Aerothermal Paper Session

Aerothermal Paper Session #1 (Monday 1:00 PM to 3:00 PM)

ID	Title	Author(s)	Affiliation	Email
TFAWS-AE-001	Lessons Learned from the Ground Operations, Launch and Ascent Thermal Analysis of the Lunar Atmosphere and Dust Environment Explorer Mission	Kan Yang	NASA GSFC	kan.yang@nasa.gov
TFAWS-AE-002	Thermographic phosphor measurements of shock-shock interactions on a swept cylinder	Michelle Jones	NASA LaRC	michelle.l.jones@nasa.gov
TFAWS-AE-003	Computational investigation of shock-shock interactions at Mach 6	Michelle Jones	NASA LaRC	michelle.l.jones@nasa.gov
TFAWS-AE-004	Development of Atomistically informed Chemical Kinetics Modeling of Ablative Rubber Composite Materials	Tapan Desai	Advanced Cooling Technologies, Inc	Tapan.Desai@1-act.com

Aerothermal Paper Session #2 (Wednesday 9:00 AM to 11:30 AM)

TFAWS-AE-005	Preliminary Reentry Trajectory, Aeroheating, and TPS Performance Predictions for the Inspiration Mars Mission	Thomas Squire	NASA ARC	thomas.h.squire@nasa.gov
TFAWS-AE-006	Development and Implementation of an Aerothermostructural Model to Examine Multi-Disciplinary Problems in Hypersonic Flight	Chris Kostyk	NASA DFRC	chris.b.kostyk@nasa.gov
TFAWS-AE-007	An Upgrade of the Aeroheating Software “MINIVER”	Pierce Louderback	NASA KSC AI Solutions	pierce.m.louderback@nasa.gov
TFAWS-AE-008	Space Launch System (SLS) Small Protuberance Aerodynamic Heating Methodology	Chris Morris	NASA MSFC	christopher.i.morris@nasa.gov
TFAWS-AE-009	Simplified Method for Simulating Ascent Configuration Changes of Large Scale Integrated Launch Vehicles in Thermal Desktop	Robert Kwas	NASA KSC	robert.j.kwas@nasa.gov

TFAWS-AE-001

Lessons Learned from the Ground Operations, Launch and Ascent Thermal Analysis of the Lunar Atmosphere and Dust Environment Explorer Mission

Kan Yang, NASA GSFC

ABSTRACT

The Lunar Atmosphere and Dust Environment Explorer (LADEE) mission is scheduled to launch in mid-2013 aboard the maiden flight of the Orbital Sciences Corporation Minotaur V Launch Vehicle to study the Moon's exosphere and environmental impacts on lunar dust. To determine the pre-launch and launch and ascent environments and their impact on the spacecraft, thermal analysis was conducted to ensure that the existing design of the launch vehicle, gantry and storage facilities at Wallops Island, VA were sufficient to meet the thermal constraints of the space vehicle. In addition, a strict temperature and solar exposure requirement was imposed on the launch vehicle itself which necessitated thermal analysis of the Minotaur V motors during storage, gantry operations, and gantry roll-back. These thermal analyses required the creation of thermal models which accounted for convective effects as well as launch thermal loads, somewhat outside of the normal capacities of the conduction- and radiation-driven Thermal Desktop and SINDA/FLUINT programs primarily used by NASA Goddard Space Flight Center Thermal Engineering Branch. This paper seeks to capture the lessons learned from these analyses by discussing the numerous modeling considerations taken to capture such a complex thermal environment. The major environmental drivers for rapid temperature changes on the launch vehicle and space vehicle will be discussed. The largest contributors to the difficulty of this analysis included determining the appropriate convective coefficient for different thermal environments and the appropriate amount of model detail in various portions of the launch vehicle, such that it is enough to resolve thermal gradients without hindering runtime. The need to resolve these difficulties required the development of innovative approaches to reach logical, physically sound solutions. Lessons learned throughout the thermal modeling process are presented in hopes that future missions with similar requirements can benefit from the challenges overcome for LADEE.

TFAWS-AE-002

Thermographic phosphor measurements of shock-shock interactions on a swept cylinder

Michelle Jones, NASA LaRC

ABSTRACT

The effects of fin leading-edge radius and sweep angle on peak heating rates due to shock-shock interactions were investigated in the NASA Langley Research Center 20-inch Mach 6 Air Tunnel. The fin model leading edges, which represent cylindrical leading edges or struts on hypersonic vehicles, were varied from 0.25 inches to 0.75 inches in radius. A 9° wedge generated a planar oblique shock at 16.7° to the flow that intersected the fin bow shock, producing a shock-shock interaction that impinged on the fin leading edge. The fin angle of attack was varied from 0° (normal to the free-stream) to 15° and 25° swept forward. Global temperature data was obtained from the surface of the fused silica fins using phosphor thermography. Metal oil flow models with the same geometries as the fused silica models were used to visualize the streamline patterns for each angle of attack. High-speed zoom-schlieren videos were recorded to show the features and temporal unsteadiness of the shock-shock interactions. The temperature data were analyzed using one-dimensional semi-infinite as well as one- and two-dimensional finite-volume methods to determine the proper heat transfer analysis approach to minimize errors from lateral heat conduction due to the presence of strong surface temperature gradients induced by the shock interactions. The general trends in the leading-edge heat transfer behavior were similar for the three shock-shock interactions, respectively, between the test articles with varying leading-edge radius. The dimensional peak heat transfer coefficient augmentation increased with decreasing leading-edge radius. The dimensional peak heat transfer output from the two-dimensional code was about 20% higher than the value from a standard, semi-infinite one-dimensional method.

TFAWS-AE-003

Computational investigation of shock-shock interactions at Mach 6

Michelle Jones, NASA LaRC

ABSTRACT

The effects of fin sweep angle on peak heating rates due to shock-shock interactions were simulated at conditions corresponding to the NASA Langley Research Center 20-inch Mach 6 Air Tunnel. The fin angle of attack was varied from 0° (normal to the free-stream) to 15° and 25° swept forward. Global heat transfer data was available for comparison, obtained using a phosphor thermography measurement technique.

The results were obtained using the Langley Aerothermodynamic Upwind Relaxation Algorithm. A structured grid was used to model the flow in front of a semi-cylindrical geometry with a leading edge radius of 0.25 inches. A planar incident shock was assumed at 16.7° in the simulated boundary conditions of the flow to induce a shock-shock interaction on the swept fin. Computed numerical schlieren data from a time-accurate simulation was compared to high-speed experimental zoom schlieren data to assess the features and temporal unsteadiness of the shock-shock interactions. Computed streamlines from the numerical simulations were compared to the surface patterns from experimental oil flow models. The heat transfer due to the shock-shock interactions from the numerical simulations was compared qualitatively to contour maps of the one-dimensional semi-infinite heat transfer coefficients derived from the experimental data. The results appear to be in good agreement between the computational and experimental data for the investigated shock-shock interactions. A quantitative comparison between these sets of data is forthcoming.

TFAWS-AE-004

Development of Atomistically informed Chemical Kinetics Modeling of Ablative Rubber Composite Materials

Tapan G. Desai and Srujan K. Rokkam, Advanced Cooling Technologies, Inc.
Raghavan Ranganathan, Rensselaer Polytechnic Institute.

ABSTRACT

Ablative rubber composite materials are widely used as a part of thermal protection systems (TPS) in many defense and aerospace applications. Typically, they are used in solid rocket motors (SRM) to thermally insulate the motor case from high-temperature gases and particle streams generated from propellant combustion. The ablative layer absorbs a part of heat to undergo endothermic pyrolysis which results in the formation of a thermally insulating char. The gases generated during pyrolysis further carry away the remaining portion of heat. During operation, the ablator surface is exposed to high temperature, high pressure environments and combustion gases which can induce chemical reactions and energy exchanges that significantly affect the functionality of the TPS layer. The current tools and methodologies used to analyze the ablative composites are limited to modeling equilibrium chemistry of single active species and result in uncertainties while modeling multiple species environments. Hence, there is a need to gain fundamental understanding of the thermo-chemical interactions and to develop new chemical kinetics reference models for the in-situ reactions associated with the composite ablator.

We are currently developing a computational framework which can accurately investigate the thermo-chemical interactions and facilitate chemical kinetics reference models which account for all reactions between the ablator and edge gases, in response to surface conditions. Using atomistic level molecular dynamics (MD) simulations performed with reactive force fields, we extract the reaction chemistry necessary to detail new chemical kinetic models. The methodology is applied to ethylene propylene diene monomer (EPDM) rubber composites which belong to the same family of materials commonly used in SRM systems. This presentation will briefly discuss the methodology development and thermo-chemical characterization of the EPDM rubber. The degradation behavior of EPDM studied using reactive MD simulation of thermal pyrolysis over a temperature range of 1750K to 3000K will be discussed. The products formed and the chemical reaction pathways leading to these products are analyzed. Reactions associated with EPDM interaction with edge gas species and corresponding chemical kinetics model development will be discussed briefly. The resulting reaction pathways and chemical kinetics parameters can be further used to improve the fidelity of (continuum level) ablation modeling codes and allow for more efficient design of future TPS systems.

TFAWS-AE-005

Preliminary Reentry Trajectory, Aeroheating, and TPS Performance Predictions for the Inspiration Mars Mission

Thomas H. Squire, David Kinney, Kathy McGuire, and Jose Aliaga, NASA ARC

Loc Huynh, Science & Technology Corp.

Dinesh Prabhu, ERC, Inc.

ABSTRACT

The Inspiration Mars organization (www.inspirationmars.org), lead by Dennis Tito, is planning to send two humans on a fly-by mission to Mars in early 2018. The mission takes advantage of a fast, "free-return" orbital trajectory to Mars and back. The trajectory requires no major propulsive maneuvers once the vehicle is on its way to Mars and the entire round trip will be only 501 days. The fast trip means that, upon return to Earth, the atmospheric reentry speed will be 14.2 km/s, making it the fastest Earth reentry of any man-made vehicle. This reentry condition creates a major challenge to the design and validation of the thermal protection system (TPS). In order to get a head start on this challenge, the Inspiration Mars organization entered into a Reimbursable Space Act Agreement with NASA Ames Research Center in early 2013 to investigate the reentry phase of the mission and predict the trajectory profiles, aeroheating conditions, and TPS material performance. This paper describes the approach and preliminary results of this investigation.

TFAWS-AE-006

Development and Implementation of an Aerothermostructural Model to Examine Multi-Disciplinary Problems in Hypersonic Flight

Chris Kostyk and Tim Risch, NASA-DFRC

ABSTRACT

The harsh and complex hypersonic flight environment has driven design and analysis improvements for many years. One of the defining characteristics of hypersonic flight is the coupled, multi-disciplinary nature of the dominant physics. In an effort to examine some of the multi-disciplinary problems associated with hypersonic flight engineers at the NASA Dryden Flight Research Center developed a non-linear 6 degrees-of-freedom full vehicle simulation that includes the necessary model capabilities: aerothermal heating, ablation, and thermal stress solutions. Development of the tool and results for some investigations will be presented. Requirements and improvements for future work will also be reviewed.

TFAWS-AE-007

An Upgrade of the Aeroheating Software "MINIVER"

Pierce Louderback, NASA KSC AI Solutions

ABSTRACT

Many software packages assist engineers with performing flight vehicle analysis, but some of these packages have gone many years without updates or significant improvements to their workflows. One such package, known as MINIVER, is a powerful yet lightweight tool that is used for aeroheating analyses. However, it is an aging program that has not seen major improvements within the past decade. As part of a collaborative effort with Florida Institute of Technology, MINIVER has received a major user interface overhaul, a change in program language, and will be continually updated to improve its capabilities.

The user interface update includes a migration from a command-line interface to that of a graphical user interface supported in the Windows operating system. The organizational structure of the preprocessor has been transformed to clearly defined categories to provide ease of data entry. Helpful tools have been incorporated, including the ability to copy sections of cases as well as a generalized importer which aids in bulk data entry. A visual trajectory editor has been included, as well as a CAD Editor which allows the user to input simplified geometries in order to generate MINIVER cases in bulk.

To demonstrate its continued effectiveness, a case involving the JAXA OREX flight vehicle will be included, providing comparisons to captured flight data as well as other computational solutions. The most recent upgrade effort incorporated the use of the CAD Editor, and current efforts are investigating methods to link MINIVER projects with SINDA/FLUINT and Thermal Desktop.

TFAWS-AE-008

Space Launch System (SLS) Small Protuberance Aerodynamic Heating Methodology

Chris Morris and Chong Lee, MSFC EV33

ABSTRACT

One component of the Space Launch System (SLS) Design Analysis Cycle 2 external thermal environments is a set of charts that can be used by thermal analysts to independently determine aerodynamic heating to small protuberances. These criteria provide thermal designers the information they need without requiring the NASA Marshall Space Flight Center Aerosciences Branch (EV33) to generate environments for every bolt, small step, and minor contour change on the vehicle. In the past, these criteria have been based on a semi-empirical formula (Jaeck, C. L., "Analysis of Pressure and Heat Transfer Tests on Surface Roughness Elements with Laminar and Turbulent Boundary Layers," NASA CR-537, 1966). This formula was developed based on so-called shallow wave theory during the X-20 development period in the 1960s for laminar flow, was later empirically modified for turbulent flow, and was approximately validated with experimental results.

In this paper, results from a parametric two-dimensional (2-D) computational fluid dynamics (CFD) analysis of small protuberance aerodynamic heating are reported. In this study, the protuberance geometry, height, height to width ratio, and boundary layer thickness were parametrically varied at relevant SLS flight conditions. Analysis of the results has identified scenarios in which the original semi-empirical formula previously used was accurate, but also scenarios in which it was not. The results have been adapted into a set of small protuberance aerodynamic heating amplification charts for various zones on the SLS Block 1 vehicle. The paper will discuss the CFD modeling approach, the parametric variations in the study, and the collapse of the results as a function of protuberance height to boundary layer displacement thickness.

TFAWS-AE-009

Simplified Method for Simulating Ascent Configuration Changes of Large Scale Integrated Launch Vehicles in Thermal Desktop

Robert J. Kwas, NASA KSC

ABSTRACT

Integrated Launch Vehicles (ILV) typically undergo several major changes to their outer mold line configuration during their ascent mission phase. These changes are usually induced by events such as first stage separation, upper stage separation, and payload fairing jettison. In Thermal Desktop, ILV ascent configuration changes are traditional simulated by developing specific cases to represent each of the configurations attained by the ILV during its ascent mission phase. For each case, User Defined Build Statements (UDBS) and Radiation Analysis Groups (RAG) are utilized in an effort to build only that portion of the SINDA network associated with the current case configuration. Finally, all cases are thermally integrated by setting their initial temperatures to the final temperatures predicted from the previous case. While feasible, this method presents significant challenges when used in conjunction with large scale ILV models, including manual verification/management of lengthy UDBS and SINDA submodels.

Recently, a new method for simulating ILV ascent configuration changes in Thermal Desktop has been developed. This method utilizes Thermal Desktop articulators to physically translate specific parts of the ILV geometry during the ascent mission phase. The method avoids the need to use UDBS, multiple RAGS, and multiple cases for the ascent mission phase. The method is shown to be quite simple to implement, verify, and very portable. This method also proves quite effective in handling ILV attitude control maneuvers such as Passive Thermal Control (PTC) rolls.