Aerothermal Paper Session Abstracts

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TFAWS2011-AE-011	Numerical Simulation of Massively Separated flow over Apollo Command Module: Validation Study	Balasubramanyam Sasanapuri	ANSYS Inc	balasubramanyam.sasanapuri@ansys.com

Title: Simulation of flow through Supersonic Cruise Nozzle: A validation study

Author: Balasubramanyam Sasanapuri, Manish Kumar, Sutikno Wirogo

Abstract:

A supersonic cruise aircraft must be capable of operating in a big envelop of altitude and velocity, which includes subsonic take-off and landing, subsonic cruise, climb and supersonic cruise. One of the solutions for meeting such varied requirements is a variable-cycle engine which uses variable-geometry nozzle and combustion arrangement to operate like a turbofan or turbojet or a hybrid combination to suite the mission requirement. Design of such a variable geometry nozzle requires testing for wide envelope of flow conditions and geometry variations. Prototyping and testing for such envelope would be very time consuming and expensive. Computation Fluid Dynamics (numerical simulation) offers quick and less expensive solution to reduce the design time and cost. In the present study one of the configurations of a supersonic cruise nozzle is simulated for a range of Nozzle Pressure Ratios (NPR) and the results are compared with experimental data [1]. The pressure and density based solvers in ANSYS FLUENT software are used for the validation study and solution based adaption has been tried out to check if the accuracy could be improved. A first test is done for free stream Mach number of 0.6 and NPR 2.5 and the best solution process has been used for a second set of cases with zero free stream Mach number and range of NPR from 2.5 to 7.0. The simulation results show good agreement with the experimental data. This study provides an optimized process to simulate the entire envelope of flow and nozzle geometry conditions.

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Title: The Experimental Measurement of Aerodynamic Heating About Complex Shapes at Supersonic Mach Numbers

Authors: Richard D. Neumann, Delma C. Freeman

Abstract:

Fifty years ago, faced with the need for design data to support flight objectives and a dearth of available test facilities in which to acquire that data, the NASA Langley Unitary Plan Tunnel was modified to allow the acquisition of heat transfer data at supersonic Mach numbers. Using the measurement technology of that day, a significant body of data was acquired which has served the industry for the past half-century. More recently, that published heat transfer technology has been re-visited using, once again, this durable legacy facility in which more modern measurement technology has been applied. This paper will discuss the measurement techniques used, the spectrum of configurations tested, examples of the data acquired, and the uniqueness and value of the current program to acquire and utilize maps of recovery temperature on and about protuberance shapes to more completely understand protuberance heating . The recovery temperature data is highlighted because, for the first time, we are able to visualize and speculate on the complex, three-dimensional nature of the recovery temperature fields and the flow field structure they contain.

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Title: Space Shuttle Boundary Layer Transition Flight Experiment Overview

Author: Karen T. Berger, Brian P. Anderson, Charles H. Campbell, Michael T. Garske, Gerald R. Kinder

Abstract:

In support of the Boundary Layer Transition Flight Experiment (BLT FE) Project, a manufactured protuberance tile was installed on the port wing of Space Shuttle Orbiter *Discovery* for the flights of 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. This paper provides an overview of the BLT FE Project. 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 were significantly higher than observed flight temperatures.

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Title: Post-Flight Analysis of HIFiRE-1 Aerothermal Data

Author: Thomas H. Squire, Parul Agrawal, Dinesh Prabhu

Abstract:

The Hypersonic International Flight Research and Experimentation (HIFiRE) program is a joint effort of the Australian Defence Science and Technology Organisation (DSTO) and the US Air Force Research Laboratory (AFRL), with support from NASA, commercial space companies, and academia. The goal of the program is to investigate fundamental hypersonic flight phenomena, such as boundary layer transition and shock/boundary layer interactions. The program includes flight tests of heavily-instrumented ballistic vehicles to gather high-fidelity, aerothermal data. In March 2010, HIFiRE-1 was successfully flown in the Woomera test range in Australia. The vehicle was instrumented with nearly 200 thermocouples on the surface, as well as other sensors. A team of thermal and CFD analysts at NASA Ames have been analyzing the TC data in order to “back out” the actual heat flux experienced by the vehicle during the flight. The analysis approach and some preliminary results for the first 23 seconds of the ascent portion of the flight will be presented. The heat flux distributions calculated from flight data show remarkably good agreement with CFD predications and appear to validate the turbulent transition model used in the CFD analysis.

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Title: Analysis of Post-Reentry Heating and Soak-Back Affects in Unsealed Reentry Vehicles

Author: Erika T. Bannon, Jared Leidich, Alex Walker

Abstract:

Maintaining low temperature payloads through atmospheric reentry and ground recovery is becoming a larger focus in the space program as work in temperature dependent sciences becomes a higher goal on the International Space Station (ISS) and extraterrestrial surfaces. Paragon has become involved in reentry system thermal control, particularly technology regarding small thermally controlled payloads anticipated for use in sample return from the ISS.

To minimize system mass and utilize the powerful insulative properties of a hard space vacuum the internal cavity of a small reentry vehicle can be left open. Thermally this causes concern during reentry, as even at very high altitudes there is enough pressure to cause a significant impact on insulation stratagems, such as MLI that rely on a high vacuum. At lower altitudes the vehicle is moving much slower, so the intense heat load of reentry is finished but soak-back from outer heated surfaces to the payload is a significant issue when air is present to facilitate heat transfer between layers. The impacts of this, during the last phases of an atmospheric reentry were investigated leading to the conclusion that analyses of lower atmospheric portions of a reentry are critical to reentry studies and significantly changed the results.

An updated design is theorized using the knowledge gained from the preliminary studies called the Cryogenic Extended Duration and Reentry Thermal Control System (CEDR TCS). The design is fully passive making it a low-complexity, zero-power system that does not use any consumables. The CEDR TCS uses a two-way pressure relief valve or “breather valve” that allows pressures inside and outside the vehicle to equilibrate once a great enough pressure differential is applied.

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Title: Combined Aerothermal CFD and Material Response Simulations for MSL

Authors: Todd White, Ioana Cozmuta

Abstract:

The Mars Science Laboratory (MSL) is to launch in late 2011, and is equipped with a heat shield instrumentation system. This system, the MSL Entry Descent and Landing Instrumentation (MEDLI) consists of pressure ports and transducers, and co-located thermocouples and isotherm-tracking sensors embedded in the thermal protection material. Pressure ports and transducers are part of MEADS (Mars Entry Atmospheric Data System) and thermocouple and isotherm sensors make up the MISP (Mars Integrated Sensor Plug). This presentation focuses primarily on simulated response of the MISPs (T1-T7) to the anticipated Martian atmospheric entry.

The MSL heat shield was designed in part using conservative computational models and assumptions, as well as on arc-jet testing and wind-tunnel. These tools include the Data-Parallel Line Relaxation (DPLR) flow solver and the Fully Implicit Ablation and Thermal response (FIAT) program. These same tools are being used to reconstruct the aerothermal environment and detailed TPS response before and after the return of MEDLI data. However, for the MISP pre-flight predictions and later reconstruction, there is much greater emphasis on best estimated, or nominal conditions, instead of the bounded and margined predictions necessary for vehicle design. This presentation will describe the range of models available in the state of the art modeling tools, and iterative coupling between hypersonic computational fluid dynamics (CFD) and material response simulations used to generate nominal data sets for each MISP plug.

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Title: Ares I-X Heating Data and Statistical Aeroheating Predictions

Authors: C. P. Schmitz

Abstract:

The CLVMIN and CLVSTATE engineering codes are being used to predict future launch vehicle ascent and re-entry aerodynamic heating. An engineering analysis is developed which yields reasonable predictions for the design environments using a statistical methodology rather than the "worst-on-worst" methodology used for Shuttle. The analysis approach is validated using flight data from Shuttle and Ares I-X. Updates to the CLVMIN and CLVSTATE methodology are shown to improve the accuracy of the aeroheating predictions which will result in increased confidence in future vehicle designs.

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Title: Ares I-X First Stage Internal Aft Skirt Re-entry Heating Data and Modeling

Authors: C. P. Schmitz, S.B. Tashakkor

Abstract:

The CLVSTATE engineering code is being used to predict Ares-I launch vehicle first stage re-entry aerodynamic heating. An engineering analysis is developed which yields reasonable predictions for the timing of the first stage aft skirt thermal curtain failure and the resulting internal gas temperatures. The analysis is based on correlations of the Ares I-X internal aft skirt gas temperatures and has been implemented into CLVSTATE. Validation of the thermal curtain opening models has been accomplished using additional Ares I-X thermocouple, calorimeter and pressure flight data. In addition, a technique which accounts for radiation losses at high altitudes has been developed which improves the gas temperature measurements obtained by the gas temperature probes (GTP). Updates to the CLVSTATE models are shown to improve the accuracy of the internal aft skirt heating predictions which will result in increased confidence in future vehicle designs.

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Title: Base heating sensitivity study for a 4-cluster rocket motor configuration in supersonic freestream

Author: Manish Mehta, Francisco Canabal, Sheldon D. Smith, Scott B. Tashakkor

Abstract:

In support of launch vehicle base heating and pressure prediction efforts using the Loci-CHEM Navier-Stokes computational fluid dynamics solver, 35 steady-state numerical simulations of the NASA TND-1093 wind tunnel test have been modeled and analyzed. This test article is composed of four JP4/LOX 2.2 kN rocket motors exhausting into a Mach 2 – 3.5 wind tunnel at various ambient pressure conditions. These water-cooled motors are attached to a base plate of a standard missile forebody. We explore the base heating profiles for fully coupled finite-rate combustion simulations, one-way coupled RAMP (Reacting And Multiphase Program using Method of Characteristics)-BLIMPJ (Boundary Layer Integral Matrix Program – Jet Version) derived solutions and variable and constant specific heat ratio frozen flow simulations. Variations in turbulence models, temperature boundary conditions and transport properties of the plume have been investigated at two ambient pressure conditions: 12.2 kPa and 1.7 kPa. It is observed that the base heat flux and base temperature are most sensitive to the nozzle inner wall thermal boundary layer profile which is dependent on the wall temperature, boundary layer's specific energy and transport properties. Turbulence models and external nozzle wall thermal boundary layer profiles show less sensitivity to base heating characteristics. Finite-rate chemistry nozzle internal flow solutions show that the thermal boundary layer profile and shock locations lead to different exhaust plume products and chemical reactions within this layer and as a result may influence base heating. The base pressure and base heat flux show an agreement within +/-5% and -15% with respect to test data, respectively.

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Title: High-Fidelity Material Model Development for Hypersonic Thermal Protection Flight Vehicles

Author: Bruce Moylan, Gerald Russell

Abstract:

The Army's Aviation and Missile Research, Development, Engineering Center (AMRDEC) realizes the necessity for the development of high-fidelity ablation and erosion models for high temperature thermal protection system (TPS) applications. The availability of historical models is few, and the development of high temperature ceramic matrix composite (CMC) materials that have no historical pedigree necessitates a comprehensive approach to include the currently available ground test facilities.

As material ablation characteristics are a function of temperature, pressure, and mass transfer, no one facility can span the typical flight environments that a system might encounter. It is therefore necessary to perform multiple tests at different facilities in order to obtain enough relevant data to develop a material model for flight performance predictions. Such facilities include arc heaters, and high energy lasers. The processes required to developed such high-fidelity material models will be discussed in detail.

In addition, as flight systems operating in the real-world will encounter different forms of adverse weather systems, material erosion models must also be developed. AMDREC has been performing research into system weather requirements, ground testing, and material G-law model development for a variety of TPS materials. While a G-law model assumption may not be appropriate for all material types, it is an acceptable method of predicting the mass loss due to particulate impacts for a wide variety of thermal protection materials.

In order to standardized the ablation/erosion model development process, AMRDEC has developed a comprehensive material model development roadmap . This roadmap includes facility calibration efforts, relevant ground testing methods, and material model development to include flight performance predictions. This presentation outlines the TPS roadmap, and highlights the research efforts of AMRDEC in the development and validation of these high-fidelity models.

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Title: Numerical Simulation of Massively Separated flow over Apollo Command Module: Validation Study

Author: Balasubramanyam Sasanapuri, Manish Kumar, Angela Lestari, Konstantine Kourbatski, Sutikno Wirogo

Abstract:

External aerodynamics of the Apollo command module was studied extensively and experimental data is available for low subsonic to hypersonic regimes. In the present study Reynolds Averaged Navier Stokes (RANS) computations are done (Mach number 1.2, Reynolds number 3.7E+06) with SST k-omega turbulence model and Scale Adaptive Simulation (SAS) turbulence model available in ANSYS FLUENT CFD solver. Simulations are performed for different Angles of Attack (AoA) and the Coefficients of Lift (Cl) & Drag (Cd) are compared with experimental data (see Ref [1]). A base line test was done with a hexahedral mesh of 4.5 Million (mesh-0) Cells & SST model has shown good match of Cl for the whole range of angles of attack, but the Cd was off for the AoA 0, 30, 150 and 180. Further analysis is done for the AoA 180 case, with mesh refinement and SAS model. Mesh refinement study is performed with two types of meshes: 1. Hexahedral mesh (20.5 Million cells) with refined surface mesh, improved resolution near the shock and wake regions. 2. Cartesian mesh (10.8 Million Cells) with prism layers on the wall and cut cells in transition, with excellent control over the mesh refinement in the wake and shock regions. The two refined meshes have shown significant improvement in the results with the error in Cd compared to experimental data at 3.8% (mesh-1, SST) and 1.5% (mesh-2, SAS). The combination of Cartesian mesh combined with SAS model provides most promising results for these massively separated flows.

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