SSC11-X-5

Isothermal Structural Panels for Spacecraft Thermal Management

Scott Schick, Blake Rusch, and J. Clair Batty
Thermal Management Technologies
1750 Research Park Way, Ste 104, N. Logan, UT, 84341; 435-713-3731
scott.schick@tmtsdl.com

ABSTRACT

Realization of Responsive Space (RS) program goals requires further progress in reducing the time required for spacecraft system design, analysis, fabrication, assembly, integration, testing, and deployment. Of particular need is an enabling technology that will reduce the design and integration-test time of the thermal subsystem. One such technology is the Thermal Control Panel (TCP) being developed by Thermal Management Technologies under SBIR contract to AFRL Space Vehicles Directorate (AFRL/RV). This technology provides isothermal structural panels and low thermal impedance joints for use in an isothermal spacecraft structure. Each light weight panel provides the spacecraft structure while simultaneously exhibiting an effective thermal conductivity/mass ratio much greater than traditional spacecraft materials.

In various forms the TCP can be used to spread heat, create nearly isothermal spacecraft structures, and to provide highly efficient space radiators. The technology is applicable to spacecraft structures at all levels of size and complexity. The panels have an operating temperature range of -30 to +65 C. The technology development is on track to complete space qualification testing in early 2012.

INTRODUCTION

In order to make Responsive Space (RS) systems a reality continued advancement in subsystem development is necessary. One step toward this process is enabling a faster system design and integration-test function through simplifications in the thermal subsystem. Through SBIR funding from AFRL/RV, Thermal Management Technologies (TMT) is developing Thermal Control Panels that provide a near isothermal spacecraft. Previous studies have shown how an isothermal bus is one way to reduce both system analysis and system layout functions.[1,2] This spacecraft technology reduces the need for balancing thermal loads thus eliminating multiple iterations with thermal, structural and electrical subsystems.

An isothermal spacecraft can reduce time spent on orbital analysis as well. A straight forward analysis of typical hot and cold cases can be done just by knowing the overall power dissipation within the bus. This will allow the initial design layout to be completed by specifying such mission specific parameters as radiator surfaces, insulation, and extended radiators.

The AFRL/RV SBIR funded development was focused on applying the technology to a PnPSat-2 compatible panel. The panels were designed to mechanically attach to the current bus using the existing fastener locations and layout. The entire AFRL/RV project objective includes developing isothermal panels and low thermal resistance panel to panel connections. Figure 1 illustrates the panel design as it would be assembled into PnPSat-2 spacecraft sides. The design and development testing of these panels has been accomplished. Complete qualification testing is on-going. The remainder of this paper provides an overview of the thermal control panel and the potential uses of such technology.

Figure 1: TCP Incorporated into PnPSat-2 Configuration

THERMAL CONTROL PANEL OVERVIEW

Thermal Control Panel (TCP) technology was developed to provide isothermal panels and low thermal resistance joints for spacecraft applications.

The enabling technology is a phase change fluid incorporated into flat, structural panels that can withstand the rigors of space flight. The panels not only uniformly spread heat, but also provide structural interface to spacecraft components. Figure 2 illustrates a functional block diagram of the AFRL/RV panel system.

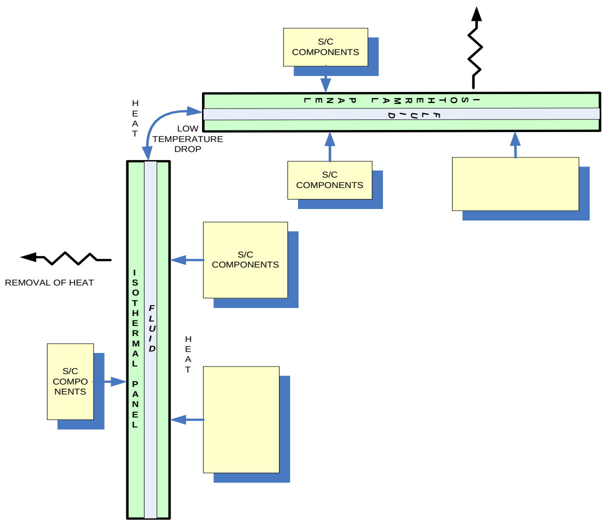

Figure 2: Isothermal Panel Block Diagram

Key requirements for the development TCP are shown in Table 1.

Table 1: TCP Key Requirements

Requirement	Value	Comments
Panel Temperature Difference	<5 C	At 100 W/m imposed load
Panel to Panel Temperature Difference	<3 C	At 100 W/m imposed load
Panel Operational Temperature	-30 to +65 C Operating -40 to +75 C Survival	
Space Environment	Survive space environment and launch	Drives material selection and design environments
Limit Loads	12.5 g's	

Temperature requirements were defined by the customer and provide the ability to limit the temperature difference around a spacecraft. The temperature values are specified at a heat load of 100 W/m of panel width. For the AFRL/RV project, this is amounts to 56 watts per panel for the 22 inch square size. The wide temperature range allows the panels to support a broad range of applications. Finally, it is key that the technology be able to survive the rigor of space flight and the environment of space. This is especially important as the panels are not only thermal but the prime structure for the spacecraft.

Panels consist of inner and outer isothermal skins separated and tied together through a honeycomb structure. A frame surrounds the panels to thermally and structurally tie the individual panels together.

The full set of requirements for the panel design was derived from the top level AFRL/RV SBIR requirements, RS bus requirements, and appropriate aerospace requirements.[3,4,5,6,7] Included in the requirements are the thermal, structural, interface and test requirements.

Key Design Features

The key features of the design are the wide operating temperature range, elimination of single point failures by utilizing multiple fluid chambers, integrated frames, honeycomb panel assembly for structure, integrated fasteners, and the ease of assembly for the user. The mechanical design is illustrated in Figure 3.

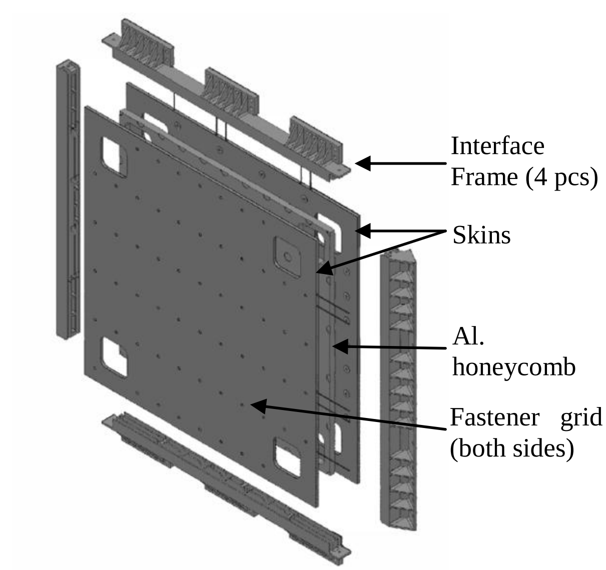

Figure 3: Exploded View of Panel Configuration

One driving consideration in the design of the panels was developing a technology that would work over a wide operating temperature range encompassing typical electronic design temperatures.

Using multiple fluid channels reduces concerns over single point failure and provides a convenient location for fasteners. Leak or damage to any one fluid chamber does not impact the operation of other chambers.

The integrated frame creates a low thermal resistance from the panel skin into the joint. The goal was to limit the number of bolted joints that create thermal uncertainty for the assembly. Assembly of the spacecraft is eased by creating individual panels that bolt together to make the spacecraft structure.

The challenges for this development are to achieve isothermal panels and low thermal resistance joints that also function as the spacecraft structure.

Thermal Design

The Thermal Control Panel provides for application and removal of heat from any location on the panel surface. The AFRL/RV SBIR specification is based on heat being moved from one edge to the other within the specified 5 C temperature difference.

The basis for the TMT thermal design is bi-directionally oriented channels that uniformly spread heat throughout the panel. The outer and inner skins have the channels oriented 90 degrees from one another. They are tied together both through the intermediate honeycomb structure and the surrounding frame. The thermally conductive frame connects the isothermal fluid channels to the panel interface. A single bolted joint on each edge minimizes losses between adjacent panels.

Thermal analyses were performed on the panels to guide the design and to verify the uniform nature of the panel configurations. Figures 4 and 5 illustrate the panel expected performance with a 56 watt edge load and panel load respectively. The analysis shows the panels will meet the required temperature drops both across the panel and between adjacent panels. This analysis is a worst case configuration based on the specification. In a real situation, heat applied using this Thermal Control Panel technology would immediately spread in two dimensions sharing the heat to the top and bottom decks as well as the opposite panel.

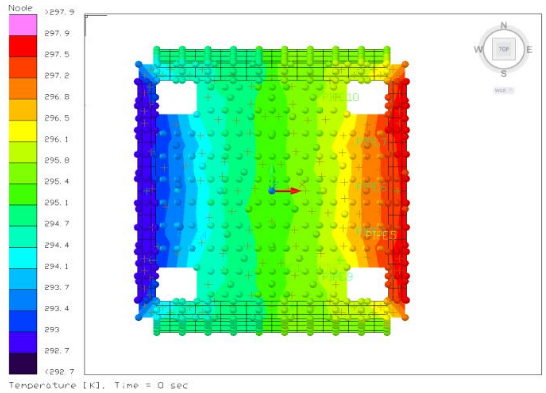

Figure 4: Panel Temperatures; 56 W Input; Total Panel Delta T=4.5 C

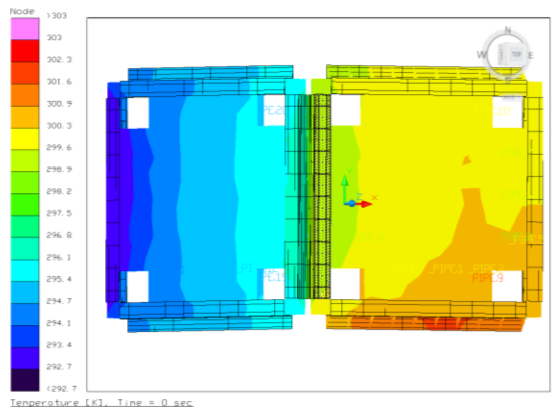

Figure 5: Two panel; Panel heat load 56 W; Total Panel Delta T=3.8 C, Joint Delta T=2.5 C

Mechanical Design

Thermal Control Panels are mechanically robust. The TCP utilizes isothermal skins which consist of flat heat pipes sandwiched between thin structural sheets. In order to enhance the structural stiffness and thermal performance of the TCP, two isothermal skins are laminated onto a honeycomb core to create a sandwich panel.

The frame around the perimeter of each TCP provides mechanical connection between panels. Panel interfaces are straightforward to support RS rapid assembly desires. A cable pass-through hole is provided at each corner of the TCP and 5 cm x 10 cm pattern of threaded fasteners is provided on both sides of the TCP to facilitate mounting of spacecraft components.

The mechanical design was specified to handle four masses totaling 25 kg/panel located on opposite sides and quadrants of each panel as shown in Figure 6.

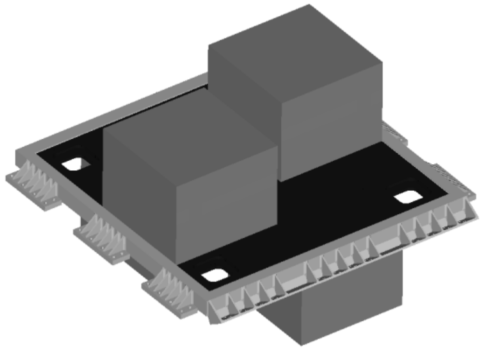

Figure 6: TCP with Attached Masses

Structural analyses were performed on the TCP configuration. Because a full bus was not being designed, individual panel requirements were set for the project. A summary of the analysis is discussed in the following paragraphs.

Normal modes analysis indicates that when a single TCP with attached masses is constrained around the edges, the first resonant frequency exceeds the required 270 Hz as illustrated in Figure 7.

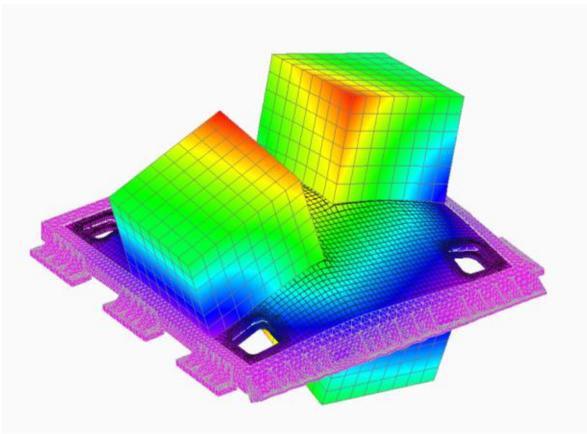

Figure 7: First Mode Shape of TCP with Attached Masses

Limit load analyses indicates that the TCP with attached masses has sufficient strength to withstand 12.5 g acceleration in each of three orthogonal axes orthogonally with high margins of safety.

Thermal stress was one of the big issues that had to be overcome during the design. Several design iterations were needed to develop a configuration in which positive margins of safety will be maintained when the TCP is thermally cycled between -40 C and 75 C.

Because the design uses a contained working fluid, pressure analyses were performed. The flat heat pipes used in TCPs have been designed to withstand internal pressures in excess of 4 times the maximum operational internal pressure in order to meet pressure vessel requirements.

Preliminary Test Data

Preliminary tests have been performed on subscale (13.7 in x 12.4 in) isothermal skins. The thermal performance of these panels and the pressure holding capability of the flat heat pipes contained in the panels has exceeded expectations.

One subscale isothermal skin has been thermally tested. The configuration for this thermal testing is shown in Figure 8. Grooved aluminum plates were bonded to two sides of the heat spreading skin to simulate the aluminum frame on the TCP. The skin was maintained in a horizontal orientation while heat was applied via resistance heaters on one side of the skin and heat was removed with a cold bar on the opposite side. The bottom of the skin was insulated while the top was left exposed to facilitate IR imaging.

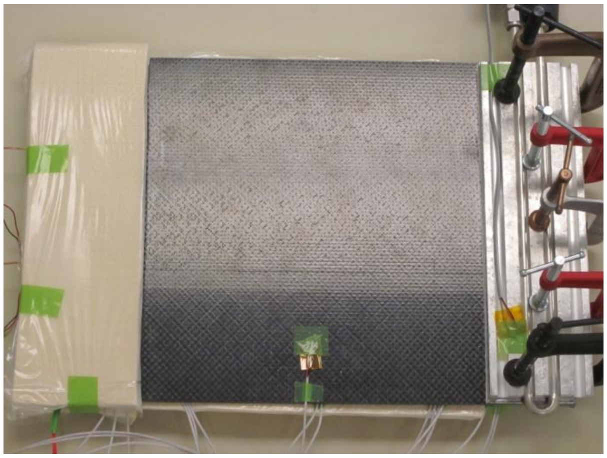

Figure 8: Subscale Isothermal Skin Thermal Test Setup

The required heat load across the subscale skin was 31.5 W with a gradient of less than 5 C. The subscale isothermal skin successfully transferred 60 W with a temperature difference of <1 C across the exposed section, see Figure 9. Note that the 60 W is 1.6 times the AFRL/RV SBIR required value for this size.

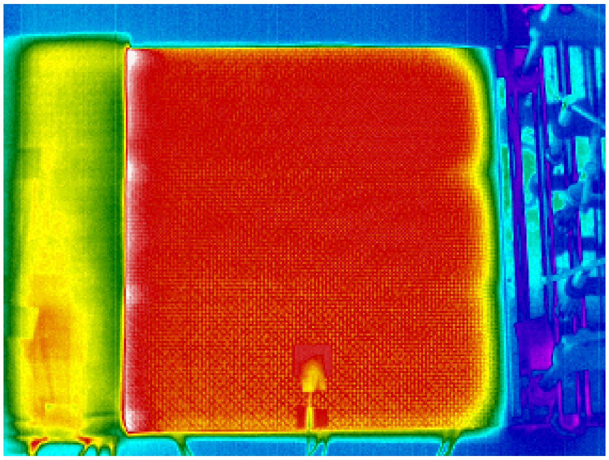

Figure 9: IR View of Subscale Isothermal Skin Transferring 60 W from Left to Right

An isothermal skin similar to the one shown in Figure 8 was burst pressure tested to 4.5 times maximum design pressure.

THERMAL CONTROL PANEL APPLICATIONS

Applications of Thermal Control Panels are numerous and will be expanded as users expand ways to apply the technology to their unique thermal control problems. Figure 10 qualitatively shows the relative capability of TMT's Thermal Control Panels versus other common spacecraft materials. Note that the TCP value is for a single isothermal skin, not the entire structural panel. The primary space applications are: thermal/ structural panels, radiator panels, and spacecraft heat spreading.

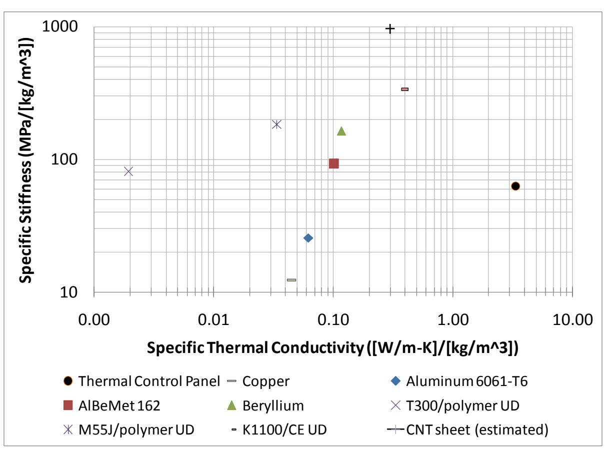

Figure 10: Spacecraft Material Comparison (typical values)

Thermal/ Structural Panels

The current panel design is for a thermal/ structural application. As part of the AFRL/RV SBIR program the development was funded to apply the technology as a spacecraft structure that also spreads heat uniformly across a panel. This unit is depicted in Figure 11. In this application, the TCP is the spacecraft structure. Components can be mounted to the panel without additional structure. In this configuration, a thin isothermal panel is mounted on the inside and outside surfaces, separated by aluminum honeycomb as described previously. Each thin panel spreads the heat to the surrounding frame structure while communicating thermally through the honeycomb. The frame creates a method for connecting panels both mechanically and thermally. Interface flanges are specific to the application.

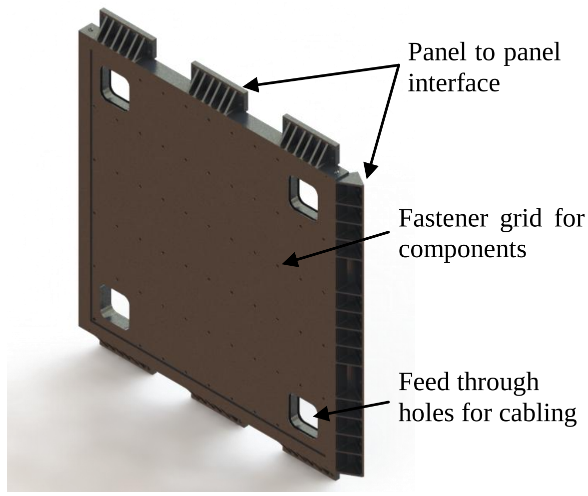

Figure 11: Typical TCP for Structural-Thermal Applications

Radiators

A straight forward application of the technology is radiator panels as depicted in Figure 12. Because the TCP is nearly isothermal with heat applied to one edge, a radiator panel is very efficient. TMT radiator panels would use one of the thin isothermal skin sections discussed above since they do not need to support heavier components.

Recently, radiator configurations have been studied to apply the technology to a similar sized spacecraft. Figure 13 below shows a simple Thermal Desktop® model comparison of a 100 W radiator using aluminum honeycomb versus a Thermal Control Panel. In this model, heat is applied along one edge and the panel allowed to radiate from the top surface to space. The back side and edges are assumed insulated.

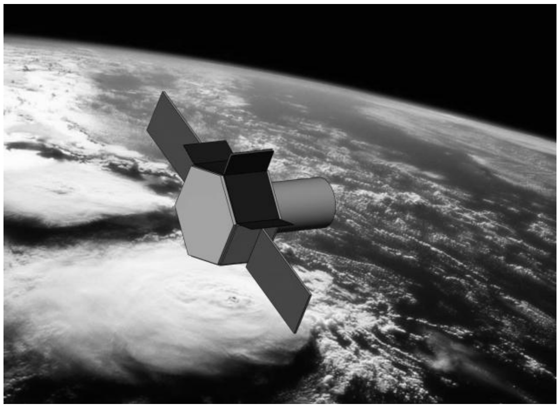

Figure 12: Isothermal Radiators for Spacecraft

Clearly the TCP provides a much more uniform temperature with gradients < 3 C vs >90 C for the TCP and aluminum radiators respectively.

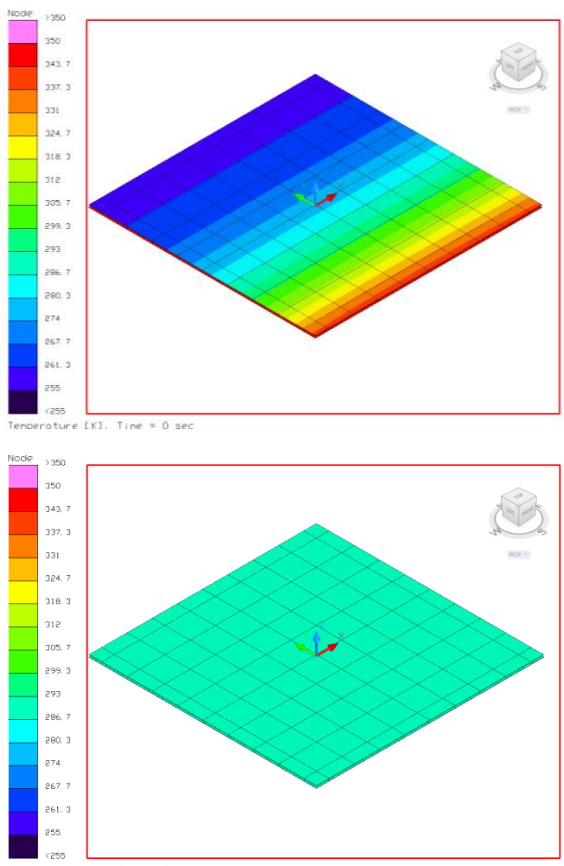

Figure 13: Comparison of Aluminum Honeycomb (top) and TMT-Thermal Control Panel (bottom) 100 W Radiators (56 cm x 56 cm)

Heat Spreading

Design of spacecraft is more efficient when making use of available space within the structure. One potential application of a TCP is to make a deck within the structure where heat dissipating components can be mounted. The TCP then provides the structure and a path to properly get the heat from the middle of the structure to external radiating surfaces. This can be accomplished by utilizing a TCP honeycomb structural panel that will interface to the sides of the spacecraft. Components mounted on that panel will spread their heat to all sides of the bus where there are mounting points. In this way, the honeycomb structure used to mount the components also is the thermal control hardware for moving the heat to the outer portions of the spacecraft. This makes efficient use of mass and resources.

ROAD TO SPACE QUALIFICATION

TMT is aggressively pursuing space qualification of the panel technology. As part of the AFRL/RV SBIR development, the panel technology will undergo a series of qualification tests to ensure the technology can withstand the rigor of space launch and on-orbit operation.

Once development testing is complete, a set of panels will undergo flight qualification testing. The test flow is shown in Figure 14 below.

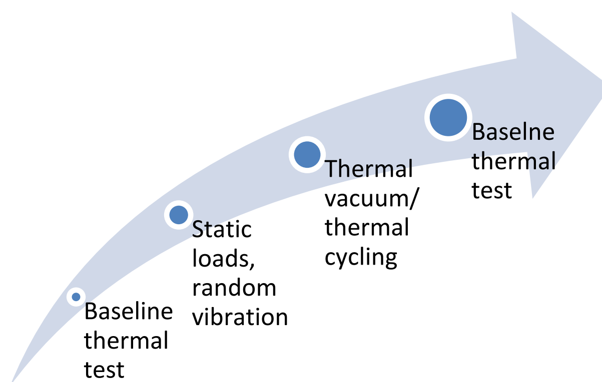

Figure 14: Road to Space Qualification

TMT is currently exploring spaceflight, microgravity test opportunities to perform final space qualification testing of the panels. Testing to date have verified the pressure capability of the design, and have shown the technology to create isothermal skins at heat loads 5 times the required value. Testing shown in Figure 14 are planned to be complete by the first quarter of 2012.

Acknowledgments

The authors are grateful to AFRL/RV for funding on this SBIR development project. We also acknowledge contributions from Space Dynamics Laboratory personnel who provided input on various aspects of the project. Additionally, we appreciate the cooperation of SpaceWorks in providing information on the PnPSat-2 bus configuration and interfaces.

References

1. Lyall, M.E., D.W. Hengeveld, and Q.E. Young, "Thermal Subsystem Design Methodology for Responsive Space Missions," Proceedings of the 7th Responsive Space Conference, Los Angeles, CA, April 2009.
2. Williams, A.D. and S.E. Palo, "Issues and Implications of the Thermal Control Systems on the "Six Day Spacecraft," Proceedings of the 4th Responsive Space Conference, Los Angeles, CA, April 2006
3. Operationally Responsive Space (ORS), General Bus Standard (GBS), ORSBS-002-GBS, Rev. R3.1, April 2008.
4. Department of Defense Handbook: Test requirements for Launch, Upper Stage, and Space Vehicles, MIL-HDBK-340A, 01-Aril 1999.
5. Military Handbook: Design, Construction, and Testing Requirements for One of a Kind Space Equipment, DoD-Hdbk-343, 01-February-1986
6. American Institute of Aeronautics and Astronautics, Space Systems- Structures, Structural Components, and Structural Assemblies, AIAA S-110-2005, 12 July 2005
7. American Institute of Aeronautics and Astronautics, Space Systems- Metallic Pressure Vessels, Pressurized Structures, and Pressure Components, AIAA S-080-1998, 13 Sept. 1999