X-33 METALLIC TPS TESTS IN NASA-LARC HIGH TEMPERATURE TUNNEL

Stanley A. Bouslog
Brad Moore
Ron J. Scanlon
BF Goodrich Aerospace
Aerostructures Group
Chula Vista, CA

and

James Wayne Sawyer
NASA Langley Research Center
Hampton, VA

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Introduction

The X-33 flight vehicle is being developed by a team consisting of Lockheed Martin, NASA, BF Goodrich Aerospace, Boeing Rocketdyne, Allied Signal, and Sverdrup. The X-33 flight vehicle is being built and flown to demonstrate key technologies for the Reusable Launch Vehicle (RLV) a Single Stage To Orbit (SSTO) launch vehicle. Three of the key technologies being demonstrated on X-33 are a linear aerospike engine, composite fuel tanks, and advanced metallic thermal protection system (TPS). In order to qualify the nominal metallic panel assembly for flight on the X-33, a combined design analysis and test program was defined to verify that this assembly complies with the design requirements when exposed to flight-like environments. One of the key tests in this program was the NASA-LaRC 8-foot High Temperature Tunnel (HTT) test. A description of the planned tests was presented in Ref. 1. The proposed paper shall provide a short description of this test, present data obtained during the test, and provide comparisons with predictions.

Test Objectives

Three major test objectives were defined for the metallic honeycomb panel assembly HTT test series. The first objective was to obtain thermal and structural data on the as-designed assembly for correlation of analytical models while the test article is exposed to aerothermodynamic environments comparable to those expected in X-33 flight. These analytical models are used to verify that structure below the metallic panel TPS is maintained below specified temperature limits. The second objective was to evaluate the durability of the panel-to-panel interfaces while exposed to several cycles of combined high temperature, hypersonic flow. The third objective was to obtain thermal and structural data for hardware off-design cases. These cases included vertical misalignments between metallic panels, missing fasteners, and damaged panel-to-panel interface seals.

Test Facility

The 8-Foot High Temperature Tunnel (HTT) is a large, blow down wind tunnel that combusts stored air with methane to create high enthalpy flow representative of flight conditions at 80k to 130k feet altitude. Combusted gases are expanded to approximately Mach 7 by a contoured nozzle with an eight foot exit diameter. Total temperature of the combustor can be varied from 2400 °R to about 3600 °R with total pressures approaching 2400 psia. The nozzle extends into a twenty-six foot diameter test chamber that houses the eight foot diameter, twelve foot long open jet test section. A schematic of the HTT facility is shown in Figure 1.

Two banks of quartz lamps are located below the test section for radiant pre-heating of test models prior to insertion into the flow. A typical test run of a TPS model consists of a radiant heat exposure to bring the model up to expected temperatures prior to re-entry simulation. After the radiant pre-heat cycle, the lamp bank is retracted and the model is rapidly inserted into the open jet of the wind tunnel by means of an elevator system. Aerothermal exposure of the model varies from 30 to 60 seconds depending on the test conditions selected.

Test Fixture and Test Article

The model consists of seven Inconel 617 TPS panels and is approximately 32" X 54" in size. Six of the panels around the model perimeter are a "home plate" configuration and the center panel is a "diamond" shaped panel. The panel geometries are representative of the flat region of the X-33 windward surface (≈ vehicle station 250 to station 620) shown in Figure 2. The panels are made of (2) .006" Inconel 617 face sheets that are brazed to Inconel 617 honeycomb core (3/16" cell and.0015" foil thickness). The surfaces of the TPS panels are painted with Pyromark 2500™ thermal paint to achieve a high (≅.85), uniform emissivity. One and one-quarter inches of 3.5 lb/ft^3 Q-fiber felt insulation are encapsulated on the backside of each honeycomb panel with a resistance welded .003" Inconel 617 pan. Vents are provided in the insulation pans to accommodate the pressure changes associated with the tunnel start up and shut down. The TPS panels mount to rosette attachment clips made of Rene 41 alloy. The rosettes mount to a representation of the LMSW X-33 substructure which consists of mounting beams and attachment clips. The clips, which were provided by Lockheed-Martin Skunk Works, are representative of the flight vehicle whereas the tank ring frames and longerons are simulations (aluminum vs. Gr/BMI composite) modeled to provide comparable flexural rigidity. Movements in the TPS substructure due to fuel tank displacements are not simulated in the model.

The X-33 TPS model is designed to fit in the standard model holder, also referred to as a panel holder or sled, supplied by NASA LaRC for Thermal Protection System testing. The sled is rectangular with a half-wedge leading edge and a 42" x 60" x 10" cavity to accommodate the test model and instrumentation. One inch thick ceramic glassrock tiles are bonded to the sled surface to serve as a thermal barrier and blank off unused areas of the sled cavity.

To accommodate the objective of measuring mass flow past the seals on the TPS test article, a plenum box was supplied by BFG for the test. The plenum is a large, mild steel box which fits inside the sled cavity and is attached with bolts around the perimeter. The plenum contains an exit port on its aft end which connects to a mass flow meter that is located in the aft cavity of the sled.

Results

The first segment of the test has been completed and included eight radiant heat exposure cycles in which the surface temperature was 1000 F or above and five aerothermal runs which included a radiant pre-heat. All of these runs were made with the nominal model. Unfortunately, during the sixth aerothermal run, the tunnel experienced cooling problems and in the shut-down process a shock wave impacted the panel-holder sled and destroyed the test article. Presently, a new set of metallic panels are being installed into the sled and the testing is planned to continue and be completed within the next two months. Nevertheless, sufficient data have been obtained to meet the first two objectives of the testing.

Radiant Heat Data

The array of radiant heat lamps positioned above the panel holder in the retracted position provides the capability to pre-heat the test article and reduce the thermal shock as the model is inserted into the Mach 7 flow. This capability also provides the opportunity to obtain temperature and strain measurements during radiant heat only environments which shall be used to correlate thermal math models and structural deflection models. The final paper shall includes samples of these data and comparisons with predictions.

Aerothermal Data

Figure x presents temperature histories for one aerothermal run of the nominal model. These temperatures were measured on the forward most panel in the array on the backside of the outer and inner facesheets and on the bottom outside of the insulation pan. The different phases of the run can be determined from the outer facesheet temperatures as shown in Figure x. The radiant pre-heat included a 10 F/sec ramp up rate and a dwell at a commanded temperature of 1300 F. At the end of the dwell, the radiant heat lamps are shut off and retracted and the model is moved vertically upwards into the flow. The data clearly show the expected trends for the thermal response of the metallic panel assembly.

The heat transfer that occurs below and between the metallic panels has been an area of concern for this metallic TPS. Therefore, a water-cooled heat flux calorimeter was located 4 inches below the surface and centered in the interface between two adjacent panels. Data from this instrument are presented in Figure x. During the radiant pre-heat phase, the calorimeter is measuring the radiation emitted from the hot Inconel honeycomb panel edges and extensions and the sides of Inconel insulation pans. These data assist in correlating radiation heat transfer models for prediction of the heat transfer to internal hardware located below the TPS assembly. When the model is inserted into the flow, a small increase in the calorimeter measurement is observed. These data shall be used to correlate the interface leakage convective heat transfer models.

Conclusions

The first series of metallic TPS tests in the NASA-LaRC Mach 7 High Temperature Tunnel has been completed. Additional testing is in progress and shall provide data for off-design configurations for the metallic TPS. The available data are being analyzed and being used to correlate analytical models to be used for X-33 flight design analysis. The final paper shall present additional data from these tests and comparisons between the data and analytical predictions.

Acknowlegements

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References

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2. Deveikis, W. D. and Hunt, L. R., "Loading and Heating of a Large Flat Plate at Mach 7 in the Langley 8-foot High-Temperature Structures Tunnel," NASA TN D-7275, Sept. 1973.

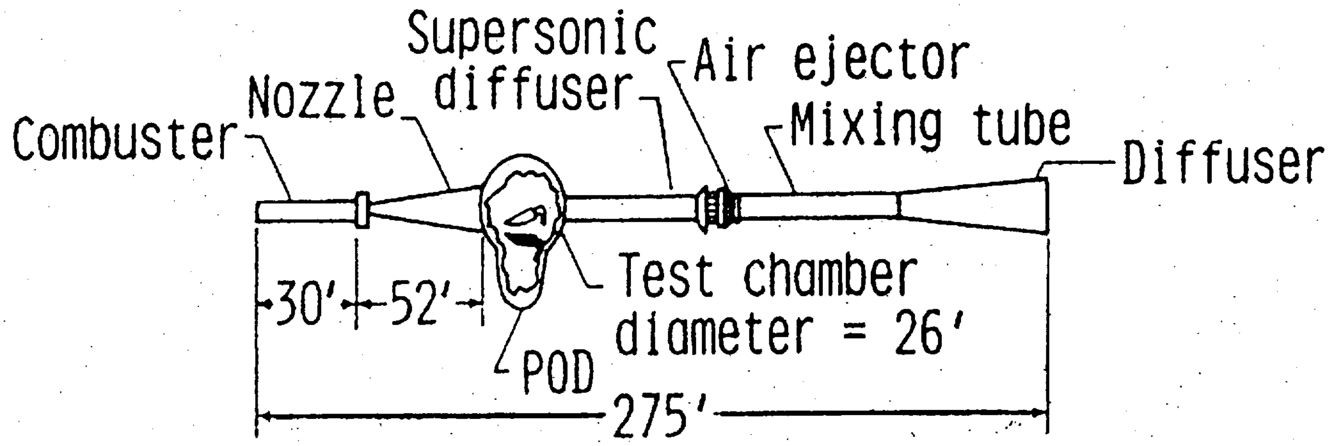

Figure 1 - NASA Langley Reseach Center High Temperature Tunnel.

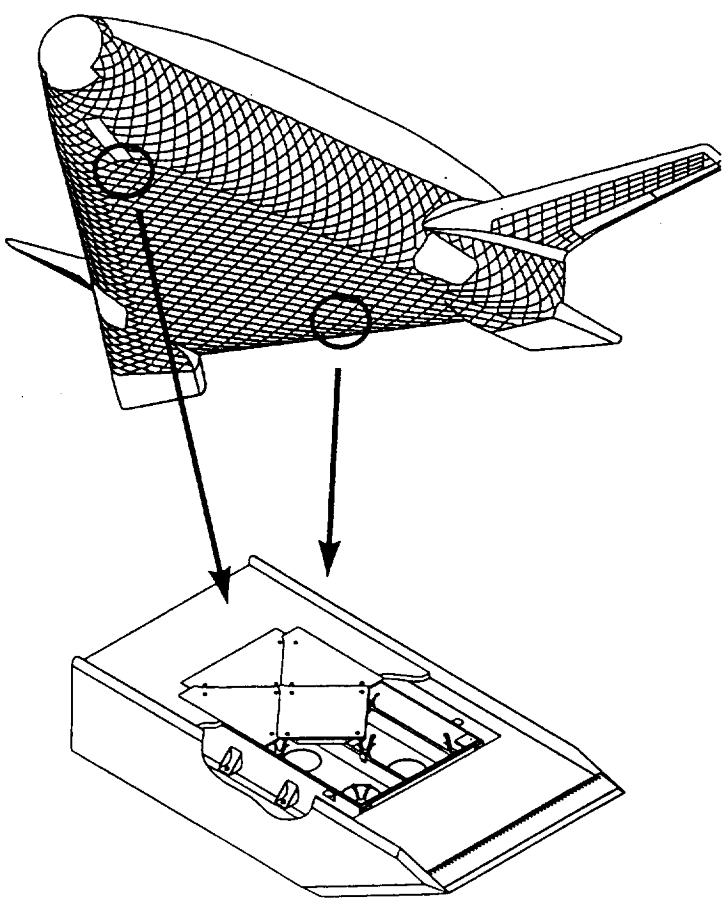

Figure 2 - Sketch of Panel-Holder Sled with Metallic TPS Assembly.

Chart1

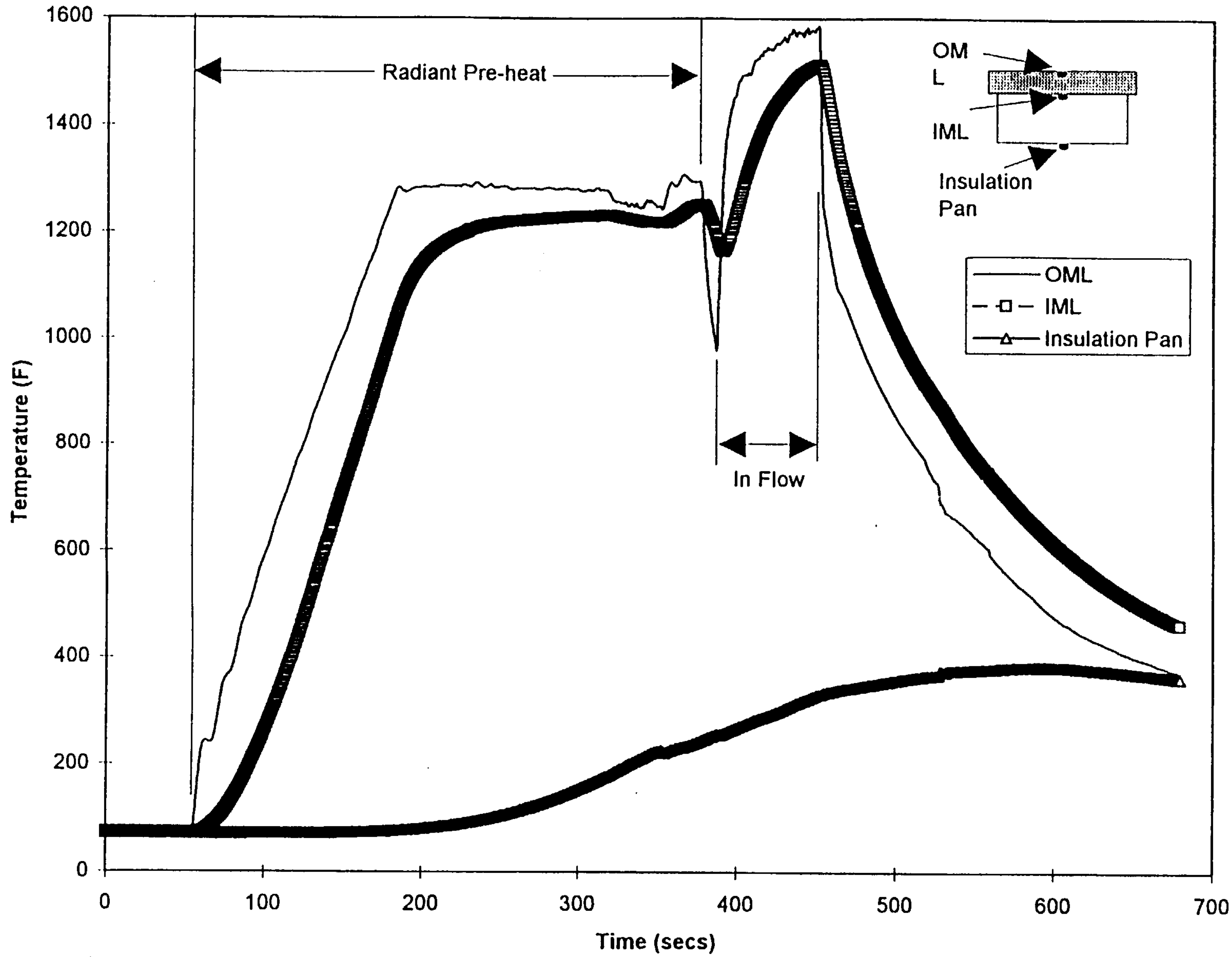

Figure 3 - Temperature Measurements on Metallic TPS Panel.

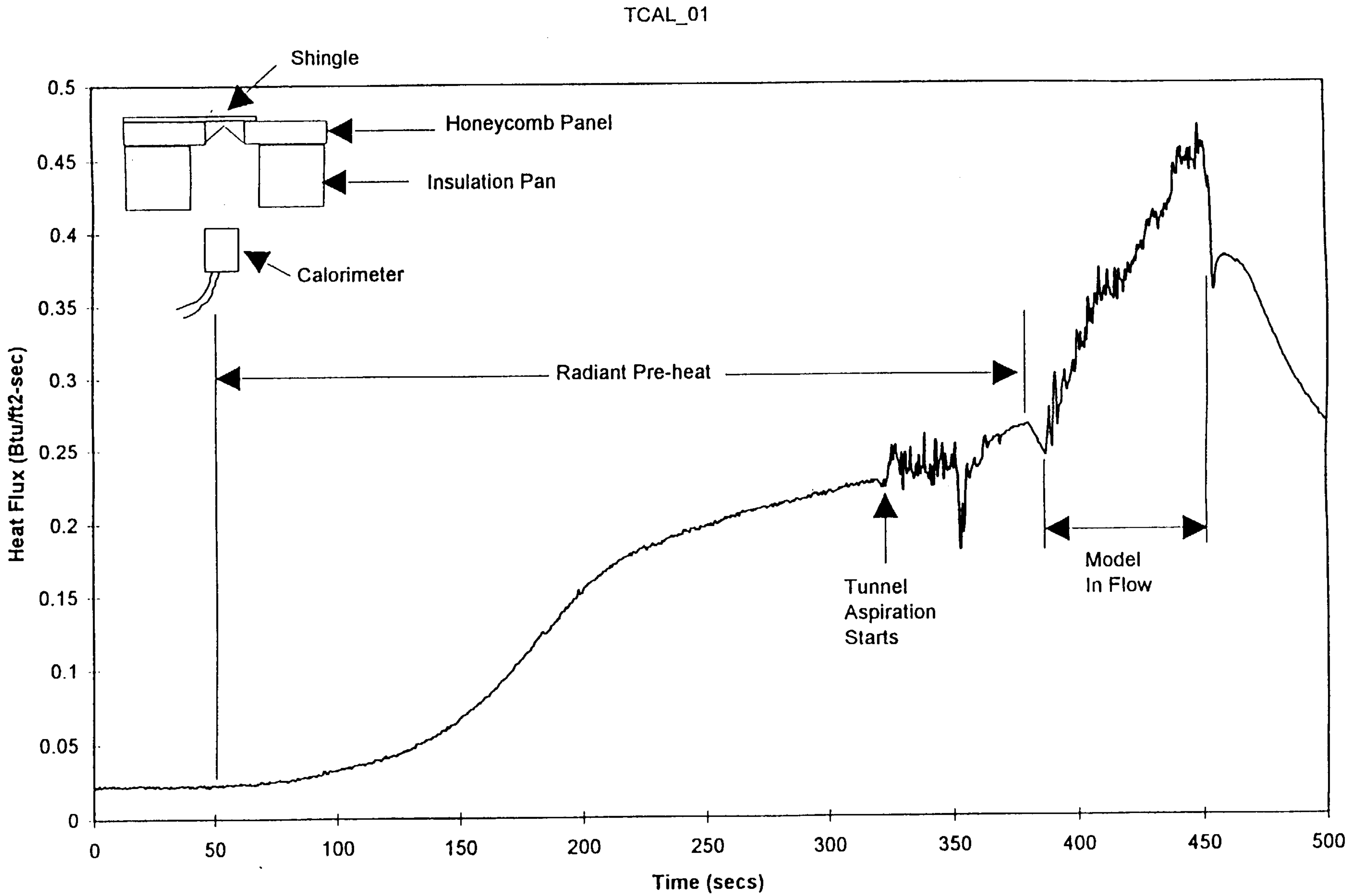

Figure 4 - Heat Flux Measurements of Region between Metallic Panels.