Interdisciplinary Paper Session

Interdisciplinary Paper Session #1 (Tuesday 9:00 AM to 11:00 PM)

ID	Title	Author(s)	Affiliation	Email
TFAWS-IN-001	Coupling Lithium Ion Battery Electrochemical-Thermal Math Models with Orbital-Thermal Analysis Software "Thermal Desktop"	William Walker	NASA JSC	william.walker@nasa.gov
TFAWS-IN-002	Development and Implementation of Efficiency-Improving Analysis Methods for the SAGE III on ISS Thermal Model	Katilin Liles	NASA LaRC	kaitlin.a.k.liles@nasa.gov
TFAWS-IN-003	Multi-parameter Optimization and Experimental and Numerical Study of Heat Transfer of Gas Turbine Blade Snubber	Mengmeng Liu	Florida Tech	jzhang@fit.edu
TFAWS-IN-004	Benchmarking of Parallelized Thermal Solver Technology	Carl Poplawsky	Maya Simulations	carl.poplawsky@mayasim.com

Interdisciplinary Paper Session #2 (Thursday 1:00 PM to 3:00 PM)

TFAWS-IN-005	Induction Heating Model of Cermet Fuel Element Environmental Test (CFEET)	Carlos Gomez	NASA MSFC	carlos.f.gomez@nasa.gov
TFAWS-IN-006	Unsteady Simulation of Launch-Site Pressure Environment	Christoph Brehm	NASA ARC	christoph.brehm@nasa.gov
TFAWS-IN-007	Feasibility Study of Venus Surface Cooling Using Chemical Reactions with the Atmosphere	Christopher Evans	NASA MSFC	christopher.j.evans@nasa.gov
TFAWS-IN-008	Orion MPCV Integrated Overall Thermal Mathematical Model Development	Lorenzo Andrioli	Thales Alenia Space, Turin, Italy	lorenzo.andrioli@thalesaleniaspace.com

TFAWS-IN-001

Coupling Lithium Ion Battery Electrochemical-Thermal Math Models with Orbital-Thermal Analysis Software "Thermal Desktop"

W. Walker and Dr. H. Ardebili, NASA JSC, TX

ABSTRACT

Lithium-ion batteries (LIBs) will soon replace some of the Nickel Metal Hydride (NiMH) batteries on the International Space Station. Knowing that LIB efficiency and survivability are highly influenced by the effects of temperature, this study focused on coupling orbital-thermal analysis software, Thermal Desktop (TD) v5.5, with LIB electrochemical-thermal math models representing the local heat generated during charge/discharge cycles. Before attempting complex orbital analyses, a simple sink temperature model needed development to determine the compatibility of the two techniques. LIB energy balance equations solved for local heating (Bernardi's equation) were used as the internal volumetric heat generation rate for native geometries in TD. The sink temperature, various environmental parameters, and thermophysical properties were based on those used in an electrochemical-thermal math model developed by Chen et. al. for the end of 1, 2, & 3 Coulomb (C) discharge cycles of a 185 Amp-Hour (Ah) capacity LIB. Two techniques were examined in TD; for Technique 1, the model used constant values for the three variables in the energy balance equation (open circuit potential, working voltage, and temperature), while with Technique 2 the variables of Bernardi's equation were a function of time in the discharge cycle and local temperatures that updated after each iteration. The TD model successfully mirrored Chen's temperature vs. depth of discharge (DoD) profiles and temperature ranges for all discharge and convection variations with minimal deviation. Parametric studies concluded that the reason for most deviation in the final TD temperature ranges was because an exact replication of Chen's contact resistances (conductances) between the case, contact layer, and core was not possible due to a lack in data. However, the capability of programming the logic of the variables and their relationship to DoD into TD was successfully developed. Future research should validate the TD techniques through continued parametric analysis to determine the appropriate contact resistances compared with highly controlled testing of a LIB for validation; charging profiles should also be incorporated (this study focused only on discharge for simplicity). This coupled version of orbital thermal analysis software and electrochemical-thermal math models, once test validated, will provide a new generation in techniques for analyzing thermal performance of batteries in orbital-space environments.

TFAWS-IN-002

Development and Implementation of Efficiency-Improving Analysis Methods for the SAGE III on ISS Thermal Model

Katilin Liles, Ruth Amundsen, and Warren Davis, NASA Langley Research Center, VA

Steven Tobin, Shawn McLeod, and Salvatore Scola, Analytical Mechanics Associates, Hampton, VA

ABSTRACT

The Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument is the fifth in a series of instruments developed for monitoring aerosols and gaseous constituents in the stratosphere and troposphere. SAGE III will be delivered to the International Space Station (ISS) via the SpaceX Dragon vehicle in 2015. A detailed thermal model of the SAGE III payload has been developed in Thermal Desktop (TD). Several novel methods have been implemented to facilitate efficient payload-level thermal analysis, including the use of a design of experiments (DOE) methodology to determine the worst-case orbits for SAGE III while on ISS, use of TD assemblies to move payloads from the Dragon trunk to the Enhanced Operational Transfer Platform (EOTP) to its final home on the Expedite the Processing of Experiments to Space Station (ExPRESS) Logistics Carrier (ELC)-4, incorporation of older models in varying unit sets, ability to change units easily (including hard-coded logic blocks), case-based logic to facilitate activating heaters and active elements for varying scenarios within a single model, incorporation of several coordinate frames to easily map to structural models with differing geometries and locations, and streamlined results processing using an Excel-based text file plotter developed in-house at LaRC. This document presents an overview of the SAGE III thermal model and describes the development and implementation of these efficiency-improving analysis methods.

TFAWS-IN-003

Multi-parameter Optimization and Experimental and Numerical Study of Heat Transfer of Gas Turbine Blade Snubber

Mengmeng Liu, Zhiqing Wu, Ju Zhang, Pei-feng Hsu, and C. S. Subramanian Florida Institute of Technology, Melbourne, FL

ABSTRACT

Multi-parameter Optimization and Experimental and Numerical Study of Heat Transfer of Gas Turbine Blade Snubber Mengmeng Liu, Zhiqing Wu, Ju Zhang, Pei-feng Hsu, and C. S. Subramanian Florida Institute of Technology, Melbourne, FL, 32901

Our earlier work on optimization of the fourth-stage hydrogen gas turbine blade mid-span shroud ring structure (snubber) has been extended in the current work to include more geometrical parameters, i.e., individual fillet radii, to explore more ways of further reducing drag and structural stress. The method involves the problem of optimizing shroud geometry for minimum drag force and maximum component service life (through minimizing the maximum equivalent stress). Fluent and ANSYS Structure software tools were used to simulate the aerodynamics and structural forces and the solution is optimized with the Isight optimization environment. About 4% and ~16% reduction in drag and maximum equivalent stress were achieved, respectively, compared with the original design.

Heat transfer process around the snubber for the fourth-stage hydrogen gas turbine blade is also investigated both experimentally and numerically. The snubber is heated by a thin film heater while air flows around it in the cascade wind tunnel. The thermochromic liquid crystal (TLC) coatings were employed to measure the temperature on the surface of the snubber. The recorded steady state surface temperature distribution is used to calculate the convection heat transfer coefficients. It is observed that the convection heat transfer coefficients are the highest near the leading edge of the snubber. This is also confirmed by numerical simulations. The relatively thin thermal boundary layer the in the leading edge stagnation region is believed to be responsible for this enhancement.

TFAWS-IN-004

Benchmarking of Parallelized Thermal Solver Technology Using NX9 Space Systems Thermal

Carl J. Poplawsky, Maya Simulation Technologies.

ABSTRACT

Recent high performance computing (HPC) hardware advancements have enabled the use of parallelized solver technology for CAE applications, including spacecraft orbital thermal analysis. Domain decomposition techniques can be used to parallelize the solver function that resolves the thermal solution matrix. Advantages include a significant reduction in thermal solution total elapsed time for large models and long transient simulations, and the ability to process much larger models than had previously been possible.

This paper details benchmarking using the parallelized NX9 Space Systems Thermal solver for a transient solution of a large spacecraft model typical of those produced by NASA users. A Linux Red Hat single-node system with 24 CPU cores was used for this activity, and multiple solutions were run to establish sensitivity to number of CPU cores. Results show a dramatic reduction in total elapsed solution time, with improvements proportional with number of CPU cores.

TFAWS-IN-005

Induction Heating Model of Cermet Fuel Element Environmental Test (CFEET)

C.F. Gomez, D.E. Bradley, D.P. Cavender, O.R. Mireles, R.R. Hickman, NASA Marshall Space Flight Center, Huntsville, AL

ABSTRACT

Deep space missions with large payloads require high specific impulse and relatively high thrust to achieve mission goals in reasonable time frames. Nuclear Thermal Rockets (NTR) are capable of producing a high specific impulse by employing heat produced by a fission reactor to heat and therefore accelerate hydrogen through a rocket nozzle providing thrust. Fuel element temperatures are very high (up to 3000 K) and hydrogen is highly reactive with most materials at high temperatures. Data covering the effects of high-temperature hydrogen exposure on fuel elements are limited. The primary concern is the mechanical failure of fuel elements due to large thermal gradients; therefore, high-melting-point ceramics-metallic matrix composites (cermets) are one of the fuels under consideration as part of the Nuclear Cryogenic Propulsion Stage (NCPS) Advance Exploration System (AES) technology project at the Marshall Space Flight Center. The purpose of testing and analytical modeling is to determine their ability to survive and maintain thermal performance in a prototypical NTR reactor environment of exposure to hydrogen at very high temperatures and obtain data to assess the properties of the non-nuclear support materials. The fission process and the resulting heating performance are well known and do not require that active fissile material to be integrated in this testing. A small-scale test bed; Compact Fuel Element Environmental Tester (CFEET), designed to heat fuel element samples via induction heating and expose samples to hydrogen is being developed at MSFC to assist in optimal material and manufacturing process selection without utilizing fissile material. This paper details the analytical approach to help design and optimize the test bed using COMSOL Multiphysics for predicting thermal gradients induced by electromagnetic heating (Induction heating) and Thermal Desktop for radiation calculations.

TFAWS-IN-006

Unsteady Simulation of Launch-Site Pressure Environment

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ABSTRACT

Time-accurate high-fidelity computational fluid dynamics simulations are employed to analyze the loads on existing and newly developed space vehicles in the launch environment. The capability to accurately predict certain aspects of the launch environment, such as ignition over-pressure waves and launch acoustics, is paramount to mission success.

Incorporating the geometric complexity of the launch tower, exhaust hole, main flame deflector, and the flame trench in the simulations is essential in predicting the wave reflections and scattering. These simulations will provide an insight into the highly non-linear ignition over-pressure wave generation process and the wave propagation pattern around the launch vehicle.

Additionally, the validity and ramifications of assuming an inviscid fluid for such simulations is investigated. With an inviscid simulation, the grid generation process can be dramatically reduced by employing Cartesian grids while utilizing an immersed boundary method (IBM) to account for the wall boundary conditions. The IBM methodology, however, is limited to slip-wall flows because the cell count becomes prohibitively large for flows with thin boundary layers due to the isotropic nature of Cartesian cells. The inviscid assumption during the ramp-up of the engines is studied and the effect of possible separation in nozzle during this transient is analyzed. Furthermore, it must be emphasized that by employing Euler simulations instead of Navier- Stokes simulations (including URANS or LES-type models) can significantly reduce the computational expense for the ignition over-pressure simulations.

TFAWS-IN-007

Feasibility Study of Venus Surface Cooling Using Chemical Reactions with the Atmosphere

Christopher Evans, NASA Marshall Space Flight Center, Huntsville, AL

ABSTRACT

A literature search and theoretical analysis were conducted to investigate the feasibility of cooling a craft on Venus through chemical reformation of materials from the atmosphere. The core concept was to take carbon dioxide (CO2) from the Venus atmosphere and chemically reform it into simpler compounds such as carbon, oxygen, and carbon monoxide. This process is endothermic, taking energy from the surroundings to produce a cooling effect. A literature search was performed to document possible routes for achieving the desired reactions. Analyses indicated that on Venus, this concept could theoretically be used to produce cooling, but would not perform as well as a conventional heat pump. For environments other than Venus, the low theoretical performance limits general applicability of this concept, however this approach to cooling may be useful in niche applications. Analysis indicated that environments with particular atmospheric compositions and temperatures could allow a similar cooling system to operate with very good performance. This approach to cooling may also be useful where the products of reaction are also desirable, or for missions where design simplicity is valued. Conceptual designs for Venus cooling systems were developed using a modified concept, in which an expendable reactant supply would be used to promote more energetically favorable reactions with the ambient CO2, providing cooling for a more limited duration. This approach does not have the same performance issues, but the use of expendable supplies increases the mass requirements and limits the operating lifetime. This paper summarizes the findings of the literature search and corresponding analyses of the various cooling options.

TFAWS-IN-008

Orion MPCV Integrated Overall Thermal Mathematical Model Development

Lorenzo Andrioli, Alessandro Mannarelli, Alessio Tilloca, Thales Alenia Space – Turin, Italy

ABSTRACT

The development workflow of thermal and thermal-fluidic Integrated Overall Thermal Mathematical Model (IOTMM) of the Orion Multi-Purpose Crew Vehicle (MPCV) ESM (European Service module) is presented. Orion MPCV is an affordable solution for multiple mission capability, and as such shall be designed to withstand a large variety of environments going from International Space Station (ISS) to Low Lunar Orbits.

The model simulates the behavior of the ESM Active and Passive Thermal Control Systems (ATCS & PTCS). The high integration of the ATCS and PTCS as well as the adoption of breakthrough concept components represented a challenging modeling activity. This resulted into the most complex model so far developed in Thermal Desktop environment by TAS-I.

The IOTMM development relied also on several multiphysics software tools - such as ANSYS Workbench and COMSOL Multiphysics - to reach the suitable degree of accuracy into the modeling of radiators, coldplates, and brackets.

The results obtained through the analysis campaign are a key point for the ATCS and PTCS design assessment in the frame of the MPCV ESM Preliminary Design Review (PDR) achievements. Thanks to the adopted modeling techniques an highly paremeterized IOTMM was built, minimizing user-level operations. This made possible to cope with the fast changing design typical of dense schedule development phases. Moreover, the large set of missions the Orion MPCV ESM shall be able to deal with required fast yet precise design trimming, for which the IOTMM flexibility represented an enabling feature.

Further improvements from the thermal-fluidic modeling standpoint are foreseen, for they are currently included as external non-graphical SINDA/FLUINT submodels. Nevertheless the presented activity is an important heritage step forward into the adoption of a fully graphical approach to the development of complex IOTMMs.