environmental degradation and need less power margin, allowing the use of less-expensive parts and/or eliminating redundant systems. The combination of small size and short mission enables such vehicles to be pre-positioned on larger host vehicles, allowing them to be activated as needed for their specific mission. From an education standpoint, very small, short-duration spacecraft are within the capabilities of an undergraduate team to design, build and operate within their “lifetime” as students.

What missions – if any – can be met by such small, short-duration systems? We believe that one such mission is on-orbit servicing. On-orbit servicing (inspection, repair, refueling) is a key enabling technology for future missions, and it has “responsive” needs of its own. In 2005, both NASA and the Air Force flew demonstration servicing missions, with several more planned for the near future.

Servicing missions have both ‘long-period’ functions (power generation, long-range communications, momentum management) and mission-specific ‘short-period’ functions (agile maneuvers over small distances, sensing, mechanical manipulation). The recent servicing missions described above use the same vehicle for both long-period and short-period functions, which results in a spacecraft larger than strictly necessary for servicing. Instead, we propose the Bandit concept, which splits the long-period and short-period functions between a host vehicle and a drone vehicle. Bandit has the following enabling elements:

- A very small (< 10kg), maneuverable drone capable of independent (or lightly supervised) operation on 10 or more sorties lasting up to 2 hours each
- A host vehicle (possibly the service recipient) with the following interfaces:
 - A launch containment system to carry the drone to orbit
 - An on-orbit docking system to allow a drone to “sleep” between sorties
 - A recharging (and possibly refueling) system in conjunction with the dock.
 - A short-range, low-power communications link to the drone

This concept also creates “responsive” engineering education; early student teams create the platform and design/test infrastructure, and successive generations improve on the design. We have already seen the benefits of this approach over the past four years.

At present, Bandit-C is being developed as part of the AFRL/NASA/AIAA University Nanosat-4 student satellite competition. This paper outlines the Bandit mission in more detail, including current design, prototyping activities and functional/environmental testing. Special emphasis is placed on hardware testing using a 3DOF air-bearing testbed and operations/autonomous control testing on the 6DOF software-based simulator. Design of the 25 kg host spacecraft Akoya is also discussed. We conclude by presenting sample missions for future Bandits.

3005 “ORS Phase III Bus Standards Status”

**J. Christopher Garner, Michael Hurley, Gurpatap S. Sandhoo, U.S. Naval Research Laboratory
Eric J. Finnegan, Patrick A. Stadter, Brian Kantsiper, Johns Hopkins University/Applied Physics Laboratory**

The U.S. Naval Research Laboratory and the Johns Hopkins University/Applied Physics Laboratory are collaborating with many industry partners to write bus standards for responsive spacecraft buses as part of the ORS/JWS Phase III. The next Phase, Phase IV led by SMC, will use the standards as input to the procurement of responsive spacecraft buses in 2008. More than 8 industry partners (Spectrum-Astro, Design-Net, Swales, Orbital, Raytheon, Loral-Microcosm, and Microsat Systems Inc) are under contract to NRL to participate in the integrated systems engineering team (ISET). The ISET has been meeting since June 2005 and has produced the first drafts of the payload developers guide (PDG) and the bus standards documents. Currently, an NRL/APL team is working to develop a prototype spacecraft bus to mature portions of the standards and supply the spacecraft bus for the TacSat 4 mission. This paper will discuss the ISET team process in developing the bus standards and the progress of experimentation with the prototype bus. Phases I-III of this effort are funded by OSD’s Office of Force Transformation, Phase IV effort will be funded by SMC.

3006 “HexPak Testbed Development”

Michael Hicks, Michael Enoch, Larry Capots, Lockheed Martin Advanced Technology Center, Palo Alto, CA

HexPak is a scalable spacecraft structure with the requisite features that enable responsive space missions. The structure consists of hexagonal equipment/payload bays with embedded harnessing to support multiple mission-specific component layouts. Scalability is supported via embedded network connectivity for plug’n’play avionics and expansion bays. The hexagonal bays are stacked for launch in a self-supporting structure which efficiently packs in the launch fairing, and deploys on orbit to form a large deployed aperture for payload equipment. The large deployed area provides large aperture payloads un-inhibited viewing angle. Since the structure is self-supporting, multiple payloads and multiple manifest are possible with minimal mass impact due to launch support structures. Since each bay is fabricated and tested individually, and easily accessible from all sides, the time/unit mass to manufacture a complete spacecraft is greatly improved over more traditional structures. For missions that require a large number of platforms, the modular structure offers easy interchangeability of HexPak bays which makes it possible to maintain a consistent production flow even during periods of parts shortages. Standard physical interfaces also allow for commonality in tooling, fixturing, testing and ease of satellite integration. The hexagonal geometry is near optimum for taking advantage of available fairing envelopes and the folded structure is self-supporting, which minimizes the need for additional structure to support launch.

A full-scale mechanical testbed for demonstration of HexPak deployment was built last year and is described, along with the physical integration of a JINI based plug’n’play network onto the structure. Because the structure and C&DH system are physically scalable, their combination provides a clear route for the transfer of the rapid integration advantages of responsive space to more traditional missions.

SESSION IV — TACSAT (4/26/06, 1:45 pm – 3:10 pm, Chair: Stan Kennedy, SSTC, Lockheed Martin)

4002 “Pulling the Pieces Together at AFRL”

Peter M. Wegner and Col. Rex R. Kiziah, USAF AFRL/VS

In partnership with Air Force Space Command, the Office of Force Transformation, and the other military services’ S&T and R&D organizations, the Space Vehicles Directorate of the Air Force Research Laboratory is aggressively pursuing the

development of responsive space technologies and spacecraft. The Directorate has made responsive space one of its six core thrusts. The objective of the responsive space thrust is to develop and demonstrate the technologies that will enable spacecraft with the following attributes:

- Operational within six days of call-up
- Total mass (<400 kg) and low-cost (<\$30M mission costs, including spacecraft, launch and operations)
- Tasking and data dissemination utilizing existing warfighting equipment and architectures
- Satellite payloads are taskable by theater commanders/forces with direct downlink/data dissemination into theater assets
- Missions-tailored for a specific theater of operations

In order to realize this objective, the responsive space thrust consists of a robust portfolio of technology investments, ground and space experiments, and strategic collaborations. Even beyond this thrust, the philosophy of utilizing small, low-cost satellites with valuable military capability is a key component of the Space Vehicles' vision for the future. This philosophy and experimental approach is reflected in the recent, highly successful XSS-11 Spacecraft and the upcoming TacSat-2 and TacSat-3 experiments. This paper will discuss the work being performed by the Air Force Research Laboratory and its strategic partners to enable the future vision of low-cost, highly responsive, militarily useful spacecraft. This will include a discussion of the XSS-11 spacecraft and its highly successful experiments, current investments in plug-n-play technologies, the development of a modular spacecraft bus based upon these technologies, a ground-based test-bed to enable rapid experimentation with these technologies, and the TacSat-2 and TacSat-3 space flight experiments to explore the military utility of this new class of space systems.

4003 “Development of the Tactical Satellite 3 for Responsive Space Missions” Thomas M. Davis, Capt. Stanley D. Straight, USAF, AFRL

Numerous Department of Defense studies show implementing a responsive satellite capability provides for significant military utility to augment or surge current space capabilities. The TacSat concept explores the capability/technological maturity of small, low-cost satellites with the most prominent efforts currently being conducted within the Science and Technology (S&T) Program. In addition to providing for ongoing innovation and demonstration in this important technology area, these S&T efforts also help mitigate technology risk and establish a concept of operations (CONOP) for future acquisitions. TacSat efforts underway by the Air Force Research Laboratory (AFRL) and the Naval Research Laboratory (NRL) are focused on demonstrating small (<500kg), operationally responsive, low-cost satellite and launch capabilities to support warfighter.

AFRL's Space Vehicles Directorate is leading the Tactical Satellite 3 (TacSat-3) team and partners include Space and Missiles Center Detachment 12, the Army Space Battle Laboratory, the Air Force Space Warfare Center, the Office of Naval Research, and the DoD Office of Force Transformation. Building on the experiences with TacSats 1 and 2, TacSat-3's mission was vetted through a formal payload selection process with Air Force Space Command (AFSPC) and Combatant Commands (COCOMs). TacSat-3's mission was selected for specific capabilities to meet user needs, and to demonstrate those capabilities within cost and schedule constraints. A building block for Operationally Responsive Space, TacSat-3 will experiment with a Hyperspectral Imaging (HSI) capability direct to the tactical warfighter within 10 minutes of a collection opportunity.

The TacSat-3 demonstration features a low cost “plug and play” modular bus and low cost militarily significant payloads – a Hyperspectral Imager and a secondary payload demonstrating data exfiltration provided by the Office of Naval Research. TacSat-3 will demonstrate evolutionary steps and traceability towards objective system goals for the capabilities and processes including rapid response to a user defined need for material detection and identification, and battle damage assessment. Additionally, it will demonstrate traceability to enable launch processing at the launch base faster than 7 days. Finally, it will feature a rapid development of the space vehicle and integrated payload and spacecraft bus by using components and processes developed by the Operationally Responsive Space Modular Bus program.

Design constraints established for the TacSat-3 program include a total program cost to be less than \$50M, to fit on a low cost responsive space booster and a satellite weight of less than 400 kilogram, with a build time for payload and modular bus of less than 18 months. The TacSat-3 CONOPS breaks old paradigms and gives COCOMs first realistic opportunity for responsive, dedicated space capabilities at the operational and tactical level. The TacSat-3 spacecraft will collect and process images and then downlink material ID text and geolocation or downlink full data image using a Common Data Link. An in-theater tactical ground station will have the capability to uplink tasking to spacecraft and will receive full data image.

4004 “Sounding Rocket Technology Demonstration for Small Satellite Launch Vehicle Project” John Tsohas, Lloyd J. Droppers, Stephen D. Heister, Purdue University

Purdue University is embarking on a program to demonstrate technologies critical to the development of a small satellite launch vehicle. The first phase of the program involves design, fabrication, testing and flight of a hybrid propulsion sounding rocket from the NASA Wallops flight facility. This paper details the design and test work that has been achieved to date. Propulsion work includes successful hot fire tests of a flight weight, 180 lbf thrust hydrogen peroxide / HTPB hybrid rocket motor at the Purdue rocket test facilities. The tests confirmed the structural integrity of the engine, verified the thermal insulation ablator design, helped determine solid grain regression rate and verified the engine performance characteristics with

the internal ballistics simulation code. Detailed design of vehicle plumbing, structure, propulsion, avionics, and recovery subsystems has been completed. The rocket consists of a carbon-fiber composite aero-structure, welded aluminum oxidizer tank, and a fiberglass composite internal structure. A nitrogen blowdown system is used to provide the engine with oxidizer, and the recovery system has dual redundancy. In addition, detailed design has been completed on the ground support equipment used for remote loading and draining operations of liquid hydrogen peroxide to and from the vehicle, while monitoring critical vehicle parameters. Remote disconnect of umbilical cords, engine ignition, launch and aborts are also functions of the ground support equipment. A trajectory analysis and vehicle aerodynamics code was developed to design the vehicle geometry, stability, and mass allocation. Follow-on flights of the technology demonstration vehicle will include the addition of a pressure fed cycle and a thrust vector system with associated guidance and control hardware and software.

The second phase of the paper details the conceptual design of a small satellite launch vehicle designed to place 10 lb university or research payloads in low Earth orbit. In order to make use of the already existing rocket test facilities at Purdue and to keep test costs low, the thrust of the first stage engine was constrained to less than 10,000 lbf. To reduce costs associated with structural design, analysis and manufacturing, a three stage launch vehicle with a low propellant mass fraction for each stage (~76%) would be designed. Hybrid propulsion would be used due to its relative simplicity and safety over liquid bi-propellant systems. Hydrogen peroxide would be used as an oxidizer due to the high density Isp and its non-toxic, and non-cryogenic properties. This would lead to a reduction in operations costs and increased safety in propellant handling in comparison with other candidate oxidizers. A small composite solid propellant third stage would provide the final delta-V at the desired orbital altitude. Thus, a three stage launch vehicle with a GLOW of 6,400 lb and 8,700 lbf thrust first stage engine would satisfy the above design requirements.

4006 "A TACSAT & ORS Update Including TACSAT-4"

Col. Tom Doyne, Cdr. Greg Glaros, OSD, Peter Wegner, AFRL, Lt. Col. Randy Riddle, SMC Detachment 12, Mike Hurley, Ken Weldy, Chris Garner, Naval Research Laboratory

In May of 2003, the Office of the Secretary of Defense's Office of Force Transformation (OFT) undertook an initiative to perform Operationally Responsive Space (ORS) experimentation. Three years later TacSat-1, 2, 3, and 4 experiments are all underway. TacSat experiments are now jointly selected each year via an iterative mission development process engaging the operational community, COCOMs & Services, and the DoD S&T community. TacSat experimentation leadership and funding has largely transitioned to the DoD S&T community with OSD's Office of Force Transformation continuing to provide guidance and bus standards development. Each TacSat experiment tests key elements needed for an operational system by taking frequent tangible steps to spiral capability and receive operational feedback, while moving toward an acquisition. The TacSat-4 experiment will use the prototype ORS system-level bus standards and fly in a "low" Highly Elliptical Orbit (HEO) enabling a new set of ORS missions that require dwell, such as communications. In addition to experimentation, ORS has made significant strides toward an operational system. The formal ORS requirements are being developed in the Joint Capabilities Interface Development System (JCIDS) process and preparation of a Joint Program Office, formally planned for FY08, has also begun. This paper discusses the above and, for context, includes portions of the 2003, 2004, and 2005 papers.

SESSION V — INSTRUMENTS

**(4/26/06, 3:40 pm – 5:05 pm, Chair: Dr. Jeff Puschell, SSTC, Raytheon;
Scott Jenson, SSTC, Space Dynamics Lab)**

5001 "SciBox[®] Based Uplink Operations Planning Concepts for Responsive Space"

Andy McGovern, Johns Hopkins University Applied Physics Laboratory

Time sensitive targeting is of keen interest in the C2 arena. Implementations of this concept also appear in civilian space missions in the form "responsive targeting," meaning an unexpected event warrants a rapid response. The goal in both C2 and civilian arenas is to quickly produce the desired effect at minimal cost and low risk. Techniques that greatly simplify and streamline the processes of mission planning, command sequence generation and command upload have been developed in the civilian space arena by the Applied Physics Laboratory of Johns Hopkins University. We have developed innovative mission operations techniques and software tools for the CRISM instrument on board the Mars Reconnaissance Orbiter (MRO). CRISM is a gimbaled visible/infrared spectrometer for analyzing the Martian surface and atmosphere. CRISM's gimbaled platform and MRO's roll capabilities make responsive targeting and pointing a challenge that we have addressed. We streamline the process of planning, command sequence generation and upload by linking flight software with planning software via a macro library and a visualization tool. Our approach enables the scientist (or the field commander) to directly task the instrument without the need of an operations support center. Part of CRISM's mission is to target dust storms which form and dissipate rapidly during one season. Our approach, which enables the scientist to command the instrument at a high level and visualize predicted results, is critical for these time sensitive observations. This presentation provides an overview of our approach to responsive targeting in the context of the CRISM mission and how it may be implemented for responsive space systems.

5003 “Reconnaissance Payloads for Responsive Space”
Stanley Kishner, David Flynn, Charles Cox, Goodrich Optical and Space Systems Division

A key mission fueling the interest in Responsive Space is optical reconnaissance. Minimizing the cost and delivery schedules of optical reconnaissance payloads having true operational capability will be key to success of these missions. Modification of existing proven airborne reconnaissance payloads provides a practical path for achieving this Responsive Space capability.

In addition to space sensors such as the Multispectral Thermal Imager developed for Sandia Laboratories and launched in early 2000, Goodrich currently provides a range of imaging sensor systems and services for airborne reconnaissance. Goodrich has provided the reconnaissance cameras for the U-2 since 1957, with the current SYERS electro-optical system providing a robust set of outputs supporting IMINT and MASINT missions. The capabilities of the SYERS system have continually improved through our P3I program. From a low earth orbit of 300 kilometers, a SYERS system modified for use in space could provide a ground sample distance of approximately 1-meter. It is this system and its functional elements that form the basis for our Responsive Space Reconnaissance (RSR) approach.

The Goodrich approach for producing payloads for RSR can be visualized as pulling from our “product stream” of airborne sensors to build an inventory of RSR payloads that can be made available upon short notice. The major effort for adapting the SYERS sensor system for responsive space is associated with the focal plane and electronics. Retaining the current operational functionality and architecture could be implemented with parts and processes compatible with a short lived vacuum environment and aimed at reducing the power consumption for compatibility with the low-cost spacecraft bus. Our vision for RSR Payloads is to establish a pre-positioned, rapid-response process that can adapt our continually evolving product line of high acuity airborne sensors for responsive space missions as the need for such missions is identified.

In this paper we will describe the SYERS sensor, its modification for use in space and interfaces to candidate spacecraft. We will also address the CONOPS that will allow a modified SYERS sensor to meet responsive space needs.

In summary, optical imaging payloads for Responsive Space can be evolved from our operationally-proven line of tactical and strategic airborne sensors, which have demonstrated on-demand support to our warfighters. These existing airborne systems emphasize operational availability and can be readily adapted for RSR missions. This philosophy and capability is directly aligned with Responsive Space needs.

4005 “Responsive Space’s Spacecraft Design Tool (SDT)”
Robert Strunce, Fred Eckert, Craig Eddy, Star Technologies

Star Technologies Corporation has developed a “.Net Framework Simulation Architecture”, “Spacecraft Design Tool” (SDT), which is an open framework for Responsive Space’s rapid design concept spanning mission capture to deployment. SDT has been incorporated in all the test cells at AFRL’s Responsive Space Test Bed. SDT is integrated into the Mission Design phase for spacecraft simulation and analysis as well as providing the spacecraft dynamics/kinematics, earth environment, and sensor/actuator models in the real time hardware-in-the-loop (HITL) test cells. SDT can simulate a sensor/actuator, or interface to its respective hardware emulator or interface to the actual hardware through the Responsive Space’s Plug-n-Play (PnP) electronic environment. SDT provides a true software PnP environment where the User can seamlessly inherit properties from within SDT as well as add his own component or subsystem capabilities such as complex propulsion or electrical power subsystem. SDT has a 3D Visual game engine for display of the earth, sun, moon as well as multiple articulated spacecraft. SDT has been used to model TacSat2, a generic Responsive Space satellite, and TacSat3.

SDT provides an environment for rapid prototyping of spacecraft using true software PnP of components and subsystems. In other words, the SDT application recognizes new components such as attitude control sensors and actuators in the same way that your computer recognizes that a new printer has been added. This is accomplished through the latest software technologies of COM and .NET Framework. The .NET Framework provides a higher level of interoperability than COM especially over networks and the internet where COM is a subset of the overall capability. Under the .NET Framework, objects such as a specific Sun Sensor can be written in any language (C#, C++, Fortran, ADA, Basic, Perl) and execute on different computer platforms (PC, PowerPC, Sun) and under different operating systems (Windows, Solaris, Linux). Although SDT is currently aimed at spacecraft, the “.Net Framework Simulation Architecture” can be applied to any multi-body dynamic system such as launch vehicles, robotics or land rovers. SDT has supported NASA efforts in electro-dynamic tethers as well as tethers employed in future NASA Scientific Missions such as SPECS or TetraStar and is hosted in GSFC’s Formation Flying Test Bed (FFTB).

This paper will discuss the implementation and utilization of SDT within the AFRL’s Responsive Space Test Bed.

5005 “On-orbit Calibration and Focus of Responsive Space Remote Sensing Payloads”
Thomas Chrien, Stephen Schiller, Raytheon Space and Airborne Systems

Radiometric, spectral, and spatial response performance and calibration knowledge requirements have been traditional cost drivers for remote sensing payloads. Performance has a direct relationship to the usefulness of the information product, including (1) bore-sight calibration in order to achieve geolocation accuracy, (2) optimization of focus to maximize spatial resolution, and (3) absolute spectral and radiometric calibration for effective atmospheric compensation. Meeting strict requirements prior to launch is problematic. Careful (and costly) compensation must be made for gravity effects, and thermal vacuum test conditions can only approximate on-orbit thermal environments. Furthermore, the trauma of launch and

subsequent space contamination can invalidate a “perfect” pre-launch calibration. An alternative approach is to fine tune focus and calibration after the payload is on orbit using vicarious calibration techniques. This reduces cost and schedule by relieving the accuracy requirements and complexity of pre-launch calibration measurements. Cost / benefit rationale as well as conceptual approaches to pre-launch testing and on-orbit focus and vicarious calibration will be presented.

SESSION VI — PLUG AND PLAY **(4/27/06, 9:30 am – 10:15 am, Chair: Norman Anderson, SSTC, Ball Aerospace)**

6001 “Issues and Implications of the Thermal Control System on the “Six Day Spacecraft”

Andrew D. Williams, AFRL, Scott E. Palo, University of Colorado

The traditional approach to satellite design is a customized and highly optimized satellite bus. The primary design driver is to minimize mass but often at the expense of time and money. To meet the goals of Operationally Responsive Space (ORS), the satellite must be adaptable to different missions, changing threats, and emerging technologies. One of the subsystems that will be challenging for the development of robust and modular architectures is the Thermal Control Subsystem (TCS). To design the TCS, virtually every aspect of the mission, the satellite, and the components must be known. The overall goal of the engineer is to reduce the mass of the system by trading cost and engineering time. As a result, every design is unique and requires extensive design, modeling, analysis, and test programs.

One philosophical approach to achieve the goals of responsive space in the near term is to separate the design and engineering of the payload from the bus. The bus would have a standard design providing a specific set of baseline capabilities and would have limited upgradeability. The disadvantage with most standardized bus development programs is that the bus eventually becomes obsolete and must be completely redesigned as new technologies are developed. One of the goals of the ORS program is the development of technologies that provide robust and flexible bus designs. The Space Avionics Plug-and-Play (SPA) system in development by Air Force Research Laboratory, Space Vehicles Directorate addresses the software and electrical interfaces, but other efforts are needed to address the mechanical and thermal interfaces.

For responsive space, the ideal TCS would be modular and robust to accommodate the wide range of orbits, components, and payloads with minimal survival heater power. In addition, the design and assembly time must be dramatically decreased. The ultimate goal would be a TCS with an inherent plug-and-play capability. One hindrance is that the missions, payloads, and requirements for ORS are still somewhat nebulous. As a result, bus architectures and specific components have not been identified, which makes it difficult to derive even initial thermal system requirements. To provide a baseline for the TCS design and to help bound the problem for the development of thermal plug-and-play systems, the range of external and internal heat loads for small satellites are evaluated. From this analysis, the worst hot and cold cases are identified. Using these two cases, various design parameters are evaluated, and the feasibility of a one-size-fits-all approach is assessed. Finally, critical design parameters are identified and recommended figures of merit are established.

6002 “Java-based Plug-N-Play (Flight) Control Systems for Responsive Space”

Constantine Orog, Michael Enoch, Donald Flagg, Lockheed Martin Advanced Technology Center

A major challenge to achieving a usable and useful “6-day spacecraft” for Operationally Responsive Space is the ability to rapidly compose the system to perform both the needed mission- and spacecraft-oriented functionality using the available “Plug-N-Play” (PnP) spacecraft components. Physical assembly of the PnP spacecraft components is a necessary, but insufficient condition for achieving a fully realized operational system. The assembled system needs to provide the functional capabilities to support the intended mission and also needs to provide the functional capabilities to ensure the operational health and safety of the resulting spacecraft. A preliminary service-oriented spacecraft architectural model to provide a reusable infrastructure is under development as part of the AFRL Responsive Space Testbed effort.

The Lockheed Martin ATC is pursuing the development of a Java-based distributed architecture environment that supports this service-oriented, reference spacecraft architectural model. This work draws on the research experience at the LM ATC since the mid-1990s directed towards the problem of performing multi-fidelity, “composable” simulations, with the ultimate objective being the ability to simulate the entire life cycle of a space system. A key component of this approach involves a simulation architecture that is based on spacecraft services, much like the service-oriented models now widely used in the consumer marketplace. It is but an evolutionary step to extend this approach from simulation to operations.

To seamlessly span the entire range from simulation to operations, a single vertically integrated software architecture was needed. The Java-based distributed architecture provided such an environment with its evolution from desktop, to enterprise, to mobile devices, and now to real time systems. The Java environment addresses the complexity needed for operational simulations and ultimate deployment for integrated spacecraft flight and payload control systems. The Real Time Specification for Java (RTSJ) supports hard real time, soft real time and non-real time processes all interoperating within the same virtual machine. Initial prototyping is being done using IBM’s Real Time Java (RTJ) implementation of the RTSJ.

Along with the development of the Java platform came the development of a multitude of supporting APIs, and one in particular, the JINI protocol, which supports the operation of dynamically changing networks of distributed services (and

devices). Using JINI, running as a non-real time process within IBM's RTJ, provides the rich set of Plug-N-Play capabilities needed to demonstrate both automatic configuration, as would be needed for I&T, as well as for operational fault tolerance and reconfigurability needed for on-orbit operations.

6003 alt "Implications of Responsive Space on the Flight Software Architecture"
Jonathan Wilmot, NASA Goddard Space Flight Center

The Response Space initiative has several implications for flight software that need to be addressed not only within the run-time element, but the development infrastructure and software life-cycle process elements as well. The run-time element must at a minimum support "Plug & Play", while the development and process elements need to incorporate methods to quickly generate the needed documentation, code, tests, and all of the artifacts required of flight quality software. Very rapid response times go even further, and imply little or no new software development, but using only pre-developed and certified software modules that can be integrated and tested through automated methods. These elements have typically been addressed individually with significant benefits, but it is when they are combined that they can have the greatest impact to Responsive Space. The Flight Software Branch at NASA's Goddard Space Flight Center has been developing the run-time, infrastructure and process elements needed for rapid integration with the Core Flight software System (CFS) architecture. The architecture consists of three main components; the core Flight Executive (cFE), the component catalog, and the Integrated Development Environment (IDE). This paper will discuss the design of the components, how they facilitate rapid integration, and lessons learned as the architecture is utilized for an upcoming spacecraft.

SESSION VII — OPERATIONS
(4/27/06, 10:45 am – 12:30 pm, Chair: Norman Reese, SOSTC, Honeywell)

7001 "Autonomous Operations For Responsive Spacecraft"
Jackie Reilly, a.i. solutions, Terrance Yee, MicroSat Systems

MicroSat Systems, Inc. (MSI) is currently supporting the Air Force Research Laboratory (AFRL) on several responsive space programs demonstrating tactically useful small satellites with autonomous operations. Contrary to previous autonomy efforts, these missions have autonomous on-board software which is specifically designed to allow end-users (or Warfighter), with no satellite expertise, to task the vehicle directly. This capability puts the Warfighter in direct control of a spacecraft changing several aspects of the original paradigm throughout the mission.

The use of autonomy tools and modular software elements change the paradigms for traditional spacecraft operations. The change in the operational concept creates implications for overall project development timelines and for the end user in the field. Autonomous operations must be accounted for at the beginning of the requirements definition phase. While it is possible to upgrade existing systems after they are already designed, it is much more straightforward to initially design with the non-expert end-user in mind. This allows the appropriate selection of command and telemetry architecture to accommodate both the traditional expert end-user and a specialized interface for the Warfighter. Designing the Warfighter interface to be simple and minimalist from the beginning has profound impacts on the structure of the entire autonomous software.

There is a major impact on spacecraft integration and testing throughout the development cycle and during on-orbit commissioning. There is significant synergy gained from coordinating the automation software (that performs ground testing), on-board testing (to verify state of health), and commissioning the spacecraft on orbit. By careful design of these capabilities, it is possible to not only save time but also increase the degree to which the ground team follows the "test like you fly" principle.

The net impact of these changes is the following: shorten the time needed to deliver a working product to the end user, bring the end user concerns closer to the design team, change the focus of spacecraft utility design from a strategic asset to one which has short term tactical significance, and to place extremely powerful space assets in the hands of ground forces within minutes of request. This places a unique set of requirements on the software to be as easy to use as possible while also ensuring the safe operation of the spacecraft. Pairing the expertise of ground support and current autonomous ground system software with the expertise of spacecraft developers and current on-board software will help to design the on-board autonomous software that accomplishes this task.

7002 "Responsive Payload Accommodations and Integration Operations for Dedicated CubeSat Missions"
John M. Garvey, Garvey Spacecraft Corporation, Dr. Jordi Puig-Suari, Lori Brooks,
California Polytechnic State University

A key factor to achieving responsive space operations is the availability of standardized payload accommodations that can simplify integration tasks and reduce costs. Several such standards are beginning to emerge in the very small end of the payload market that is characterized by the so-called CubeSat class of spacecraft. These also happen to be compatible with proposed nanosat launch vehicle (NLV) concepts that are intended to enable dedicated CubeSat missions that are free from the operational constraints associated with traditional secondary payload manifest opportunities. The Poly-Picosat Orbital Deployer (P-POD) under development by California Polytechnic University, San Luis Obispo (Cal Poly SLO) is one such system that is now transitioning to flight status.

The viability and merits of such dedicated CubeSat missions was highlighted recently during flight testing of the Prospector 7 prototype reusable launch vehicle (RLV) that was developed by Garvey Spacecraft Corporation (GSC) and California State University, Long Beach (CSULB)). In this case, an engineering prototype of the P-POD unit manifested and then deployed a set of three simulated CubeSats twice within a period of just 3.5 hours. The entire program, from authority to proceed through launch, took only six months, as compared to lead times that are measured in years for larger launch systems.

Future plans envision extending the operational environments that the P-POD will be evaluated under as the NLV development program transitions to higher-performance test vehicles. Besides continued evaluation of refined payload accommodations and integration techniques, it is anticipated that future CubeSat payloads will help monitor and characterize NLV payload environments. Throughout this endeavor, students from Cal Poly SLO, CSULB and other participating academic institutions will continue to gain valuable experience with flight hardware integration and responsive launch operations.

7003 “Concept of Operations for Operationally Responsive Space” Don Knight, General Dynamics C4 Systems

This paper provides a Concept of Operations (CONOPS) on how United States Strategic Command (USSTRATCOM) and theater Combatant Commands (COCOM) might deploy and employ, and how the services might organize, train, and equip an Operational Responsive Space (ORS) weapon system. Since this CONOPS only covers satellite systems, it uses the term ORS over Joint Warfighter Space (JWS) as JWS has evolved to include both space and near-space forces. While the paper does not necessarily reflect the views and/or positions of any service, combatant command, or Department of Defense, it is based upon over 30 different technical interchange meetings conducted over the last two years with a multiple of agencies involved with ORS.

ORS satellites can augment Space Force Enhancement (SFE), Space Control (SC), and Space Force Application missions. For classification purposes, this paper only covers SFE operations, but also has some applicability to SC missions. Space Force Application requires its own separate CONOPS.

The paper begins by identifying the various SFE missions an ORS could perform and recognizing that they fall into two natural orbit regimes: LEO and MAJIC. It then looks at four different trigger events that would cause the deployment of an ORS constellation. Next, the paper identifies launch parameters, constellation sizing, launch windows (to include a Time Phased Force Deployment List of ORS missions), and early orbit check-out timelines required to support the theater commander.

Under employment, the paper first examines how the roles and responsibilities for an ORS would be divided between USSTRATCOM and the theater commander. It then presents how mission planning; collection; mission data downlinking; mission data processing; and telemetry, tracking and commanding would be accomplished.

Switching to the services' responsibilities, the paper provides an organizational structure to include the types and numbers of both the operational and acquisition units required.

“Training the way we will fight” is a vital aspect of the warfighter acceptance of ORS and the paper identifies how peacetime training would be accomplished.

The paper concludes with a table of allowance for equipping an ORS weapon system to include both an Initial and Final Operational Capability.

7004 “Navy Team Responds to Bandwidth Challenges in Support of War Efforts with Innovative Employment of UHF Follow-On (UFO) and LEASAT Satellites” Mike Mattis, Neil Butler, Jack Turner, Maxim Systems, Inc.

The U.S. Navy's UFO satellite constellation is the replacement for the Fleet Satellite (FLTSAT) and LEASAT spacecraft and maintains the Navy's global narrowband communications network. In mid 2002, the operational community expressed the need for increased narrow-band bandwidth in support of Operation Enduring Freedom (OEF). The Naval Networks and Space Operations Command (NNSOC) and the Navy Communications Satellites Program (PMW146) were tasked to investigate methods to increase narrow-band capacity. The 11th UFO spacecraft would not be available until the second quarter of FY04 so the UFO/LEASAT team examined a wide variety of options, including employment of the UFO on-orbit spare satellite (UFO-2). Analysis and testing proved a frequency reuse scheme could allow 12 UFO-2 channels to be turned on to result in a 30% capacity increase in the CENTCOM Area Of Responsibility (AOR). This improved capacity realized by the warfighter in support of OEF saved approximately \$1M/month for equivalent commercial services.

In Oct 2002, the UFO/LEASAT team, acting as the Acquisition agent for the Joint Staff, inquired about the cost and availability of LEASAT satellites to support emerging bandwidth requirements in the CENTCOM AOR utilizing some of the new frequency reuse techniques developed for UFO-2. Although the LEASAT contract had been terminated once the UFO constellation was deployed; the Program Office coordinated an acquisition scheme with the Royal Australian Navy and negotiated a Memorandum of Agreement with the Australian Ministry of Defense to procure services and share LEASAT-5. To better support users, Strategic Command (STRATCOM) requested LEASAT-5 be moved to the Indian Ocean (IO) to support emerging requirements for Operation Iraqi Freedom (OIF). The UFO/LEASAT team obtained approval for LEASAT-5 reactivation and coordinated use of the Guam TT&C equipment to support the relocation effort. Even after the TT&C facility in

Guam was unexpectedly destroyed by a typhoon in December 2002, a new TT&C site in Australia was brought on line, avoiding a three-month delay of the satellite repositioning effort and enabling immediate initiation of the move. Upon receipt of funding and final approval from the Joint Staff, the UFO/LEASAT team had the LEASAT contract modification fully funded and the LEASAT-5 spacecraft moving within 24 hours.

In response to this urgent requirement to provide an additional SATCOM asset in the IO, STRATCOM also requested development of a situational awareness tool that could be used by warfighters and communications planners to show LEASAT-5 availability as it was being moved into theater. The team used Satellite Tool Kit (STK) modeling software to produce a simple self extracting flash video tool that could be quickly sent to communications planner and warfighters in country to determine when link closure would occur as the satellite drifted west to its final station. Often time Responsive Space is thought of as responsive launch. In this case the Navy utilized innovative reuse of existing assets and applied new Concepts of Operations (CONOPS) to identify additional assets and support mechanisms to rapidly mobilize additional SATCOM bandwidth to support the Warfighter.

7005 “Time Critical Targeting Using Responsive Tactical Satellites”
John Carrico, Applied Defense Solutions, Travis Langster, Analytical Graphics, Inc.

A key enabler for responsive space is the capability to respond to unanticipated military needs in any geographical theater in a timely fashion. The CONOPS and utility for Unmanned Aerial Vehicles (UAVs) have become critical assets in current military operations. UAVs are deployed to specific theaters of ongoing operations. However, when an unexpected national security event of interest occurs, UAVs can not provide the same capability to any location on the globe within hours. However, the migration of UAV CONOPS to space could re-locate an asset to any geographical theater within hours. This paper will discuss the utility of pre-deployed tactical satellites to achieve national security responsive space through modeling & simulation techniques.

Scenario — A high value target on the ground is identified via HUMINT sources. A military plan is required to nullify the target. The military plan requires time critical targeting information for pre-mission operations which include imagery and other intelligence data. There are no airborne sensors in-theater to support the mission within the desired timeline. The theater commander requests a capability of a tactical satellite with appropriate sensors be tasked to provide mission support to a forward unit.

Concept — A concept of operations for this solution utilizes knowledge and information about the orbit of a rapid response satellite. An in-theater soldier utilizes an existing chat tool (Instant Messenger in the business world or Jabber in military intelligence operations) for computing the window of opportunity for the in-theater soldier to know precisely when an overhead responsive satellite would be able to image or intercept signals from the target location. The same device used for the chat session receives imagery or other data via e-mail from the satellite as it passes overhead. Data is downloaded from responsive space satellite to handheld device with Time Critical Targeting information (e.g. imagery, target coordinates, etc...). Alternatively, the device could be outfitted to upload tasking commands of known targets for imagery or signals collection. The commercial software tool computes the precise time of collection opportunity and this start/stop time is uploaded in the tasking plan.

Summary — The technology to compute precise collection opportunities and provide them in-realtime to in-theater soldiers is available today. Responsive space concepts can be achieved prior to launching new systems. By implementing unique modeling, simulation & analysis techniques with existing space platforms and within existing military, intelligence, and DoD infrastructures – tactical data from space platforms can be delivered. Responsive space concepts can have immediate military utility and can be enhanced with dedicated responsive space platforms.