Integration and Testing Challenges of the Operationally Responsive Space (ORS) Phase III Bus Standards Prototype

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Introduction: On 25 April 2008 the Operationally Responsive Space (ORS) Phase III Bus Prototype spacecraft, being used for the TacSat-4 mission, was successfully bought off by the Director of Defense Research and Engineering (DDR&E), formerly the Office of Force Transformation, the sponsor of this major third phase of the four-phase Standard Bus Initiative. On 30 May 2008 the flight lithium-ion battery was formally delivered. These two events officially marked the completion of the prototype Bus and delivery to the TacSat-4 program. The objective of the Office of the Secretary of Defense's ORS Standard Bus Initiative is to develop and test bus standards and then transition them for acquisition. Ideally, one or two different types of spacecraft buses will support a variety of interchangeable payloads, to achieve the ORS goal of rapid integration, launch, and deployment of satellites in response to emerging needs. To achieve the modularity and responsiveness envisioned for an ORS system, standardized interfaces between, and potentially within, the buses, payloads, and boosters have to be developed and verified. This article presents the challenges of performing spacecraft electrical, mechanical, and system integration and testing (I&T) to develop and mature ORS bus standards in the absence of a payload.

ORS Phase III Bus Prototype Development: The Naval Research Laboratory (NRL) and The Johns Hopkins University/Applied Physics Laboratory (JHU/APL) jointly executed the Bus project, in collaboration with a large industry partnership known as the Integrated Systems Engineering Team (ISET). The main goals of Phase III were to develop ORS bus standards in an open environment, and to produce a prototype for flight experimentation.

TacSat-4 Mission: The prototype Bus and the Office of Naval Research (ONR)-sponsored communication experiment payload, COMMx, together form the key on-orbit space vehicle (SV) elements of the TacSat-4 mission (see Fig. 4). TacSat-4 is a Navy-led joint mission, with NRL as the Program Manager, to provide operationally relevant capabilities and to advance the state of ORS development in spacecraft bus standards, payload standards, long dwell orbits, dynamic tasking, and net-centric operations.

Spacecraft System Testing: For ORS, the basic test flow and philosophy is rapid integration of spacecraft bus to payload, followed by integration of space vehicle to launch vehicle (LV). This necessitates high-level "embedded" built-in-test capabilities for the spacecraft bus and payload, as well as standardized interfaces/connectivity to common ground test equipment. The ORS model mandates independent test programs for bus and payload, mandates that bus and payload developers sufficiently test interfaces to ensure minimal risk to mission success, and recommends use of simulators for validation of hardware and software interfaces and performance.

For the prototype Bus, assembly and initial system integration and testing were complete by December 2007. During the subsequent four months, the Bus underwent final system I&T consisting of physical alignments, EMI/EMC, solar array illumination and deployment mechanism release, mass properties, random vibration, and thermal vacuum (TVAC). Functional testing and flight software I&T were performed throughout the system I&T flow. Some of the tests are described here.

Mechanical Subsystem: Static loads and sine vibration testing of the primary bus structure were performed using payload mass simulators to verify the mechanical properties prior to subsystem integration (Fig. 5(a)). The system-level bus vibration test used another payload mass simulator (Fig. 5(b)). The SV-LV interface was also tested. The SV is integrated onto the LV with a motorized Lightband Separation System (LSS) that will deploy TacSat-4 from the LV once on-orbit. TacSat-4 is, to date, the largest-mass, highest center of gravity space vehicle utilizing the LSS. In addition to the standard static loads, random vibration, and TVAC tests, sine-sweep testing of the LSS was performed using a mass simulator representing the TacSat-4 SV (Fig. 5(c)). Specifically, the sine-sweep testing verified LSS stiffness and separation switch electrical performance. The sweeps were conducted bi-directionally (from 5 Hz to 100 Hz and back to 5 Hz) in all three axes to verify the absence of any stiffness non-linearities.

Thermal Subsystem: The ORS philosophy requires that the bus-payload interface be conductively isolated and the radiative effects minimized. Spacers made of G-10 (epoxy-impregnated glass fabric) provide the conductive resistance at the bus-payload interface (Fig.

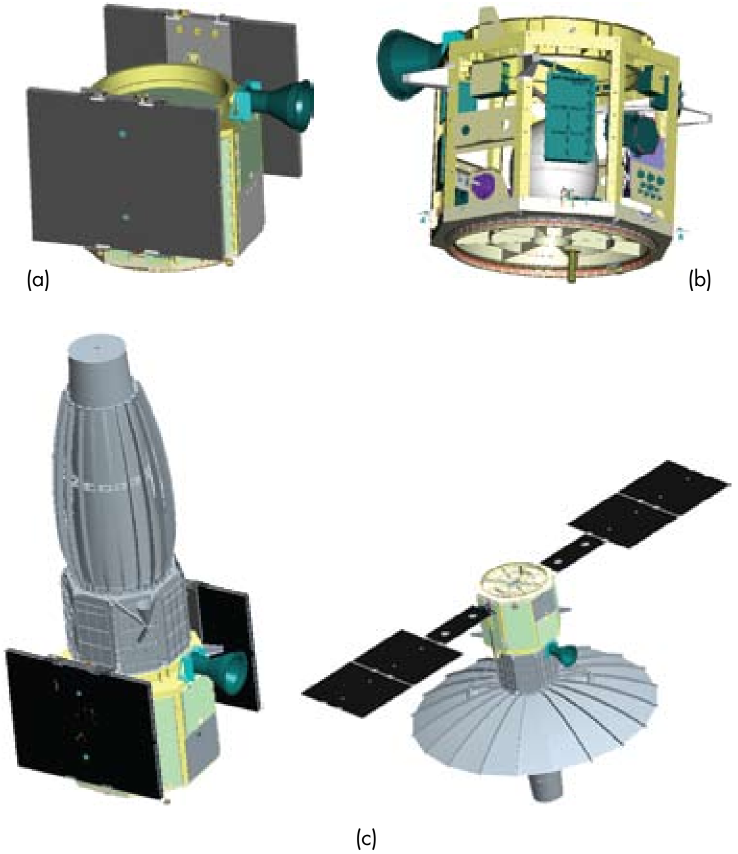
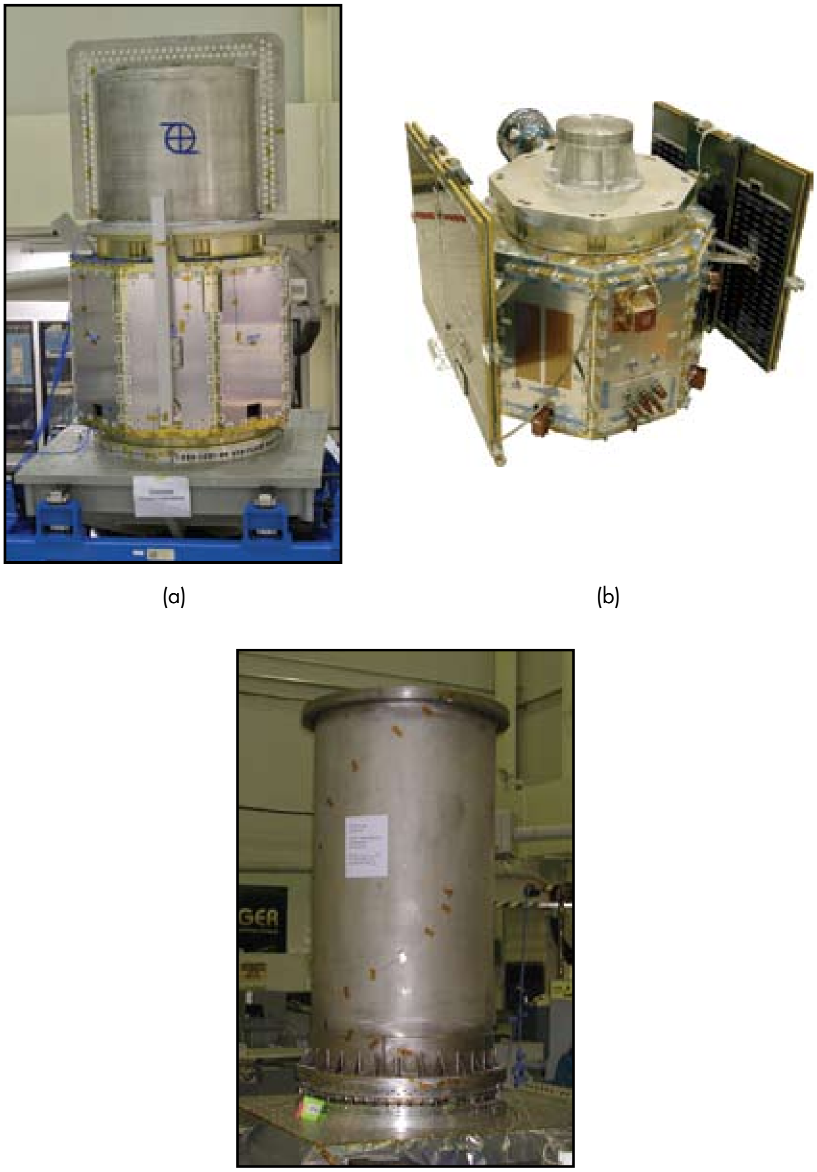


FIGURE 4
Prototype ORS spacecraft configuration: (a) and (b) spacecraft Bus component layout; (c) space vehicle configuration, stowed and deployed.

6). TVAC testing was performed to verify this interface and to verify all subsystem performance over mission temperature extremes. A test heater plate simulated the extreme temperatures of the payload, and both sides of the interface were monitored to control the heat transfer between bus and payload and to validate the thermal design and implementation.

Command Telemetry and Data Handling (CT&DH) System: The flight software and CT&DH system underwent extensive integration and subsystem acceptance testing using test beds that stimulated all external command and data electronics (CDE) input interfaces and captured all CDE external output interfaces. The test beds provided flight equivalent electrical simulation of all interfaces, high fidelity simulation of the attitude control system components, medium fidelity simulation of the payload, and a high fidelity attitude and orbit dynamics simulation. At the system level, payload simulators allowed for validation of the bus-payload interface throughout the entire environmental test program. RS-422/HDLC and Spacewire interfaces were connected to payload simulators for all environmental tests. The payload simulator validated electrical characteristics, data protocols, and data transportation envelopes.

Telecommunications System: Standard RF ground support equipment (GSE) was able to support system operability of all RF functions during environmental tests. TacSat-4 mission design required that the second SGLS antenna be placed on the forward end of the COMMx antenna. Without the payload, the second RF path could not be tested in its entirety during Bus I&T. In the absence of this path, hard-wired GSE cables were used to achieve end-to-end telecommunications testing. Portions of the RF telecommunications path that reside on COMMx will undergo testing during SV I&T. The Bus I&T program modified RF power levels to account for the absence of the antenna and associated cables. When cables were unavailable or inappropriate for a given test, RF terminators were used to present a good match to the RF subsystem. See Fig. 7 for the RF block diagram. EMI/EMC testing was conducted on the standalone Bus. Of critical importance was the verification of emissions with specified payload susceptibility. Radiated emission excursions were identified and corrected.



(a)

(b)

(c)

FIGURE 5
Vibration test configurations: (a) primary structure with payload mass simulator, (b) Bus system, (c) Lightband Separation System with SV mass simulator.

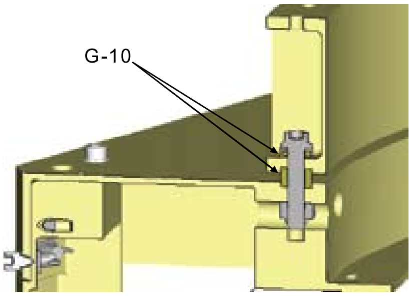


FIGURE 6
G-10 washers for thermal isolation at the bus-payload interface.

Electrical Power System (EPS): Payload power simulators were used during the Bus test program to validate bus EPS components. A fixed load simulator was installed to validate critical bus feeds to the payload. Variable load simulators were installed to validate high power feeds to the payload. Illumination of the outer solar arrays was performed pre- and post-vibration test to verify function. During component-level testing, a temperature chamber malfunctioned and overheated the lithium-ion battery. The battery had to be replaced, preventing it from entering Bus I&T, and a battery simulator was used in its absence. The standards requirement for the battery to be modular, specifically for rapid integration at the launch site, allowed I&T to be completed despite the malfunction.

Conclusion: The Bus and associated hardware and software underwent an innovative I&T process to verify and validate the critical bus/payload interface standards as defined by the ISET, with only three exceptions: SV-level magnetic dipole, EMI/RF, and command control performance tests. The combined space vehicle will validate these requirements. The Bus program and ISET efforts produced an extensive and well-documented set of standards and interfaces for cost-effective spacecraft systems for TacSat-4 class missions for the ORS initiative. Verification of the standards was a direct result of the Bus I&T process. Validation of these standards proceeded through the development of the Bus in an open manner that has allowed government and industry insight into challenging issues and subsequent successful implementation approaches.

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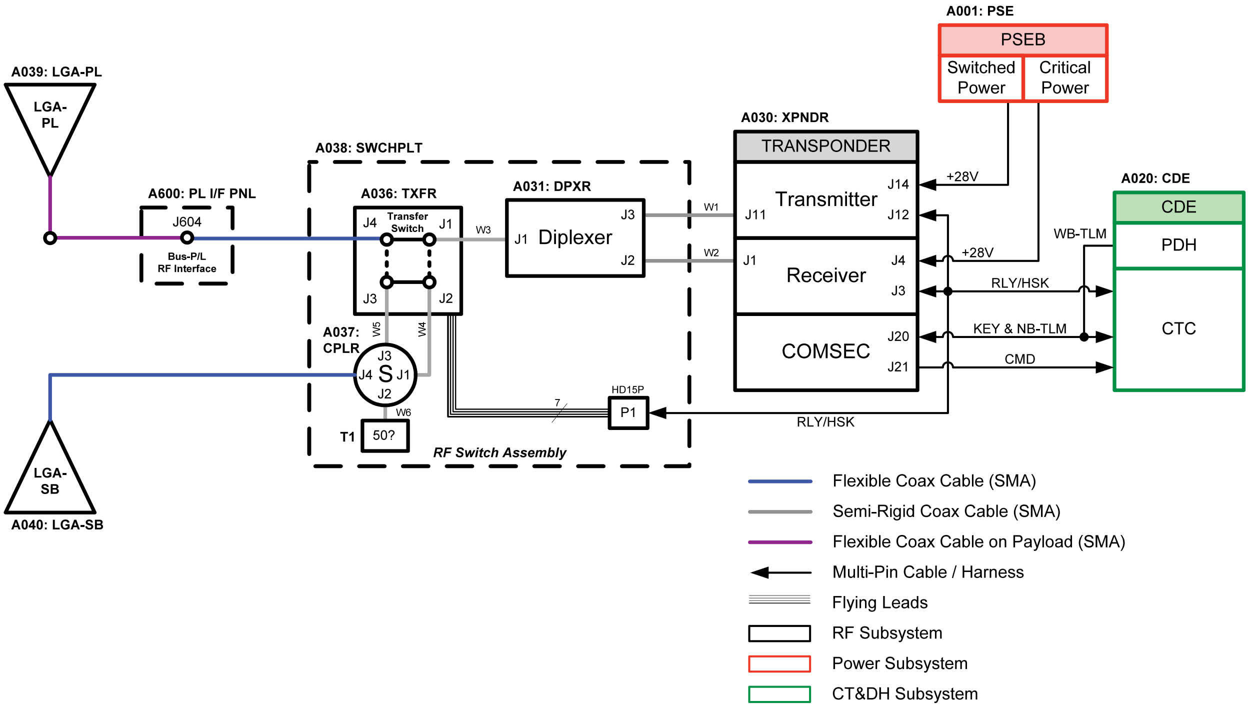

FIGURE 7
RF system block diagram.