## Active Thermal Paper Session I - Monday, August 4

*8:00am – 11:00am*
*Room 1*
Session Chairs: Steve Barsi (NASA-GRC) & Craig Dinsmore (NASA-JSC)

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|---|---|---|
| *8:00 AM* | TFAWS2014-AT-01 | "CFD Analysis of Thermal Control System Using NX Thermal & Flow"<br>*Presenter: Craig Fortier (NASA-KSC)* |
| *8:30 AM* | TFAWS2014-AT-02 | "Thermal Analysis of Cryogenic Hydrogen Liquid Separator"<br>*Presenter: Craig Fortier (NASA-KSC)* |
| *9:00 AM* | TFAWS2014-AT-03 | "Application of CFD to Simulate Water Droplet Impingements for Aircraft Icing Analysis"<br>*Presenter: Nili Bachchan (Metacomp Technologies)* |
| *9:30 AM* | TFAWS2014-AT-04 | "One Dimensional Analysis Model of a Condensing Spray Chamber Including Rocket Exhaust Using SINDA/FLUINT and CEA"<br>*Presenter: Barbara Sakowski (NASA-GRC)* |
| *10:30 AM* | TFAWS2014-AT-05 | "Different Kinds of Heat Pipes"<br>*Presenter: Bill Anderson (ACT, Inc.)* |

## Active Thermal Paper Session II - Wednesday, August 6

*1:15pm – 4:45pm*
*Room 1*
Session Chairs: Steve Barsi (NASA-GRC) & Craig Dinsmore (NASA-JSC)

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|---|---|---|
| *1:15 PM* | TFAWS2014-AT-06 | "Water-Based Phase Change Material Heat Exchanger Development"<br>*Presenter: Scott Hansen (NASA-JSC)* |
| *1:45 PM* | TFAWS2014-AT-07 | "Launch Vehicle Avionics Passive Thermal Management"<br>*Presenter: Bill Anderson (ACT, Inc.)* |
| *2:15 PM* | TFAWS2014-AT-08 | "Spacesuit Water Membrane Evaporator, An Enhanced Evaporative Cooling System for the Advanced Extravehicular Mobility Unit Portable Life Support System"<br>*Presenter: Grant Bue (NASA-JSC)* |

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| *3:15 PM* | TFAWS2014-AT-09 | "Mini-Membrane Evaporator for Contingency Spacesuit Cooling"<br>*Presenter: Janice Makinen (NASA-JSC)* |
| *3:45 PM* | TFAWS2014-AT-10 | "Low Cost Radiator for Fission Power Thermal Control"<br>*Presenter: Bill Anderson (ACT, Inc.)* |
| *4:15 PM* | TFAWS2014-AT-11 | "SINDA/FLUINT Stratified Tank Modeling For Cryogenic Propellant Tanks"<br>*Presenter: Barbara Sakowski (NASA-GRC)* |

## Passive Thermal Paper Session I - Tuesday, August 5

*1:15pm – 4:45pm*
*Room 1*
Session Chairs: Laurie Carrillo (NASA-JSC) & A.J. Mastropietro (NASA-JPL)

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| *1:15 PM* | TFAWS2014-PT-01 | "Adaptation of 25-Node Human Thermal Model for use in Sierra Nevada's Dream Chaser® System-Level Thermal Desktop Model"<br>*Presenter: James Byerly (Sierra Nevada Corp)* |
| *1:45 PM* | TFAWS2014-PT-02 | "Precision Tracking Space System (PTSS) Infrared Sensor Thermal Testing and Model Correlation"<br>*Presenter: Carl Ercol (JHUAPL)* |
| *2:15 PM* | TFAWS2014-PT-03 | "Preliminary Development of a TSS and SINDA/FLUINT to ESARAD/ESATAN Thermal Model Converter"<br>*Presenter: Kan Yang (NASA-GSFC)* |
| *3:15 PM* | TFAWS2014-PT-04 | "Thermal Control Design for the Subarcsecond Telescope and BaLloon Experiement (STABLE)"<br>*Presenter: Hared Ochoa (NASA-JPL)* |
| *3:45 PM* | TFAWS2014-PT-05 | "LUROVA – From Render Engine to Thermal Model"<br>*Presenter: Ron Creel (DoD)* |
| *4:15 PM* | TFAWS2014-PT-10 | "Thermal Modeling and Test Correlation for the High Fidelity Data Acquisition System"<br>*Presenter: Christopher Evans (NASA-MSFC)* |

## Passive Thermal Paper Session II - Thursday, August 7

*8:00am – 11:00am*
*Room 1*
Session Chairs: Laurie Carrillo (NASA-JSC) & A.J. Mastropietro (NASA-JPL)

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|---|---|---|
| *8:00AM* | TFAWS2014-PT-06 | "Thermal interface materials and challenges faced by thermal interface material suppliers"<br>*Presenter: Jason Strader (Laird)* |
| *8:30AM* | TFAWS2014-PT -07 | "LTCS (Laser Thermal Control System) test supporting the improvement of DeCoM (Deepak Condenser Model)"<br>*Presenter: Deepak Patel (NASA-GSFC)* |
| *9:00AM* | TFAWS2014-PT-08 | "Using SpaceClaim/TD Direct for Modeling Components with Complex Geometries for the Thermal Desktop-based Advanced Stirling Radioisotope Generator Model"<br>*Presenter: William Fabanich (NASA-GRC)* |
| *9:30AM* | TFAWS2014-PT-09 | "Cube Flux Method to Generate Spacecraft Thermal Environments"<br>*Presenter: Siraj Jalali (Oceaneering)* |
| *10:30AM* | TFAWS2014-PT-11 | "Passive Thermal Design approach for the Space Communications and Navigation (SCaN) experiment on the International Space Station (ISS)"<br>*Presenter: James Yuko (NASA-GRC)* |

## Aerothermal Paper Session - Wednesday, August 6

*9:15am – 11:15am*
*Room 1*
Session Chairs: Karen Berger (NASA-LaRC) & Jason Mishtawy (NASA-MSFC)

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|---|---|---|
| *9:15AM* | TFAWS2014-AE-01<br>(ITAR Session*) | "A New High Temperature Thermopile Heat Flux Sensor at AEDC"<br>*Presenter: Stuart Coulter (Arnold Air Force Base)* |
| *10:00AM* | TFAWS2014-AE-02 | "Space Shuttle Boundary Layer Transition Flight Experiment Ground Testing Overview"<br>*Presenter: Karen Berger (NASA-LaRC)* |
| *10:30 AM* | TFAWS2014-AE-03 | "Langley Aerothermodynamic Labs: Testing Capabilities"<br>*Presenter: Karen Berger (NASA-LaRC)* |

* Only US Citizens and US Resident Aliens are permitted to attend ITAR sessions. At the time of registration, attendees planning to attend an ITAR session must present the required proof of citizenship. U.S. Citizens can show proof of citizenship using a passport, birth certificate, voters registration card, or naturalization papers and U.S. resident aliens can show proof with a resident alien card

## Interdisciplinary Paper Session – Thursday, August 7

*1:15pm – 2:45pm*
*Room 1*
Session Chairs:  Richard Wear (NASA-SSC) & Xiaoyen Wang (NASA-GRC)

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| *1:15 PM* | TFAWS2014-I-01 | "SRTMV-N2 Plume Impingement Test Panel Thermal Analysis"<br>*Presenter:  Vincent Cuda (NASA-MSSC)* |
| *1:45 PM* | TFAWS2014-I-02 | "Flow characteristics of a strut injector for scramjets: numerical and experimental results"<br>*Presenter:  Valerio Viti (ANSYS, Inc.)* |
| *2:15 PM* | TFAWS2014-I-04 | "Thermal Acoustic Oscillation: Causes, Detection, Analysis, and Prevention"<br>*Presenter:  Robert Christie (NASA-GRC)* |

# Paper Abstracts: Active Thermal

## *Active Thermal Paper Session I*

**TFAWS2014-AT-01**

### CFD Analysis of Thermal Control System Using NX Thermal & Flow

Craig Fortier, NASA Kennedy Space Center
Michael Harris, NASA Kennedy Space Center
Stephen McConnell, NASA Kennedy Space Center

**Abstract**
The Thermal Control Subsystem (TCS) is a key part of the Advanced Plant Habitat (APH) for the International Space Station (ISS). The purpose of this subsystem is to provide thermal control, mainly cooling, to the other APH subsystems. One of these subsystems, the Environmental Control Subsystem (ECS), controls the temperature and humidity of the growth chamber (GC) air to optimize the growth of plants in the habitat. The TCS provides thermal control to the ECS with three cold plates, which use Thermal Electric Coolers (TECs) to heat or cool water as needed to control the air temperature in the ECS system. In order to optimize the TCS design, pressure drop and heat transfer analyses were necessary.

The analysis for this system was performed in Siemens NX Thermal/Flow software (Version 8.5). NX Thermal/Flow has the ability to perform 1D or 3D flow solutions. The 1D flow solver can be used to represent simple geometries, such as pipes and tubes. The 1D flow method also has the ability to simulate either fluid only or fluid and wall regions. The 3D flow solver is similar to other Computational Fluid Dynamic (CFD) software.
TCS performance was analyzed using both the 1D and 3D solvers. Each method produced different results, which will be evaluated and discussed.

**TFAWS2014-AT-02**

### CFD Analysis of Thermal Control System Using NX Thermal & Flow Thermal Analysis of Cryogenic Hydrogen Liquid Separator

Jared Congiardo, NASA Kennedy Space Center
Craig Fortier, NASA Kennedy Space Center
Michael Harris, NASA Kennedy Space Center

**Abstract**
Engine conditioning for the Space Launch System core stage requires a high liquid hydrogen flowrate through the engines during terminal count. Analysis of the performance of the ground-side portion of the hydrogen bleed system indicated a strong possibility that this liquid hydrogen flow would not completely vaporize prior to reaching the facility flare stack. This would exceed the design capability of the flare stack.

In order to protect the flare stack while meeting SLS vehicle requirements, a cryogenic hydrogen liquid separator is being developed to detain the bulk of the liquid hydrogen flowing from the vehicle. The detained liquid hydrogen will be removed via either drain or boiloff following either liftoff or scrub. Such separators are common in petroleum industry processes in order to extract entrained liquid droplets from a gas stream. Removal of the gas component of a saturated liquid flow, particularly of a cryogen, is much less common.
Thermal Desktop analysis has been performed to ensure that the separator will operate as intended without adversely affecting vehicle interface conditions. Volume of Fluids (VOF) CFD analysis has also been performed in order to adequately capture multidimensional effects.

**TFAWS2014-AT-03**

## Application of CFD to Simulate Water Droplet Impingements for Aircraft Icing Analysis

Neil Bachchan, Metacomp Technnologies, Inc
Inchul Kim, Metacomp Technnologies, Inc
Oshin Peroomian, Metacomp Technnologies, Inc
Sukumar Chakravarthy, Metacomp Technnologies, Inc

**Abstract**
In the design of ice-protection systems, numerical approaches are employed to support experimental testing over a range of aircraft flight conditions and configurations. For icing and impingement problems, an important parameter is the collection efficiency. The collection efficiency β, is defined as the ratio of the mass flow rate of the impinging droplets on a surface to the mass flow rate of the freestream. Accuracy in the prediction of collection efficiency is a preliminary step in icing analysis and the determination of ice accretion on aircraft surfaces. A collection efficiency model is implemented into the Eulerian Dispersed Phase (EDP) module in CFD++, the commercial CFD code from Metacomp Technologies, and is used to study collection efficiencies for small and large droplet conditions. An Eulerian-Eulerian approach is employed which solves the differential transport equations for each of the continuous and dispersed phases simultaneously. Equal and opposite source terms are used to accurately model the momentum and energy transfer between the two phases. Validation cases are presented for two and three dimensional bodies including engine nacelles, airfoils and glaze ice shapes, for which experimental impingement data has been obtained at the Icing Research Tunnel at NASA. Applications to icing clouds with median volumetric diameters greater than 50 microns which fall outside the Appendix C envelope have also been studied. Ice accretion due to Supercooled Large Droplets (SLD) can cause severe aircraft performance degradation. The numerical prediction of large droplet impingements require an extended numerical model to account for additional droplet-wall interaction regimes. Recently, the numerical model in CFD++ has been extended to account for droplet rebound and splash mechanisms, to improve the prediction of droplet impingement behavior within the SLD regime. Predictions of collection efficiencies with SLD modeling are presented for airfoils and glaze ice shapes for median volumetric diameter conditions up to 236 microns. CFD simulations have been carried out with the extended numerical model to include the effects of bouncing and splashing for SLDs. The results show

that the maximum values of the collection efficiency peaks are slightly reduced in all droplet MVD cases. These peak values were over-predicted without the SLD model for the larger droplet impingement cases. Improved predictions are obtained on the lower and upper airfoil surfaces away from the leading edge with the SLD model, compared to without the model. The close agreement with experimental data near the impingement limits is attributed to the substantial mass loss from droplet bouncing. For the five glaze ice shapes simulated with SLD modeling, the predictions show that slightly higher peak values were obtained from CFD compared to experimental data. The collection efficiency peak values near the airfoil leading edges are significantly reduced with SLD modeling due to the mass loss. The largest discrepancies are found in the horn region of the ice shapes, however, the trends in these regions are similar to experiment in most cases. Away from the main impingement zone, the SLD model correctly predicts experimental trends with nearly identical levels compared to experimental data obtained by Papadakis et al.

**TFAWS2014-AT-04**

## Analysis One Dimensional Analysis Model of a Condensing Spray Chamber Including Rocket Exhaust Using SINDA/FLUINT and CEA

Barbara Sakowski, NASA Glenn Research Center
Daryl Edwards, NASA Glenn Research Center

**Abstract**
Modeling droplet condensation via CFD codes can be very tedious, time consuming, and inaccurate. CFD codes may be tedious and time consuming in terms of using Lagrangian particle tracking approaches or particle sizing bins. Also since many codes ignore conduction through the droplet and or the degrading effect of heat and mass transfer if noncondensible species are present, the solutions may be inaccurate. The modeling of a condensing spray chamber where the significant size of the water droplets and the time and distance these droplets take to fall, can make the effect of droplet conduction a physical factor that needs to be considered in the model. Furthermore the presence of even a relatively small amount of noncondensible has been shown to reduce the amount of condensation [Ref. 1]. It is desirable then to create a modeling tool that addresses these issues. The path taken to create such a tool is illustrated.

The application of this tool and subsequent results are based on the spray chamber in the Spacecraft Propulsion Research Facility (B2) located at NASA's Plum Brook Station that tested an RL-10 engine. The platform upon which the condensation physics is modeled is SINDA/FLUINT. The use of SINDA/FLUINT enables the ability to model various aspects of the entire testing facility, including the rocket exhaust duct flow and heat transfer to the exhaust duct wall. The ejector pumping system of the spray chamber is also easily implemented via SINDA/FLUINT. The goal is to create a transient one dimensional flow and heat transfer model beginning at the rocket, continuing through the condensing spray chamber, and finally ending with the ejector pumping system. However the model of the condensing spray chamber may be run independently of the rocket and ejector systems detail, with only appropriate mass flow boundary conditions placed at the entrance and exit of the condensing spray chamber model.

The model of the condensing spray chamber takes into account droplet conduction as well as the degrading effect of mass and heat transfer due to the presence of noncondensible. The one dimension model of the condensing spray chamber makes no presupposition on the pressure profile within the chamber, allowing the implemented droplet physics of heat and mass transfer coupled to the SINDA/FLUINT solver to determine a transient pressure profile of the condensing spray chamber. Model results compare well to the RL-10 engine pressure test data.

**TFAWS2014-AT-05**

## Different Kinds of Heat Pipes

William G. Anderson, Advanced Cooling Technologies

**Abstract**

Most people in the spacecraft thermal control community are familiar with Constant Conductance Heat Pipes (CCHPs) to transport heat from point A to Point B. Similarly, Variable Conductance Heat Pipes (VCHPs) are used to maintain the heat pipe evaporator at a relatively constant temperature. This presentation will briefly review the standard uses for CCHPs and VCHPs, and then discuss other heat pipe types and applications. The presentation will include:

- Standard Heat Pipes (CCHPs), which act as a thermal superconductor
  - Aluminum/ammonia grooved heat pipes
  - Copper/water and copper/methanol heat pipes
- Annular Heat Pipes, which have an inner cavity and are highly isothermal
- Variable Conductance Heat Pipes (VCHPs), which have a non-condensable gas loading to help maintain the evaporator temperature under changing conditions
  - VCHPs for Passively Controlling Temperature
  - VCHPs for Over-Temperature Protection
  - VCHPs for Variable Thermal Links
  - Gas Loaded (Variable Conductance) Heat Pipes for Start-Up from a Frozen State
- Pressure Controlled Heat Pipes (PCHPs), a form of VCHP where the reservoir size or gas loading can be changed
  - PCHPs for Precise Temperature Control
  - PCHPs for High Temperature Power Switching
- Vapor Chambers, which allow heat flux transformation, and heat spreading in two dimensions
- High Conductivity Plates, which have heat pipes embedded in plates to improve the effective thermal conductivity to 500-1200 W/m K
- Heat Pipe Heat Exchangers
  - VCHP Heat Exchangers
- Diode Heat Pipes, which allow heat flow in only one direction
  - Liquid Trap Diode Heat Pipes
  - Vapor Trap Diode Heat Pipes

- Thermosyphons, which are gravity aided heat pipes
    - Loop Thermosyphons, a thermosyphon variant with different flow paths for the vapor and liquid
- Rotating Heat Pipes, where the centrifugal forces generated in a rotating system return the fluid, rather than relying on a wick
    - Rotating shafts with multiple heat pipes embedded in a rotating shaft, allowing higher performance than a single rotating heat pipe

## *Active Thermal Paper Session II*

**TFAWS2014-AT-06**

### Water Based Phase Change Material Heat Exchanger Development

Scott Anderson, NASA JSC
Rubik B Sheth, NASA JSC
Matt Atwell, University of Texas
Ann Cheek, University of Houston
Muskan Agarwal, University of Houston
Steven Hong, University of Houston
Aashini Patel, University of Houston
Lisa Nguyen, University of Houston
Luciano, Pasado, University of Houston

**Abstract**

In a cyclical heat load environment such as low Lunar orbit, a spacecraft's radiators are not sized to reject the full heat load requirement. Traditionally, a supplemental heat rejection device (SHReD) such as an evaporator or sublimator is used to act as a "topper" to meet the additional heat rejection demands. Utilizing a Phase Change Material (PCM) heat exchanger (HX) as a SHReD provides an attractive alternative to evaporators and sublimators as PCM HXs do not use a consumable, thereby leading to reduced launch mass and volume requirements. Studies conducted in this paper investigate utilizing water's high latent heat of formation as a PCM, as opposed to traditional waxes, and corresponding complications surrounding freezing water in an enclosed volume. Work highlighted in this study is primarily visual and includes understanding ice formation, freeze front propagation, and the solidification process of water/ice. Various test coupons were constructed of copper to emulate the interstitial pin configuration (to aid in conduction) of the proposed water PCM HX design. Construction of a prototypic HX was also completed in which a flexible bladder material and interstitial pin configurations were tested. Additionally, a microgravity flight was conducted where three copper test articles were frozen continuously during microgravity and 2-g periods and individual water droplets were frozen during microgravity. Future direction is also suggested for future bladder PCM HX development.

**TFAWS2014-AT-07**

## Launch Vehicle Avionics Passive Thermal Management

Cameron Corday, Advanced Cooling Technologies
Mike DeChristopher, Advanced Cooling Technologies
John R. Hartenstine, Advanced Cooling Technologies
Taylor Maxwell, Advanced Cooling Technologies
Carl Schwendeman, Advanced Cooling Technologies
Calin Tarau, Advanced Cooling Technologies
William G. Anderson, Advanced Cooling Technologies

**Abstract**

A passive thermal management system was developed to cool avionics on a launch vehicle, with three different thermal modes:

1. Cooling for avionics while on ground prior to launch (indefinitely)
2. Cooling for avionics during launch (~10min)
3. Cooling on-orbit (indefinitely)

In pre-launch a nitrogen purge duct serves as the heat sink (~19.4°C) for the thermal control device. The purge duct is located above the avionics, and along with the passive thermal system, must maintain the avionics within a safe operating temperature range (-6.6 to 25.5°C) while on the ground. At lift-off the nitrogen purge ceases. Potential thermal solutions for ascent period of ~10 minutes include: Phase Change Material (PCM), Hydride Thermal Storage, Launch Vehicle Skin and the Fuel. Hydride Thermal Storage cannot be used due to vented gas, the launch vehicle skin cannot be used due to skin structure, and the fuel cannot be used, which leaves PCM as the best thermal solution during ascent. While on-orbit the electronics radiate to space using an external radiator. Fuel was considered, but is not feasible as a long term heat rejection solution.

**TFAWS2014-AT-08**

## Launch Vehicle Avionics Passive Thermal Management

Grant Bue, NASA JSC
Janice, V. Makinem, NASA JSC
Sean Miller, NASA JSC
Colin Campbell, NASA JSC
Bill Lynch, Jacobs Engineering
Matt Vogel, Jacobs Engineering
Jesse Craft, Jacobs Engineering
Robert Wilkes, Jacobs Engineering
Eric Kuehnel, Jacobs Engineering

**Abstract**
Development of the Advanced Extravehicular Mobility Unit (AEMU) portable life support subsystem (PLSS) is currently under way at NASA Johnson Space Center. The AEMU PLSS features a new evaporative cooling system, the Generation 4 Spacesuit Water Membrane Evaporator (Gen4 SWME). The SWME offers several advantages when compared with prior crewmember cooling technologies, including the ability to reject heat at increased atmospheric pressures, reduced loop infrastructure, and higher tolerance to fouling. Like its predecessors, Gen4 SWME provides nominal crew member and electronics cooling by flowing water through porous hollow fibers. Water vapor escapes through the hollow fiber pores, thereby cooling the liquid water that remains inside of the fibers. This cooled water is then recirculated to remove heat from the crew member and PLSS electronics. Test results from the backup cooling system which is based on a similar design and the subject of a companion paper, suggested that further volume reductions could be achieved through fiber density optimization. Testing was performed with four fiber bundle configurations ranging from 35,850 fibers to 41,180 fibers. The optimal configuration reduced the Gen4 SWME envelope volume by 15% from that of Gen3 while dramatically increasing the performance margin of the system. A rectangular block design was chosen over the Gen3 cylindrical design, for packaging configurations within the AEMU PLSS envelope. Several important innovations were made in the redesign of the backpressure valve which is used to control evaporation. A twin-port pivot concept was selected from among three low profile valve designs for superior robustness, control and packaging. The backpressure valve motor, the thermal control valve, delta pressure sensors and temperature sensors were incorporated into the manifold endcaps, also for packaging considerations. Flight-like materials including a titanium housing were used for all components. Performance testing of the Gen4 SWME is underway.

**TFAWS2014-AT-09**

## Mini-Membrane Evaporator for Contingency Spacesuit Cooling

Janice V. Makinen, NASA JSC
Grant C. Bue, NASA JSC
Colin Campbell NASA JSC
Jesse Craft, Jacobs Engineering
William Lynch, Jacobs Engineering
Robert Wilkes, Jacobs Engineering
Matthew Vogel, Jacobs Engineering

**Abstract**
The next-generation Advanced Extravehicular Mobility Unit (AEMU) Portable Life Support System (PLSS) is integrating a number of new technologies to improve reliability and functionality. One of these improvements is the development of the Auxiliary Cooling Loop (ACL) for contingency crewmember cooling. The ACL is a completely redundant, independent cooling system that consists of a small evaporative cooler--the Mini Membrane Evaporator (Mini-ME), independent pump, independent feedwater assembly and independent Liquid Cooling Garment (LCG). The Mini-ME utilizes the same hollow fiber technology featured in the

full-sized AEMU PLSS cooling device, the Spacesuit Water Membrane Evaporator (SWME), but Mini-ME occupies only 25% of the volume of SWME, thereby providing only the necessary crewmember cooling in a contingency situation. The ACL provides a number of benefits when compared with the current EMU PLSS contingency cooling technology, which relies upon a Secondary Oxygen Vessel; contingency crewmember cooling can be provided for a longer period of time, more contingency situations can be accounted for, no reliance on a Secondary Oxygen Vessel (SOV) for contingency cooling--thereby allowing a reduction in SOV size and pressure, and the ACL can be recharged—allowing the AEMU PLSS to be reused, even after a contingency event. The first iteration of Mini-ME was developed and tested in-house. Mini-ME is currently packaged in AEMU PLSS 2.0, where it is being tested in environments and situations that are representative of potential future Extravehicular Activities (EVA's). The second iteration of Mini-ME, known as Mini-ME2, is currently being developed to offer more heat rejection capability. The development of this contingency evaporative cooling system will contribute to a more robust and comprehensive AEMU PLSS.

**TFAWS2014-AT-10**

## Low Cost Radiator for Fission Power Thermal Control

Taylor Maxwell, Advanced Cooling Technologies
John R. Hartenstine, Advanced Cooling Technologies
Calin Tarau, Advanced Cooling Technologies
William G. Anderson, Advanced Cooling Technologies
Ted Stern, Vanguard Space Technologies
Nicholas Walmsley, Vanguard Space Technologies
Maxwell Briggs, NASA GRC

**Abstract**
NASA Glenn Research Center (GRC) is developing fission power system technology for future Lunar surface power applications. The systems are envisioned in the 10 to 100kW$_e$ range and have an anticipated design life of 8 to 15 years with no maintenance. NASA GRC is currently setting up a 55 kW$_e$ non-nuclear system ground test in thermal-vacuum to validate technologies required to transfer reactor heat, convert the heat into electricity, reject waste heat, process the electrical output, and demonstrate overall system performance. Reducing the radiator mass, size, and cost is essential to the success of the program. **Error! Reference source not found.** illustrates a conventional dual facesheet VCHP radiator, and a single direct-bond facesheet radiator that is currently being developed under an SBIR program with NASA GRC.

**TFAWS2014-AT-11**

### SINDA/FLUINT Stratified Tank Modeling For Cryogenic Propellant Tanks

Barbara Sakowski, NASA GRC

**Abstract**

A general purpose SINDA/FLUINT (S/F) stratified tank model was created and used to simulate tank pressurization as well as axial jet mixing within the liquid of the tank. The stratified layers in the vapor and liquid regions of the tank are modeled using S/F lumps. The model was constructed to analyze a general purpose stratified tank that could incorporate the following additional features:

- Multiple or singular lumps in the liquid and vapor regions of the tank
- Real gases (also mixtures) and compressible liquids
- Venting, pressurizing, and draining
- Condensation and evaporation/boiling
- Wall heat transfer
- Elliptical, cylindrical, and spherical tank geometries

These features employ extensive user logic that could be tailored to a user's specific needs. Most of the code input for a specific case could be done through the Registers Data Block. Specific naming conventions for S/F nodes, lumps, and connectors are illustrated in great detail in an ASCII text format that explicitly guides the user in creating models. Results were compared to KSITE self-pressurization tests with and without axial jet mixing.

# Paper Abstracts: Passive Thermal

## *Passive Thermal Paper Session I*

**TFAWS2014-PT-01**

### Adaptation of 25-Node Human Thermal Model for use in Sierra Nevada Corporation's Dream Chaser® System-Level Thermal Desktop Model

R.S Mishkovish, ATA Engineering
J.V. Byerly, Sierra Nevada Corporation
S.W. Miller, Sierra Nevada Corporation

**Abstract**

Sierra Nevada Corporation ("SNC") is currently working with NASA's Commercial Crew Program to develop and configure the Dream Chaser spacecraft for transportation services to low-Earth orbit destinations, including the International Space Station (ISS). Part of this effort is a system-level thermal model of the vehicle to predict its thermal response during the various phases of flight, and to help with the design of active and passive thermal control systems. Since the

Dream Chaser is capable of piloted or autonomous flight, the thermal response is important to the overall thermal design, especially in the crew configuration.

NASA and its contractors have developed various human thermal models since the 1960's. Two of note include the early 25-node human thermal model [STOLWIJK1971] and its successor, the 41-node METMAN model [BUE1989]. The model divides the human body into 6 or 10 compartments. Both models use 4 nodes to model the core, muscle, fat, and skin of each compartment. The final node is to model the blood flow. Heat losses due to convection, radiation, perspiration, and respiration are modeled. The major differences between these two models are that the 41-node model distinguishes between left and right arms and legs, and also has the ability to work with humans of various sizes. However, both of these models are executed in FORTRAN programs, and have not been adapted for public use in a system-level thermal model.

This paper describes how SNC and ATA Engineering, Inc. converted the 25-node thermal model for use in the Thermal Desktop system-level thermal model, and added features from the METMAN model to model humans of different size and anthropomorphic constituency. The models consist of a combination of SINDA nodes and conduction, along with control logic to compute the metabolic heat loads based on environmental conditions and human activity. The models can be connected to a cabin air node or to an LCG loop node. The model also allows for the ability to compute human CO2 and water vapor production for cabin air environment modeling.

**TFAWS2014-PT-02**

## Precision Tracking Space System (PTSS) Infrared Sensor Thermal Testing and Model Correlation

Matt Felt, Space Dynamics Laboratory, Utah State University
Brian Thompson, Space Dynamics Laboratory, Utah State University
Lorin Zollinger, Space Dynamics Laboratory, Utah State University
Mike Marley, Applied Physics Laboratory/ John Hopkins University
Ed Hawkins, Applied Physics Laboratory/ John Hopkins University
Patrick Stadter, Applied Physics Laboratory/ John Hopkins University

**Abstract**
The Precision Tracking Space System (PTSS) was a constellation of infrared (IR) sensors planned by the US Missile Defense Agency (MDA) to observe and track ballistic missile objects in flight. The PTSS program funded testing to characterize the parasitic heat loads expected on the actively-cooled multi-band IR sensor assembly, a subassembly within the optical telescope, thereby reducing uncertainty in the cooler heat lift requirements and system power budget. A detailed flight-like thermal analog of the sensor assembly, including designed conductances, surface treatments, and multi-layer insulation, was tested in a fixture that simulated its flight interfaces with a controllable interface temperature. A heat flow sensor, located at the flight cold-head attachment point, provided heat lift measurements. Testing was performed with

various boundary conditions and a least squares fit was used to discriminate between the conduction and radiation parasitic heat load components. This knowledge was used to correlate a detailed thermal model built in Thermal Desktop that could then be used to accurately predict flight heat lift and perform system level design trades. This document presents a detailed description of the testing, test results, model correlation methodology and results, and lessons learned.

**TFAWS2014-PT-03**

## Preliminary Development of a TSS and SINDA/FLUINT to ESARAD/ESATAN Thermal Model Converter

Kan Yang, NASA GSFC
Hume Peabody, NASA GSFC

**Abstract**
In collaborative spacecraft projects between NASA and ESA, cross-agency exchanges of thermal models are necessary to facilitate thermal design as well as generate temperature and heat predictions at the observatory level. The standard thermal software used within NASA for the Geometric Math Model (GMM) is typically the Thermal Synthesizer System (TSS) or Thermal Desktop, while SINDA/G or SINDA/FLUINT is used for the Thermal Math Model (TMM). However, the standard for the majority of ESA projects remains ESARAD for the GMM and ESATAN for the TMM. Although ESATAN was developed from a SINDA-like framework, several crucial differences in thermal model structure and GMM features make any effort to translate between the two model formats a painstaking task. A recent effort has been initiated by the NASA Goddard Thermal Engineering Branch to develop a standardized converter between the TSS with SINDA/FLUINT and ESATAN/ESARAD formats. Developed in the VB.NET language, this converter tool provides a Graphical User Interface (GUI) to facilitate the conversion process among end users, and employs a framework of two top-level classes for importing, manipulating, and exporting data from GMMs and TMMs. The GMM class stores information regarding input and output files, units, emulation for unsupported surface types, and data structures for Entities, Variables, Optical Properties, and Thermophysical Properties. For surfaces that require emulation, the GMM converter also seeks to devolve more complex geometries into base primitive shapes such that they can be passed between programs. The TMM class stores information regarding nodes, conductors, arrays, and registers, and converts all data types supported by both programs. A preliminary effort has also been made to translate model logic between SINDA/FLUINT and ESATAN. It is hoped that development of this conversion tool will facilitate inter-agency collaborations for NASA and its ESA partners on current and future projects.

**TFAWS2014-PT-04**

## Thermal Control Design for the Subarcsecond Telescope And Balloon Experiment (STABLE)

Hared Ochoa, NASA JPL
Robert Effinger, NASA JPL
Rachael Tompa, NASA JPL
Michael Porter NASA JPL

**Abstract**
The thermal modeling, design and analysis of the Subarcsecond Telescope And BaLloon Experiment (STABLE) payload is presented. STABLE is a high precision pointing demonstration project and is part of the BIT-STABLE mission (Balloon-borne Imaging Testbed). BIT-STABLE has three main contributors: the Jet Propulsion Laboratory, the University of Toronto, and the University of Durham (UK). The STABLE payload, whose main optical element is a 50cm aperture telescope, will fly on a high altitude balloon inside the BIT gondola designed by the University of Toronto. Once at float, the STABLE payload will use a point source of visible light to demonstrate pointing precision within 0.1 arc seconds for at least 60 seconds. This paper will discuss the thermal design and analysis of the STABLE payload. The wide range in potential thermal environments and the thermal sensitivity of the off-the-shelf telescope impose a challenge to the thermal control system. The design calls for a thorough investigation and understanding of the flight environments, detailed modeling and analysis, and strategically chosen passive hardware to bias the payload cold and active hardware to heat the payload to the optimal temperature ranges. Along with a detailed discussion on the thermal design this paper will also review the expected thermal performance of the system and the uncertainties of the model and design. STABLE is a project under the JPL Phaeton program -- a training program for early career hires.

**TFAWS2014-PT-05**

## LUROVA – From Render Engine to Thermal Model

Ron Creel, NASA(Retired Apollo Lunar Roving Vehicle Team Member)

**Abstract**
Render Engine created surface data provides high quality polygon faces and vertex information for potential use in constructing thermal radiation analytical models. The original Apollo LUnar ROVing Adventures (LUROVA) mission support thermal model, presented at TFAWS-2006, has been restored and upgraded using detailed render engine surface data. Polygon crunching and other developed surface data conversion and visualization software was used to reduce 800,000+ “faces” and 400,000+ “vertices” into a representative and manageable smaller surface model (~7800 surface nodes) to be run on the NASA Thermal Radiation Analysis System (TRASYS) computer program. The surface data conversion process is described, and the calculated surface radiation and heating environments for the enhanced thermal model are

compared to previous mission support analysis results. Future plans for LUROVA thermal model and “Edutainment” game/simulation enhancements are also discussed.

**TFAWS2014-PT-10**

## Thermal Modeling and Test Correlation for the High Fidelity Data Acquisition System

Chris Evans, MSFC

**Abstract**
This paper discusses the thermal modeling of the High Fidelity Data Acquisition System (HiDAQ) avionics box, including an assessment of copper versus aluminum heat spreaders and post-test model correlation. HiDAQ is a compact electronics “black box” designed for data recording in harsh acoustic and thermal environments, such as areas around a rocket motor. To provide thermal management and vibration protection, the box is filled and completely sealed with a thermally conductive epoxy. Embedded metal heat spreader plates are also utilized to channel the heat from the densely-packed electronics. Thermal models of the box and its internal boards/components were developed in Thermal Desktop to predict component temperatures and to assess the ability of the internal epoxy and heat spreader design to meet thermal requirements. The models were also used to perform simulations with alternative heat spreader material options in an effort to reduce weight and cost. Thermal test data was used to partially validate the models. This paper summarizes the thermal model, heat spreader material trade study, assessment of the effect of the epoxy fill in assisting thermal control, and the test correlation efforts.

# *Passive Thermal Paper Session II*

**TFAWS2014-PT-06**

## Thermal Interface Materials and Challenges Faced by Thermal Interface Material Suppliers

Jason Strader, Laird
Rich Hill, Laird

**Abstract**
Many electronic components generate excess heat requiring a variety of methods and cooling devices such as heat sinks, heat pipes, and even water cooling. In order to optimize the thermal contact between the electronic device and heat removal components, a thermal interface material is generally placed in-between in order to fill in the interstitial spaces between the non-flat non-planar surfaces. We will present the wide variety of thermal interface materials available, and discuss the various situations each are typically used in and why. Thermal interface suppliers encounter many challenges including customer interpretation of

specifications, maintaining consistent performance for many years, and issues presented by raw material supplies. Methods to avoid and/or solve these issues will be introduced.

**TFAWS2014-PT-07**

## LTCS (Laser Thermal Control System) Test Supporting the Improvement of DeCoM (Deepak Condenser Model)

Deepak Patel, GSFC

**Abstract**

On Dec 2013 a Loop Heat Pipe (LHP) test was performed as part of the integral Laser Thermal Control System (LTCS). During the balance portion of this testing it was noticed that the LHP was not going to be able to maintain temperature on the operational thermal mass. The test was stopped. After multiple meetings with the LTCS designers, LHP experts (in house and external) it was concluded that gravity was preventing the control heaters to maintain control on the reservoir. A heater was installed onto the liquid return line as part of the fix. After implementing the fix on the liquid return line, the test on May 2014 proved that the system works in vertical orientation using the liquid line heater. Through this testing, the correlation of the Deepak Condenser Model (DeCoM) was possible. This paper describes that DeCoM predicts the vapor and liquid behavior through the condenser well within 3C of the test temperatures. There is still much to understand at the exact two-phase location where the vapor starts condensing and liquid bubbles start forming. Future studies will focus on how to improve the code to accurately identify the exact phase change location.

**TFAWS2014-PT-08**

## Using SpaceClaim/TD Direct for Modeling Components with Complex Geometries for the Thermal Desktop-based Advanced Stirling Radioisotope Generator Model

William Fabanich, NASA GRC

**Abstract**

SpaceClaim/TD Direct has been used extensively in the development of the Advanced Stirling Radioisotope Generator (ASRG) thermal model. This paper outlines the workflow for that aspect of the task and includes proposed best practices and lessons learned. The ASRG thermal model was developed to predict component temperatures and power output and to provide insight into the prime contractor's thermal modeling efforts. The insulation blocks, heat collectors, and cold side adapter flanges (CSAFs) were modeled with this process.

The model was constructed using mostly TD finite difference surfaces/solids. However, some complex geometry could not be reproduced with TD primitives while maintaining the desired degree of geometric fidelity. Using SpaceClaim permitted the import of original CAD files and

enabled the defeaturing/repair of those geometries. TD Direct (a SpaceClaim plug-in from C&R Tech) adds features that allowed the "mark-up" of that geometry.

These mark-ups control how finite element (FE) meshes were generated and allowed the "tagging" of features (e.g. solids, surfaces). These tags represent parameters that include: submodels, material properties, material orienters, optical properties, and radiation analysis groups. TD aliases were used for most tags to allow analysis to be performed with a variety of parameter values. "Domain-tags" were also attached to individual and groups of surfaces and solids to allow them to be used later within TD to populate objects like, for example, heaters and contactors. These tools allow the user to make changes to the geometry in SpaceClaim and then easily synchronize the mesh in TD without having to redefine these objects each time as one would if using TD Mesher.

The use of SpaceClaim/TD Direct has helped simplify the process for importing existing geometries and in the creation of high fidelity FE meshes to represent complex parts. It has also saved time and effort in the subsequent analysis.

**TFAWS2014-PT-09**

## Cube Flux Method to Generate Spacecraft Thermal Environments

Siraj A Jalali, Oceaneering Space Systems

**Abstract**
Spacecrafts are exposed to various environments that are not present at the surface of the earth, like plasmas, neutral gases, x-rays, ultraviolet (UV) irradiation, high energy charged particles, meteoroids, and orbital debris. The interaction of these environments with spacecraft cause degradation of materials, contamination, spacecraft glow, charging, thermal changes, excitation, radiation damage, and induced background interference. The damaging effects of natural space and atmospheric environments pose difficult challenges for spacecraft designers. ISS/Shuttle thermal model was used to develop a program to determine environment around an orbiting spacecraft. The method was applied to compare environments around the ISS/Shuttle in Earth and Mars orbits. The method was also applied on a Satellite in Lower Earth Orbit (LEO) and Geosynchronous Orbit (GEO) and results were compared.

To determine the thermal environments around the ISS/shuttle 1 cubic foot arithmetic cubes were placed 1 foot above the surfaces where thermal environments were needed. The ISS/Shuttle was placed in Earth and Mars orbits with required beta, attitudes, and altitude. The applicable solar, Albedo, and IR fluxes were applied on the model depending upon summer or winter solstice. Model was analyzed such that absorbed solar fluxes and surface temperatures of all cube surfaces were obtained. A routine (HTFLXCAL ) was developed to calculate Infrared fluxes for all cube surfaces using cube absorbed solar fluxes and surface temperatures. The solar and infrared fluxes at a cube location were used to calculate orbital sink temperatures at that location. The sink temperatures at a cube location for tools, spacecraft surfaces, or space suit are extreme temperatures those components will be exposed to at that location.

The method presented here is efficient and simpler since the space vehicle model and flux generation routine (HTFLXCAL) are run from Thermal Desktop® in a single run, and Solar and IR fluxes for all cube locations are generated. The sink temperatures generation routine for required materials using Solar and IR fluxes is also part of the main routine.

**TFAWS2014-PT-11**

### Passive Thermal Design approach for the Space Communications and Navigation (SCaN) experiment on the International Space Station (ISS)

John Siamidis, NASA GRC

**Abstract**
The SCaN payload provides an on-orbit, adaptable, SDR/STRS-based facility to conduct a suite of experiments to advance the Software Defined Radio (SDR) Space Telecommunications Radio Systems (STRS) Standards, reduce risk (TRL advancement) for candidate Constellation space flight hardware/software, and demonstrate space communication links critical to future NASA exploration missions.

The SCaN Project provides NASA, industry, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in the laboratory and space environment based on reconfigurable, software defined radio platforms and the STRS Architecture.

The SCaN payload is resident on the P3 Express Logistics Carrier (ELC) on the exterior truss of the International Space Station (ISS). The SCaN payload launched on the Japanese Aerospace Exploration Agency (JAXA) H-II Transfer Vehicle (HTV) and was installed on the International Space Station (ISS) P3 ELC located inboard RAM P3 site.

## Paper Abstracts: Aerothermal

**TFAWS2014-AE-01**

### A New High Temperature Thermopile Heat Flux Sensor at AEDC (ITAR)

Stuart Coulter, Aerospace Testing

**Abstract**
This abstract is unable to be released in this document due to ITAR restrictions. A copy of the abstract and paper submission will be available upon request to attendees meeting the ITAR requirements (US Citizen or Permanent Resident). Please direct such request to the paper session chairs.

**TFAWS2014-AE-02**

## Space Shuttle Boundary Layer Transition Flight Experiment Ground Testing Overview

Karen Berger, NASA LaRC
Brian Anderson, NASA JSC
Charles Campbell, NASA JSC

**Abstract**

In support of the Boundary Layer Transition (BLT) Flight Experiment (FE) Project in which 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 Space Shuttle Endeavour for STS-134, a significant wind tunnel test campaign was completed. The primary goals of the test campaign were to provide ground test data to support the planning and safety certification efforts required to fly the flight experiment as well as validation for the collected flight data. These test included Arcjet testing of the tile protuberance, aerothermal testing to determine the boundary layer transition behavior and resultant surface heating and planar laser induced fluorescence (PLIF) testing in order to gain a better understanding of the flow field characteristics of the flight experiment. This paper provides an overview of the BLT FE Project ground testing. High-level overviews of the facilities, models, test techniques and data are presented, along with a summary of the insights gained from each test.

**TFAWS2014-AE-03**

## Langley Aerothermodynamic Labs: Testing Capabilities

Kevin Hollingsworth, Jacobs Technology
Sheila Wright, Jacobs Technology
Karen Berger, NASA LaRC
Shann Rufer, NASA LaRC

**Abstract**

A description of the NASA Langley Research Center's (LaRC) Langley Aerothermodynamics Laboratory (LAL) will be presented in the paper, along with descriptions and details of the facility test techniques and recent upgrades. The LAL consists of three hypersonic blow-down wind tunnels with Mach numbers of 6 and 10 and Reynolds number ranges of 0.5 to 8 million per foot as well as a 60-ft Vacuum Sphere Test Chamber. All three wind tunnel facilities utilize dried, filtered and heated air as the test gas. LAL facilities are used to study and define the aerodynamic performance and aeroheating characteristics of flight vehicle concepts. Data collected in the facilities has been used for design and optimization, anchoring computations predictions, generation of aerodynamic databases, and design of Thermal Protection Systems (TPS). Over the years since initial construction, modifications and enhancements have been made to the facility hardware and instrumentation to increase efficiency, data quality, capabilities and reliability to better meet the programmatic requirements. Recent utilization information illustrates the need for the capabilities associated with these facilities. Test

programs to utilize the facilities recently include the Space Shuttle Program, Crew Exploration Vehicle (CEV)/Orion, Hypersonic International Flight Research Experimentation (HIFiRE), Mars Science Laboratory (MSL), Hypersonic Inflatable Aerodynamic Decelerator System (HIADS) and X-51 among others and usage has been split between NASA, Department of Defense and private company programs. Plans for future improvements to the facility infrastructure and instrumentation will also be presented.

# Paper Abstracts: Interdisciplinary

**TFAWS2014-I-01**

## SRTMV-N2 Plume Impingement Test Panel Thermal Analysis

Vincent Cuda Jr, NASA LaRC
David Witte, NASA LaRC
Jason Mishtawy, NASA MSFC
Jeremy Pinier, NASA LaRC

**Abstract**
A heavily instrumented, 15-5 stainless steel test panel (30 inches wide by 36 inches in length by 1.0 inches in thickness), referred to as the Plume Impingement Test Panel was instrumented with over 200 thermal and pressure sensors and positioned 48 inches downstream of a 24-inch diameter solid rocket test motor to intersect with the expanding exhaust gas from the rocket nozzle. The panel was inclined six degrees into the exhaust resulting in the aft end penetrating further into the exhaust plume. The instrument suite employed a novel array of thermal sensors to provide three different approaches to determining the surface heat flux along the test panel. One direct heat flux sensor measurement technique was employed along with two indirect temperature measurement techniques to deduce the surface heat flux. The panel also included the installation of two thermal protection system (TPS) samples. One test coupon of VAMAC and one of P-50 cork were installed near the aft end of the test panel above centerline to expose these two TPS samples to the highest expected heating loads.

The data record from the thermal instrumentation provided a detailed description of the exhaust plume environment. The outer exhaust plume region had radiant heating profiles larger than expected. The total surface heating profiles downstream of the plume impingement point on the test panel were consistent with convection dominated heating. No exhaust plume core heating was evident on the test panel. Comparison of the three different methods for determining total surface heat transfer rate showed fairly good agreement during the initial portion of the test. The data from this test can be used to validate CFD predictions of the aerothermal loads from plume impingement.

**TFAWS2014-I-02**

## Flow characteristics of a strut injector for scramjets: numerical and experimental results

Cody Ground, Aerodynamics Research Center, University of Texas at Arlington
Fabrizio Vergine, Aerodynamics Research Center, University of Texas at Arlington
Luca Maddalena, Aerodynamics Research Center, University of Texas at Arlington
Valerio Viti, ANSYS

**Abstract**
A peculiar dynamical interaction of two supersonic counter-rotating vortex pairs (CVPs) has been generated by a pair of overlapping expansion ramps mounted on a strut injector in a Mach 2.5 flow. Similar CVP configurations generated by overlapping ramps on the same modular strut injector have previously been studied by the authors and experimentally corroborated the predictions based on the in-house developed reduced order model, VorTx. Two co-rotating vortices at the center of the generated structure have either merged or begun to orbit each other. However, for the case discussed in this work, experiments have revealed an additional structure; in fact, instead of the expected four streamwise vortices in the flowfield consisting of two inner co-rotating vortices and two oppositely rotating external vortices, the formation of a fifth structure, a central vorticity patch, was detected. The manuscript presents a detailed experimental characterization of the flow of interest via the use of stereoscopic particle image velocimetry and a parallel computational effort based on the solution of the Reynolds Averaged Navier-Stokes equations with the ANSYS Fluent CFD Package. The results of the CFD simulations highlight the near injector flowfield, which is unable to be characterized experimentally, in order to focus upon the mechanism that result in the formation and the effects of the central vorticity patch.

**TFAWS2014-I-04**

## Thermal Acoustic Oscillation: Causes, Detection, Analysis and Prevention

Robert J. Christie, NASA GRC
Jason W. Hartwig, NASA GRC

**Abstract**
Thermal Acoustic Oscillations (TAO) can occur in cryogenic systems and produce significant sources of heat. This source of heat can increase the boil-off rate of cryogenic propellants in spacecraft storage tanks and reduce mission life. This paper discusses the causes of TAO, how it can be detected, what analyses can be done and how to prevent it from occurring. The paper provides practical insight into what can aggravate instability, practical methods for mitigation and when TAO does not occur. A real life example of a cryogenic system with an unexpected heat source is discussed, along with how TAO was confirmed and eliminated.