

## AEROTHERMAL SESSION TOPICS

### Aerothermal Paper Session (Tuesday 7:30AM to 11:30 AM)

Time	ID	Title	Author(s)	Affiliation	Email
7:30AM	TFAWS2012-AE-01	<a href="#">Sizing and Margins Assessment of the Mars Science Laboratory Aeroshell Thermal Protection System (AIAA San Antonio, TX, 41<sup>st</sup> Thermophysics Conference)</a>	Mike Wright, Robin A.S. Beck, Karl T. Edquist, David Driver, Steven A. Sepka, Eric M. Slimko, William H. Willcockson, Anthony DeCaro, Helen H. Hwang	NASA ARC NASA LRC Eloret Corporation JPL Lockheed Martin Space Systems	<a href="mailto:Michael.J.Wright@nasa.gov">Michael.J.Wright@nasa.gov</a>
8:00AM	TFAWS2012-AE-02	<a href="#">A Simplified Plume and Aerothermal Heating Analysis for LDSD</a>	Mike Pauken	JPL	<a href="mailto:Michael.T.Pauken@jpl.nasa.gov">Michael.T.Pauken@jpl.nasa.gov</a>
8:30AM	TFAWS2012-AE-03	<a href="#">Numerical Modeling of Solid Rocket Motor Plumes</a>	Manish Mehta Brandon Williams Gabriel C. Putnam Sheldon D. Smith	NASA MSFC CFDRC APL Jacobs ESTS Group - Plumetech	<a href="mailto:Manish.Mehta@nasa.gov">Manish.Mehta@nasa.gov</a>
9:00AM	TFAWS2012-AE-04	<a href="#">A Plume Impingement Test for Code Validation</a>	Jason Mishtawy	NASA MSFC	<a href="mailto:Jason.E.Mishtawy@NASA.gov">Jason.E.Mishtawy@NASA.gov</a>
10:00AM	TFAWS2012-AE-05	<a href="#">Space Launch System Base Convective Heating Test: Preliminary Design Analyses and Test Improvements</a>	Manish Mehta Mark Seaford Brandon L. Mobley Robert D. Kirchner Carl D. Engel	NASA MSFC Jacobs – Qualis	<a href="mailto:Manish.Mehta@nasa.gov">Manish.Mehta@nasa.gov</a>
10:30AM	TFAWS2012-AE-06	<a href="#">Interfacial Design of Composite Ablative Materials</a>	Tapan Desai Dr. John Lawson Prof. Pawel Keblinski	Advanced Cooling Technologies, Inc. ARC Rensselaer Polytechnic Institute	<a href="mailto:Tapan.Desai@1-act.com">Tapan.Desai@1-act.com</a>
11:00AM	TFAWS2012-AE-07	<a href="#">Space Shuttle Boundary Layer Transition Flight Experiment</a>	Karen Berger Brian P. Anderson	NASA LARC NASA JSC	<a href="mailto:Karen.T.Berger@nasa.gov">Karen.T.Berger@nasa.gov</a>

		<a href="#">Overview</a>	Charles H. Campbell Michael T. Garske Gerald R. Kinder Ann Micklos	The Boeing Company United Space Alliance	
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## **SIZING AND MARGINS ASSESSMENT OF THE MARS SCIENCE LABORATORY AEROSHELL THERMAL PROTECTION SYSTEM**

**Mike Wright, NASA Ames Research Center**

**Robin A.S. Beck, NASA Ames Research Center**

**Karl T. Edquist, NASA Langley Research Center**

**David Driver, NASA Ames Research Center**

**Steven A. Sepka, Elore Corporation**

**Eric M. Slimko, Jet Propulsion Laboratory, California Institute of Technology**

**William H. Willcockson, Lockheed Martin Space Systems**

**Anthony DeCaro, Elore Corporation**

**Helen H. Hwang, NASA Ames Research Center**

The methodology employed for the thermal design and margins assessment of the Mars Science Laboratory aeroshell thermal protection system is reviewed. A new thermal margins policy was developed in the course of this work that provides additional rigor over previous methods. Due to a late change of thermal protection materials from the heritage SLA-561V to PICA, the design of the heatshield followed a non-traditional path in which the flight thickness was selected based on a mass (rather than thermal) limit. The material switch was followed by detailed thermal analyses that demonstrated that the baselined thickness was sufficient to provide adequate thermal protection to the vehicle without violating design requirements during a 3-sigma worst-case entry condition. The backshell material thickness was also finalized before the thermal sizing was completed, and the resulting analysis showed that there was more than sufficient material on the backshell. The parachute cone cover and backshell interface plate were the only major thermal protection system elements that followed a standard design process. Thermal sizing was performed for acreage and special features on the cone cover and interface plate, and the hardware was manufactured according to those analyses.

## **SIMPLIFIED PLUME AND AEROTHERMAL HEATING ANALYSIS FOR LDSD**

**Mike Pauken, Jet Propulsion Laboratory, California Institute of Technology**

### **ABSTRACT**

The Low Density Supersonic Decelerator (LDSD) project is developing a series of vehicles focused on decelerating large payloads from planetary entry velocity to landing on the Mars surface. The LDSD airborne test vehicles would be launched on a balloon to a high altitude on Earth that simulates the conditions of the Mars atmosphere. Once the balloon reaches a stable float position, the vehicle is released from the balloon and during free fall it is spun up using rocket motors to provide stability before firing a large rocket motor that propels the vehicle to supersonic speeds.

Heat loads are imposed on the vehicle from aerodynamic frictional heating and from the plume of the rocket motor. A simplified thermal analysis of the aerothermal heating and the plume heating are presented to demonstrate the vehicle can be protected from these heat loads using commercial insulation products. The heatshield is covered with a layer of cork insulation while the backshell is covered with an insulation blanket made from a heat reflecting fabric cover and a silica ( $\text{SiO}_2$ ) fiber felt. Testing of the cork and the backshell insulation blanket were performed using a radiant heat flux to verify the performance of the materials would protect the LDSD vehicle structure.

## **NUMERICAL MODELING OF SOLID ROCKET MOTOR PLUMES**

**Manish Mehta, NASA Marshall Space Flight Center**

**Brandon Williams, Computational Fluid Dynamics Research Corporation (CFDRC)**

**Gabriel C. Putnam, All-Points-Logistic (APL)**

**Sheldon D. Smith, Jacobs ESTS Group - Plumetech**

### **ABSTRACT**

In support of prediction of the launch pad plume deflector environments during solid rocket booster derived NASA STS (Space Shuttle) vehicle ascent, the solid rocket motor plumes have been successfully modeled and analyzed with the Loci-CHEM Navier-Stokes computational fluid dynamics (CFD) code - Lagrangian Model at a steady-state approximation. Three main areas have been addressed in this paper: (1) sensitivity study of the Loci-CHEM-Lagrangian model with various other Loci-CHEM modeling approaches; (2) in-depth analysis of the aerophysics associated with solid rocket motor plumes; (3) comparison studies between the CFD numerical simulations and flight data and an independent engineering code, Reacting and Multi-Phase Program (RAMP2). The reusable solid rocket motor plumes are a multi-phase flow which contains both plume gases and ~16% solid aluminum oxide particles by mass. This contribution of solid particles is shown to have a large impact on the aerophysics of the plume gases and the environments of the launch pad plume deflector. The Loci-CHEM-Lagrangian model shows the best overall agreement with plume deflector flight data and the RAMP2 engineering code. These modeling approaches are being implemented to conduct higher fidelity numerical simulations for the Space Launch System ascent and launch pad environments.

## **A PLUME IMPINGEMENT TEST FOR CODE VALIDATION**

**Jason Mishtawy, NASA Marshall Space Flight Center**

### **ABSTRACT**

A 20 second ground test firing of the Solid Rocket Test Motor (SRTMV) was conducted at NASA Marshall Space Flight Center (MSFC) on March 15 2012. This test, designated as N2, was conducted to test nozzle materials and investigate the influence of small flaws in the propellant grain. A piggy-back test was included placing a highly instrumented 36" x 32" x 1" stainless steel panel 4' downstream from the nozzle exit, ~17" outboard from the centerline and inclined 6° to the plume thrust vector to measure direct plume impingement environments. In addition two material samples, P-50 sheet cork and Vamac, were integrated into the test panel to measure material recession throughout the test. High quality test data were recorded for 96 static pressure measurements, 6 unsteady pressure measurements, 46 surface temperature measurements, 12 surface total heat flux measurements, 4 radiative heat flux measurements, and 9 accelerometer measurements. Additionally 13 backside wall temperatures, 3 backside ambient temperatures and 12 TPS sample bond-line temperatures were also recorded. Data from this test compares various heat transfer measurement techniques and instrumentation types and includes a new instrument that simultaneously measures surface temperature and material temperature at two depths below the surface called a tri-coaxial thermocouple. Initial findings indicate agreement between various instrumentation types and seemingly physical trends throughout the test firing. Data gathered from this test is suited for code validation.

## **SPACE LAUNCH SYSTEM BASE CONVECTIVE HEATING TEST: PRELIMINARY DESIGN ANALYSES AND TEST IMPROVEMENTS**

**Manish Mehta, NASA Marshall Space Flight Center**

**Mark Seaford, NASA Marshall Space Flight Center**

**Brandon L. Mobley, Jacobs – Qualis**

**Robert D. Kirchner, Jacobs – Qualis**

**Carl D. Engel, Jacobs – Qualis**

### **ABSTRACT**

The NASA Marshall Space Flight Center Aerosciences Branch (EV33) is responsible for developing ascent plume induced thermal design environments for the Space Launch System (SLS) 10001 vehicle. Due to the complex nature of the rocket plume-induced flows within the launch vehicle base during ascent, testing is required to mitigate unknown risks. A sub-scale SLS base heating test is being designed to verify our semi-empirical and CFD models and to more accurately predict base flight environments. This sub-scale hot-fire test will be conducted at the Calspan-University of Buffalo Research Center's (CUBRC) LENS II facility to simulate altitudes from sea-level to 200 kft.

Five areas of analyses in support of these tests are presented in this paper: (1) determination and prediction of the target design altitude points which feed into the test matrix, (2) core-stage and booster element nozzle material and scale sensitivity study, (3) core-stage and booster element inner-nozzle boundary layer specific enthalpy flow analysis, (4) dynamic similarity analysis and (5) core-stage gas propellant feed system design. The preliminary analyses recommend various innovative testing methodologies to improve data fidelity and feed into the test facility and instrumentation optimization.

## **INTERFACIAL DESIGN OF COMPOSITE ABLATIVE MATERIALS**

**Dr. Tapan G. Desai, Advanced Cooling Technologies, Inc.**

**Dr. John Lawson, NASA Ames Research Center**

**Prof. Pawel Keblinski, Rensselaer Polytechnic Institute**

### **ABSTRACT**

Ablative materials are thermal insulators used in hypersonic space vehicles. They are typically carbon reinforced composites with a phenolic resin matrix, which absorb heat in part through endothermic pyrolysis of the matrix. The char produced as a result of these reactive processes yields a thermally insulating and protective layer at the material surface. Optimization of the thermal protection system requires accurate prediction of the (currently ambiguous) pyrolysis process and the evolution of char morphology. A materials development software package is currently being developed that will consist of the following two modules: (i) an experimentally validated, atomistic-level simulation engine capable of predicting the role of interfacial structure on the resin-to-carbon process and (ii) atomistically-informed continuum-level thermo-mechanical performance analyzer for composite ablative materials subjected to transient pyrolytic conditions. The presentation will include a brief summary of this package and detailed results on reactive molecular dynamics simulations performed to study the initial stage of pyrolysis of phenolic polymers with carbon nanotube and carbon fiber. Furthermore, the effect of degree of crosslinking on pyrolysis and graphitic precursor formation will be presented.



## **SPACE SHUTTLE BOUNDARY LAYER TRANSITION FLIGHT EXPERIMENT OVERVIEW**

**Karen T. Berger, NASA Langley Research Center**  
**Brian P. Anderson, NASA Johnson Space Center**  
**Charles H. Campbell, NASA Johnson Space Center**  
**Michael T. Garske, NASA Johnson Space Center**  
**Gerald R. Kinder, The Boeing Company**  
**Ann Micklos, United Space Alliance**

### **ABSTRACT**

In support of the Space Shuttle Boundary Layer Transition Flight Experiment (BLT FE) Project, a manufactured protuberance tile was installed on the port wing of Space Shuttle Orbiter Discovery for STS-119, STS-128, STS-131 and STS-133 as well as the Space Shuttle Orbiter Endeavour for STS-134. Additional instrumentation was installed in order to obtain more spatially resolved measurements downstream of the protuberance. Prior to the STS-134 flight, configuration changes were made to the Endeavour instrumentation in an attempt to better understand and possibly mitigate a thermocouple anomaly associated with the BLT FE and other shuttle flights. This presentation provides an overview of the BLT FE Project with a specific focus on the changes made to the orbiter prior to the STS-134 flight and the resulting data. Significant efforts were made to place the protuberance at an appropriate location on the Orbiter and to design the protuberance to withstand the expected environments. A high-level overview of the in-situ flight data is presented, along with a summary of the comparisons between pre- and post-flight analysis predictions and flight data and a discussion of the observed thermocouple anomaly and the effect on the flight data collected. Comparisons show that predictions for boundary layer transition onset time closely match the flight data, while predicted temperatures did not match as closely to the observed flight temperatures.