

# Application of Thermally Isolating Payloads from Bus for Vehicle Thermal Testing

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## **Abstract**

The Aerospace Corporation has recently investigated common spacecraft architectures and designs to increase customer flexibility in reconfiguring payloads suites in space. These studies determined that a near-adiabatic payload-bus thermal interface is an optimal choice for meeting enhanced program and mission requirements. This report adds to these discussions by focusing on how a near-adiabatic payload-bus interface design impacts subsystem and vehicle integration and testing, and the results showed several advantages over current single line flow integration, including:

- Simplified and improved integration and thermal testing
- Cost savings from reduced vehicle-level testing
- Better test effectiveness and requirements verification during thermal testing
- Elimination of the vehicle-level thermal vacuum testing

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# 1. Introduction

Different ways of thinking about how payloads are integrated onto spacecraft buses is a relatively new space vehicle architectural approach that provides potential flexibility in payload selection and mission support. The Aerospace Corporation (Aerospace) recently investigated several spacecraft designs with specific payload-to-bus interface requirements, including:

- Common Payload Interface Standard (CoPaIS) [1]
- Payload-to-Spacecraft Bus Interface Specification (PSIS) [2][3]
- Combat Bus – Standard Interface Specification (SIS) [4]
- A proposal for military spacecraft program

Thermal engineers at Aerospace supported these studies, investigating optimal interface thermal designs to meet overall mission requirements. While the current thermal control approach for mounting payloads to a spacecraft bus is generally to allow free heat exchange with a relatively conductive bolted interface, these studies identified a more restrictive thermal interface as one that could increase possibilities for supporting different mission payload suites. Specifically, the engineers explored how different heat transfer design techniques (conductive and radiative) at the payload-to-bus interface could meet thermal design goals and requirements. They also investigated the consequences, advantages, and disadvantages of limiting or redirecting the heat transfer across the interface.

Of these four studies, only the military spacecraft proposal application included how thermally isolating payloads from the spacecraft bus could affect the vehicle integration and test process, but not in any detailed sense. The discussions in the text that follows goes beyond the results of the military spacecraft proposal and more fully describes how limiting interface heat transfer will affect thermal testing of the space vehicle.

## 1.1 Background

The CoPaIS study assessed design techniques for an adiabatic interface for payloads that could be mounted to the bus while in space. No interface can be truly adiabatic because any temperature difference between the bus and the payload will result in some heat transfer. The CoPaIS task identified a realistic limit to the maximum heat transfer across the interface. Thermal analyses of spacecraft in various orbits determined that a maximum interface heat transfer of  $5 \text{ W/m}^2$  could be obtained for the total heat transfer at any time in the orbit [5].

The goal of the PSIS project was to develop an interface specification to improve the mission of continuous production agility (CPA) based on current design practices and the needs of future military space programs. The specifications assessed payload-to-spacecraft interfaces on current and past military space programs for several mission types to find commonality. Various thermal interface approaches were summarized, and the ability of each interface type to meet program thermal requirements was assessed.

The Combat Bus – SIS project was an Air Force initiative to implement CPA strategies into larger space vehicles by using an open architecture that would be resilient, supportive of a variety of payload modules and missions, and be in a “constant state of production.” The project developed a Combat Bus – SIS to provide requirements and design techniques for a payload-to-bus interface that would meet the goals of CPA. The basic thermal design of the interface specified that temperature control of payload units would be accomplished primarily by heat conduction from the unit baseplate, with radiation heat transfer also captured in the supporting thermal analysis. Allowable minimum or maximum thermal conductance between the bus and the hosted payload units, as well as any filler materials or gaskets, would need to be

specified. The recommendations stated that the external payloads shall be conductively isolated from the bus and other payloads with “a maximum interface conductance of TBD W/°C.” The approach is similar to CoPaIS, except Combat Bus – SIS specifies a maximum interface thermal conductance, whereas CoPaIS specifies a maximum interface heat transfer.

The military spacecraft proposal application investigated different types of interfaces to determine how single-line flow of integrations would be impacted while still meeting the intent of mission performance verification in the environmental tests of Space and Missile Systems Center (SMC) Standard SMC-S-016, “Test Requirements for Launch, Upper-stage and Space Vehicles.” It proposed either an adiabatic or minimal heat transfer interface with all vehicle environmental tests moved to the bus and payload subsystem level. The project assessed how the interface requirements would be verified, but did not determine potential benefits of testing the bus and payloads separately in subsystem-level tests. The study described the necessary subsystem test provisions and verifications necessary to eliminate vehicle-level thermal and mechanical testing without incurring additional mission risk.

With the results of these projects as a background, this report will discuss possible methods of testing an adiabatic interface design meeting the intent of SMC-S-016 vehicle-level thermal test requirements. The work will draw heavily from the military spacecraft proposal application work, but will apply it to the CoPaIS design approach. While there have been military space programs that have had a requirement for limited heat transfer across a payload mounting interface, no existing spacecraft program has applied an adiabatic interface design to their primary and secondary payloads as a formal design requirement. Contractors have suggested this design technique, but such a significant change in the way payloads dissipate their heat has never been adopted.

A final note is made on the terminology that will be used in this report. It is recognized that a perfect adiabatic interface is not possible, so the term “near-adiabatic” will be used to denote applying common design techniques to minimize the heat transfer across the interface, such as might be applied on the CoPaIS program.

## 1.2 Near-Adiabatic Design Description

The interface design configurations investigated by CoPaIS and the military spacecraft proposal are similar with multiple payloads attached to a bus nadir deck with near-adiabatic conductive mountings. Several approaches were considered for achieving a minimal heat transfer interface and, for the purpose of this work, it will be assumed that a near-adiabatic interface is present. The CoPaIS study describes several methods of achieving a near-adiabatic interfaces using common thermal design approaches and hardware [1][5]. The CoPaIS analysis cases found that minimizing the radiative heat transfer from bus surfaces or adjacent payloads could be more difficult than minimizing the conduction across the mounting interface. A schematic of the vehicle configuration is shown in Figure 1. The near-adiabatic design would minimize the heat transfer in both the conductive and radiation paths shown.

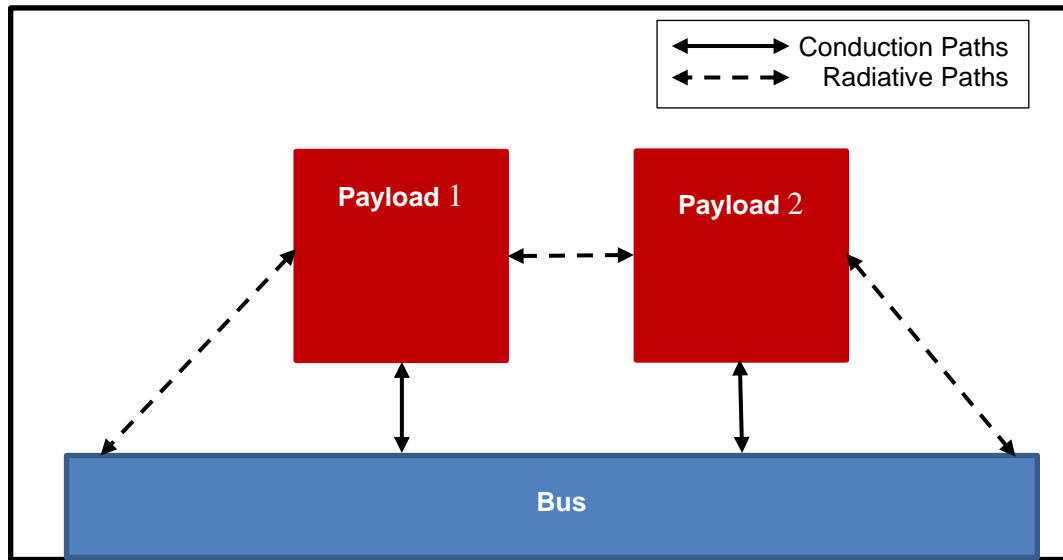


Figure 1. Schematic of Payloads on a Bus Nadir Deck.

## **2. Vehicle Testing Considerations of Near-Adiabatic Thermal Design**

Integration and ground testing need to be considered when thermal interfaces are nearly adiabatic. At the unit level of assembly, integration and testing of flight hardware are unchanged from current spacecraft designs. At the subsystem level, testing approaches will be similar, but there will be additional hardware provisions and requirements for the verification of the near-adiabatic interface.

At the vehicle level, the typical thermal test program entails a thermal vacuum test of the entire spacecraft (bus and all payloads). For a large spacecraft, this test consists of 40 to 55 days of testing with weeks of setup before and teardown after the test. For spacecraft with multiple payloads coming from different subcontractors, environmental testing cannot begin until all payloads have been delivered to the bus or prime contractor and integrated onto the bus. If the delivery of a payload is delayed, the entire program may be delayed. For vehicles with multiple payloads, such delays are common and can arise from issues associated with the design, integration, and payload testing. The advantages of and requirements necessary for streamlining spacecraft thermal testing for a vehicle with near-adiabatic interfaces are discussed in the next sections.

### **2.1 Advantages of Near-Adiabatic Thermal Design in Vehicle Testing**

In contrast to the current single-line flow process, a vehicle with near-adiabatic payload thermal interfaces may offer several cost-saving opportunities. The most significant implication is that vehicle-level thermal vacuum tests may not be required when mission performance requirements are demonstrated at the payload and bus levels of assembly. This may result in:

- Schedule savings with the elimination of the vehicle thermal vacuum test; while thermal testing of payloads and bus subsystems may increase, subsystem-level tests can be conducted in parallel
- Schedule savings by avoiding program delays when a payload is delivered late
- Improved test simplicity because bus and payload contractors can focus on their own hardware without needing in-depth knowledge of the other payloads or how the bus will thermally interact with the payloads
- More insightful and effective testing at the subsystem (bus and payload) levels due to a better perceptiveness (less hardware in the test), better tailoring of test environments to the subsystem, and increased instrumentation

The bus contractor could begin environmental testing of the bus at the completion of the bus integration (not needing to wait for all payload deliveries). The payloads would be integrated after the completion of the bus environmental testing. A Final Integration System Test would be conducted to demonstrate that the integration was done correctly and that bus-to-payloads performance (communication, timing, sequencing, etc.) meets program requirements.

### **2.2 Prerequisites for Eliminating Vehicle-Level Environmental Testing**

Prior to the elimination of the vehicle thermal vacuum testing, a contractor will need to demonstrate by analysis and test that the interfaces meet near-adiabatic heat transfer requirements. This will require subsystem thermal testing with thermal simulators of the hardware that would constitute vehicle test configurations. For development, qualification, or protoqualification thermal testing, a bus simulator

would be required for payload thermal tests and payload simulators would be required for bus thermal testing. The simulators need to be sufficiently detailed to duplicate:

- Conductive interfaces with flight or flight-like interface mounts
- Conductive leaks through cables, harnesses, and telemetry and heater wires that cross the interface
- Radiative interfaces with identical thermal surface treatments
- Radiative view factors between external surfaces using simulators sized, shaped, and configured to that of the actual flight hardware
- Thermal boundary conditions and thermocouple provisions necessary for verifying the near-adiabatic heat transfer requirements

With the verification of the near-adiabatic heat transfer requirements using detailed simulators on development, qualification, or protoqualification hardware, acceptance testing could be conducted with significantly simpler simulators driven to boundary temperatures necessary to prevent unrealistic heat losses.

To demonstrate near-adiabatic heat transfer, the bus thermal vacuum test will require individual payload simulators mounted with the same interfaces as used in the flight hardware. The interfaces need to be instrumented to determine the conductive heat transfer in different environmental and operational sequences planned for the test. Thermocouples are also placed on the simulator's external surfaces to determine the radiative heat transfer from the bus and adjacent payloads. Additional temperature sensors are required to identify and quantify other potential heat leaks such as through cables. Heaters on the simulators will need to control each simulator to pre-established temperatures that will be boundary conditions for determining interface heat transfer.

When these thermal vacuum tests verify that the interfaces meet program requirements for heat transfer exchange, the interface can be characterized as nearly adiabatic. It is recommended that the qualification or protoqualification vehicle thermal vacuum test be conducted to verify results observed in subsystem thermal tests. Thermal testing on subsequent spacecraft may be conducted at the bus and payloads levels with the vehicle thermal vacuum test waived. The thermal vacuum tests on the acceptance subsystems will still require simulators, either the same ones used to establish the near-adiabatic design or simplified simulators with nonconductive interface mounts and thermal blankets to minimize radiative heat leaks.

### **3. Summary**

Several studies are currently underway to investigate spacecraft designs that increase customer flexibility in selecting and changing out payloads for on-orbit space vehicles. These studies have identified the thermal control subsystem as an important design driver in ensuring program success, and the most common thermal design approach to achieve the study goals is a near-adiabatic payload interface. This report discusses how such a vehicle design could (1) simplify and improve integration and thermal testing, (2) result in schedule savings, (3) increase the test effectiveness and requirements verification in thermal testing, and (4) lead to the elimination of vehicle-level thermal vacuum tests.

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