TacSat-4 COMMx, Advanced SATCOM Experiment

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CONTEXT

TacSat-4 is a Navy-led, joint program. Total investment is over $140M, with the Office of Naval Research (ONR) investing about $50M. ONR is funding the payload, program management, and first year of operations. COMMx (Communications Experiment) is the primary payload on the TacSat-4 spacecraft. The OSD-OFT/DDR&E funded $45M for the standardized spacecraft bus. The ORS Office and Air Force are providing the launch on a Minotaur-IV representing $43M. The Naval Research Laboratory (NRL) is the program manager. TacSat-4 is the primary prototype in a broader Space INP, “Steady Lookout” prototype. The complete Steady Lookout is a multi-platform prototype working together to advance FORCEnet operations by bringing to bear the best characteristics of each platform to address Naval needs such as Communications-on-the-Move (COTM) and Maritime Domain Awareness (MDA).

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14. ABSTRACT
Augment and Advance Current UHF SATCOM Capabilities: TacSat-4 is focused on enabling several advanced communications capabilities such as COTM, dynamic world-wide theater access, the ability to use frequencies (up and down) over a broad spectrum, enhancement of Friendly Force Tracking and other data ex-filtration, and support for poorly covered areas of the world.

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LONG-TERM GOALS

Augment and Advance Current UHF SATCOM Capabilities: TacSat-4 is focused on enabling several advanced communications capabilities such as COTM, dynamic world-wide theater access, the ability to use frequencies (up and down) over a broad spectrum, enhancement of Friendly Force Tracking and other data ex-filtration, and support for poorly covered areas of the world.

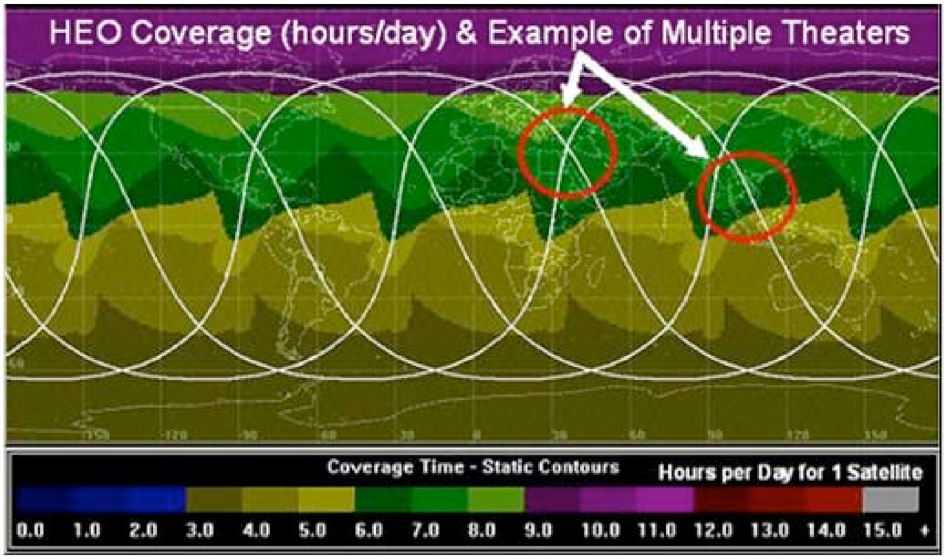
Provide an Operationally Relevant Prototype for Acquisition by ORS Office and/or PMW-146: By design, TacSat-4 capabilities augment traditional geosynchronous SATCOM well, in addition to simply providing more communication transponders. A constellation of three or four such satellites can provide 24-hour coverage in multiple theaters throughout the world. The TacSat-4 capabilities provide near term SATCOM augmentation as well as long term SATCOM acquisition considerations about architecture and future capabilities.

Advance the State of Operationally Responsive Space Systems: TacSat-4 advances long-term ORS developmental areas including spacecraft bus standards, long dwell orbits, dynamic tasking, and net-centric operations.

OBJECTIVES

Provide Communication-on-the-Move (COTM) Capabilities: COMMx is the primary payload on the TacSat-4 spacecraft. The payload's 12-foot diameter antenna and an orbit two-thirds closer than the traditional geosynchronous orbit provide high link margins These attributes enable users of legacy radios to achieve COTM using conventional omni-directional antennas that do not need pointing to track the satellite. This differs from current SATCOM which requires users to stop and point a special SATCOM antenna to use legacy radios.

Augment GEO-Provided SATCOM Coverage Including High-Latitude Coverage: Most existing SATCOM assets are in geosynchronous orbit, with the satellite positioned above the equator nominally at 0 degrees inclination. This position favors communications between +/-60 degree latitudes. TacSat-4's inclination of 63.4 degrees provides coverage at the equator but also covers the northern latitudes and pole. The maximum daily coverage in hours per day is shown in the Figure below. The red circles approximate the instantaneous field-of-view (generally for 2 hours at time) for typical legacy radios and data rates. The TacSat-4 ground track covers the earth every day, enabling coverage in several theaters throughout the world each day. The theaters supported can be changed within 24 hours under normal operations (faster in special or emergency operations) to support world events, such as a tsunami, as they unfold. By comparison, GEO SATCOM is generally stationary for a given satellite.



As depicted in the Figure, users at higher latitudes are generally served by greater coverage, nominally seven hours daily versus nominally three hours at the equator.

Augment Friendly Force Tracking/Blue Force Tracking (FFT/BFT) in Underserved Areas: TacSat-4's orbit and a redundant channel were specifically designed to augment FFT/BFT collection.

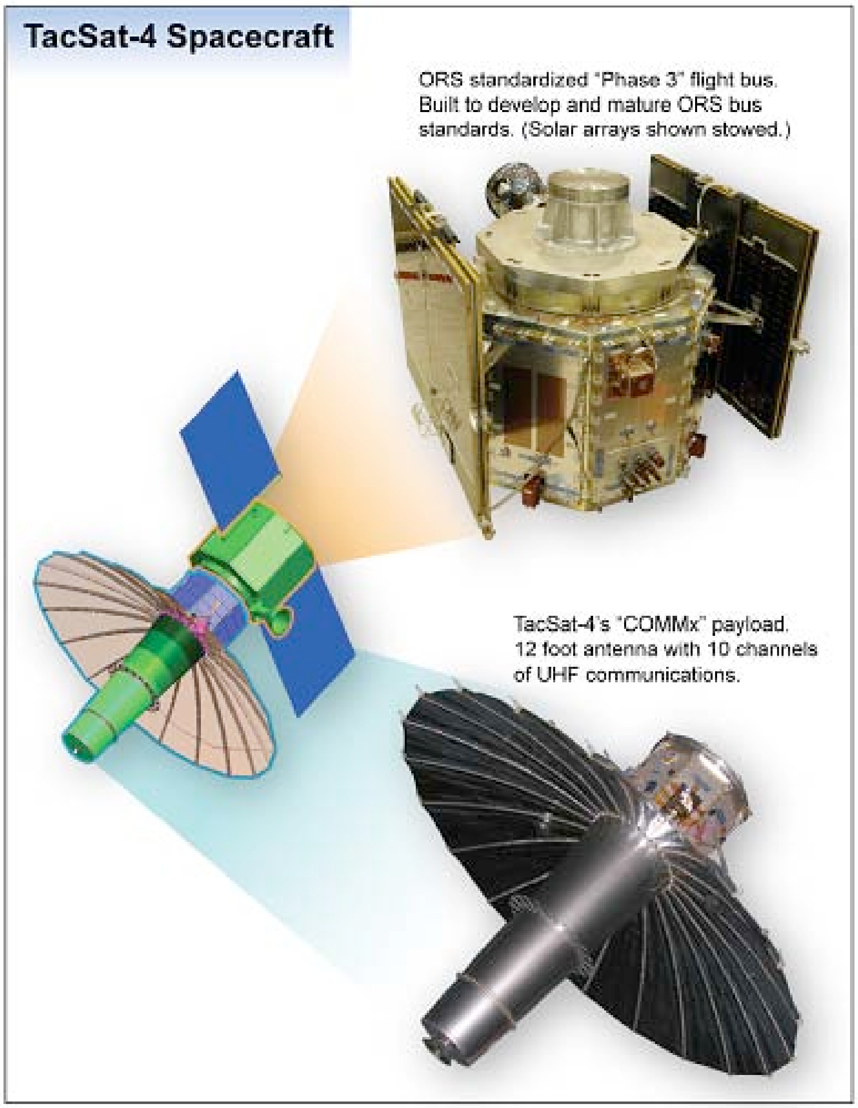
Provide Data Exfiltration Capabilities, Particularly for the Fleet: TacSat-4 carries an ODTML payload specifically for IP-based, internet data exfiltration with a store and forward capability. TacSat-4's primary COMMx payload and coverage can provide tailored SATCOM for a broad range of data-exfiltration missions including SIPRNET based applications.

Flexible Up/Down Channel Assignment to Improve Operations in Dense RF and Interfered Environments (not to be confused with jammed environments): TacSat-4 provides flexible up-link and down-link channel assignments, which increases the ability to operate in environments with RF interference, from either legitimate RF congestion or even narrowband intentional interference. This capability also provides theater frequency managers with valuable flexibility as they assign limited RF spectrum to users in the field and deconflict assignments as required.

Dynamic Reallocation to Different Theaters Worldwide: TacSat-4's routine tasking cycle of 24 hours enables quick response to users' needs. If necessary, users could change within a day the theaters and channels TacSat-4 will support.

APPROACH

The TacSat-4 COMMx mission was selected by a joint process that culminated in a Flag and General Officer vote by Army, Navy (N6), Air Force, Marines, and STRATCOM. TacSat-4 is therefore a Navy-led joint mission to provide operationally relevant capabilities and to advance the state of Operationally Responsive Space (ORS) systems. TacSat-4 provides 10 Ultra High Frequency (UHF) channels that can be used for any combination of communications, data exfiltration, or Friendly Force Tracking (FFT). The unique orbit augments geosynchronous SATCOM assets by providing near global, but not continuous, coverage that includes the high latitudes. TacSat-4 improves upon current SATCOM capabilities by providing COTM for existing radios without requiring users to point their antennas toward the satellite. TacSat-4 provides flexible up-link and down-link channel assignments, which increases the ability to operate in areas with RF interference. The dynamic tasking system, coupled with the HEO orbit, enables meeting a 24-hour response time for geographic reallocation of TacSat-4's world-wide SATCOM coverage, rapidly augmenting traditional SATCOM when unexpected operations or natural events occur. The Virtual Mission Operations Center (VMOC) provides the dynamic tasking of TacSat-4. All of TacSat-4's 10 channels can be used in 5 or 25 kHz mode. One redundant channel can be configured specifically for Friendly Force Tracking (FFT) collection, and another redundant channel provides a 5 MHz wideband "MUOS-like" channel for early testing.



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WORK COMPLETED

The TacSat-4 mission was selected by a joint process cumulating in a Flag and General Officer vote by Army, Navy (N6), Air Force, Marines, and STRATCOM in October 2005. Since then, NRL designed, built, tested and integrated the bus, payload, and associated ground systems. TacSat-4 now exists as a 450-kg, small-sat class UHF-communications satellite with a 1 kW solar array and 12-foot payload antenna.

The COMMx payload consists of a primary structure that is approximately a three-foot cube. Its 12-foot reflector dish, mounted on top with a 6-foot tall support cone for the UHF feed, will be deployed on-orbit. All of the subsystem components for COMMx have been delivered and integrated, and the satellite is currently undergoing final testing. Beyond the working prototype, NRL realized a number of significant technical achievements while developing the payload:

Dish Reflector Development: The 12 foot Dish Reflector is a completely new technological design that takes advantage of the relatively relaxed mechanical tolerances allowed when operating within the UHF band. The result is a 12 foot deployable antenna for less than $4M including non-recurring engineering, vice $6-10M available commercially with higher tolerances.

Passive Intermodulation (PIM) Test Set: Testing the COMMx payload for PIM activity required developing a high-sensitivity test set. This PIM Test Set is likely the only one in the country with sufficient sensitivity to test for PIM across such a broad portion of the UHF spectrum.

NRL also developed a *Multipactor Test Set* that is capable of testing all of the COMMx high-power UHF hardware (UHF feed, quadripole, circulator, cables, loads and filters) for multipactor.

Advanced Thermal Management System: The high power density, inherent in communications missions but exacerbated in small satellites, required a state-of-the-art thermal control system. COMMx uses a combination of constant conductance heat pipes, loop heat pipes, and a flow balancer (acting largely like a heat diode) to enable the 600W+ payload electronics to be thermally maintained in space within only about a 3 ft^3 area.

Primary capabilities available by users of the COMMx payload:

Communications on the Move: TacSat-4 will provide ten UHF channels to support a combination of COTM, Data-X, and FFT simultaneously. Legacy radios will be supported in their native modes (2.4 to 16 kbps) without any antenna pointing requirements. An in-theater ground terminal will allow voice and data from legacy radios to be Internet Protocol (IP) wrapped and networked onto the SIPRNET. One channel will support the MUOS-like 5 MHz channel, but TacSat-4 is not tied into the MUOS ground network management centers (still being built) allowing 3G wideband Code Division Multiple Access (CDMA) communications.

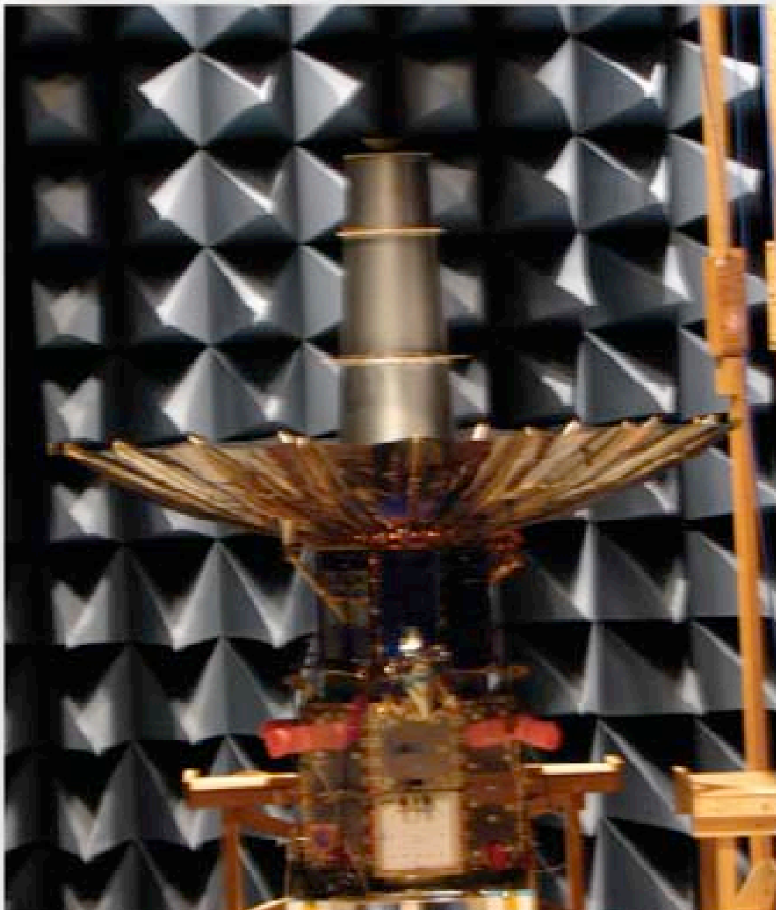
Friendly Force Tracking (FFT): Several National needs and requirements exist for FFT. TacSat experiments and future operational augmentation add value by expanding the ability to collect data from existing devices in underserved areas.

Data-X: Many needs exist to accomplish data exfiltration (Data-X). During the TacSat-4 selection process, the most prevalently discussed need concerned relaying data from buoys. Buoys are remotely deployable on the seas and often require organic air assets to support them. TacSat-4's coverage makes it a strong candidate for testing various Navy Concepts of Operation (CONOPS) for collecting and relaying data from buoys.

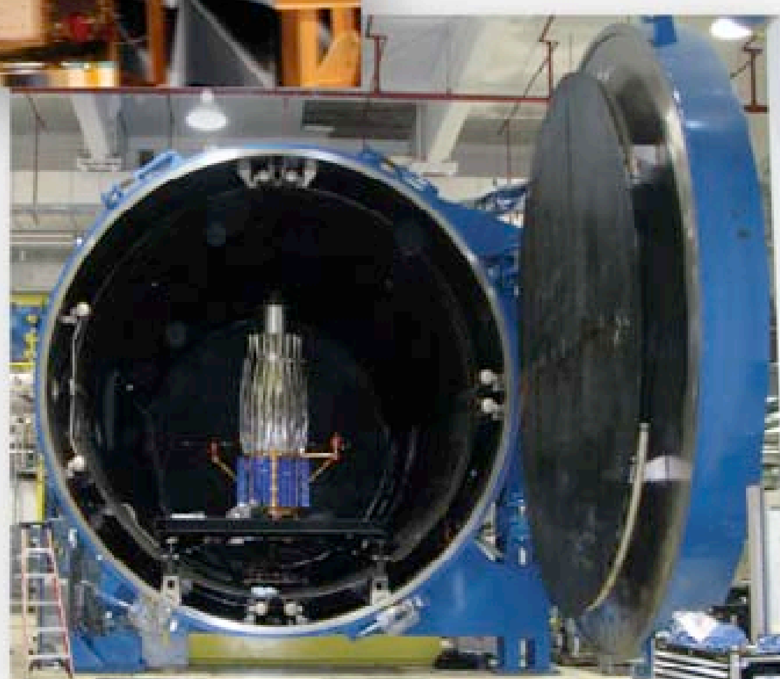
RESULTS

Completed I&T of TacSat-4 in FY09: For background, the end of FY08 marked the completion of the ORS Phase III Standardized Bus for TacSat-4 and the completion of the design and building of the COMMx payload. NRL had also started system-level environmental testing, including EMI testing of

TacSat-4 Testing



TacSat-4
RF testing



"COMMx" payload
thermal vacuum
testing

the COMMx payload. During EMI testing, an RF-system performance issue was identified, which required adding two new flight-unit RF filters. The Figure below shows the COMMx payload during RF/EMI and Thermal testing.

In fiscal year 2009, NRL procured and tested the two new high band filters. NRL also encountered and recovered from two failures during system testing: 1) A current-monitor failure in the payload interface unit, and 2) A failed capacitor in the X-band up-converter. Both failures required removing, repairing and re-qualifying the units that contained the failed components.

NRL integrated the COMMx payload with the ORS Phase III Standardized Bus, forming the complete TacSat-4 space vehicle (SV). NRL then completed all required TacSat-4 SV level environmental testing. After that successful testing, an additional COMMx system-level vibration test and TVAC test were done to ensure that the payload works properly with the new components. All COMMx re-qualification testing was completed.

The COMMx payload was placed in storage on October 9, 2009 along with the ORS Phase III Standardized Bus already in storage. TacSat-4 now awaits launch in August 2010.

Prepared Users for Experimenting with TacSat-4: NRL made significant progress in FY09 to prepare users for TacSat-4's launch, continuing its efforts to promote TacSat-4's capabilities and work with the user community toward experimentation.

Several efforts were made to keep users informed, both users interested since 2005 and those who more recently became aware of the planned capabilities. NRL hosted two User Roundtables with over 40 attendees, who represented six COCOMS and each of the Military services. The Roundtables provided a venue to update users on TacSat-4's developments, to review VMOC interfaces and to introduce the objectives of the Joint Military Utility Assessment (JMUA) further discussed below.

Efforts are underway working with PMW-170, DISA and SPAWAR to develop technical details and establish CONOPs and Test Plans. At the request of NNWC, NRL also began developing the Surface Ship and Submarine Communications CONOP that includes the additional communications support that will be available via TacSat-4, particularly at high latitudes. A JMUA was initiated and funded by the ORS Office; SPAWAR Pacific is the lead executing agent, supported by Army Space and Missile Defense Command (SMDC).

Other on-going efforts included presenting TacSat-4's capabilities at numerous conferences, such as the Navy's Narrowband SATCOM Conference, and briefings to expand the user community, support the ORS Office's Joint Military Utility Analysis Team, and to refine CONOPs and test plans for those awaiting use of TacSat-4.

TacSat-4 was formally accepted into Trident Warrior 2010 (TW10). NRL prepared for and participated in the Initial Planning Conference (IPC) for the TW10 Naval Experiment. TacSat-4 would have been particularly well-suited for participation in TW-10, since that experiment will include increased support from USMC personnel in RIMPAC Exercise concurrent with TW-10. However, the Air Force's most recent launch delay to August 2010 precludes participation by TacSat-4 until TW-11. NETWARCOM has already informed NRL of their willingness to accept TacSat-4 into TW11.

IMPACT/APPLICATIONS

The TacSat-4 impacts are three fold:

1) Operational augmentation of UHF SATCOM. The TacSat-4 will augment near-term UHF SATCOM capabilities by providing badly needed UHF SATCOM, including FFT/Data-X collections in underserved areas and users.

2) Experimentation of advanced capabilities and architectures for consideration in future SATCOM acquisitions. Potentially the most notable is the COTM for existing radios without requiring users to point their antennas toward the satellite. TacSat-4 provides flexible up-link and down-link channel assignments, which increases the ability to operate in areas with RF interference. The dynamic tasking system, coupled with the HEO orbit, enables meeting a 24-hour response time for geographic reallocation of TacSat-4's world-wide SATCOM coverage, rapidly augmenting traditional SATCOM when unexpected operations or natural events occur. The Virtual Mission Operations Center (VMOC) provides the dynamic tasking of TacSat-4. TacSat-4 provides a valuable baseline data point to the acquisition community. The acquisition impacts could range from an additional "TacSat-4-like" satellite to a constellation of satellites in HEO orbits augmenting the geo-synchronous satellites.

3) Advancement of long-term ORS developmental areas including spacecraft bus standards, long dwell orbits, dynamic tasking, and net-centric operations. Several of these impacts are already realized, such as the development of an initial set of ORS spacecraft bus standards.

TRANSITIONS

There are two transitions to discuss. The first is the transition of the TacSat-4, Space INP prototype, from the first year of experimentation focused flight operations into a fully operational mode of flight operations. NRL has been working with OPNAV N6, STRATCOM's Global SATCOM Support Center (GSSC), NETWARCOM, and NRL's BP ground station for this transition. The GSSC is planning to take on the apportionment/allocation of TacSat-4 SATCOM channels beginning at launch plus 1 year. Planning and tool development for this GSSC transition will have been in progress for almost two years prior to launch. Formal GSSC operator training is planned at launch plus 6 months to assure a sound transition. BP will continue to provide spacecraft operations using their operationally robust systems and backups. The OPNAV N6 has the POM whitepaper for extended TacSat-4 operations. In the FY11 POM this was an unfunded requirement. However, funding is needed beginning in FY12 so this year's POM process is the critical one at this point. Extending TacSat-4 flight operations requires $3.75M per year to NRL.

The second transition is for acquisition of one or more follow-on satellites. The ORS Office, Navy's PMW-146, or some combination are the likely sponsors for such an acquisition. TacSat-4 is an operational prototype which will be evaluated for acquisition. This evaluation will include a formal JMUA funded by the ORS Office. Specifications for the spacecraft bus and payload have already been written during the TacSat-4 development in anticipation of a follow-on acquisition. These technical documents and the associated costs information provide a sound, proven baseline for the acquisition community.

RELATED PROJECTS

Navy's UFO Follow-On (UFO) and Mobile User Objective System (MUOS) operational SATCOM programs.

PUBLICATIONS

AIAA-RS5-2006-4006 - A TACSAT AND ORS UPDATE INCLUDING TACSAT-4 (Michael Hurley, Mark Johnson, Ken Weldy, Naval Research Laboratory; Col. Tom Doyne, OSD's Office of Force Transformation; Peter Wegner, Air Force Research Laboratory; Lt Col Randy Riddle, SMC Detachment 12)

TACSAT-4 DESIGN & LESSONS LEARNED TO DATE, presented at the ESA 4S Symposium 2006 (Carl Ford, Mark S. Johnson, Kenneth Weldy, Robert Baldauff, Timothy Duffey, Matthew Gallelli; U.S. Naval Research Laboratory, Washington DC)

TACSAT-4 MISSION AND THE IMPLEMENTATION OF BUS STANDARDS, presented at the USU Small Sat conference, 2008 (Kenneth Weldy, Amy Hurley, Christopher Amend, Edward Becker, Michael Nurnberger, Carl Ford, Mark S. Johnson, William Raynor, Michael Hurley; U.S. Naval Research Laboratory, Washington DC)

OPERATIONALLY RESPONSIVE SPACE STANDARD BUS BATTERY BALANCE TEST AND HEAT DISSIPATION ANALYSIS (Michael Marley; Johns Hopkins University Applied Physics Laboratory)

AIAA-RS5-2007-4004 - RESPONSIVE SPACECRAFT BUS IMPLEMENTATION FOR UNIQUE HEO MISSIONS BASED ON STANDARD INTERFACES (P. A. Stadter, C. S. Schein, M. T. Marley, C. T. Apland, R. E. Lee, B. D. Williams, E. D. Schaefer, S. R. Vernon, P. D. Schwartz , B. L. Kantsiper, E. J. Finnegan;The Johns Hopkins University Applied Physics Laboratory, Laurel MD; J. Christopher Garner, Gurpartap Sandhoo, William Raynor; U.S. Naval Research Laboratory, Washington DC; Thomas A. Doyne, Colonel, USAF Rapid Reaction Technology Office, DDR&E, Washington, DC)

AIAA-RS6-2008-4003 - RESPONSIVE SPACECRAFT BUS IMPLEMENTATION FOR HEO MISSIONS DESIGNED TO BRIDGE PROTOTYPE AND OPERATIONAL SYSTEMS (P. A. Stadter, Ph.D, M. T. Marley, C. T. Apland, R. E. Lee, B. D. Williams, E. D. Schaefer, P. D. Schwartz, R. Denissen, B. Kantsiper, E. J. Finnegan; The Johns Hopkins University Applied Physics Laboratory, Laurel MD; William Raynor, Dr. Gurpartap Sandhoo, Mark S. Johnson; U.S. Naval Research Laboratory, Washington DC; J. Griswold, Colonel, USAF Rapid Reaction Technology Office, DDR&E, Washington, DC)

2009 NRL REVIEW - INTEGRATION AND TESTING CHALLENGES OF ORS PHASE III BUS STANDARDS PROTOTYPE (William C. Raynor 8212, Trevor J. Specht 8244, William R. Braun 8223, Eric A. Rossland 8243, Susie N. LaCava 8243, Mark S. Johnson 8240, U.S. Naval Research Laboratory, Washington D.C., 20375; Patrick A. Stadter, Clint T. Apland, Jonathan R. Bruzzi, Michael T. Marley, Bruce D. Williams, Ronald A. Denissen, The Johns Hopkins University/Applied Physics Laboratory Laurel, Maryland, 20723; Douglas C. Bentz, Harris IT Services, Dulles, Virginia 20166) [In Press]