National Aeronautics and
Space Administration

2019 30th Annual Thermal & Fluids Analysis Workshop (TFAWS)

August 26 to 30, 2019

City Center Marriott,
Newport News, VA

Sponsored by:
NASA Engineering and Safety Center

Hosted by:
NASA Langley Research Center

30 Years of TFAWS: Power of the Past, Force of the Future

TFAWS
LaRC 2019

https://tfaws.nasa.gov

www.nasa.gov

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Overview of TFAWS 2019

Welcome to the 30th annual Thermal and Fluids Analysis Workshop (TFAWS), sponsored by the NASA Engineering and Safety Center (NESC), and hosted by the NASA Langley Research Center (LaRC). This year's event is taking place from August 26th – 30th and is being held at the Marriott at City Center in Newport News, Virginia. To highlight the fact that TFAWS is celebrating its 30th anniversary, the conference theme for TFAWS 2019 is "30 Years of TFAWS: Power of the Past, Force of the Future."

TFAWS is an annual training and professional development workshop designed to encourage knowledge sharing, professional development, and networking throughout the thermal and fluids engineering community within NASA and the aerospace community at large. The vision of TFAWS is to maintain continuity over time and between disciplines throughout the thermal and fluids engineering community. The content of TFAWS is well-suited to everyone in the thermal and fluids engineering community including experienced engineers, new hires, and students.

The three technical areas of focus are Aerothermal, Life Support/Active Thermal, and Passive Thermal Control and Protection. The workshop features paper sessions, software and hardware demonstrations, hands-on software training, technical short courses, technical discussion forums, guest speakers, and tours of the NASA Langley Research Center.

Benefits of attending TFAWS include:

- Participants have the opportunity to share their work on the latest application of new and established methods to aerospace missions, impart engineering lessons learned, and compare/contrast engineering practices.
- Annual sharing of knowledge, hands-on instruction in relevant state-of-the-art engineering analysis tools, and seminars/short courses taught by the veterans in the thermal and fluids engineering community help to ensure that the expertise of the community is maintained.
- Networking at TFAWS gives each engineer an extensive network of contacts which serves as an excellent source of advice and technical knowledge.
- TFAWS provides tremendous opportunities for enhancing collaboration between NASA centers, other government agencies, industry, academia, and the international thermal and fluids engineering community.

The electronic version of this program can be found at https://tfaws.nasa.gov/tfaws19/agenda.

Agenda

Monday, August 26, 2019

15-minute breaks will occur at 10:00 AM and 3:30 PM.

<table>
<tr><th>Start Time</th><th>Grand Ballroom III</th><th>Grand Ballroom IV</th><th>Grand Ballroom V</th><th>Blue Point I</th><th>Blue Point II</th></tr>
<tr><td>7:00 AM</td><td colspan="5">Registration Desk & Vendor Displays Open</td></tr>
<tr><td>8:00 AM</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td rowspan="4">Intro to COMSOL Multiphysics Hands-On Training</td><td></td></tr>
<tr><td>9:00 AM</td><td>Thermal Synthesizer System (TSS) Demo</td><td rowspan="3">Generalized Fluid System Simulation Program (GFSSP) Hands-On Training</td></tr>
<tr><td>10:15 AM</td><td rowspan="2">Forum:
Thermal Properties - Do We Trust Them?</td><td>ANSA Demo</td><td rowspan="2">New & Advanced Features in Thermal Desktop Demo</td></tr>
<tr><td>11:15 AM</td><td></td></tr>
<tr><td>12:15 PM</td><td colspan="5">Lunch: Grand Ballroom II
Welcome: Dave Bowles, NASA Langley Center Director
Speaker: Representative Elaine Luria, U.S. House of Representatives - Virginia's 2nd District</td></tr>
<tr><td>1:30 PM</td><td rowspan="7">Passive Thermal Paper Session 1</td><td>*ITAR Paper Session 1: Active Thermal</td><td rowspan="2">Thermal Analysis Results Processor (TARP) Demo</td><td rowspan="9">Intro to Thermal Desktop and FloCAD Hands-On Training</td><td rowspan="9">Intro to Thermal Synthesizer System (TSS) Hands-On Training - Part 1</td></tr>
<tr><td>2:00 PM</td><td rowspan="2">*ITAR Paper Session 2: Aerothermal</td></tr>
<tr><td>2:30 PM</td><td rowspan="2">Veritrek Demo</td></tr>
<tr><td>3:00 PM</td><td rowspan="2">Aerothermal Paper Session</td></tr>
<tr><td>3:45 PM</td><td rowspan="2">Cryothermal Paper Session</td></tr>
<tr><td>4:15 PM</td><td rowspan="2">Methods for Testing Heatshield Materials Short Course</td></tr>
<tr><td>4:45 PM</td><td rowspan="2"></td></tr>
<tr><td>5:15 PM</td><td></td><td></td></tr>
<tr><td>5:45 PM</td><td colspan="5">Adjourn</td></tr>
<tr><td>6:00 PM</td><td colspan="5">Welcome Reception: Rotunda
Reservation Required</td></tr>
</table>

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Tuesday, August 27, 2019

15-minute breaks will occur at 10:00 AM and 3:30 PM.

Start Time	Grand Ballroom III	Grand Ballroom IV	Grand Ballroom V	Blue Point I	Blue Point II
7:30 AM	Registration Desk & Vendor Displays Open				
8:00 AM	Non-Intrusive Measurement Techniques for Flow Characterization of Hypersonic Wind Tunnels		Multi-Layer Insulation Demo (Aerothreads)	Capture Output and Verify Results (COVeR) Hands-On Training	Intro to Thermal Synthesizer System (TSS) Hands-On Training - Part 2
9:00 AM		Active Thermal Paper Session 1	TAITherm Heat Transfer Simulation Software Demonstration	Veritrek Open Lab	
10:15 AM			New & Improved Technology for Flexible Heaters (Fralock / DuPont)		
11:15 AM			GT-SUITE Multiphysics Demo		
12:15 PM	Lunch: Grand Ballroom II Speaker: Michelle Munk, NASA Entry, Descent, and Landing (EDL) System Capability Lead and Space Technology Mission Directorate (STMD) Principal Technologist for EDL				
1:30 PM	Interdisciplinary Paper Session 1	Passive Thermal Paper Session 2	Maya Simcenter3D Space Systems Thermal (SST) Demo	Intro to RadCAD Hands-On Training	GT-SUITE Multiphysics Hands-On Training
2:30 PM			Maya Simcenter3D Electronic Systems Cooling (ESC) Demo		
3:45 PM					
4:30 PM	Adjourn				
5:30 PM	Miss Hampton Sunset Boat Cruise *Reservation Required*				

Wednesday, August 28, 2019

15-minute breaks will occur at 10:00 AM and 3:30 PM.

Start Time	Grand Ballroom III	Grand Ballroom IV	Grand Ballroom V	Blue Point I	Blue Point II	Blue Point III	Other
7:30 AM	Registration Desk & Vendor Displays Open						
8:00 AM		Battery Thermal Modeling Short Course Part 1: Battery Safety and Thermal Runaway	STEP-TAS Data Exchange Standard Demo	Intro to CRTech TD Direct Hands-On Training	Maya HTT Simcenter3D Space Systems Thermal (SST) Hands-On Training	Active Thermal Technical Discipline Team (TDT) Meeting *NASA Only*	
9:00 AM	Interdisciplinary Paper Session 2		STAMP Demo				
10:15 AM		Battery Thermal Modeling Short Course Part 2: Thermal Simulations	Heat Analysis Manager Demo		Maya HTT Simcenter3D Electronic Systems Cooling (ESC) Hands-On Training		
11:15 AM							
12:15 PM	Lunch: Grand Ballroom II Speaker: Joe Gasbarre, Deputy Director for Flight Programs, LaRC Science Directorate (SD)						
1:30 PM	Forum: Additive Manufacturing, Building our Future Layer by Layer	Introduction to Numerical Methods in Heat Transfer Short Course	Active Thermal Paper Session 2	Thermal Desktop Open Lab 1	CoTherm - CAE Coupling GUI Hands-On Training		Langley Research Center (LaRC) Tour 1 *Reservation Required*
2:30 PM							
3:45 PM	Thermal & Fluids Analysis and the NASA Launch Services Program			GT-SUITE Multiphysics Open Lab 1			
4:45 PM							
5:45 PM	Adjourn						
6:30 PM	Keynote Banquet: Grand Ballroom II Speaker: Dr. Kunio Sayanagi, Associate Professor, Hampton University Department of Atmospheric and Planetary Sciences *Reservation Required*						

Thursday, August 29, 2019

15-minute breaks will occur at 10:00 AM and 3:30 PM.

Start Time	Grand Ballroom III	Grand Ballroom IV	Grand Ballroom V	Blue Point I	Blue Point II	Blue Point III
7:30 AM	Registration Desk & Vendor Displays Open					
8:00 AM		Aerothermodynamic Gridding Short Course	Heat Pipe Short Course	GT-SUITE Multiphysics Open Lab 2	Maya HTT Simcenter3D Space Systems Thermal (SST) and Electronic Systems Cooling (ESC) Open Lab	Passive Thermal Technical Discipline Team (TDT) Meeting *By Invitation Only*
9:00 AM	Interdisciplinary Paper Session 3	Aerothermodynamic CFD Analysis Short Course				
10:15 AM				PyTecplot Hands-On Training		
11:15 AM						
12:15 PM	Lunch: Grand Ballroom II Speaker: Jeanne Willoz-Egnor, Director of Collections Management and Curator of Scientific Instruments, The Mariner's Museum and Park					
1:30 PM		*ITAR Paper Session 3: Passive Thermal	Siemens Simcenter T3STER Demo	Thermal Analysis Results Processor (TARP) Hands-On Training	Intro to Thermal Synthesizer System (TSS) Hands-On Training - Part 3	
2:00 PM	Passive Thermal Paper Session 3	Aft-Body Heating on Blunt Hypersonic Vehicles Short Course (ITAR*)				
2:30 PM			Siemens Simcenter AMESim Demo			
3:45 PM			MSC SINDA and Thermica Demo			
4:45 PM						
5:15 PM	Adjourn					
5:30 PM	TFAWS Delegates' Meeting: Blue Point III *NASA Civil Servants and JPL Only*					
5:30 PM	Networking Social: Traditions Brewing Company					

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Friday, August 30, 2019

A 15-minute break will occur at 10:00 AM.

Start Time	Grand Ballroom III	Grand Ballroom IV	Grand Ballroom V	Blue Point I	Blue Point II	Other
7:30 AM	Registration Desk & Vendor Displays Open					
8:00 AM				Thermal Desktop Open Lab 2	Intro to Thermal Synthesizer System (TSS) Hands-On Training - Part 4	Langley Research Center (LaRC) Tour 2 *Reservation Required*
9:00 AM						
10:00 AM						
11:00 AM						
12:00 PM	Adjourn					

TFAWS 2019 Host Center – Langley Research Center

Langley Research Center (LaRC) was founded in 1917 as the first aeronautics research facility of the National Advisory Committee for Aeronautics (NACA) and was initially named the "Langley Memorial Aeronautical Laboratory" in honor of Samuel P. Langley, the third secretary of the Smithsonian Institution and the person who tried to build the first heavier-than-air flying machine. In 1922, the Variable Density Tunnel was completed at Langley and became the first pressurized wind tunnel in the world, which could achieve more realistic predictions of how actual aircraft would perform under flight conditions than any previous wind tunnel. Langley was officially renamed "Langley Research Center" on October 1, 1958 when the center became a component of the National Aeronautics and Space Administration (NASA).

NASA LaRC is now home to several world-class facilities, including wind tunnels that span the speed regimes from subsonic to hypersonic flow, structures and materials facilities (such as the Landing and Impact Research facility where astronauts trained to walk on the moon), and flight simulation, scientific computing, acoustics, and flight electronics facilities as well. Encompassing 764 acres in Hampton, Virginia, NASA Langley employs about 3,400 civil servants and contractors. With a legacy of over 100 years of research, Langley is now building the future by making revolutionary improvements to aviation, expanding understanding of the Earth's atmosphere and developing technology for space exploration. Centennial posters that depict LaRC's history will be displayed in the meal room during the workshop. NASA Langley will host of the 30th annual Thermal and Fluids Analysis Workshop (TFAWS) in 2019 as we explore the theme 30 Years of TFAWS: Power of the Past, Force of the Future.

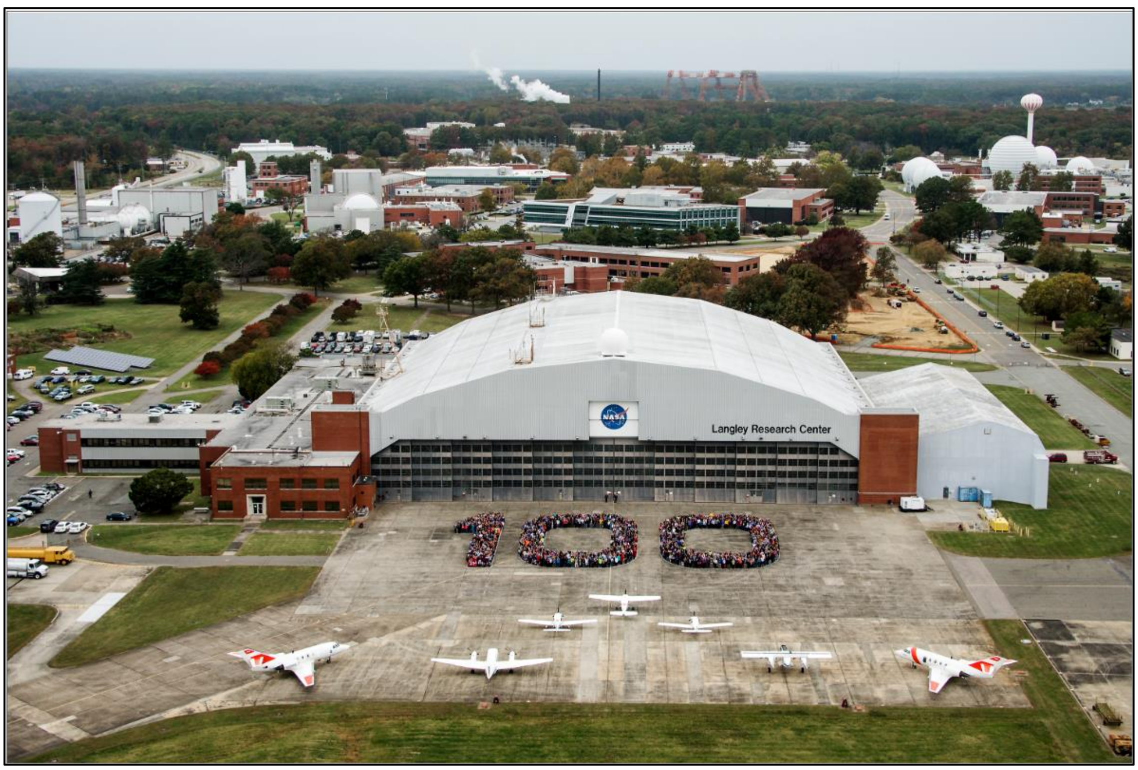


Image courtesy of: https://www.nasa.gov/langley/100/gallery

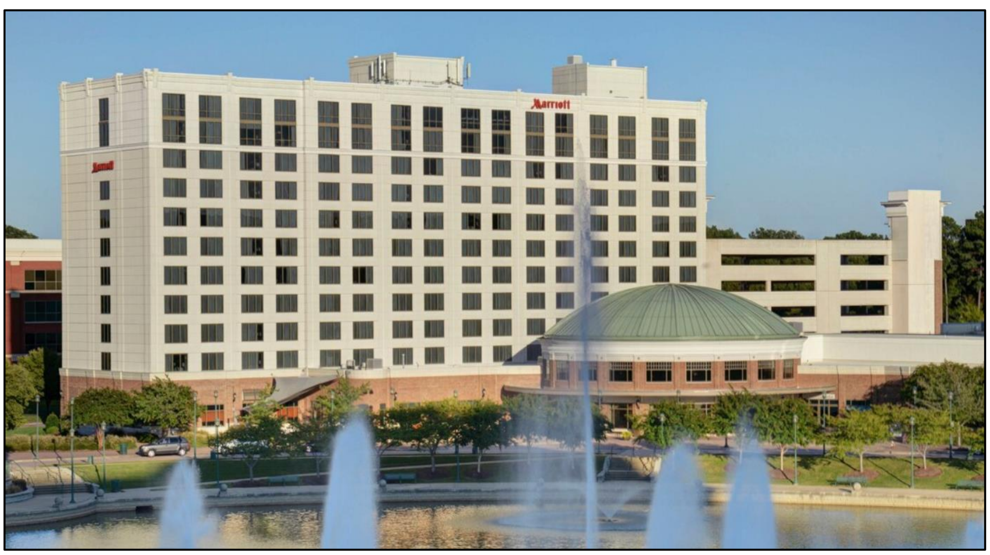
TFAWS 2019 Hotel Information

Newport News Marriott at City Center
740 Town Center Drive
Newport News, Virginia 23606
http://www.marriott.com/phfoy

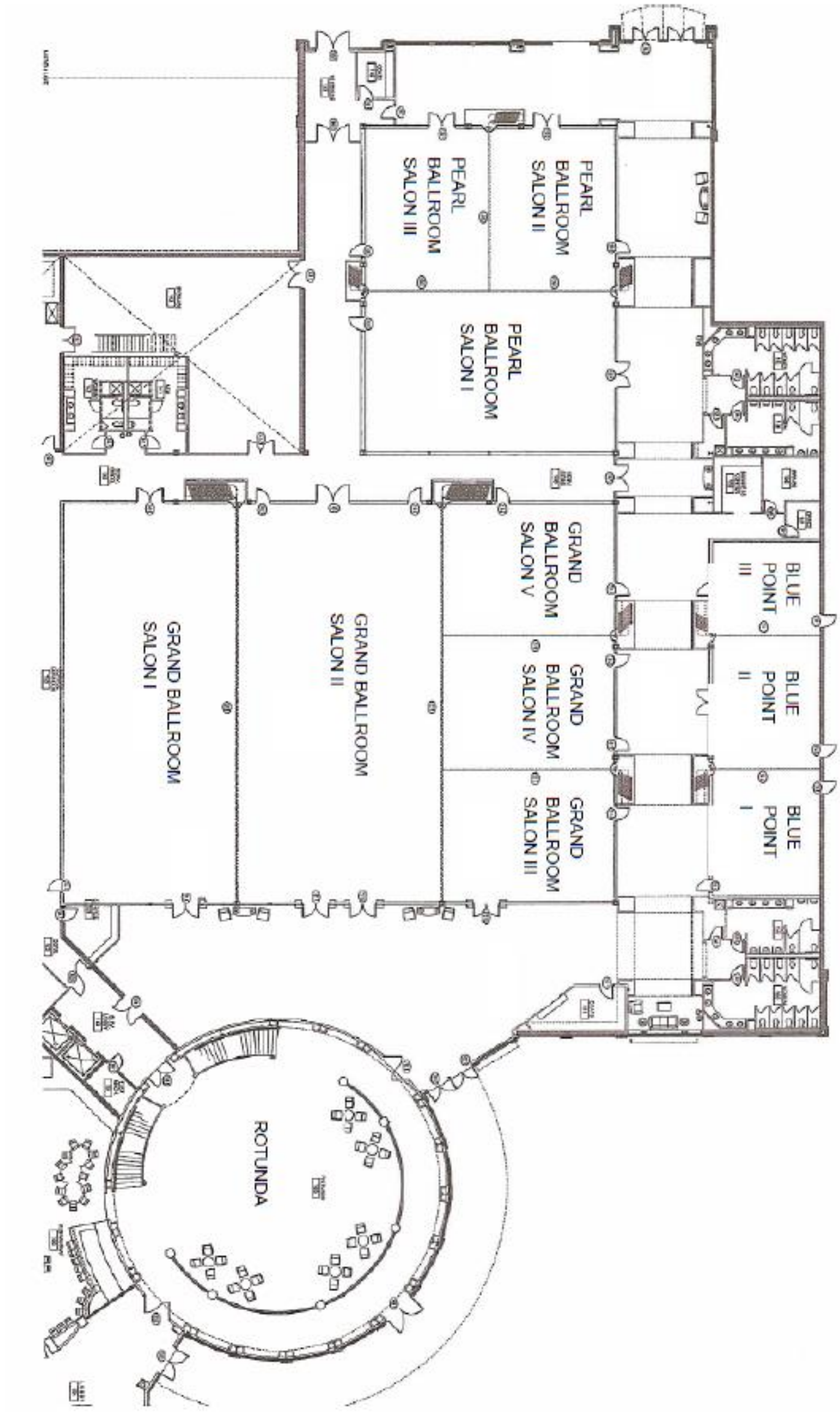
Free Wi-Fi is available for conference attendees.
Network: Marriott_CONFERENCE
Password: 2019PSAV

TFAWS 2019 will be held at the Marriott at Newport News City Center. Located in southeastern Virginia, the Hampton Roads region is rich in colonial American and maritime history and is home to a wide variety of cultural and natural attractions. Newport News is situated approximately midway between Williamsburg and Southside Hampton Roads which includes Virginia Beach, Norfolk, Portsmouth, and Chesapeake. Nearby attractions include the Virginia Air and Space Museum, the Virginia Marine Science Museum, the Virginia Living Museum, the Chrysler Museum of Art, Busch Gardens, and Colonial Williamsburg. A more complete list of local attractions can be found on the TFAWS website: https://tfaws.nasa.gov/tfaws19/venue-information/. City Center at Oyster Point is the Virginia Peninsula's meeting place featuring a wide variety of restaurants in a pedestrian-friendly environment; detailed information can be found here: https://citycenteratoysterpoint.com/. The City Center Marriott is conveniently located near the Newport News/Williamsburg International Airport and is about half an hour from the Norfolk International Airport.

Non-hotel guests are welcome to park in the garage connected to the hotel; it is complimentary for day users and $6.00 for overnight guests.



Map of City Center Marriott Meeting Space



Session Descriptions

Monday, August 26, 2019

Monday Morning Sessions

Introduction to COMSOL Multiphysics Hands-On Training

8:00 AM – 12:15 PM, Blue Point I

Instructor: Siva Sashank Tholeti (COMSOL, Inc.)

Are you interested in modeling heat exchangers or active/passive cooling or ventilation systems or turbulent or multiphase flows? If so, please join us for this hands-on training course to learn how to model heat transfer and fluid flow with COMSOL Multiphysics. In this course we will cover:

- COMSOL's capability to model
  - Conductive, convective (free and forced) and radiative heat transfer
  - Single and multiphase flows under different regimes (laminar or turbulent)
  - Heat transfer and flow through porous media
- Hands-on exercises on modeling heat transfer and fluid flow with COMSOL Multiphysics

Thermal Synthesizer System (TSS) Demonstration

9:00 AM – 10:00 AM, Grand Ballroom V

Presenter: Joe Lepore (Spacedesign Corporation)

The latest version of TSS will be showcased with a demonstration of enhancements.

Generalized Fluid System Simulation Program (GFSSP) Hands-On Training

9:00 AM – 12:15 PM, Blue Point II

Instructor: Andre LeClair (MSFC)

GFSSP is a general-purpose computer program for analyzing steady-state and time-dependent flow rates, pressures, temperatures, and concentrations in a complex flow network. The program is capable of modeling phase change, compressibility, mixture thermodynamics, conjugate heat transfer, and fluid transient (water hammer). GFSSP was been developed at MSFC for flow analysis of rocket engine turbopumps and propulsion systems. The class will show how to the user can quickly develop a system-level thermo-fluid model, discuss the capabilities of the software, and present model examples. Students will build two models as a group activity, and have the opportunity to work one or more hands-on tutorials.

Forum: Thermal Properties – Do We Trust Them?

10:15 AM – 12:15 PM, Grand Ballroom III

Moderator: Sandra Walker (LaRC)

Participants: Callie McKelvey (MSFC), Kamran Daryabeigi (LaRC), Donald Ellerby (ARC), Evan Racine (GRC)

This panel will focus on the difficulties in accurately measuring thermal properties and the accuracy of using the thermal properties in numerical models. Panelists will give a brief overview of their expertise. With the additional time, audience can ask questions to facilitate discussion. The planned timeline is shown below:

- Sandra Walker (Moderator): 5-10 mins
- Callie Mckelvey: 15-20 mins
- Kamran Daryabeigi: 15-20 mins
- Don Ellerby: 15-20 mins
- Evan Racine: 15-20 mins
- Questions and Discussion: 30-55 mins

Forum participant biographies can be found at the end of the conference program.

ANSA Demonstration

10:15 AM – 11:15 AM, Grand Ballroom IV

Presenter: Victor Rosu (BETA CAE Systems USA, Inc.)

This demonstration of the ANSA software package will include the following:

- Handling of geometry, model healing, and geometry generation
- Surface and volute mesh generation in CFD
- Morphing-based geometry parameterization and optimization

New & Advanced Features in Thermal Desktop Demonstration

10:15 AM – 12:15 PM, Grand Ballroom V

Presenters: Douglas Bell and Matt Garrett (CRTech)

This session will provide an overview of new and advanced features within the Thermal Desktop suite and provide demonstration on the use of some of those features. This session is recommended to anyone who wishes to see more advanced capabilities of the Thermal Desktop suite than can be addressed in the introductory session. Since the session is not hands-on, prior experience with Thermal Desktop is not required. Thermal Desktop is a design environment for generating thermal models with additional modules for performing radiation and heating environment calculations (RadCAD) and generating fluid flow circuits (FloCAD). Thermal Desktop is a graphical user interface for SINDA/FLUINT. OpenTD is an Application Programming Interface (API).

Monday Lunchtime

12:15 PM – 1:15 PM, Grand Ballroom II
Speaker presentation starts at 12:30pm

"Welcome to Langley"
Speaker: Dave Bowles, Langley Research Center Director

"Congressional Update from Representative Elaine Luria"
Speaker: Elaine Luria, U.S. House of Representatives – Virginia's 2nd District

All conference attendees are allowed to attend the lunch speakers; however, no outside food is permitted. Pre-purchased lunch tickets are required for hotel-provided food. For attendees choosing to attend the speaker without having pre-purchased tickets, theater-style seating will be provided.

Lunch Menu: Herb Crusted Chicken Breast with House Salad and Seasonal Vegetables. Attendees who noted dietary restrictions during registration will receive comparable meals for all purchased lunches.

Speaker biographies can be found at the end of the conference program.

Monday Afternoon Sessions

Passive Thermal Paper Session 1

1:30 PM – 5:15 PM, Grand Ballroom III
Session Chairs: Eric Groß (GSFC), Eric Malroy (JSC), and Ruth Amundsen (LaRC)

1:30 PM **Thermo-Radiative Cell - A New Waste Heat Recovery Technology for Space Power Applications**
TFAWS19-PT-01
Jianjian Wang, Chien-Hua Chen, Richard Bonner, and William Anderson

2:00 PM **Design and Test of a Structurally-Integrated Heat Sink for the Maxwell X-57 High Lift Motor Controller**
TFAWS19-PT-08
Ryan Edwards and Andrew Smith

2:30 PM **Thermal Development of a Commercial Off the Shelf (COTS) Camera for Exploration Upper Stage (EUS)**
TFAWS19-PT-10
Deborah Hernandez

3:00 PM **Thermal Design and Qualification Testing of the KA-Band Radar Interferometer (KARIN) Instrument Thermal Control System**
TFAWS19-PT-19
Louis Tse and Ruwan Somawardhana

3:30 PM **Break**

3:45 PM **Passive Thermal Analysis and Regulation for a Lightweight Lunar CubeRover**
TFAWS19-PT-07
Oleg Sapunkov

4:15 PM **Challenges of Designing a Passive Thermal Control System for the Astrobotic Peregrine Lunar Lander**
TFAWS19-PT-09
Stephanie Mauro

4:45 PM **Thermal Environment Modeling Practices for the Descent Trajectory of Lunar Landers**
TFAWS19-PT-11
Alex Szerszen

*ITAR Paper Session 1: Active Thermal

1:30 PM – 2:00 PM, Grand Ballroom IV

Session Chairs: Ryan Edwards (GRC), Ryan Gilligan (GRC), and Alex Scammell (LaRC)

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1:30 PM **Using Medium Fidelity Mockups to Visualize Internal Air Flow for NASA's Four Bed Carbon Dioxide Scrubber (RBCO2) (ITAR)**
TFAWS19-AT-15
Kevin Higdon, Shawn Breeding, and Parker Weide

Thermal Analysis Results Processor (TARP) Demonstration

1:30 PM – 2:30 PM, Grand Ballroom V

Presenter: Hume Peabody (Thermal Modeling Solutions)

TARP (Thermal Analysis Results Processor) and COVeR (Capture Output and Verify Results) are dedicated post processing programs that interface with the standard output formats of many of the network analysis codes used by the aerospace thermal industry. TARP allows the user to define various object types for the display and manipulation of data, with the end product being a Microsoft Excel workbook. The most basic object type is a DataSet, which displays all the nodal information for each timestep. Nodal data may be further represented as Groups and Parameters (e.g. Min of Group). Other DataSet types derive data from the raw output to further process the outputs. DataSets may be referenced by other objects, such as Plots, StripCharts, Tables, GraphicalTables, etc. Furthre object types allow the user to investigate and process the radiative environment. Lastly, a HeatMap workbook option exists for the investigation of heat flows. Extending this to the aforementioned Group capability gives analysts the capability to investigate heatflows in very large models through control volume analysis from base nodal results. COVeR works in conjunction with TARP, but provides its own environment for the display of thermal data. COVeR allows for both the tabular and graphical display of heat flows in a block diagram format. These Graphical HeatMaps are a powerful tool for investigating model connectivity and ensuring that a thermal model represents the intended design. Understanding heat flows within a model is a critical part of thermal design and can highlight deficiencies that may be difficult to spot in today's large thermal models.

Introduction to Thermal Desktop and FloCAD Hands-On Training

1:30 PM – 5:45 PM, Blue Point I

Instructor: Douglas Bell (CRTech)

This session will introduce the capabilities of Thermal Desktop and FloCAD through the creation of simple models. Thermal Desktop is a pre- and postprocessor for SINDA; FloCAD adds fluid model development based on thermal model geometry and flow path centerlines. No previous experience with Thermal Desktop is expected. You are welcome to join us if you are an experience user but are requested to allow new users to have priority at the workstations.

Intro to Thermal Synthesizer System (TSS) Hands-On Training – Part 1

1:30 PM – 5:45 PM, Blue Point II

Instructor: Joe Lepore (Spacedesign Corporation)

This hands-on class will progress through a thermal analysis of a spacecraft using version v15.01. The student will go through each major step in the analysis process using a simple example. This is the basic framework needed to create, analyze, and obtain temperatures using TSS. The spacecraft model will begin as a CAD file, which is moved into TSS by using the Transfer application. As each TSS application is used, user interface and TSS features are demonstrated by the instructor and utilized by the student. Calculations of radks, heating rates, conduction/capacitance network, and temperatures are performed. The latest TSS capabilities demonstrated in this class include the return of the Executive application for Windows and SindaWin application. Everyone interested in learning how to perform satellite thermal analysis should attend this class.

*ITAR Paper Session 2: Aerothermal

2:00 PM – 3:00 PM, Grand Ballroom IV

Session Chairs: Robin Beck (ARC), Jeff Hill (ARC), and Andrew Brune (LaRC)

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2:00 PM **High Altitude Vehicle Sounding Rocket Re-Entry Heating Software Assessment (ITAR)**
TFAWS19-AE-03
Lindsey Seo

2:30 PM **Ablator Thermal Analysis of a Multi-Block Radiant Test (ITAR)**
TFAWS19-AE-02
Zaida Hernandez

Veritrek Demonstration

2:30 PM – 3:30 PM, Grand Ballroom V

Presenters: Derek Hengeveld and Jacob Moulton (Loadpath)

Veritrek enhances Thermal Desktop® by enabling thousands of simulation results in seconds. Leveraging this speed, Veritrek helps teams efficiently understand a thermal design space so they can focus on improved solutions. During this demonstration, both the Veritrek Creation and Exploration Tools will be demonstrated. In addition, it will be shown how Veritrek helped solve a challenging problem for NASA's Mars 2020 Helicopter among others.

Aerothermal Paper Session

3:00 PM – 4:15 PM, Grand Ballroom IV

Session Chairs: Robin Beck (ARC), Jeff Hill (ARC), and Andrew Brune (LaRC)

3:00 PM **Aerodynamic and Aerothermal Simulations of Mars Concept Vehicles using Overset DPLR**
TFAWS19-AE-05
Chun Tang

3:30 PM **Break**

3:45 PM **Aeroheating Measurements of BOLT Aerodynamic Fairings and Transition Module**
TFAWS19-AE-04
Elizabeth Rieken and Scott Berry

Cryothermal Paper Session

3:45 PM – 4:45 PM, Grand Ballroom V

Session Chairs: Monica Guzik (GRC), Paul Whitehouse (GSFC), and Patrick Junen (MSFC)

3:45 PM **CFD Modeling of Cryogenic Chill-down through a Complex Channel**
TFAWS19-CT-02
Justin Pesich

4:15 PM **Optimization of Design and Computational Fluid Dynamic Analysis of Cryogenic Loop Heat Pipe**
TFAWS19-CT-01
Togaru Lavanith, Sirivolu Akilesh, and Naganathan Karthik

Methods for Testing Heatshield Materials Short Course

4:15 PM – 5:15 PM, Grand Ballroom IV

Instructor: Robin Beck (ARC)

This course will cover an overview of the Entry Systems and Technology Division (TS) at NASA Ames Research Center (ARC) and descriptions of the extensive arc jet testing complex managed within the branch. After a quick look at the Earth and Planetary Entry projects supported by TS, along with the inventions and software developed within the division, a description of the entry environments to which thermal protection systems (TPS) are exposed will be discussed. The question of "How do we insure TPS survival?" will be answered with descriptions of the various test facilities across the agency and beyond and their applicability. The Ames Arc Jet Complex will then be described, starting with how an arc heater works, adding in the associated infrastructure required to run an arc heater, and the capabilities of each of the test tunnels. Finally, examples of TPS test articles will round out the course.

Monday Evening Activity

Welcome Reception

6:00 PM, Rotunda

Ticket Required

Socialize and network with your colleagues in this lovely setting. Reception style hors d'oeuvres dinner including BBQ pork sliders, mini chicken cordon bleu, spicy beef empanadas, crispy pita with red pepper chickpea puree and cucumber relish, vegetable spring rolls, cookies, brownies, iced tea and water. Cash bar available. Pre-purchased tickets are required.

Tuesday, August 27, 2019

Tuesday Morning Sessions

Non-Intrusive Measurement Techniques for Flow Characterization of Hypersonic Wind Tunnels

8:00 AM – 12:15 PM, Grand Ballroom III

Presenters: P.M. Danehy and J. Weisberger (LaRC), C. Johansen (University of Calgary), D. Reese and T. Fahringer (National Institute of Aerospace), N.J. Parziale (Stevens Institute of Technology), C. Dedic (University of Virginia), J. Estevadeordal (North Dakota State University), B.A. Cruden (AMA Inc at NASA Ames Research Center)

This lecture describes the wide variety of optical measurement techniques for characterizing the flow in hypersonic wind tunnels. The introduction briefly describes different types of hypersonic wind tunnels, why they are used, and typical freestream conditions including fluctuating quantities. Description of these conditions defines the challenge for measurement techniques which have varying degrees of accuracy and precision, and work only in certain temperature, density and/or speed regimes. The rest of the lecture is broken up into sections, by measurement technique. Each technique is described and then several examples are provided. The conclusion compares and contrasts different aspects of the measurement techniques including accuracy, precision, spatial resolution and temporal resolution.

Multi-Layer Insulation Demonstration

8:00 AM – 9:00 AM, Grand Ballroom V

Presenters: Aleksandra Bogunovic and Casey Kelby (Aerothreads), Art Mallett Jr. (Dunmore) and Seth Broughton (Dunmore)

Are you nearing a Multi-layer Insulation (MLI) procurement and curious about requirements? Thermal, electrical, and mechanical considerations all have the ability to influence the quality and effectiveness of your MLI. Understanding these requirements will help your supplier provide the most robust MLI for your mission.

Aerothreads is a specialized provider of Multi-layer Insulation (MLI) blanket products, custom soft goods, and critical support services for the aerospace industry. Our extensive experience in the design, fabrication, and installation of MLI blankets for flight-qualified aerospace missions, coupled with our specialized art and design education makes us ideal innovators for the most complex MLI blanket needs.

Aerothreads is an SBA Certified HUBZone and Woman-Owned Small Business (WOSB).

Capture Output and Verify Results (COVeR) Hands-On Training

8:00 AM – 9:00 AM, Blue Point I

Instructor: Hume Peabody (Thermal Modeling Solutions)

TARP (Thermal Analysis Results Processor) and COVeR (Capture Output and Verify Results) are dedicated post processing programs that interface with the standard output formats of many of the network analysis codes used by the aerospace thermal industry. TARP allows the user to define various object types for the display and manipulation of data, with the end product being a Microsoft Excel workbook. The most basic object type is a DataSet, which displays all the nodal information for each timestep. Nodal data may be further represented as Groups and Parameters (e.g. Min of Group). Other DataSet types derive data from the raw output to further process the outputs. DataSets may be referenced by other objects, such as Plots, StripCharts, Tables, GraphicalTables, etc. Furthre object types allow the user to investigate and process the radiative environment. Lastly, a HeatMap workbook option exists for the investigation of heat flows. Extending this to the aforementioned Group capability gives analysts the capability to investigate heatflows in very large models through control volume analysis from base nodal results. COVeR works in conjunction with TARP, but provides its own environment for the display of thermal data. COVeR allows for both the tabular and graphical display of heat flows in a block diagram format. These Graphical HeatMaps are a powerful tool for investigating model connectivity and ensuring that a thermal model represents the intended design. Understanding heat flows within a model is a critical part of thermal design and can highlight deficiencies that may be difficult to spot in today's large thermal models.

Intro to Thermal Synthesizer System (TSS) Hands-On Training – Part 2

8:00 AM – 12:15 PM, Blue Point II

Instructor: Joe Lepore (Spacedesign Corporation)

This hands-on class will progress through a thermal analysis of a spacecraft using version v15.01. The student will go through each major step in the analysis process using a simple example. This is the basic framework needed to create, analyze, and obtain temperatures using TSS. The spacecraft model will begin as a CAD file, which is moved into TSS by using the Transfer application. As each TSS application is used, user interface and TSS features are demonstrated by the instructor and utilized by the student. Calculations of radks, heating rates, conduction/capacitance network, and temperatures are performed. The latest TSS capabilities demonstrated in this class include the return of the Executive application for Windows and SindaWin application. Everyone interested in learning how to perform satellite thermal analysis should attend this class.

Active Thermal Paper Session 1

9:00 AM – 12:15 PM, Grand Ballroom IV

Session Chairs: Ryan Edwards (GRC), Ryan Gilligan (GRC), and Alex Scammell (LaRC)

9:00 AM **Two-Phase Cooling System Through Loop Heat Pipes**
TFAWS19-AT-01
Togaru Lavanith and Ganesh Kumar

9:30 AM **Experimental and Numerical Analysis of Flat Plate Loop Heat Pipes Thermal Resistance Performance**
TFAWS19-AT-02
Shahid Manik, Jin Jin, Y. Guang, and Wu Jingyi

10:00 AM **Break**

10:15 AM **Advances in Cost Effective Thermal Management for Small Satellites**
TFAWS19-AT-04
Chien-Hua Chen and Ryan Spangler

10:45 AM **Numerical Simulation of Transient Behavior of Vapor-Liquid Distribution in a Loop Heat Pipe**
TFAWS19-AT-09
Takuya Adachi, Koji Fujita, and Hiroki Nagai

11:15 AM **Thermohydraulic Characterization of Additive Manufactured Heat Exchangers using Lattice Structure**
TFAWS19-AT-11
Aurelien Conrozier, Damien Serret, and Jean-Michel Hugo

11:45 AM **Fully Resolved Numerical Simulations of Complex Multiphase Flows**
TFAWS19-AT-16
Jiacai Lu and Gretar Tryggvason

TAITherm – Heat Transfer Simulation Software Demonstration

9:00 AM – 10:00 AM, Grand Ballroom V

Presenters: Craig Makens and Katy Hickey (ThermoAnalytics)

ThermoAnalytics will provide an overview of TAITherm thermal software simulating a battery pack with transient heat loads and multi-layer insulation. The TAITherm advanced 3D Human Thermal Model will be demonstrated with applications for Protective Suits and Cabin Environmental Control Systems. CoTherm, a CAE process and coupling tool, will also be demonstrated by building out and monitoring a scenario.

Veritrek Open Lab

9:00 AM – 12:15 PM, Blue Point I

Instructors: Derek Hengeveld and Jacob Moulton (Loadpath)

Veritrek enhances Thermal Desktop® by enabling thousands of simulation results in seconds. Leveraging this speed, Veritrek helps teams efficiently understand a thermal design space so they can focus on improved solutions.

Open lab sessions provide an opportunity for in-person customer support to answer general questions on software functionality or to work on a specific problem.

New and Improved Technology for Flexible Heaters

10:15 AM – 11:15 AM, Grand Ballroom V

Presenters: Bruce Webb (Fralock) and Tim Scott (DuPont)

Introduction and demonstration of flexible all polyimide (AP) heaters for space applications and the NASA S-311-P-841 approval.

Fralock will present the performance advantages and benefits of this AP technology along with the many different material configurations available. Some of the benefits to be discussed include higher watt density, faster response times, radiation resistance and ESD protection. The presentation will also include an overview of our all polyimide technology (AP) as it relates to flex cables, flex circuits and CirlexR (thick KaptonR) applications.

GT-SUITE Multiphysics Demonstration

11:15 AM – 12:15 PM, Grand Ballroom V

Presenters: Jon Zenker and Jon Harrison (Gamma Technologies)

Do you simulate complex systems requiring simulating multiple physical domains including fluids, thermal, electrical, mechanics and controls? Are you looking for a simulation tool that runs faster than 3D CFD, but powerful enough to provide predictive answers to highly transient problems? Would you like an easy-to-use tool with both a 2D sketchpad and 3D building options? If so, we welcome you to learn about how GT-SUITE can be used for solving multi-physics related problems of complex systems including cryogenic propulsion and two-phase flow systems in this 1-hour software demonstration. Following this 1-hour demo, a separate, 3-hour hands-on training will be held in the afternoon.

About Gamma Technologies: GT-SUITE is a unique transformational all-in-one CAE tool used at NASA and over 700 aerospace and automotive organizations. On one level, it is recognized to be a worldwide leader in high-level system modeling (0D/1D). But that is just the start: uniquely in the industry GT-SUITE is also a detailed 3D modeling tool, with built-in structural and thermal 3D FEA, 3-D multi-body dynamics with flexible bodies and 3D CFD. These are complemented by CAD modeling and automatic model generation from CAD.

What makes GT-SUITE especially powerful is that high-fidelity 3D component models are seamlessly integrated into 1D/0D system-level models, which supply them with accurate transient multi-physics boundary conditions and assure two-way interactions between all of the sub-systems.

Tuesday Lunchtime

12:15 PM – 1:15 PM, Grand Ballroom II
Speaker presentation starts at 12:30 PM

"NASA's Entry, Descent, and Landing (EDL) Systems and Technologies"

Speaker: Michelle Munk, NASA Entry, Descent, and Landing (EDL) System Capability Lead and Space Technology Mission Directorate (STMD) Principal Technologist for EDL

All conference attendees are allowed to attend the lunch speakers; however, no outside food is permitted. Pre-purchased lunch tickets are required for hotel-provided food. For attendees choosing to attend the speaker without having pre-purchased tickets, theater-style seating will be provided.

Lunch Menu: Taco Buffet with Chef's selection of desserts. Includes Coffee, Iced Tea and Iced Water. Attendees who noted dietary restrictions during registration will receive comparable meals for all purchased lunches.

Speaker biographies can be found at the end of the conference program.

Tuesday Afternoon Sessions

Interdisciplinary Paper Session 1

1:30 PM – 4:15 PM, Grand Ballroom III

Session Chairs: Arturo Avila (JPL), Carlos Gomez (MSFC), and Karen Berger (LaRC)

1:30 PM **Thermal Characterization of SiC MOSFET Devices**
TFAWS19-ID-09
Andras Vass-Varnai

2:00 PM **Thermal Vacuum Chamber Calibration with 12U Cubesat Model**
TFAWS19-ID-05
Nathan Cordrey and Chris Strickland

2:30 PM **Thermal Analysis and Testing of the 12.5 kW HERMeS Hall Thruster**
TFAWS19-ID-18
Sean Reilly, Robbie Lobbia, Ryan Conversano, and Rich Hofer

3:00 PM **Assembly and Integrated Systems Testing for the Flow Boiling and Condensation Experiment (FBCE)**
TFAWS19-ID-19
Jesse deFiebre and Monica Guzik

3:30 PM **Break**

3:45 PM **Current Activities at the FAA Office of Commercial Space Transportation**
TFAWS19-ID-15
Christopher Evans

Passive Thermal Paper Session 2

1:30 PM – 4:15 PM, Grand Ballroom IV

Session Chairs: Eric Groß (GSFC), Eric Malroy (JSC), and Ruth Amundsen (LaRC)

1:30 PM **Review of MLI Behavior at Low Temperatures and Application to L'Ralph Thermal Modeling**
TFAWS19-PT-04
Daniel Bae and Juan Rodriguez-Ruiz

2:00 PM **Thermal Interface Material Selection for Large Electronics Boxes**
TFAWS19-PT-12
David Steinfield

2:30 PM **Liquid Metal Elastomer Composites as a Soft Thermal Interface Material for Low Temperature (-80°C) Applications**
TFAWS19-PT-14
Navid Kazem, Mohammad Malakooti, Jiajun Yan, Eric Markvicka, Chengfeng Pan, Krzysztof Matyjaszewski, and Carmel Majidi

3:00 PM **Thermal Characterization of 3D Printed Lattice Structures**
TFAWS19-PT-15
Travis Belcher and R. Gregory Schunk

3:30 PM **Break**

3:45 PM **Application and Development of Atomic Layer Deposition Techniques to Improve Thermo-optical Coatings for Spacecraft Thermal Control and Advanced Optical Instruments**
TFAWS19-PT-17
Vivek Dwivedi

Maya Simcenter3D Space Systems Thermal (SST) Demonstration

1:30 PM – 2:30 PM, Grand Ballroom V

Presenter: Jean-Frederic Ruel (Maya Heat Transfer Technologies)

This presentation will introduce users to Simcenter3D Space Systems Thermal, a thermal simulation tool fully integrated with CAD. We will be creating a thermal simulation model of the HESSI satellite, building it block by block from the CAD and creating simulation models (FEMs) for each component and subsystem of the spacecraft. The FEMs will be combined into one assembly of FEMs (AFEM), which will remain fully associative with the CAD assembly and easily able to accommodate design changes at both the component and assembly level with little to no simulation re-work. We will also be including a detailed thermal representation of a PCB board generated from electric CAD data. This AFEM model will then be used to obtain orbital temperatures.

Introduction to RadCAD Hands-On Training

1:30 PM – 4:30 PM, Blue Point I

Instructor: Douglas Bell (CRTech)

This session will introduce the capabilities of RadCAD through the creation of simple radiation models. RadCAD performs surface-to-surface radiation exchange calculations and environmental heating calculations. No previous experience with Thermal Desktop is expected. You are welcome to join us if you are an experienced user but are requested to allow new users to have priority at the workstations.

GT-SUITE Multiphysics Hands-On Training

1:30 PM – 4:30 PM, Blue Point II

Instructors: Jon Zenker and Jon Harrison (Gamma Technologies)

This hands-on class will demonstrate the multi-physics capabilities in GT-SUITE simulation software through building a handful of examples starting with 3D CAD geometry to produce a fluid thermal model of a cryogenic system, and account for effects such as water hammer due to fluid structure interaction of a transient valve event, as well modeling various cryogenic system components including turbomachinery and heat exchangers. Discussion on two-phase and reacting flows will also be considered. Finally, the user will be shown how to explore the design space easily through optimization and DOE, as well as post-process results with the built-in post processor. Following this training, open lab time will be available to continue to experiment with GT-SUITE.

About Gamma Technologies: GT-SUITE is a unique transformational all-in-one CAE tool used at NASA and over 700 aerospace and automotive organizations. On one level, it is recognized to be a worldwide leader in high-level system modeling (0D/1D). But that is just the start: uniquely in the industry GT-SUITE is also a detailed 3D modeling tool, with built-in structural and thermal 3D FEA, 3-D multi-body dynamics with flexible bodies and 3D CFD. These are complemented by CAD modeling and automatic model generation from CAD.

What makes GT-SUITE especially powerful is that high-fidelity 3D component models are seamlessly integrated into 1D/0D system-level models, which supply them with accurate transient multi-physics boundary conditions and assure two-way interactions between all of the sub-systems.

Maya Simcenter3D Electronic Systems Cooling (ESC) Demonstration

2:30 PM – 3:30 PM, Grand Ballroom V

Presenter: Kevin Lee (Maya Heat Transfer Technologies)

This short course will provide you an overview of the creation of electronics systems thermal-flow simulation model in Simcenter3D. In this session, we will access 3D assembly CAD data from both NX Native and third party CAD tools. We will go through the preparation of a coupled thermal-flow simulation model, introducing powerful features like electronic component library and “PCB Component” simulation objects, which will enhance the workflow. We will then review the simulation results with a set of post processing tools and explore how design changes are easily accommodated with minimal simulation re-work. From this session, you will understand the advantages of CAD-based approach to thermal-flow simulation.

Tuesday Evening Activity

Miss Hampton Sunset Boat Cruise

5:30 – 8:30 PM, 710 Settlers Landing Road
Reservation Required

Relax and enjoy the unique and exciting sights and sounds of the world's largest natural harbor on this private charter cruise. Heavy hors d'oeuvres will be served. Cash bar available. More information can be found at the Miss Hampton Harbor Cruises website.

Transportation is not provided; attendees should meet at the boat launch site, 710 Settlers Landing Road, behind Hampton Marina Hotel, near the Air & Space Museum. The drive to the dock takes approximately 20 minutes (without traffic). Please consider car-pooling with other attendees. Parking is available dockside in the Hampton Marina Hotel Parking Garage (boat charter guests can park even though signs indicate use for hotel guests). Please arrive by 5:15 PM to allow the boat to depart on-time at 5:30 PM.

Wednesday, August 28, 2019

Wednesday Morning Sessions

Battery Thermal Modeling Short Course Part 1: Battery Safety & Thermal Runaway

8:00 AM – 10:00 AM, Grand Ballroom IV

Instructor: William Walker (JSC)

When developing this course several years back I asked myself, "What do I think the TFAWS community needs to know about lithium-ion batteries and why should they care?" I think the answers to these questions can be boiled down to the following statements:

1. Lithium-ion (Li-ion) battery electrical performance and efficiency are heavily driven by thermal conditions.
2. Li-ion battery assemblies can experience single cell thermal runaway events which can lead to cell-to-cell propagation; these are thermally driven failure events that can be controlled with effective thermal management systems.
3. Knowledge of BOTH Li-ion battery fundamentals AND traditional thermal design principles are required to develop safe battery assemblies that are both gravimetrically and volumetrically optimized.

This year the Short Course on Lithium-ion Batteries will be presented in a 2-part series. The first portion, "Fundamentals, Battery Safety, and Thermal Runaway," will focus on educating participants on the fundamental aspects of Li-ion batteries and on battery safety related topics (i.e. thermal runaway, cell-to-cell propagation, safe handling practices, etc…). The second portion, "Practical Thermal Simulation Techniques," will provide participants with a real time demonstration of how to use Thermal Desktop to model of Li-ion battery assemblies. This part of the lesson will cover geometry simplification, mesh development, boundary conditions, and heat loads for both nominal operations (charge and discharge) and for thermal runaway events.

STEP-TAS Data Exchange Standard Demonstration

8:00 AM – 9:00 AM, Grand Ballroom V

Presenter: James Etchells

This session will provide participants with an introduction to the STEP-TAS data exchange standard for space thermal analysis data (ECSS-E-ST-31-04C). The session will start with a presentation of STEP-TAS, giving a brief overview of its history, scope and implementation, including the existing conversion tools and other resources. Following this introduction, the session will focus on some case studies and address some of the practical challenges faced by engineers carrying out format conversion including best practice. This practical part of the session will be supported by practical demonstrations where possible, including exchanges with Thermal Desktop. Finally, some future perspectives for STEP-TAS and data exchange in general will be presented, with an opportunity for open discussion.

Introduction to CRTech TD Direct Hands-On Training

8:00 AM – 12:15 PM, Blue Point I

Instructor: Douglas Bell (CRTech)

This session will introduce the capabilities of CRTech TD Direct. TD Direct is powerful software that fills the gap between design geometry and C&R Thermal Desktop. TD Direct is an add-in to ANSYS® SpaceClaim®, a CAD tool that focuses on preparing geometry for analysis, just as Thermal Desktop is an add-in to AutoCAD. With TD Direct, you can solve many of the problems that have challenged thermal engineers for years. The starting point is the full design geometry in any format. The final product is the completed analysis in Thermal Desktop. The step in between is TD Direct, where you can easily simplify, heal, create, and alter the geometry while working with an exceedingly capable mesher.

Maya HTT Simcenter3D Space Systems Thermal (SST) Hands-On Training

8:00 AM – 10:00 AM, Blue Point II

Instructor: Jean-Frederic Ruel (Maya Heat Transfer Technologies)

This hands-on training session will take you through access and use of 3D assembly CAD geometry, geometry preparation (idealization), and preparation of a spacecraft thermal simulation model, followed by solution and post-processing, using Simcenter3D Space Systems Thermal. At that point, you will address significant design changes and see how those changes flow down through the entire simulation process with minimal simulation re-work. You will leave this session with a better understanding of the advantages of the CAD-based approach to thermal simulation.

Active Thermal Technical Discipline Team (TDT) Meeting

8:00 AM – 12:15 PM, Blue Point III

NASA Only

Annual face-to-face meeting for the Active Thermal TDT.

Interdisciplinary Paper Session 2

9:00 AM – 11:45 AM, Grand Ballroom III

Session Chairs: Arturo Avila (JPL), Carlos Gomez (MSFC), and Karen Berger (LaRC)

9:00 AM **Fluid Transient Analysis of Propellant Feedlines during a Priming Event**
TFAWS19-ID-10
Andre LeClair, Alex Boehm, and Alok Majumdar

9:30 AM **On-Orbit Xenon Refueling Loading Times and Transient Analysis**
TFAWS19-ID-16
Ben Nugent

10:00 AM **Break**

10:15 AM **Pressure-Based Venting Thermal Model for the Dream Chaser Cargo System**
TFAWS19-ID-07
R. S. Miskovish and S. W. Miller

10:45 AM **Thermal Design Challenges for In-Flight Exposure to an Electric Propulsion Plasma Plume Environment**
TFAWS19-ID-14
Evan Racine

11:15 AM **Thermal and Structural Analysis of the ExoMars Navigation and Localization Cameras**
TFAWS19-ID-01
Christopher Pye, Pierre-Luc Messier, and Tim Elgin

STAMP Demonstration

9:00 AM – 10:00 AM, Grand Ballroom V

Presenter: Hans Guijt (TERMA B.V)

During this session we will present STAMP, a software system for conducting large-scale thermal tests. Thermal testing requires coordination of numerous instruments, data sources, control circuits, and outputs over long periods of time. Software to do this must meet high requirements:

- Reliability: a failure in the software infrastructure may have costly consequences and must be avoided.
- Capacity: the software must be able to control hundreds of instruments, acquire thousands of channels, and display data on dozens of monitoring screens.
- Flexibility: the software must be able to adapt to customer requirements.
- User friendliness: (parts of) the software will be used by facility customers, who typically cannot spare much time for training during the hectic period of test preparation.
- Partitioning: user access to specific functions and data must be controlled.

STAMP meets all these requirements.

In the most recent version of STAMP we have added a comprehensive scripting system. This makes it possible to create test-specific MMIs, automate common operations, implement unique control modes for power supplies, and build custom presentations.

Battery Thermal Modeling Short Course Part 2: Thermal Simulations

10:15 AM – 12:15 PM, Grand Ballroom IV

Instructor: William Walker (JSC)

When developing this course several years back I asked myself, "What do I think the TFAWS community needs to know about lithium-ion batteries and why should they care?" I think the answers to these questions can be boiled down to the following statements:

1. Lithium-ion (Li-ion) battery electrical performance and efficiency are heavily driven by thermal conditions.
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This year the Short Course on Lithium-ion Batteries will be presented in a 2-part series. The first portion, "Fundamentals, Battery Safety, and Thermal Runaway," will focus on educating participants on the fundamental aspects of Li-ion batteries and on battery safety related topics (i.e. thermal runaway, cell-to-cell propagation, safe handling practices, etc…). The second portion, "Practical Thermal Simulation Techniques," will provide participants with a real time demonstration of how to use Thermal Desktop to model of Li-ion battery assemblies. This part of the lesson will cover geometry simplification, mesh development, boundary conditions, and heat loads for both nominal operations (charge and discharge) and for thermal runaway events.

Heat Analysis Manager Demonstration

10:15 AM – 12:15 PM, Grand Ballroom V

Presenter: Daniel G. Bae (GSFC)

Thermal engineers often create custom heat maps to analyze their thermal models. However, generating a heat map is difficult because thermal simulations only readily provide certain attributes of simulated nodes, such as temperature, capacitance, and heat generation, along with a network of conductances. Heat flow values are quantities derived from these nodal attributes, and the difficulty in data processing and management of heat flow between nodes quickly grows as node count increases for large models. Deriving a network of heat flow values requires a vast AMount of calculations and data handling, and the heat map generation process generally suffers from processing speed, loss of accuracy, and/or presentation of data in a clear and concise format. Heat Analysis Manager (HAM) is a Thermal Desktop (TD) based free multi-purpose tool developed to aid thermal engineers in analyzing thermal models which includes a heat map generation utility. HAM's heat map generator retains accuracy and fast processing speed by utilizing TD's application programming interface (API) and TD's built-in post-processor routine "Qflow from Results." Furthermore, HAM's heat map output is presented in an easily customizable format in Excel, allowing users to create various custom visual heat maps. A full description of how HAM utilizes TD's API to create a customizable heat map is provided.

Maya HTT Simcenter3D Electronic Systems Cooling (ESC)

10:15 AM – 12:15 AM, Blue Point II

Instructor: Kevin Lee (Maya Heat Transfer Technologies)

This software demonstration will introduce Simcenter3D Electronic Systems Cooling, an expert-level coupled thermal-flow analysis tool fully integrated with CAD. We will be focusing on thermal analysis of an electronic system, highlighting Simcenter3D's capability of leveraging ECAD data and automated board thermal representation. Starting from automated creation of the thermal representation for the printed circuit board and components, we will build an Assembly FEM (AFEM) which places thermal representations in their proper locations in the CAD assembly and allows the user to make changes in design with zero to little rework effort. For the electronic components, we will use the "PCB Component" entity to define simplified thermal facsimiles drawing from the JEDEC-compliant electronic components library. Finally, we will look at the thermal-flow simulation results and explore how design changes are easily accommodated with minimal simulation re-work.

Wednesday Lunchtime

12:15 PM – 1:15 PM, Grand Ballroom II
Speaker presentation starts at 12:30 PM

"Engineering NASA's Science Missions for Today and Tomorrow"

Speaker: Joe Gasbarre, Deputy Director for Flight Programs, LaRC Science Directorate (SD)

All conference attendees are allowed to attend the lunch speakers; however, no outside food is permitted. Pre-purchased lunch tickets are required for hotel-provided food. For attendees choosing to attend the speaker without having pre-purchased tickets, theater-style seating will be provided.

Lunch Menu: Lasagna with House Salad, Garlic Bread and Chef's Selection of Dessert. Includes Coffee, Iced Tea and Iced Water. Attendees who noted dietary restrictions during registration will receive comparable meals for all purchased lunches.

Speaker biographies can be found at the end of the conference program.

Wednesday Afternoon Sessions

Langley Research Center Tour 1

1:30 PM – 5:30 PM
Reservation Required

The tour will visit three sites, including the National Transonic Facility, 31-Inch Mach 10 Air Tunnel and the Integrated Structural Assembly of Advanced Composites/ISAAC (tour stops are subject to change and will depend on the size of the tour group). More detailed descriptions of the tour stops can be found at the end of the conference program.

Transportation will be provided. Tour attendees should meet in the hotel lobby no later than 1:25 PM.

Forum: Additive Manufacturing, Building Our Future Layer by Layer

1:30 PM – 3:30 PM, Grand Ballroom III
Moderator: Karen Taminger (LaRC)
Participants: Joshua Fody (LaRC), Saikumar Yeratapally (LaRC), Travis Belcher (MSFC), Jean-Michel HUGO (TEMISTh)

This panel will focus on thermal and computational fluid dynamics modeling of additive manufacturing processes at different scales. Panelists are represented from NASA and industry will present their work in a specific area relating to additive manufacturing. There will be additional time for questions and discussion of challenges, successes, and lessons learned. The planned timeline is shown below:

- Karen Taminger (Moderator): 20-25 mins
- Josh Fody: 10-15 mins
- Saikumar Yeratapally: 10-15 mins
- Travis Belcher: 10-15 mins
- Jean-Michel Hugo: 10-15 mins
- Questions and Discussion: 30-60 mins

Forum participant biographies can be found at the end of the conference program.

Introduction to Numerical Methods in Heat Transfer Short Course

1:30 PM – 5:45 pm, Grand Ballroom IV
Instructor: Steven L. Rickman (NESC)

This course provides an overview and introduction to numerical methods in heat transfer. The Heat Equation, the governing differential equation, is derived from first principles and solved for an example problem. The finite difference method is derived from the governing differential equation and applied in example problems including the effects of radiation, steady state and transient response. Numerical solution accuracy and the concept of the time constant are discussed. The Calculus of Variations is applied to derive the Euler-Lagrange equation leading to a formulation of the finite element method and applied to a variety of examples. This course is an excellent introduction for those engineers early in their career in thermal analysis or seeking information in this field and a review for experienced analysts.

Active Thermal Paper Session 2

1:30 PM – 4:45 PM, Grand Ballroom V

Session Chairs: Ryan Edwards (GRC), Ryan Gilligan (GRC), and Alex Scammell (LaRC)

1:30 PM **24 Hour Consumable-based Cooling System for Venus Lander**
TFAWS19-AT-03
Kuan-Lin Lee and Calin Tarau

2:00 PM **Post Launch and Early Mission Thermal Performance of Parker Solar Probe through the First Two Solar Orbits**
TFAWS19-AT-07
Carl Ercol and G. Allan Holtzman

2:30 PM **P1 External Active Thermal Control System (EATCS) Ammonia Leak on the International Space Station (ISS)**
TFAWS19-AT-13
Darnell Cowan, Timothy Bond, and Jordan Metcalf

3:00 PM **Demonstration Testing for Ground Servicing of the Commercial Crew Vehicle Emergency Breathing Air Assembly (CEBAA)**
TFAWS19-AT-12
Kristina Gonzalez and Zachary Shaver

3:30 PM **Break**

4:15 PM **Calculation of Radiative Fin Performance Parameters for Radiator Analysis using Numerical Methods**
TFAWS19-AT-14
Louis Jorski

Thermal Desktop Open Lab 1

1:30 PM – 3:30 PM, Blue Point I

Instructors: Douglas Bell and Matt Garrett (CRTech)

Do you have a question about CRTech software? The CRTech Open Lab provides an opportunity for in-person customer support. Bring a model or bring a laptop (with the software already installed). If you cannot make one of the Open Lab sessions, feel free stop by our display booth.

CoTherm – CAE Coupling GUI Hands-On Training

1:30 PM – 4:45 PM, Blue Point II

Instructor: Craig Makens and Katy Hickey (ThermoAnalytics)

ThermoAnalytics will lead a hands-on class that will teach users about optimizing cabin climate control to human comfort using various CAE tools. We will start off with an introduction to CoTherm, TAI's flagship co-simulation management tool. The user will be introduced to the interface, process layout, and all resources necessary to build a CoTherm simulation process. Next, we will walk through coupling with other multi-physics CAE tools such as CFD. We will tie it all together by using various optimization methods in a radiant panel cabin design configuration to achieve a minimum time to human comfort (a standardized metric used in industry). The class will be relevant for anyone interested in human thermal design for cabins, HVAC/ECS systems, CAE tools and methodology, or optimization. Those interested in a variety of other topics such as protective suits, personal cooling devices, insulation/heat shield modeling, moisture management, micro-climates, wearable sensors, performance materials, heat transfer (in general), or human safety are welcome to stop by our booth too!

Thermal and Fluids Analysis and the NASA Launch Services Program

3:45 PM – 5:45 pm, Grand Ballroom III

Presenters: Cindy Fortenberry (KSC, Thermal, Environments & Launch Approval Branch) and Brandon Marsell (KSC, Fluids, Environments & Launch Approval Branch)

This presentation provides the What, Where, Why, and How of the thermal and fluids analysis disciplines within the Launch Services Program (LSP). The LSP manages all commercial launch services to match NASA science mission payloads to the appropriate launch system. The Flight Analysis Division within the LSP provides multi-disciplinary analysis support of these flight systems to characterize payload and launch vehicle environments from payload mate to upper stage through on-orbit separation. The Thermal Analysis and Fluids Analysis teams are two distinct groups within the Flight Analysis Division of the LSP who cover a wide array of standard and non-standard analytical tasks. These teams offer a significant benefit to both the payload design and integration team and the launch vehicle supplier. These benefits, along with the tools and methods are described in this talk to inform engineers and analysts from both sides of the launch system interface how the LSP Thermal and Fluids Analysis teams can benefit the success of their mission.

GT-SUITE Multiphysics Open Lab 1

3:45 PM – 5:45 PM, Blue Point I

Instructors: Jon Zenker and Jon Harrison (Gamma Technologies)

Feel free to stop by GT-SUITE open lab time to experiment with the software yourself or share a challenging problem with GT engineers. Whether you attended a GT-SUITE session earlier in the week or are new to it, we welcome you to stop by!

Wednesday Evening Activity

Keynote Banquet

6:30 PM – 8:30 PM, Grand Ballroom II
Ticket Required

"SNAP: Small Next-generation Atmospheric Probe to Enable Future Multi-Probe Missions to the Ice Giant Planets"

Speaker: Dr. Kunio Sayanagi, Associate Professor, Hampton University Department of Atmospheric and Planetary Sciences

Please join us for the TFAWS 2019 Keynote Banquet. This year's banquet will include pan seared chicken with roasted garlic sauce, plated house salad, seasoned vegetable, rolls, and dessert, coffee, tea, and water. Attendees who noted dietary restrictions during registration will receive comparable meals for all purchased lunches. Cash bar will available. Pre-purchased tickets are required.

Speaker biographies can be found at the end of the conference program.

Thursday, August 29, 2019

Thursday Morning Sessions

Aerothermodynamic Gridding Short Course

8:00 AM – 9:00 AM, Grand Ballroom IV

Instructor: Adam Wise (LaRC)

The application of computational fluid dynamics tools plays an important and growing role in the prediction of aerothermodynamic environments for entry, descent and landing vehicles. These simulations require specialized, high-fidelity codes that can model flows in chemical, and possibly, thermal non-equilibrium, and a carefully tailored grid of the flowfield surrounding the vehicle. The type and quality of the mapped decomposition of the computational domain is critical to obtaining accurate heating rates on the vehicle surface that are then used for design and evaluation of the thermal protection system. This short course will walk through basic examples of the grid generation process, with a focus on structured grid generation.

Heat Pipe Short Course

8:00 AM – 12:15 PM, Grand Ballroom V

Instructors: William G. Anderson and Calin Tarau (Advanced Cooling Technologies, Inc.)

This Heat Pipe Short Course by Advanced Cooling Technologies, Inc. (ACT) will provide a broad overview of heat pipes for Spacecraft Thermal Control, including operating principles, limitations, design considerations, applications, and testing. The course will include the following:

- Heat Pipe Basics
- Heat Pipe Limits
- Heat Pipe Applications
- Different Types of Heat Pipes
- Heat Pipe Working Fluids and Compatibility
- Heat Pipe Wicks
- Heat Pipe Modeling
- Constant Conductance Heat Pipe (CCHP) Design
- CCHP Manufacturing and Testing
- Copper/Water Heat Pipe Design
- Copper/Water Heat Pipes in Space
- Conclusions
- References

After discussing the basics, the course will discuss heat pipe design, including heat pipe limits, and envelope/fluid selection. Different kinds of heat pipes will be discussed, including Constant Conductance Heat Pipes (CCHPs), Variable Conductance Heat Pipes (VCHPs), Pressure Controlled Heat Pipes (PCHPs), diode heat pipes (one-way heat transfer) and gravity-aided heat pipes (thermosyphons). Design constraints, modeling, and manufacturing/testing of CCHPs for spacecraft thermal control will be covered. The course will then discuss copper/water heat pipe design and applications in space.

GT-SUITE Multiphysics Open Lab 2

8:00 AM – 10:00 AM, Blue Point I

Instructors: Jon Harrison and Jon Zenker (Gamma Technologies)

Feel free to stop by GT-SUITE open lab time to experiment with the software yourself or share a challenging problem with GT engineers. Whether you attended a GT-SUITE session earlier in the week or are new to it, we welcome you to stop by!

Maya HTT Simcenter3D Space Systems Thermal (SST) and Electronic Systems Cooling (ESC) Open Lab

8:00 AM – 12:15 PM, Blue Point II

Instructors: Jean-Frederic Ruel and Kevin Lee (Maya Heat Transfer Technologies)

Open lab sessions provide an opportunity for in-person customer support to answer general questions on software functionality or to work on a specific problem.

This open lab will cover the Maya HTT Simcenter3D Space Systems Thermal (SST) and Electronic Systems Cooling (ESC) software packages.

Passive Thermal Technical Discipline Team (TDT) Meeting

8:00 AM – 12:15 PM, Blue Point III

By Invitation Only

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Annual face-to-face meeting for the Passive Thermal TDT; this meeting is for Passive Thermal TDT members only.

Interdisciplinary Paper Session 3

9:00 AM – 11:45 AM, Grand Ballroom III

Session Chairs: Arturo Avila (JPL), Carlos Gomez (MSFC), and Karen Berger (LaRC)

9:00 AM **Rocket Engine Digital Twin**
TFAWS19-ID-04
David Mena, Sylvain Pluchart, Stephane Mouvand, and Oliver Broca

9:30 AM **Thermal Analysis of M2020 DRCS Thrusters for Various EDL Trajectories**
TFAWS19-ID-20
Sean Reilly, Juan Villalvazo, and Jennifer Miller

10:00 AM **Break**

10:15 AM **Design and Test of a Direct-Metal-Laser-Sintering (DMLS) Fabricated Microchannel Heat Exchanger with Nano-enhanced Heat Transfer Fluid for Thermal Management in Space Exploration**
TFAWS19-ID-08
Jaime Rios, Takele Gemeda, and Jiajun Xu

10:45 AM **Thermal Analysis of Spacecraft using Data Assimilation**
TFAWS19-ID-03
Hiroto Tanaka, Hiroki Nagai, and Takashi Misaka

11:15 AM **Qualification of Reusable Components for Launch Vehicles**
TFAWS19-ID-11
Michael O'Malley

Aerothermodynamic CFD Analysis Short Course

9:00 AM – 11:15 AM, Grand Ballroom IV

Instructor: Kyle Thompson (LaRC)

This presentation provides an introduction to two Computational Fluid Dynamics (CFD) codes, LAURA and FUN3D, which have been developed and widely used at NASA Langley Research Center in Entry, Descent, and Landing applications. A workflow using the LAURA and FUN3D CFD codes to predict aerodynamic and aerothermodynamic engineering quantities is presented. The presentation will cover the basics of setting up and running simulations using both CFD codes, as well as how to post-process results obtained from each code. More advanced topics will also be presented, including a state-of-the-art uncertainty quantification approach to be included in the next LAURA release, and a new geometry-based workflow used with FUN3D focused on replacing user-defined meshing with an adaptation-based approach.

PyTecplot Hands-On Training

10:15 AM – 12:15 PM, Blue Point I

Instructor: John Goetz (Tecplot)

In this class you'll get hands-on with PyTecplot, the Python API to Tecplot 360. We'll start you off easy, with installation and how to record PyTecplot scripts. By the end of the class you'll know how to load data from arbitrary file formats and how to perform post-processing tasks in parallel. We'll leave you with reference scripts, example data, and tips and tricks to post-process your data quickly and efficiently.

Thursday Lunchtime

12:15 PM – 1:15 PM, Grand Ballroom II
Speaker presentation starts at 12:30 PM

"Speed and Innovation in the America's Cup"

Speaker: Jeanne Willoz-Egnor, Director of Collections Management and Curator of Scientific Instruments, The Mariner's Museum and Park

All conference attendees are allowed to attend the lunch speakers; however, no outside food is permitted. Pre-purchased lunch tickets are required for hotel-provided food. For attendees choosing to attend the speaker without having pre-purchased tickets, theater-style seating will be provided.

Lunch Menu: Roast Beef on a pretzel roll, fresh baked cookie, and a bag of chips. Includes Coffee, Iced Tea and Iced Water. Attendees who noted dietary restrictions during registration will receive comparable meals for all purchased lunches.

Speaker biographies can be found at the end of the conference program.

Thursday Afternoon Sessions

***ITAR Paper Session 3: Passive Thermal**

1:30 PM – 2:00 PM, Grand Ballroom IV

Session Chairs: Eric Groß (GSFC), Eric Malroy (JSC), and Ruth Amundsen (LaRC)

*ITAR session attendance is restricted to US Citizens and US Lawful Permanent Residents only. Those wishing to attend must have their TFAWS badges stamped at the registration desk. NASA civil servant ID, JPL ID, or a signed TFAWS 2019 ITAR Certification Form is required to receive stamp. To enter the ITAR session, attendees must present stamped badge and valid picture ID.

1:30 PM **NASA's SLS Launch Vehicle Cross-Element/Cross-Program Thermal Integration (ITAR)**
TFAWS19-PT-16
Callie McKelvey, Brian Hamill, and Patrick Junen

Siemens Simcenter T3STER Demonstration

1:30 PM – 2:30 PM, Grand Ballroom V

Presenter: Joe Proulx (Siemens Digital Industries)

The presenter will provide a short overview on thermal transient testing aimed at the quick and accurate thermal characterization of semiconductor components. He will introduce the T3Ster equipment, and demonstrate how this method can help capturing semiconductor junction temperatures accurately in-situ, without using any traditional external thermal sensor. The captured test data will be processed in order to help understanding the thermal properties of each layer in package structure and also the performance of the external cooling jig.

The presenter will explain how this technology supports package thermal design, material selection, process refinement, generating package thermal metrics and even creating better thermal simulation models.

Thermal Analysis Results Processor (TARP) Hands-On Training

1:30 pm – 5:15 PM, Blue Point I

Instructor: Hume Peabody (Thermal Modeling Solutions)

TARP is a Windows based post processing program that creates an interface between the ASCII output from numerous thermal analysis solvers and Microsoft Excel. Users define the post processing objects within the TARP environment to create in the output Excel workbook, including: DataSets, Plots, Tables, etc. A user also has the ability to define further data points, such as group averages, maximums, and minimums. Lastly, a feature exists for the creation of a specialized workbook for the evaluation of nodal heatflows, which can be further extended to heatflows between the defined groups.

Intro to Thermal Synthesizer System (TSS) Hands-On Training – Part 3

1:30 pm – 5:15 PM, Blue Point II

Instructor: Joe Lepore (Spacedesign Corporation)

This hands-on class will progress through a thermal analysis of a spacecraft using version v15.01. The student will go through each major step in the analysis process using a simple example. This is the basic framework needed to create, analyze, and obtain temperatures using TSS. The spacecraft model will begin as a CAD file, which is moved into TSS by using the Transfer application. As each TSS application is used, user interface and TSS features are demonstrated by the instructor and utilized by the student. Calculations of radks, heating rates, conduction/capacitance network, and temperatures are performed. The latest TSS capabilities demonstrated in this class include the return of the Executive application for Windows and SindaWin application. Everyone interested in learning how to perform satellite thermal analysis should attend this class.

Passive Thermal Paper Session 3

2:00 PM – 5:15 PM, Grand Ballroom III

Session Chairs: Eric Groß (GSFC), Eric Malroy (JSC), and Ruth Amundsen (LaRC)

2:00 PM **Variable View Factor Two-Phase Radiator**
TFAWS19-PT-02
Andrew Lutz and Calin Tarau

2:30 PM **Modelling of Radiative Heat Transfer of a Square Trihedral Design Radiator Panel on the Lunar Surface**
TFAWS19-PT-03
Colin Butler, Ronan Flanagan, Jeff Punch, and Nick Jeffers

3:00 PM **Optimizing Thermal Radiator Designs Using the Veritrek Software**

TFAWS19-PT-06
Lina Maricic, R. Scott Miskovish, Jacob Moulton, and Derek Hengeveld

3:30 PM **Break**

3:45 PM **Thermal Vacuum Testing and Feasibility Investigations for VO_2-Based Variable Emittance Coatings**
TFAWS19-PT-13
Sydney Taylor and Liping Wang

4:15 PM **Using Thermal Desktop for Heater Design in Thermal Vacuum Chambers**
TFAWS19-PT-05
Tayera Ellis and Ryan Noe

4:45 PM **A Streamlined Approach to Spatial Mapping of Complex 3D Thermal Boundary Condition Data**
TFAWS19-PT-18
Robert Hawkins and Carl Poplawsky

Aft Body Heating on Blunt Hypersonic Vehicles (ITAR*)

2:00 PM – 5:15 PM, Grand Ballroom IV

Instructors: Karl Edquist (LaRC), Richard Thompson (LaRC), Adam Wise (LaRC), Christopher Johnston (LaRC)

*ITAR session attendance is restricted to US Citizens and US Lawful Permanent Residents only. Those wishing to attend must have their TFAWS badges stamped at the registration desk. NASA civil servant ID, JPL ID, or a signed TFAWS 2019 ITAR Certification Form is required to receive stamp. To enter the ITAR session, attendees must present stamped badge and valid picture ID.

The complex flow associated with the aft-body of blunt (re)entry vehicles poses unique challenges in physical understanding and prediction of the aerothermodynamic environment. In typical thermal protection systems (TPS), it is desired to use thinner and less dense materials in the aft region for weight savings and better mass distribution, so the accuracy of engineering heating models is important for design and vehicle thermal management. This short course will give an overview of issues in modelling the aft-body environment including topics such as flow separation, radiation, reaction control jet (RCS) interaction, and feature modelling. The challenges and solutions derived for current NASA programs (e.g. Mars2020, Orion) will be presented during the course.

Siemens Simcenter AMESim Demonstration

2:30 PM – 3:30 PM, Grand Ballroom V

Presenter: Olivier Broca (Siemens Digital Industries)

The presenter will provide a short overview of the Simcenter AMESim systems simulation environment for thermal fluid systems. He will demonstrate how many satellite and launcher subsystems can be modeled in their entirety and with a high degree of fidelity using validated libraries of physical components and allowing. From cryogenic propulsion to satellite thermal management and actuator systems, the foundation of this method allows for a thorough energetical analysis and optimization of the systems.

MSC SINDA and Thermica Demonstration

3:45 PM – 4:45 PM, Grand Ballroom V

Presenter: Lixin Zhao (MSC)

MSC Sinda is a world-class advanced thermal analyzer with 56 years of proven track record in the aerospace and high tech arenas. Since 1982, Sinda has become an industry standard with hundreds of companies and organizations. MSC Sinda fully integrates with MSC Patran and MSC Thermica and provides the best thermal analysis solutions for MSC users.

This demo shows the steps to build satellite models in MSC Patran, set up Trajectory (Orbit), Kinematics (Pointing), and Mission in MSC Thermica to compute orbital fluxes and radiation exchange factors, and call MSC Sinda (called SINDA/G before 2008) to calculate temperature, heat flux, and temperature gradient results. The demo will also show the advanced features of MSC Thermica mission management.

Thursday Evening Activities

NASA Delegates' Meeting

5:30 PM – 7:00 PM, Blue Point III
NASA Civil Servants and JPL Only

The purpose of this meeting is to provide annual face-to-face discussion among colleagues in the thermal and fluids fields from all Centers. Topics may include (but are not limited to) lessons learned and future plans for TFAWS, discipline best practices, current issues within disciplines, and ideas for improvement.

Food and beverages may be purchased from the hotel restaurant and brought into the meeting room. Attendees may pre-order at the bar during the afternoon break, if desired.

Networking Social – Traditions Brewing Company

5:30 PM, 700 Thimble Shoals Boulevard

Come and enjoy an evening with your colleagues and enjoy some local brews. Traditions is a 0.8 mile walk from the conference venue. You can meet the walking group in the lobby at 5:30 PM or make your way over at your convenience.

Stuft Tacos (stuftstreetfood.com) will be providing dinner at the Traditions Brewery Networking Social for individual purchase. Veggie options are available. *No federal endorsement implied.*

Friday, August 30, 2019

Langley Research Center Tour 2

8:00 AM – 12:00 PM
Meeting point:
Reservation Required

The tour will visit three sites, including the National Transonic Facility, 31-Inch Mach 10 Air Tunnel and the Integrated Structural Assembly of Advanced Composites/ISAAC (tour stops are subject to change and will depend on the size of the tour group). More detailed descriptions of the tour stops can be found at the end of the conference program.

Transportation will be provided. Tour attendees should meet in the hotel lobby no later than 7:55 AM.

Thermal Desktop Open Lab 2

8:00 AM – 10:00 AM, Blue Point I
Monitor: Douglas Bell and Matt Garrett (CRTech)

Do you have a question about CRTech software? The CRTech Open Lab provides an opportunity for in-person customer support. Bring a model or bring a laptop (with the software already installed). If you cannot make one of the Open Lab sessions, feel free stop by our display booth.

Intro to Thermal Synthesizer System (TSS) Hands-On Training – Part 4

8:00 AM – 12:00 PM, Blue Point II
Instructor: Joe Lepore (Spacedesign Corporation)

This hands-on class will progress through a thermal analysis of a spacecraft using version v15.01. The student will go through each major step in the analysis process using a simple example. This is the basic framework needed to create, analyze, and obtain temperatures using TSS. The spacecraft model will begin as a CAD file, which is moved into TSS by using the Transfer application. As each TSS application is used, user interface and TSS features are demonstrated by the instructor and utilized by the student. Calculations of radks, heating rates, conduction/capacitance network, and temperatures are performed. The latest TSS capabilities demonstrated in this class include the return of the Executive application for Windows and SindaWin application. Everyone interested in learning how to perform satellite thermal analysis should attend this class.

Paper Abstracts

Active Thermal Paper Session 1

TFAWS19-AT-01

“Two-Phase Cooling System Through Loop Heat Pipes”

Togaru Lavanith and Ganesh Kumar

A loop heat pipe (LHP) is a two-phase heat transfer device that uses capillary action to remove heat from a source and passively move it to a condenser or radiator. LHPs are similar to heat pipes but have the advantage of being able to provide reliable operation over long distance and the ability to operate against gravity. They can transport a large heat load over a long distance with a small temperature difference. This paper summarizes the new design, computational fluid dynamics (CFD) and thermal analyses of loop heat pipe (LHP) wicks (primary and secondary wicks). The project was motivated to evaluate the best performance conditions of LHP for an increase in effectiveness with reduction of cost in production by employing selective laser melting (SLM) an additive manufacturing technology The work was completed in a multi-step process. Key aspect for achieving the optimum performance of loop heat pipe is to ensure that the wick structure and its appropriate assemblage perform within their original thermal-physical design specifications for this first LHP wicks was designed to control the porosity and to increase its permeability, which is not possible in traditional manufacturing practice (sintering). To enhance the working efficiency and to increase LHP effectiveness by using different working fluids, wick material, shape of different parts of LHP are analyzed using CFD and thermal analyses tools. From CFD results, the design was optimized and parts of LHP were redesigned accordingly, this design is made compatible with the additive manufacturing (AM) technique SLM for fabrication of LHP wick(s) which is advantageous to control its geometric size of the internal wick passages, aiming to achieve an optimal design according to the specified requirements. It highlights the relevance of this optimization procedure in the performance from the start-up behavior under different working conditions: input power, ambient temperature and mass charge.

TFAWS19-AT-02

“Experimental and Numerical Analysis of Flat Plate Loop Heat Pipes Thermal Resistance Performance”

Shahid Manik, Jin Jin, Y. Guang, and Wu Jingyi

The article is an experimental and numerical analysis of flat plate loop heat pipes thermal resistance performance. The loop heat pipe (LHP) used to two-phase heat transfer device which the operation of latent heat, capillary pressure, and vaporization of working fluid for heat transfer. LHP can be employed for wider application areas, especially for advanced technology, it can be used for satellite thermal control devices. The improvement of LHP devices thermal performance can be achieved through experimental and theoretical analysis and considerable advantage can be gained on the heat sink and heat load variation of LHP. In this paper, a heat load range from 75W – 260W is analyzed and a temperature range from 75°C – 145°C. The corresponding minimum values of the intimal Thermal resistance of the devices are 0.27°C /W, and the maximum one is 1.12°C/W 0.89°C/W and 0.54°C/W, under the consideration of 10°C, 20°C and 30°C heat sink temperature respectively. The evaporator wall temperature according to corresponding sink temperatures of 10°C, 20°C and 30°C , were investigated to be; 116.7°C, 120.2°C 123.64°C respectively which equals to 100W power input. Numerical models were developed to aid in the design phase of the study by estimating the properties of different heat sink temperature, calculating fluid inventory, and sizing the compensation chamber. The models also provide the foundation for future work one ethylene glycol will be cooling and R134a should be working fluid to predict operational characteristics such as steady-state temperatures and LHP total thermal resistance, system pressure drop and mass flow rate for any given design.

TFAWS19-AT-04

"Advances in Cost Effective Thermal Management for Small Satellites"

Chien-Hua Chen and Ryan Spangler

As the capabilities of small satellites increase, so do the thermal spreading and heat rejection requirements. A thermal management strategy must be able to handle relatively high heat fluxes from high power electronic components, and be capable of transporting heat to radiators with minimal temperature drop. In this work, two advancements in cost effective thermal management technologies are presented. These are freeze tolerant copper-water heat pipes for heat spreading/transport, and 3D printed loop heat pipes (LHPs) for heat transport to deployable radiators.

Copper-water heat pipes are a well-established and cost-effective method of heat spreading used for high power electronics in many terrestrial applications. However, copper-water heat pipes have not been used in space due to concerns with freezing water leading to vessel failure, and a lack of testing in a microgravity environment. Freeze tolerant copper-water heat pipes were fabricated by precisely controlling the AMount of water in each heat pipe to prevent the presence of free liquid which could cause the heat pipe to burst due to expansion during the freezing process. Testing was conducted aboard the International Space Station (ISS) under the Advanced Passive Thermal eXperiment (APTx) project funded by the ISS Technology Demonstration Office at NASA JSC. The heat pipes were embedded in a high conductivity (HiK™) aluminum base plate and subject to a variety of thermal tests over a temperature range of -10 to 38 ºC for a ten-day period. Results showed excellent agreement with both predictions and ground tests. The HiK™ plate underwent 15 freeze-thaw cycles between -30 and 70 ºC during ground testing, and an additional 14 freezethaw cycles during the ISS testing. Additional ground testing (powered freeze-thaw, cold start) have been completed and support the argument for copper-water heat pipes as a reliable and robust technology available for space.

While Loop Heat Pipes (LHPs) are capable of transporting heat across deployable radiators, they are currently too expensive and take too long to fabricate for most small satellite applications. The largest cost comes from the fabrication of the primary wick which requires multiple machining steps as well as a knife-edge seal. 3D printing of LHP wicks using a direct metal laser sintering (DMLS) process offers several advantages. The overall cost can be significantly reduced by eliminating multiple machining steps, the risk of failure can be reduced by eliminating a knifeedge seal between dis-similar metals, and full pump bodies can be produced in a fraction of the time. The challenge with 3D printing of LHPs is achieving a porous wick structure. A pore radius and permeability study was conducted for optimization of DMLS methods and parameters for fabricating porous wick structures. A pore radius of 5-7µm was achieved using stainless steel. A complete LHP prototype with 3D printed primary wick was fabricated using the optimized DMLS parameters. A maximum power of 125W was achieved during steady state testing with AMmonia as the working fluid. Additional tests on the prototype were completed including adverse elevation, power cycles, sink temperature cycles, and low power start-up.

TFAWS19-AT-09

"Numerical Simulation of Transient Behavior of Vapor-Liquid Distribution in a Loop Heat Pipe"

Takuya Adachi, Koji Fujita, and Hiroki Nagai

Loop heat pipes (LHPs) are highly efficient heat transfer devices, which utilizes the phase-change of working fluid. An LHP has an evaporator, vapor line, condenser, liquid line, and reservoir. The working fluid evaporates and absorbs heat in the evaporator. The vapor generated in the evaporator goes to the condenser, and the heat is released by condensation. The porous wick in the evaporator produces the capillary force, which is a driving force of the LHP. Therefore, the LHP can work without electric power and transport a large AMount of heat over a long distance. Due to these advantages, many LHPs are used for thermal control of the spacecraft.

The startup is one of the significant problems for the LHP. Although the LHP must start its operation successfully, the LHP sometimes fails its startup. So far, the vapor-liquid distribution in the evaporator is considered important for a startup. When the vapor groove is filled with liquid, nucleate boiling must occur, and the superheat of nucleate boiling causes the startup failure. However, some experiments indicated that the vapor-liquid distribution in the vapor line, condenser, and liquid line also affected the startup characteristics.

It is difficult to visualize the vapor-liquid distribution in the entire LHP in an experiment. Numerical simulation is useful to investigate the internal vapor-liquid distribution. However, the vapor-liquid distribution in the previous mathematical model of the LHP is assumed to be ideal, and the influence of the distribution cannot be understood. In this study, we developed a numerical model of an LHP using the Volume of fluid method. The numerical model can reproduce the different vapor-liquid distribution in the LHP.

TFAWS19-AT-11

"Thermohydraulic Characterization of Additive Manufactured Heat Exchangers using Lattice Structure"

Aurelien Conrozier, Damien Serret, and Jean-Michel Hugo

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more process fluids. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally, they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperators.

The development of new classes of heat exchangers is ever in progress, both for seeking to reduce the volume of the heat exchanger and to enhance the performances in terms of pressure drop or heat transfer capacity. Clearly, studies in these fields also consider the methods of design, the numerical tools to investigate the performances of a heat exchanger, and also the times that such a tool requires for a reasonable (Bejan A., 2008) (Caputo AC, 2008) (Bejan A, 2011) (Yang J, 2014) (You Y, 2015).

Heat exchangers are commonly used to cool hydraulics, rammed air, auxiliary power units, electronic components, and many other components that consist of a spaceship. At high altitudes, the density of air is drastically lower, so it takes more airflow to remove the same AMount of heat. In space, there is only radiation and storage due to absence of Air. Compact heat exchangers are particularly suitable for the aerospace applications due to their less weight, greater compactness, and higher performances due to the improved heat transfer surfaces. In aerospace industries, furthermore, attention is paid on size and weight without compromising on performance aspects. An elementary channel of heat exchanger and a porous approach simulation of the device.

In this paper, we will present the work funded by European Union under the of NATHENA project. First, a short review of heat exchanger optimization using additive manufacturing is made. We will, then, present a study dealing with the development of a porous approach to design heat exchanger and present this relationship between additive manufactured geometry and thermo-hydraulic performances. Both numerical and experiment study is made in order to predict performances.

TFAWS19-AT-16

"Fully Resolved Numerical Simulations of Complex Multiphase Flows"

Jiacai Lu and Gretar Tryggvason

Detailed numerical simulations of multifluid and multiphase flows have advanced significantly during the last two decades and it is now possible to simulate fairly complex flows accurately. Results are available for low Reynolds number laminar flows in complex geometries and turbulent flows containing bubbles and drops, as well as flows with more complex physics, such as heat transfer and thermocapillary motion, electrostatic effect on droplet flows, boiling and solidification. We briefly reviewing a hybrid Eularian/Lagranian method, where the governing equations are solved on a fixed structured grid and the fluid interface is followed by connected marker particles, forming a moving unstructured grid. Then we focus on recent results for flows with massive topology changes, including the challenges of how to rupture interfaces and what effect the modeling of the rupture has on statistical quantities. The effect of the Weber number and the void fraction on turbulent multiphase flows in vertical channels is examined and how to best characterize such flows. Various multiscale aspects of multiphase flow simulations, including how to capture small scale features using embedded analytical descriptions, as well as the use of machine learning for closure modeling and interface retaining coarsening for complex interfacial flows are also addressed.

Active Thermal Paper Session 2

TFAWS19-AT-03

"24 Hour Consumable-based Cooling System for Venus Lander"

Kuan-Lin Lee and Calin Tarau

A reliable thermal management system that will enable at least 24-hours of operation of Venus landers in the extreme environment (460°C, 92 bar) is highly desirable for NASA future Venus in-situ exploration missions. ACT has developed a novel thermal management system for 24 hour-life Venus landers utilizing a consumable-based cooling concept. Through venting a mixture of consumable fluid consisting of a two-phase working fluid (ammonia) and a compressed gas (e.g. helium) into Venus ambient, the proposed system is able to manage both internal electronics heat load as well as the incoming environmental heat leaks from Venus ambient for at least 24 hours. The consumable-based cooling concept was fully demonstrated in Phase I through mathematical modeling, prototype testing and numerical simulation. ACT showed that by adding compressed gas into a venting vessel that contains working fluid at saturation, the resulted mixture can be vented into a higher-pressure environment than the vapor pressure corresponding to the payload setpoint. As a bonus, a heat guarding system with multilayer structure is designed to utilize the remaining sensible heat capacity of the mixture to collect and further vent the incoming environmental heat leaks.

TFAWS19-AT-07

"Post Launch and Early Mission Thermal Performance of Parker Solar Probe through the First Two Solar Orbits"

Carl J. Ercol and G. Allan Holtzman

Parker Solar Probe (PSP) will explore the inner region of the heliosphere through in situ and remote sensing observations of the magnetic field, plasma, and accelerated particles. PSP will travel closer to the sun [9.86 solar radii (RS)] than any previous spacecraft to obtain repeated coronal magnetic field and plasma measurements in the region of the sun that generates the solar wind. The mission will entail 7 years from launch on 12 August 2018 until the completion of the 24th orbit, projected to be on 19 June 2025. During its lifetime, the spacecraft will be exposed to wide-ranging thermal environments, from the cold of Venus eclipse to exposures to the sun's corona that produce a mission minimum perihelion of 9.86 RS and equivalent solar constant in excess of 480 suns. Spacecraft power is generated using photovoltaic solar arrays that are actively cooled by the SACS (Solar Array Cooling System manufactured by Collins Aerospace). This paper will discuss the thermally critical post-launch SACS activities and also provide an overview of the SACS and spacecraft thermal performance through the mission's first two solar orbits that each have identical perihelion of 35.7 Rs (38 suns).

TFAWS19-AT-13

"P1 External Active Thermal Control System (EATCS) Ammonia Leak on the International Space Station (ISS)"

Darnell Cowan, Timothy Bond, and Jordan Metcalf

Ammonia is used in the Starboard 1 (S1) and Port 1 (P1) External Active Thermal Control System (EATCS) to cool the pressurized modules, and some of the external electrical power distribution hardware. Leaks that develop in these critical cooling systems that deplete in-line tanks can ultimately result in loss of cooling, which can have devastating impacts to the mission, science and crew onboard the ISS. A slow AMmonia leak was initially observed from the P1 EATCS in 2011, but later in 2013 the leak rate began to accelerate. The AMmonia inventory eventually began to decay exponentially, raising concerns that the inventory could drop to levels where the system would not be operational.

The Robotic External Leak Locator (RELL) was built and launched to the ISS to detect and help locate AMmonia leaks using the ISS Robotic Arm and remote ground operator control without constant crew involvement. RELL pinpointed the AMmonia leak to the two flexible jumper hose assemblies connecting one of two fluid loops in one of the three deployable radiators to the P1 EATCS. The AMmonia inside the two hose assemblies and that radiator fluid loop was isolated and vented to space in 2017. This stopped the leak and an Extravehicular Activity was conducted to remove the two hose assemblies so they could be returned to ground for further Test, Teardown and Evaluation (TT&E). The purpose of this presentation is to discuss this leakage scenario and the TT&E efforts.

TFAWS19-AT-12

"Demonstration Testing for Ground Servicing of the Commercial Crew Vehicle Emergency Breathing Air Assembly (CEBAA)"

Kristina Gonzalez and Zachary Shaver

The new Commercial crew vehicle Breathing Air Assembly (CEBAA) is a Composite Overwrapped Pressure Vessel (COPV) filled with high-pressure air, which is designed to provide portable emergency breathing air for up to five crew in the event of an AMmonia leak aboard the International Space Station (ISS). Industrially, several common methods of delivering breathing air exist; however, ground processing constraints and flight requirements necessitate the more unusual approach of servicing a COPV with high purity gaseous nitrogen and oxygen serially to achieve a specific mixture of breathing air at approximately 4000 PSIA. A dwell period allows the gases to mix before sampling for composition verification. The novelty of this approach led to concerns about acceptable gas mixing and the ability to deliver accurate gas compositions. Tests examining mixing rate over a series of post-servicing dwell periods were conducted to determine the optimal time for achieving a homogeneous mixture. Further testing was conducted to examine process accuracy using temperature-pressure load criteria to target a specific concentration of oxygen and nitrogen. Test results show that while some stratification of nitrogen and oxygen was observed, a seven-day dwell is adequate time to achieve an acceptable level of mixing, and that existing ground support equipment can accurately service CEBAA COPVs to the required temperature, pressure and composition for flight.

TFAWS19-AT-14

"Calculation of Radiative Fin Performance Parameters for Radiator Analysis using Numerical Methods"

Louis Jorski

Active radiators have historically provided the only source of heat rejection for long duration manned spacecraft, and consequently, they are integral components of such vehicles. In basic, functional form, a spacecraft radiator consists of a series of tubes bonded to a highly conductive sheet with a specialized surface coating to maximize its radiative heat loss. Effectively, the radiator surface functions as a series of fins which extend the surface areas of the individual flow tubes. As with all fins, as the distance from the heat source increases, the temperature of the surface decreases due to the conductive resistance of the material. Consequently, some measure of how effectively this sheet extends the heated surface area is required to accurately predict a radiator's performance.

The preferred measure of a radiator surface's performance is a fin efficiency curve which is simply the ratio of a fin's actual heat rejection to the heat rejection which would be attained if the entire surface were heated to the source temperature. Once computed, fin efficiency curves are a valuable tool for optimizing radiator configurations and rapidly predicting heat rejection. Unfortunately, despite its simplicity in form and use, calculating the fin efficiency for a given configuration is a surprisingly challenging task. The difficulty lies in the basic governing equation for extended surface heat transfer. When applied to radiative fins, this equation becomes a nonlinear second order differential equation which cannot be fully solved analytically.

Historically, several methods were developed to overcome this impasse, but they relied upon looking up the values of specialized nondimensionalized parameters from families of pre-calculated curves, and while they were capable of yielding useful results, these methods were not very efficient or precise. In more recent years, a variety of methods have been developed to evaluate multi-mode heat transfer from extended surfaces which could be applied to spacecraft radiators, but they are far more complex than needed for this relatively simple application.

Consequently, an improved method of calculating radiative fin performance tailored to this specific situation has been developed. This methodology utilizes some processes developed by the historical solution methods to transform the governing equation into a suitable form, but then leverages basic numerical techniques to develop a solution to the resultant expression. The end result is a fairly straightforward algorithm which can be coded in any standard programming language and yields highly accurate results with minimal computation time. Although originally created to calculate efficiency curves, to this approach can also be modified to calculate other useful parameters such as normalized heat rejection and surface temperature distribution.

In order to validate the results, this solution method was used to calculate the efficiency curve for the International Space Station's radiators, and the result were compared to the efficiency curve embedded in the original space station thermal model. This comparison showed good correlation between the curves, but it also highlighted the fact that unlike convective fins, the efficiency curves for radiative fins do vary with operating temperature. Consequently, a brief investigation into the sensitivity of radiative fin efficiency curves to the various input parameters is also presented.

Aerothermal Paper Session

TFAWS19-AE-05

"Aerodynamic and Aerothermal Simulations of Mars Concept Vehicles using Overset DPLR"

Chun Tang

NASA's Descent System Studies (DSS) Program is studying various concept vehicles to enable landing of heavy payloads on the surface of Mars. Due to the complex geometry of these designs, an overset approach is used to run high-fidelity CFD simulations at flight and wind tunnels conditions. This paper describes a simple process of generating overset grids that are suitable for hypersonic aerodynamic and aerothermal analysis: grids that can be easily sequenced, reclustering of the mesh spacing at the wall surface, and grid alignment with the bow shock. The current methodology is tested on a lifting-body configuration using the overset DPLR code.

TFAWS19-AE-04

"Aeroheating Measurements of BOLT Aerodynamic Fairings and Transition Module"

Elizabeth Rieken and Scott Berry

The Air Force Office of Scientific Research (AFOSR) has sponsored the Boundary Layer Transition (BOLT) project with an objective to investigate hypersonic boundary layer transition mechanisms on a complex geometry. Johns Hopkins University Applied Physics Laboratory is overseeing the BOLT team, which includes members from across government, academia, and industry. Progressing from the Hypersonic International Flight Research Experimentation Program (HIFiRE) axisymmetric circular cone (HIFiRE-1) and nonaxisymmetric elliptical cones (HIFiRE5A/HIFiRE-5B), the BOLT geometry is a low-curvature concave surface with swept leading edges. The BOLT experiments are designed to use numerical prediction tools and ground-test campaigns to estimate transition on the BOLT geometry. The project will culminate in a sounding rocket flight experiment to test the prediction effort.

The BOLT sounding rocket flight experiment is made-up of the BOLT experimental payload, or "Flight Geometry", the Payload System, which includes systems to support data acquisition, telemetry, and GPS, and the Launch Vehicle System which consists of a two-stage sounding rocket stack. Leading up to the BOLT Critical Design Review (CDR), there was a concern about the interface between the BOLT Flight Geometry and the Payload System. Aerodynamic fairings were deemed necessary to reduce flow separations and reattachments on the Transition Module (TSM) portion of the Payload System. One month prior to the CDR, the team at NASA Langley received the final aerodynamic fairing design and ran a fast-paced wind tunnel test to investigate and identify any aeroheating issues on the fairings and TSM for inclusion in the CDR proceedings. Additional numerical modeling work has been done by JHU/APL and the Air Force Research Laboratory (AFRL) to look at the complex flow field that the BOLT geometry creates on the fairings and TSM. Comparisons of experimental and numerical data are ongoing.

The focus of this presentation is aeroheating measurements from the NASA Langley 20-Inch Mach 6 Air Tunnel on the fairing and TSM sections of the BOLT flight research vehicle. The presentation will detail the wind tunnel model, test conditions, data reduction, and results. It will summarize the main trends seen in the global aeroheating data and include heating analysis of offnominal flight conditions for application to TSM thermal protection decisions.

Cryothermal Paper Session

TFAWS19-CT-02

"CFD Modeling of Cyrogenic Chill-down through a Complex Channel"

Justin Pesich

Future NASA architectures have baselined cryogenic propulsion systems as well as cryogenic fluid management to support lunar missions and ultimately to support future missions to Mars. These missions will require chilling hardware down prior to engine restart as well as chilling lines and tanks prior to transferring and refueling these propulsion elements in orbit. In lieu of expensive tests conducted on-orbit, accurate predictive computational models of these chill-down processes can be used to reduce system and propellant mass as well as mission risk. To gain confidence in these computational models, appropriate anchoring and validation to experimental data in a relevant environment needs to be performed. Recent ground and sub-orbital flight experiments conducted by the Japan Aerospace Exploration Agency (JAXA) investigated chill-down of a complex channel resembling a turbo-pump bearing cavity at low flow rates. This work presents Computational Fluid Dynamics (CFD) model development of the chill-down experiment employing two-phase flow boiling models available in commercial CFD software STAR-CCM+ using Volume of Fluid (VOF) and the traditional Euler-Euler multiphase flow solvers. Preliminary comparisons of the numerical and experimental results under terrestrial and low-gravity conditions are presented. An assessment of solid wall temperatures and flow structures yielded important insights into multiphase solver choice, dependence on gravity environment, and challenges associated with cryogenic flow boiling prediction and validation.

TFAWS19-CT-01

"Optimization of Design and Computational Fluid Dynamic Analysis of Cryogenic Loop Heat Pipe"

Togaru Lavanith, Sirivolu Akilesh, and Nagananthan Karthik

Cryogenics is the branches of engineering that involve the study of very low temperatures, how to produce them, and how materials behave at those temperatures. Like a Loop Heat Pipe (LHP), a Cryogenic Loop Heat Pipe (CLHP) is a passive two-phase heat transport system that utilizes the capillary pressure developed in a fine pore evaporator wick to circulate the system's working fluid.

This paper summarizes the new design, computational fluid dynamics (CFD) analysis of Cryogenic Loop Heat Pipe (CLHP). The work was completed in a multi-step process. In which total CLHP is redesigned to improve the working efficiency and to increase effectiveness by using different working fluids, wick material, shape of different parts of CLHP are analyzed using CFD. These CFD results were aimed to achieve an optimal design according to the specified requirements.

Interdisciplinary Paper Session 1

TFAWS19-ID-09

"Thermal Characterization of SiC MOSFET Devices"

Andras Vass-Varnai

To determine the thermal properties of power semiconductor devices and structures, the JEDEC JESD 51-1 static, electrical test method is a well-known and industry-wide accepted technique. The approach provides accurate and repeatable results in case of silicon based transistors in all cases. For certain compound semiconductor components, such as SiC MOSFET-s and GaN HEMT structures, the application of the electrical test method becomes in some cases challenging. If traditional test setups are used, in the unit step response function, due to parasitic effects, an electric signal may superpose on the thermal signal of interest, making it hard or even impossible to analyze the test results. If the structure has a physical diode as well, it can be used to understand the thermal properties of the package and its layers. This information can be applied in another step to gather the thermal properties from die transistors' point of view as well, without measuring it. In this article we will show a combined measurement and simulation based method, which allows the accurate thermal characterization of such components, even if other approaches may fail.

TFAWS19-ID-05

"Thermal Vacuum Chamber Calibration with 12U Cubesat Model"

Nathan Cordrey and Chris Strickland

Gradients within the thermal vacuum chamber is a known issue many thermal engineers face during testing. Thermal vacuum chamber control systems vary from chamber to chamber, and between test facilities. All with different trades in regards to performance and cost. The objective of this study is to understand the thermal characteristics of the thermal vacuum chamber at Wallops Flight Facility in F-7. This methodology is repeatable to chambers across NASA to improve the knowledge of the thermal conditions during testing.

The thermal vacuum chamber at Wallops Flight Facility is of particular interest due to its unique design. The chamber has the added functionality to control particular zones of the chamber individually with 12 separate shrouds. This increased functionality comes at the cost of additional complexity. This paper develops a methodology to test the thermal characteristics of the chamber utilizing a mock 12U satellite.

The mock satellite design thermally isolates each face of the 12U satellite in order to understand what each section of the chamber is radiating to the test article. Each face of the satellite has one heater in order to test the thermal predictive capability of the chamber thermal model. The mock satellite was tested in the chamber at -80°C, -40°C, and 40°C.

This test provided important characterization data on the Wallops Flight Facility thermal vacuum chamber in F-7. The chamber was successfully able to provide a stable temperature to the payload. However, it did bring awareness to a significant difference between the set control temperature and the chamber temperature, especially at extreme temperatures. This chamber calibration process is repeatable at thermal chambers across NASA and industry of varying types to improve understanding of the thermal characteristics during testing to improve payload reliability.

TFAWS19-ID-18

"Thermal Analysis and Testing of the 12.5 kW HERMeS Hall Thruster"

Sean Reilly, Robbie Lobbia, Ryan Conversano, and Rich Hofer

The Hall Effect Rocket with Magnetic Shielding (HERMeS) is a 12.5 kW electric propulsion thruster designed for interplanetary solar electric propulsion (SEP). Solar electric propulsion is an extremely mass efficient means for generating propulsion and enables many different types of missions. Hall thrusters present many exciting opportunities to explore our solar system but come with some unique thermal challenges associated with their operation. An environmental test campaign on the HERMeS thruster was carried out at the Jet Propulsion Laboratory in 2018 in which the HERMeS thruster was operated at steady state temperature extremes in order to develop a better understanding of the potential operating limits of the thruster. The thruster was repeatedly started from a "cold-fire" condition of -120°C and operated in a simulated 0.8AU environment. The thruster was then switched off and re-started to test its "hot-fire" capability. Three thermal cycles were completed and provided a wealth of data informing future high power hall thruster designs. This paper will detail the thermal test design, implementation, and results of the HERMeS environmental test. Some of the unique challenges associated with this type of test and analysis will be discussed, in addition to some of the future challenges and opportunities for high powered Hall thruster thermal designs and developments.

TFAWS19-ID-19

"Assembly and Integrated Systems Testing for the Flow Boiling and Condensation Experiment (FBCE)"

Jesse deFiebre and Monica Guzik

The Flow Boiling and Condensation Experiment (FBCE) is a flight experiment that is designed to operate in the Fluids Integrated Rack (FIR) on the International Space Station (ISS). The objective of the FBCE is to develop an integrated two-phase flow experiment that will serve as a primary platform for obtaining flow boiling and condensation heat transfer data in microgravity. This data will enable the design and analysis of two-phase thermal management systems for future NASA missions that require increased efficiency beyond the current single-phase systems. The FBCE consists of seven modules, each of which must link together mechanically, electrically, and fluidically upon final integration. Five of the modules provide the fluidic and electronic components required to bring the test fluid to the inlet conditions required by the test module, where the primary science is conducted. These inlet conditions encompass fluid quality ranging from a superheated vapor to a subcooled liquid at a variety of flow rates and pressures. The FBCE is currently manufacturing two test modules, each of which has its own separate test campaign with the five support modules. Each of the modules presents a unique challenge in its assembly and checkout, particularly related to ensuring the final hardware configuration can meet the fluid and thermal requirements levied upon them. Following assembly, a series of flight verification tests will be performed, including thermal testing, EMI testing, and final integration in a FIR Ground Integration Unit. This presentation discusses the status of the FBCE as it continues through final verification testing, including current test results and lessons learned throughout the assembly and integration phase of the project. In addition, future options for additional flight test sections will be explored that will benefit the broader NASA thermal and fluids community.

TFAWS19-ID-15

"Current Activities at the FAA Office of Commercial Space Transportation"

Christopher Evans

Commercial space activity has rapidly increased in recent years, and this trend is likely to continue in the future. In the United States, all commercial space launches and launch sites are regulated by the Federal Aviation Administration's Office of Commercial Space Transportation (AST). This paper provides an overview of the Office of Commercial Space Transportation and a review of the Office's research and development activities. The overview of the Office covers its core functions, organization, and how the Office has evolved over its history and is expected to change in the future. The review of research activities discusses current research priorities, topic areas of interest, and how they relate to the Office's core mission. Current and past research projects are described, with a review of significant results and findings and their implications for the future of commercial space launches.

Interdisciplinary Paper Session 2

TFAWS19-ID-10

"Fluid Transient Analysis of Propellant Feedlines during a Priming Event"

Andre LeClair, Alex Boehm, and Alok Majumdar

During the startup of the propulsion system of a spacecraft, the process of filling an evacuated pipe line is called priming. After the sudden opening of the valve, priming can generate severe water hammer spikes due to the column of liquid striking a closed thruster valve. The peak pressure and the frequency of the oscillation must be predicted accurately to ensure the structural integrity of the propulsion system fluid network. This paper presents several priming analyses performed using the Generalized Fluid System Simulation Program (GFSSP), a general purpose flow network code developed at NASA/Marshall Space Flight Center. GFSSP uses a finite volume method to solve the conservation equations of mass, momentum and energy of a real fluid in an arbitrary flow network. Four experimental set-ups were modeled: (1) Priming in a straight pipe with entrapped air, (2) Priming in a straight evacuated pipe, (3) Priming in an evacuated flow network, and (4) Priming in a straight evacuated pipe and an evacuated manifold. For all cases, the GFSSP predictions are compared with the test data. The predicted peak pressures match well with the test data in most cases. However, in some cases GFSSP predicts higher peak pressures than the test data.

TFAWS19-ID-16

"On-Orbit Xenon Refueling Loading Times and Transient Analysis"

Ben Nugent

The Power and Propulsion Element (PPE) of the Lunar Orbital Platform-Gateway will demonstrate the first on-orbit refueling of xenon propellant for a solar electric propulsion system. An analysis was performed in Microsoft Excel to determine what factors influence the overall refueling time of a single 2,000 kg capacity xenon propellant tank, as well as provide estimates for overall refueling duration. Due to the high heat of compression of xenon, the propellant tank could exceed its maximum allowable temperature during refueling if the xenon flow rate and temperate are unregulated. In order to prevent overheating, a logic based "bang-bang" operation was used for refueling, shutting off the mass feed when the tank reached a maximum temperature. Heat is removed from the tank via radiation to the surrounding spacecraft bus. The analysis shows that optimizing key parameters such as mass flow rate into the tank, residual propellant in the tank during the onset of refueling, and tank diameter significantly reduces the overall refueling duration. Optimization is not straightforward, however, as the loading time does not trend monotonically with the parameters. Overall, the most significant impact on loading duration comes from altering the residual propellant in the tank. Increasing the mass of residual propellant from 2% to 20% reduces the overall refueling duration by 56%. Future work based on this analysis includes creation of a SINDA/FLUINT model and building a groundbased xenon refueling system emulator.

TFAWS19-ID-07

"Pressure-Based Venting Thermal Model for the Dream Chaser Cargo System"

R. S. Miskovish and S. W. Miller

As a part of the design and testing of the Dream Chaser Cargo system, Sierra Nevada Corporation (SNC) sought to simulate the venting and repressurization of the interstitial bays within our Thermal Desktop (TD) integrated thermal model. While venting can be simulated within TD's FloCAD module, SNC is pursuing a stand-alone capability to perform venting simulations for various different ascent and reentry conditions.

Previously, SNC had a MATLAB simulation that takes approximately 10 minutes to solve, and the team prefers a method that solves much faster. In response to this need, ATA Engineering (ATA) worked with SNC to develop a venting and repressurization software package called Venting and Repressurization (VRP) that can be used both as a stand-alone executable or coupled with TD. The software package assumes ideal gas properties, allowing the energy equations to be reformulated to solve directly for pressure and not temperature. The package was developed in Fortran to be compatible with TD's userwritten subroutine capabilities. The package has been compared against equivalent TD FloCAD models, as well as against a version of the MATLAB code developed by SNC, and shown to compare favorably to both. This paper will explore the software properties, strengths and benefits in modeling a Dream Chaser low-Earth orbit mission.

TFAWS19-ID-14

"Thermal Design Challenges for In-Flight Exposure to an Electric Propulsion Plasma Plume Environment"

Evan Racine

The use of electric propulsion to carryout NASA in-space propulsion demands has been increasing. A big part of fulfilling this demand is the Power and Propulsion Element (PPE) for NASA's Lunar Gateway. When built, the PPE will have the largest electric propulsion system to ever fly on a spacecraft, which brings new and difficult challenges. The environment created by the electric propulsion system during on-orbit operation of the thrusters has been shown to be different than those measured during operation in terrestrial vacuum facilities. Understanding the on-orbit environment created by the thrusters and its impacts on the spacecraft is the goal of the Plasma Diagnostic Package (PDP). The PDP is a sensor package, which is being developed by NASA GRC, to fly on the PPE. The PDP will measure different aspects of the thruster plume in order to develop higher fidelity modeling of EP systems. In order to capture quality measurements of the plume the PDP will need to install sensors in close proximity of it. This poses several unique thermal design challenges. Some of these challenges include: the long duration exposure to plume induced heating, the effects of plume induced erosion and sputter deposition on thermal control surfaces, and the extreme environments of a cis-lunar orbit. This paper looks to define the thermal challenges, explain modeling techniques, and offer design solutions for unique challenges of the PDP mission.

TFAWS19-ID-01

"Thermal and Structural Analysis of the ExoMars Navigation and Localization Cameras"

Christopher Pye, Pierre-Luc Messier, and Tim Elgin

The European Space Agency's ExoMars rover uses a pair of identical stereo cameras for navigation and localization. The cameras must meet a demanding accuracy requirement when exposed the harsh Martian environment. This paper describes the thermal and structural analysis of the camera design. The goal was to validate the thermal performance of the camera and to determine the impact of thermo-elastic distortion on the optical performance of the camera.

The thermal analysis was performed with Simcenter 3D Space Systems thermal and the structural analysis with NX Nastran. The paper includes the approach used to model the Mars environment and the mapping process used to transfer the temperatures from thermal to structural models.

Interdisciplinary Paper Session 3

TFAWS19-ID-04

"Rocket Engine Digital Twin"

David Mena, Sylvain Pluchart, Stephane Mouvand, and Oliver Broca

The study aims to present modeling and simulation activities foreseen on an upper stage rocket engine, the RL10A-3-3A expander cycle engine. Once the engine model is validated, it is coupled with a flight dynamic launcher model. A typical mission profile of Delta IV is selected - GTO (Geostationary Transfer Orbit) for this example. This plant model framework integration can help the predesign of the thrust control vectoring strategy (actuation and control) and support the gimbal laws definition.

TFAWS19-ID-20

"Thermal Analysis of M2020 DRCS Thrusters for Various EDL Trajectories"

Sean Reilly, Juan Villalvazo, and Jennifer Miller

The Mars 2020 mission is a build to print Mars rover mission that is similar to the Mars Science Lab (MSL) in many ways, especially for EDL. However, as Mars 2020 would have a different landing zone from MSL, new entry descent and landing trajectories needed to be analyzed to determine component level compliance with thermal requirements. This work is focused on analysis efforts carried out by the authors in IDEASTMG to model the thermal effects of various trajectories on the Descent Reaction Control System (DRCS) rocket motors. These motors help to steer the M2020 Powered Descent Vehicle through the upper Martian atmosphere as it closes in on its landing site. Various trajectories result in different duty cycles on the thrusters which affect the thermal soak-back into internal descent stage components. These duty cycles were incorporated with aerothermal loads provided by NASA Langley to set up thermal math model runs. Additionally, Mars 2020 incorporated radiative heating to its DRCS analysis, which had not been done on MSL. This paper will detail the results of these analyses and the various aerothermal environments that were considered bounding for the M2020 mission. It will also detail some of the unique challenges associated with this analysis, including using IDEAS-TMG to perform the analysis. This work plays an important role in the verification of the M2020 thermal design in advance of its 2020 launch date.

TFAWS19-ID-08

"Design and Test of a Direct-Metal-Laser-Sintering (DMLS) Fabricated Microchannel Heat Exchanger with Nano-enhanced Heat Transfer Fluid for Thermal Management in Space Exploration"

Jaime Rios, Takele Gemeda, and Jiajun Xu

Effective system energy management and cooling is critical for a range of increasingly complex systems and missions. Various industries and agencies seek technologies and design techniques for best thermal management solutions in various applications, and thereby increase system energy efficiencies. There has been an increasing interest in exploiting the use of additive manufacturing in developing nontraditional cooling schemes to be built directly into components. Especially, at NASA, Space Technology Mission Directorate (STMD**)** has the following research priorities: 1. Advanced manufacturing methods for space and in space; and 2. Low size, weight, and power components for small spacecraft including power generation and energy storage, thermal management.

This study represents a pilot study on combing additive manufacturing and nanotechnology and providing novel thermal management solutions that can enable future deep space exploration. Specifically, this study has investigated the heat transfer and pressure loss performance of an additively manufactured micro-channel heat exchanger with nano-enhanced heat transfer fluids. Recently, the authors have proposed a radically new design for thermal fluids, “nanoemulsion fluids” that completely eliminates solid particles, and instead, uses liquid nanostructures. Nanoemulsion fluids are suspensions of liquid nano-sized droplets (<100 nm) in fluids, which are part of a broad class of multiphase colloidal dispersions. Unlike conventional (macro) emulsions, the nanoemulsion fluids are thermodynamically stable. For thermal management purpose, these phase changeable nanodroplets can be used to enhance the thermophysical properties and heat transfer coefficient of the base fluid and meet different heat transfer needs. Some nanoemulsion fluids have been experimentally confirmed that their nucleation can enhance the heat transfer coefficient dramatically. Utilizing this group of nanoemulsion fluids, it can allow the space saving via existing thermal management system and meet higher thermal management threshold. In this current study, a micro-channel heat exchanger with 30 circular channels of 600 micron in diameter has been designed and manufactured via Direct Metal Laser Sintering (DMLS) method and tested at a range of Reynolds numbers. The experimental results are benchmarked with the authors’ previous studies on mini-channel heat exchanger of similar dimensions but manufactured traditionally. The results have shown that although DMLS fabricated micro-channel heat exchanger yield a higher-pressure loss, but it has shown significantly improved convective heat transfer coefficient compared to a mini-channel heat exchanger of similar channel dimensions fabricated traditionally. It is likely that non-post processed surface of the micro-channels manufactured from DMLS process are the main contributor of this augmented heat transfer. This study has also confirmed that the nanodroplets introduced inside the base fluid can enhance the heat transfer coefficient, and the enhancement can be significant when phase change is also initiated. This preliminary study has the promising future application of such technique in space related applications and it has provided suggestions for future study of this system.

TFAWS19-ID-11

“Qualification of Reusable Components for Launch Vehicles”

Michael O'Malley

With the advent of launch vehicles being recovered after a mission with the goal of reuse for multiple missions, Qualification and Acceptance of already flown components is becoming a real concern. Besides a brief mention in MIL-HDBK-340A, a literature search for Government standards, handbooks or specifications to provide guidance for this issue finds little material. A procedure for qualification and flight acceptance of reusable components for multiple mission launch vehicles will be presented.

ITAR Paper Session 1: Active Thermal

TFAWS19-AT-15 (ITAR)

“Using Medium Fidelity Mockups to Visualize Internal Air Flow for NASA’s Four Bed Carbon Dioxide Scrubber (4BCO2)”

Kevin Higdon, Shawn Breeding, and Parker Weide

A common issue in the thermal analysis of components within an internal enclosure is the derivation of convective heat transfer coefficients. Internal enclosures typically house electronics, cabling, and other equipment with air used as the primary means of cooling the components. If the air velocity across a specific component is known, the convective heat transfer coefficient can be derived from simple heat transfer equations. In today’s computational world, the preferred method for determining heat transfer coefficients is through the use of Computational Fluid Dynamics (CFD). However, complex models must be greatly simplified, and a significant AMount of assumptions must be made to produce converged solutions. In addition, CFD models are typically solved for either laminar or turbulent cases and require validation with test data. In the example of NASA’s Four Bed Carbon Dioxide Scrubber (4BCO2) project, an internal air flow system called the Avionics Air Assembly (AAA) provides air used for thermal management of electronics and other devices within an International Space Station (ISS) Basic Express Rack (BER). Because the AAA system is the primary method of cooling for the 4BCO2 system, the convective heat transfer coefficients within the system must be predicted accurately in order to correctly analyze component surface temperatures and prevent potential overheating. Also, the use of a mockup provided a simplified method to determine how the air flow within the system is diverted due to cooling fans within the Avionics enclosures. The mockup approach differs from CFD in that the air flow regime is assumed before the analysis but the ground test mockup approach shows the air flow regimes that include laminar, turbulent, and vorticity in different areas. Results from air flow testing of two assemblies, the Avionics controller enclosure and the AAA flow through the 4BCO2 system are presented in this work. A discussion of the benefits of using this approach to determine nominal and off-nominal conditions is also presented. The major advantage of this testing approach is the ability to quickly reconfigure geometry setups and gather accurate air flow data.

ITAR Paper Session 2: Aerothermal

TFAWS19-AE-03 (ITAR)

“High Altitude Vehicle Sounding Rocket Re-Entry Heating Software Assessment”

Lindsey Seo

The NASA Goddard Space Flight Center, Sounding Rocket Program Office (SRPO) located at Wallops Flight Facility asked the Mechanical Systems Branch (Code 548) to investigate reentry heating of their high altitude rockets. As part of an early career student project, research was performed to find a reentry aerothermal prediction software that could provide better aerothermal analysis of their higher apogee rockets. Currently, the SRPO uses a one-degree-of-freedom heat transfer program called “Heat1D”.

The “Heat1D” program calculates heat transfer through the skin of the rocket at a single point on the reentry body across the entire flight timeline although it does not consider orthogonal heat transfer. To have a full understanding of the heating upon re-entry, each point on the re-entry body would need to be evaluated individually, which requires many program executions and an extensive AMount of time. All returned data is given as a “.txt” file where it is converted to a Windows Excel file and the temperature is plotted against the flight time for each iteration. Research and testing went into a trade study that gave the SRPO options for new analysis software packages. Steps taken to complete this part of the project included creating a market study of the most prominent aerothermal analysis software available. Subsequently, a set of three software packages were selected based on availability, functionality, predicted ease of use and insight from colleagues. These software packages included: ANSYS Fluent, Transient Thermal Analysis Software (TTAS), and Configuration Based Aerodynamics (CBAero).

A trade study scoring chart of the three software packages was produced based on the following criteria: function, ease of use, price, and support. After presenting the study to SRPO, a decision was made to continue working towards the collection of flight temperature data of re-entry bodies in order to have a better comparison tool for future software evaluation. Also, we will continue to study the capabilities of software program by practice and in working with the developer. SRPO looks forward to further development in aerothermal prediction to further increase their capabilities.

TFAWS19-AE-02 (ITAR)

“Ablator Thermal Analysis of a Multi-Block Radiant Test”

Zaida Hernandez

Thermal protection systems (TPS) such as ablators are used to protect a spacecraft from extreme atmospheric entry. The Orion TPS utilizes a block architecture for the heatshield with each block made from molded Avcoat. The gaps between blocks are filled with RTV-560 mixed with phenolic microballoons. The thermal response of the molded Avcoat ablator is currently modeled using a code developed at NASA, Charring Ablation Response Code (CHAR). CHAR is capable of solving multi-dimensional problems but 1D models are more commonly utilized due to the reduction in complexity and computation time. In order to validate these computational models, which are used for the TPS design, ground test facilities are utilized including the Radiant Heat Transfer Facility (RHTF) at Johnson Space Center. A multi-block test article with filled gaps was radiantly tested to demonstrate the design under thermal loads and correlate both thermal and structural models.

This paper discusses the 3D modeling of an ablator using CHAR to obtain full field temperature maps for comparison to radiant test data and use in thermo-structural analysis.

ITAR Paper Session 3: Passive Thermal

TFAWS19-PT-16 (ITAR)

"NASA's SLS Launch Vehicle Cross-Element/Cross-Program Thermal Integration"

Callie McKelvey, Brian Hamill, and Patrick Junen

NASA's Space Launch System (SLS) is a multi-element/multi-program launch vehicle, with complex thermal interfaces at the vehicle integration level. These conduction, convection, and radiation interfaces are characterized as a set of thermal design environments produced by NASA Marshall Space Flight Center's Spacecraft and Vehicle Systems Thermal Analysis & Control Branch. Inputs from each of the SLS Programs and Elements are used to create integrated analytical models to capture the thermal interactions at hardware attachment points and across shared volumes. External thermal natural environments and induced flight thermal environments were also applied to the integrated thermal models. This approach enables each element/program to include simplified, bounding representations of all interfaces with other elements/programs without generating a detailed thermal model of another element/program's hardware. Some of the more difficult interfaces to characterize include internal purged compartment convection and external radiation exchange between elements during flight mission phases. Without the benefit of integrated thermal tests during the development phases, the integrated thermal models were validated through a multi-part process, which included peer reviews, similarity to previous flight programs, and independent analytical assessments.

Passive Thermal Session 1

TFAWS19-PT-01

"Thermo-Radiative Cell - A New Waste Heat Recovery Technology for Space Power Applications"

Jianjian Wang, Chien-Hua Chen, Richard Bonner, and William Anderson

In order to satisfy the long-lasting and high energy/power density requirements for NASA deep space exploration missions, Pu-238 has been identified as one of the most suitable radioisotope fuels for GPHS modules since the 1960s. The currently extremely limited availability of Pu-238 suggests that efficiently using the heat generated by the GPHS is very important and critical for NASA space applications. However, the efficiency of the most widely used radioisotope thermoelectric generators is only about 6-8%, which means that a significant AMount of energy is dissipated as waste heat via radiators such as metallic fins. In deep space, the extremely cold universe (3K) provides a robust heat sink. Even for a heat source with a temperature below 373K, the corresponding Carnot efficiency can be more than 99%. In this paper, we show a proof-ofconcept demonstration of a thermo-radiative cell, a new technology concept conceived in 2015, to convert heat to electricity. The predicted efficiency of thermo-radiative cells is significantly higher than thermoelectrics at peak power output, and can be even higher at reduced power output. Integrating thermo-radiative cells with radioisotope heating units (high-grade heat) or radioisotope power system (RPS) radiators (low-grade waste heat) could provide a new way to significantly increase the energy efficiency of Pu-238 or other radioisotope fuels. Preliminary calculations indicate that when combining the thermo-radiative cells with RPS radiators, the thermoelectric RPS efficiency could be doubled from 6% to 12%, and the dynamics RPS efficiency could be increased from 28% to 37%.

TFAWS19-PT-08

"Design and Test of a Structurally-Integrated Heat Sink for the Maxwell X-57 High Lift Motor Controller"

Ryan Edwards and Andrew Smith

A structurally-integrated heat sink was devised for the X-57 Maxwell (formerly SCEPTOR) high lift motor controller. The nacelle-conforming sink is designed to dissipate heat from the power electronics assembly while simultaneously acting as the mechanical load path between the wing structure and high lift motor. Severe constraints on assembly mass and form factor were coupled with a compressed development and test schedule.

The development of lightweight, high efficiency components is a crucial step toward the success of electric aircraft. The Generalized Intelligent Motor Controller (GIMC) was developed at NASA's Glenn Research Center (GRC) for the purpose of converting the DC battery power into AC power to drive each of the 12 high lift motors on the X-57 Maxwell aircraft. Due to low mass budget of the X-57 aircraft, the GIMC inverter system was levied a proportionally small mass budget of less than 1kg and was limited to the existing Outer Mold Line (OML) of the nacelle. A conventional propulsor with segregated thermal and structural components would have exceeded the allotted mass budget. A highly integrated mechanical load-bearing thermal management system was devised to reconcile these conflicting design constraints.

TFAWS19-PT-10

"Thermal Development of a Commercial Off the Shelf (COTS) Camera for Exploration Upper Stage (EUS)"

Deborah Hernandez

NASA's Flight Imagery Launch Monitoring Real-time System (FILMRS) cameras were originally developed for Space Launch System (SLS) Core Stage. These Commercial Off the Shelf (COTS) cameras have been redesigned and reduced in size by an order of magnitude for the Exploration Upper Stage (EUS). The change in thermal environment has led to application of various passive thermal control methods and addition of a heater option. This paper will give a summary of the design and development test effort associated with adapting the COTS camera for the demands of the space environment and associated thermal mitigations applied as the project prepares to complete the design. The application of this camera for other space systems is discussed.

TFAWS19-PT-19

"Thermal Design and Qualification Testing of the KA-Band Radar Interferometer (KARIN) Instrument Thermal Control System"

Louis Tse and Ruwan Somawardhana

The Ka-band Radar Interferometer (KaRIn) instrument is being built for use on the Surface Water and Ocean Topography (SWOT) mission to conduct high-resolution measurement of ocean surface height and continental water levels, which aids global freshwater management and climate modeling. KaRIn requires strictly controlled thermal stability (< 50 mK/min) in order to achieve its design performance and error budget. The instrument electronics are mounted on four thermal pallets which utilizes aluminum-ammonia constant-conductance heat pipes to transport heat from electronics boxes of varying power densities. This paper presents the thermal control design, as well as the characterization and qualification test campaign to validate the thermal design and verify workmanship. Analysis of steady-state and transient data demonstrated the compliance to satisfy the thermal requirements, and enabled correlation of analytical thermal models.

TFAWS19-PT-07

"Passive Thermal Analysis and Regulation for a Lightweight Lunar CubeRover"

Oleg Sapunkov

Remote-control robotic vehicles have been used to explore astronomical bodies since the Russian Lunokhod 1 lunar rover began exploring the Sea of Rains on the Moon in November, 1970. Advances in microelectronics in subsequent decades have enabled development and production of increasingly capable robotic platforms for conducting scientific research off of our home planet. Most successful efforts, so far, have focused on the development of rovers on the order of hundreds of kilograms in weight, such as NASA's Spirit and Opportunity Mars rovers, the Soviet Union's Lunokhod 1 and Lunokhod 2, and China's Yutu 1 and Yutu 2 Moon rovers, and NASA's Curiosity Mars rover. Lighter designs, on the order of 10 kilograms in weight, have also been proposed and developed, but only one has been successfully deployed and operated to date: NASA's Sojourner Mars rover in 1997. We present the thermal analysis of a lunar CubeRover, on the order of 1 kilogram in weight, currently under NASA contract and being developed by Carnegie Mellon University and the Pittsburgh-based company, Astrobotic.

The CubeRover is envisioned as a lightweight, mass-produced, modular rover, which offers considerable benefits in the reduction of development, production, and launch costs, mission flexibility, and programmatic risk mitigation. Rovers of such low weight present unique challenges in the development of an integrated thermal management solution, since they cannot rely on heavy thermal control systems which enable active cooling or heating of temperature sensitive components. Several independent methods used to develop thermal models of the lightweight CubeRover design in spaceflight and lunar surface operation thermal environments are presented, along with computational results, including comparison with results using primary NASA thermal analysis codes. The benefits and limitations of each method are discussed, and recommended future work is outlined.

TFAWS19-PT-09

"Challenges of Designing a Passive Thermal Control System for the Astrobotic Peregrine Lunar Lander"

Stephanie Mauro

The Astrobotic Peregrine Lunar Lander is a lunar lander currently being designed by Astrobotic Technology with help from NASA through the Lunar Cargo Transportation and Landing by Soft touchdown (Lunar CATALYST) program. Part of what makes this design problem unique is the considerations related to working with a commercial company, such as yet unknown payloads, and requirements and design changes specifically to appeal to stakeholders. This paper will discuss the challenges of designing a passive thermal control system for the lander and how the design has evolved from the initial passive concept. These challenges include drastically varying worst hot and worst cold thermal environments, narrow temperature limits of critical components, limited available locations for spacecraft component mounting, co-location of high heat dissipating components, and unexpected changes causing significant thermal impacts. The initial thermal control strategy was to cold-bias the spacecraft by thermally coupling all spacecraft components to one mounting deck, which also doubled as a radiator, and use heaters to maintain each component's temperature above its lower temperature limit when in the cold environments. As the design evolved, this strategy alone became inadequate. As heat dissipations were increased and additional components with varying operation through different mission phases were added, changes were made to the thermal design and additional thermal control technologies were added. To maintain components temperatures, the available locations for spacecraft components has been expanded, a thermal switch and radiator have been added, and heat pipes are now utilized in several possible locations. Additional design changes will likely be made as the design continues to evolve to create the most effective thermal control system. The thermal design of Peregrine is still underway, with Critical Design Review scheduled for December 2020.

TFAWS19-PT-11

"Thermal Environment Modeling Practices for the Descent Trajectory of Lunar Landers"

Alex Szerszen

With the current push to send landers back to the moon, properly modeling the thermal environment for the descent is critical. Descent in this paper is described as: descending from low lunar orbit to touch down on surface. There are several challenges during this period, including: many electronics (such as battery, avionics, transponder, etc…) have higher heat loads due to higher power levels, a significant portion of the view factor to space has been blocked out by the moon making heat rejection less efficient, components that normally do not have direct line of sight to the sun may get exposure due to the lander rotating to align for descent, and thruster firing will dump more heat into the lander. All these factors combine during the most critical phase of a lander mission make it essential that the thermal environment has been properly set up during design and analysis. This paper presents one method of setting up the thermal environment during descent in thermal desktop and will also include some tips and tricks.

Passive Thermal Session 2

TFAWS19-PT-04

"Review of MLI Behavior at Low Temperatures and Application to L'Ralph Thermal Modeling"

Daniel Bae and Juan Rodriguez-Ruiz

In this presentation, the theory and application of multi-layer insulation (MLI) behavior, with a specific focus on lower temperature applications (<180K), is discussed. Many parameters can affect the performance of MLI (i.e. construction method, size, materials, grounding, penetrations, etc.) and these factors can make the prediction of MLI performance a challenge. Often, MLI performance is measured in terms of estar, and analysts commonly apply bias between a high and a low estar value. However, this approach can be dangerous when a mission goes through a wide range of temperatures during its lifetime (such as our mission, L'Ralph) due to temperature dependence of estar, with estar values increasing exponential as temperatures get colder. Many research papers and correlations have been published about MLI behavior, showing how estar values can rapidly rise at low temperatures. These correlations also show how the different parameters of MLI can affect and AMplify this growth. Various correlations are presented as well as how L'Ralph is approaching the MLI problem. L'Ralph thermal model is built with Thermal Desktop (TD), and a discussion of how to apply the temperature dependent MLI behavior within TD is included. The presentation also includes reviews of different methods of mitigating heat leaks through MLI, touching briefly on topics such as integrated-MLI (IMLI), Dacron vs silk netting, and using multi-layered meshes to improve estar performance.

TFAWS19-PT-12

"Thermal Interface Material Selection for Large Electronics Boxes"

David Steinfield

Electronics Boxes with high heat dissipations use a thermal interface material to increase heat transfer to the radiator in a vacuum/space environment.

There are lots of materials to choose from, but for Spacecraft applications, there are more than high heat transfer metrics which must be met. Contamination (both particle generation and outgassing), ease of cutting, and removal are just as important metrics in material selection. However, vendor data of material thermal conductance is usually based on a 1"X 1" piece of material under high uniform pressures. Large Electronics boxes almost never have optimal pressures, as they are bolted along the perimeter and leave gaps in the center regions.

In order to characterize the relative thermal conductance for large Electronics boxes, an 8" X 8" plate was fabricated to simulate an electronics box bottom and bolted around the perimeter to a cold plate. Various thermal interface materials were inserted between the box and cold plate, and overall thermal conductances were calculated.

A table was generated which compares the full gamut of thermal interface materials for large boxes, from a dry joint to a wet joint. Materials were placed in order of high to low conductances, so an engineer can compare the benefit of each material in a real-world scenario.

TFAWS19-PT-14

"Liquid Metal Elastomer Composites as a Soft Thermal Interface Material for Low Temperature (-80°C) Applications"

Navid Kazem, Mohammad Malakooti, Jiajun Yan, Eric Markvicka, Chengfeng Pan, Krzysztof Matyjaszewski, and Carmel Majidi

Emerging trends in wearable computing, soft robotics, and compact electronics have created a demand for soft, multifunctional materials, especially in applications related to thermal management and flexible electronics. Liquid metal embedded elastomers (LMEEs) represent a novel class of these soft, multifunctional composite fabricated by dispersing micro- and nanoscale liquid metal (LM) inclusions in an elastomer matrix. In contrast to conventional rigid filler particles, the embedded liquid metal droplets are highly deformable and can stretch with the surrounding elastomer without introducing significant mechanical resistance or inducing internal stress concentrations. Moreover, because they are metallic, the droplets can serve as functional units for tailoring the electric permittivity, thermal conductivity, or electrical conductivity of the composite. As shown previously, the combination of a rubbery matrix and a liquid-phase emulsion filler has enabled the development of highly compliant and stretchable composites with exceptional thermal and electrical performance. These properties include: enhanced dielectric constant and breakdown, enhanced thermal conductivity, high electrical conductivity with limited electromechanical coupling, extreme toughness, and electrically selfhealing ability. However, the effect of supercooling on the liquid phase, which has a bulk melting point of 15.5°C, is not fully understood. Here, we investigated the effect of low temperature exposure on LMEE composites with the micro- and nano-scale liquid fillers. We used Dynamic Mechanical Analyzer (DMA) and Differential Scanning Calorimetry (DSC) to characterize the crystallization and melting point of LMEEs. Surprisingly, micro- and nanodroplets of LM remain liquid at temperatures down to −80°C. This reduction in the crystallization temperature is due to the combination of i) supercooling of the liquid metal and ii) the micro- and nano-scale size of the inclusions. The onset of LM crystallization was observed by the stiffening of the composite at T = −80°C using DMA and was well-correlated with a corresponding peak in the DSC data. Additionally, we found that the supercooling effect is independent of both matrix material and synthesis process. These results indicate that LMEEbased devices are capable of operation over a wide temperature range and open up new possibilities and applications of LMEE in extreme environments, particularly space applications.

TFAWS19-PT-15

"Thermal Characterization of 3D Printed Lattice Structures"

Travis Belcher and R. Gregory Schunk

3D printing has revolutionized the way that intricate parts are fabricated, giving engineers the ability to exercise greater power in creating innovative and clever component designs. Specifically, this technology development enables thermal engineers to add design features which tailor material performance by varying topology. Additively manufactured lattice structures are among the more enticing of these design features because they combine the strength to support loads with the lower relative density to drive down thermal conductivity and reduce mass. Additionally, some processes of 3D printing, such as binder jetting, create parts which are not fully dense and therefore do not have the same material properties as their fully dense counterparts. While these non-fully dense components are often considered problematic because of their inferior properties, some niche applications for them have been found, such as printing refractory ceramics, where their low density allows them to act as thermal insulators in ultra-high temperature applications, similar to the aforementioned lattice structures. In order to accurately model heat flow through these structures when analyzing them for use on spacecraft and vehicles, both thermal conductivity and

radiation must be taken into consideration, especially as the temperature increases and the AMount of internal heat transfer via radiation begins to influence the effective thermal conductivity. Unfortunately, as a consequence of how the lattice structure topology is generated, creating radiation models of these lattice structures in programs such as Thermal Desktop and COMSOL has proven to be immensely computationally expensive. This has led to the formulation of a campaign to benchmark computational models with experimental test data. Acquiring data from this experiment is a unique challenge in that the test apparatus is measuring effective thermal conductivity through a geometry and not as a material property. Both transient and steady state thermal conductivity measurement devices based on ASTM E1225 and ASTM D5470 require that the material sample be fully dense and homogeneous, which does not adhere to the purpose of the experiment. When a commercial solution did not present itself, a test apparatus was designed using a modified approach to the ASTM E1225 and ASTM D5470 standards to facilitate testing of these lattice samples. This capability has been developed at NASA's Marshall Spaceflight Center and is currently being utilized to investigate the effective thermal conductivities of these lattice structures.

TFAWS19-PT-17

"Application and Development of Atomic Layer Deposition Techniques to Improve Thermo-optical Coatings for Spacecraft Thermal Control and Advanced Optical Instruments"

Vivek Dwivedi

A key technology development driver in environmental control systems and next generation optics are discussed utilizing thin film development borrowed from the semiconductor industry. The optical and physical properties of spacecraft radiator coatings are dictated by orbital environmental conditions. For example, coatings must adequately dissipate charge buildup when orbital conditions, such as polar, geostationary or gravity neutral, result in surface charging. Current dissipation techniques include depositing a layer of ITO (indium tin oxide) on the radiator surface in a high temperature process. The application of these enhanced coatings must be such that the properties in question are tailored to mission-specific requirements. The multi-billion-dollar semiconductor industry has adopted Atomic Layer Deposition (ALD) for self-assembly and atomic-scale placement. ALD is a cost-effective nanoadditive-manufacturing technique that allows for the conformal coating of substrates with atomic control in a benign temperature and pressure environment. By using ALD, modification of these coatings can be accomplished during coating application preprocessing. The preprocessing is rendered directly on the coating dry pigment before binding. Through the introduction of paired precursor gases, thin films can be deposited on a myriad of substrates ranging from glass, polymers, aerogels, metals, powders, and other high aspect-ratio micro- and nano-structures. By providing atomic-level control, where single layers of atoms can be deposited, the fabrication of metal transparent films, precise nano-laminates, and coatings of nanochannels and pores is achievable. A method has been demonstrated for the ALD of In2O3 and films on a variety of substrates from Si(100) wafers, glass slides, and on Z93P pigments resulting in a direct spaceflight application. Results will be presented that verify the chemical composition of ALD pigments and charge dissipation properties when the pigment goes through its binding and coating process and we present early results of ALD for carbon nanotube formation.

Passive Thermal Session 3

TFAWS19-PT-02

"Variable View Factor Two-Phase Radiator"

Andrew Lutz and Calin Tarau

Essentially all manned spacecraft, satellites, and unmanned spacecraft need to reject waste heat by radiating heat through a radiator, while maintaining the battery and electronics temperatures within specified limits. The AMount of waste heat, and the heat sink conditions can vary widely, e.g., when a satellite moves behind the earth. Typically, radiators are sized for the highest power at the hottest sink conditions, so they are oversized most of the time. Hence, there is a need to develop light-weight and efficient radiators for future spacecraft and satellites which offers the capability of significant turndown. Advanced Cooling Technologies, Inc. (ACT) has developed a novel vapor-pressure-driven variable-view-factor and deployable radiator that passively operates with variable geometry (i.e., form factor) and offers high turndown ratio. The device, utilizes two-phase heat transfer and novel geometrical features that adaptively (and reversibly) adjust the view factor in response internal pressure (working fluid vapor pressure) in the radiator. The radiator folds into a tear drop shape to minimize the view factor when cold, and opens up to maximize the view factor when heated. This is facilitated by a dynamic feedback between the internal pressure inside the hollow curved panels of the radiator and the radiator structure itself, which permits a change of shape within the elastic limit of the material – thereby resulting in a passive, reversible, deployable and variable-view-factor radiator, which enables heat spreading via two-phase mechanism and further rejection via radiation.

TFAWS19-PT-03

"Modelling of Radiative Heat Transfer of a Square Trihedral Design Radiator Panel on the Lunar Surface"

Colin Butler, Ronan Flanagan, Jeff Punch, and Nick Jeffers

This work investigates the potential of arrayed square trihedral elements as an effective radiator panel for passive thermal management of spacecraft. The geometry of these retroreflector-like elements intends to maximise the radiative cooling to deep space, while at the same time minimising the negative effects of environmental irradiation. This is achieved whereby at any given time, and corresponding Sun position, the total irradiation incident on all radiator surfaces is reduced due to the orientation of the faces and the compounding shading effects of surrounding elements when compared to a flat panel. An analytical model is used to determine the thermal energy balance on participating radiator surfaces taking into account all heat loads in order to calculate the net radiative power dissipation. These include the direct solar irradiation and resulting reflections, lunar albedo, lunar infra-red radiation and internal heat generation for a conceptual lunar lander. Results are presented for a preliminary model consisting of 7 trihedral elements for varying apex angles in order to determine the optimal configuration for different mounting positions on the lander, i.e. top or side surfaces. The selection of the optimal apex angle is a trade-off between minimising both incident solar irradiation and radiation view factor to the lunar surface.

TFAWS19-PT-06

"Optimizing Thermal Radiator Designs Using the Veritrek Software"

Lina Maricic, R. Scott Miskovish, Jacob Moulton, and Derek Hengeveld

A common thermal design problem exists in the aerospace industry where the thermal design is driven by minimizing survival power while maintaining compliance with allowable flight temperatures (AFTs) in a variable thermal environment. Finding optimal design solutions can be time-consuming and requires a large number of simulations using detailed thermal math models, especially as the complexity of the thermal design grows when the number of radiators and electronics increases. A generic spacecraft model was created in Thermal Desktop® (TD) to emulate this problem. A six-sided box, with electronics mounted on three side faces, was placed in a low earth orbit. The constraints of the problem are twofold. First, the maximum temperatures of electronics in the worst hot environment cannot exceed maximum AFTs. Second, the duty cycle of survival powers used to maintain the electronics above the minimum AFTs cannot exceed 80%. In order to determine the optimal radiator sizes given electronic power dissipations, ATA used Veritrek, a reduced-order modeling software that helps thermal teams efficiently understand a thermal design space to improve design solutions. Using Veritrek, ATA created a reduced order model (ROM) to explore the thermal design space and find optimal design solutions, such as optimal radiator sizes. Although hundreds of training data simulations generated from the TD model were required to create a reliable ROM in the Veritrek Creation Tool, design and verification of the thermal system in a variable thermal environment was executed in real time in the Veritrek Exploration Tool.

TFAWS19-PT-13

"Thermal Vacuum Testing and Feasibility Investigations for VO_2-Based Variable Emittance Coatings"

Sydney Taylor and Liping Wang

Thermochromic variable emittance radiators can provide passive variable heat rejection capabilities for missions with significant changes in thermal environment and spacecraft heat loads. Vanadium dioxide (VO_2) is a thermochromic insulator-to-metal phase transition material which typically undergoes a drastic change in optical properties at 341 K. Given this shift in optical properties, a variable emittance coating can be designed for use in a wide range of spacecraft thermal control applications. When the radiator surface temperature is high, the coating has comparatively high mid-infrared emissivity to promote radiative cooling through heat rejection. Conversely, when the radiator surface temperature is low, the coating has low emissivity to prevent additional heat loss. By adjusting its emissivity based on temperature, a multilayer radiation coating which integrates VO_2 can adapt its radiative properties according to changes in spacecraft heat load or environment. In this study, the variable heat rejection capabilities for two VO_2-based variable emitters are demonstrated via thermal vacuum tests. Additionally, black ($\varepsilon \approx 1$) and aluminum ($\varepsilon \approx 0.03$) references are also measured to represent the maximum and minimum heat rejection possible, respectively. The heat flux is determined from a calorimetry test, where the steady state temperature of the sample is measured as a function of heater input. The heat flux is then calculated via the system energy balance, where the conduction and radiation losses are determined from the black reference. During these experiments, the two VO_2-based emitters exhibited a considerable increase in the emitted heat flux as the heater power was increased. Several other critical characteristics of the VO_2 are also studied to determine its feasibility for spacecraft applications. The cryogenic and high temperature stability of the VO_2 is assessed through FTIR measurements. The sample's susceptibility to thermal cycling is also tested. Finally, the hysteresis behavior of the VO_2 if it does not complete a full heating cycle is investigated. In this investigation, the VO_2 is heated to temperatures within its transition regime to see if the cooling hysteresis is similar to when the VO_2 completes a full heating and cooling cycle. A model is developed to predict the observed behavior and to assist in future spacecraft thermal modeling efforts. Techniques to reduce the VO_2 hysteresis are also explored.

TFAWS19-PT-05

"Using Thermal Desktop for Heater Design in Thermal Vacuum Chambers"

Tayera Ellis and Ryan Noe

Historically, thermal vacuum chambers within the Systems Test Branch at NASA Johnson Space Center have used quartz lamps to reach "hot" temperatures on test articles. These quartz lamps emit in the solar wavelength, which is reflected by most test articles. Heating elements that can emit more in the infrared wavelength allow for hotter target temperatures on the test article when compared to solar-emitting heating elements. Due to the increase in requests for high temperatures (418 K) on test articles, tubular heaters have been investigated as an alternative in thermal vacuum chambers. These tubular heaters have a similar composition to quartz lamps with their nickel chromium or tungsten resistance coil filament, with the difference being the material surrounding the coil. The quartz lamp is surrounded by a gas and glass casing, while the tubular heater is surrounded by a highly compacted magnesium oxide and protective Nickelbased sheath. Monte Carlo ray tracing in Thermal Desktop was used to finalize a reflector design and produce a heater assembly from concept to test. Additional Thermal Desktop analysis was used to predict coupon temperatures. When compared to initial analysis, test data had a discrepancy of more than 50 K between the coupons tested and the coupons modeled. To better correlate test data and the analytical model, the Thermal Desktop model will be reworked with more accurate inputs such as optical properties, thermophysical properties, and chamber surfaces. The ultimate goal is to use modeling to provide an arrangement of multiple heaters (known as a heater array) that will provide a uniform temperature across large test articles.

TFAWS19-PT-18

"A Streamlined Approach to Spatial Mapping of Complex 3D Thermal Boundary Condition Data"

Robert Hawkins and Carl Poplawsky

Spatial mapping of 1D, 2D, and particularly 3D thermal boundary condition data is essential for accurate thermal simulation of spacecraft and launch vehicles. This information typically is available in simple ASCII file format but can be problematic to use for thermal simulations. Difficulties that can be encountered include the ability to directly use the available file format, transformation of the data into the desired reference coordinate system in 3D space, and accurate interpolation of the data onto the thermal calculation domain. This paper presents a streamlined approach to spatial mapping of complex unsymmetrical 3D cold wall heat flux data using the fields' capability in Simcenter3D. A recent example of 3D thermal plume simulation at MSFC will be employed to illustrate the use of text, csv, and Excel files, specifying coordinate systems for transformation of data in 3D space, and use of the various interpolation schemes available for spatial mapping. Spatial boundary condition verification is also very important, and the spacecraft thermal analyst needs effective visualization tools to develop confidence in the boundary condition definitions. Visualization of the spacecraft plume raw field data, the calculated field data, and the interpolated field data onto the thermal calculation domain will be discussed, with a particular focus on real-time viewing of the interpolated data for available interpolation schemes.

Speaker Biographies

Monday Lunch Speakers:

Dave Bowles

Langley Research Center Director

Dr. David E. Bowles, director of NASA's Langley Research Center, Hampton, Virginia, has been an active member of the Langley community for some 39 years. He began his career conducting research in advanced materials for use on aerospace vehicles and then focused on materials to be used in space. He has published many research papers on the effects of materials degradation on structural and thermal properties. Before serving as Director of Langley's Exploration and Space Operations Directorate from 2007 to 2012, he spent 11 years involved with program and project management for both aeronautics and space-related activities at the center. He served as Manager for Airframe Structures Integrity and Composites for NASA's Advanced Subsonic Technology Program and as the Vehicle Systems Research and Technology Project Manager for NASA's Next Generation Launch Technology Program. He joined the Director's Office in 2012 as Associate Director, progressed to Deputy Director in 2014, and was appointed Center Director in June 2015. Dr. Bowles — who holds bachelor's, master's and doctoral degrees in engineering mechanics from Virginia Tech — is the recipient of numerous awards, including NASA's Outstanding Leadership Medal, which he accepted in both 2005 and 2015.

Elaine Luria

U.S. House of Representatives – Virginia's 2nd District

U.S. Rep. Elaine Luria represents Virginia's Second Congressional District. Prior to her election in 2018, Rep. Luria served two decades in the Navy, retiring at the rank of Commander. Rep. Luria served at sea on six ships as a nuclear-trained Surface Warfare Officer, deployed to the Middle East and Western Pacific, and culminated her Navy career by commanding a combat-ready unit of 400 sailors. A member of the House Armed Services Committee and the House Committee on Veterans' Affairs, Rep. Luria was one of the first women in the Navy's nuclear power program and among the first women to serve the entirety of her career in combatant ships. She leads the House Veterans' Affairs Subcommittee on Disability Assistance and Memorial Affairs, and is Vice Chair of the House Armed Services Subcommittee on Seapower and Projection Forces. Of all members in the House Democratic Caucus, she served the longest on active duty, having completed 20 years of active military service with the U.S. Navy. Rep. Luria graduated from the U.S. Naval Academy and received a master's in engineering management from Old Dominion University.

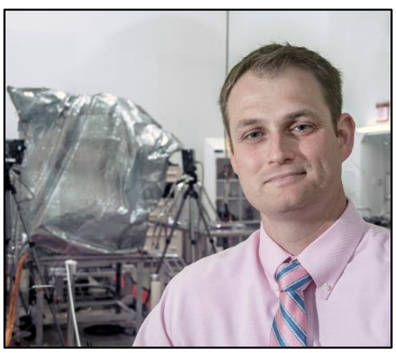
Tuesday Lunch Speaker: Michelle Munk

NASA Entry, Descent, and Landing (EDL) System Capability Lead and Space Technology Mission Directorate (STMD) Principal Technologist for EDL

Ms. Michelle Munk has served NASA Headquarters as the Entry, Descent and Landing (EDL) System Capability Lead since May 2017, and the Principal Technologist for EDL technologies within NASA's Space Technology Mission Directorate (STMD) since 2013. Ms. Munk has broad experience in orbital mechanics, trajectory simulation, flight hardware, and technology development from three different NASA centers: Johnson, Marshall, and Langley. Her past work includes nine years as the Lead Engineer and Project Manager for the In-Space Propulsion Technology (ISPT) Aerocapture project, and subsystem lead and Deputy Project Manager for the Mars Science Laboratory Entry, Descent and Landing Instrumentation (MEDLI) flight payload. Ms. Munk holds a B. S. in Aerospace Engineering from Virginia Tech. She was selected for the 2019 AIAA Associate Fellow class, participates in educational outreach and international EDL efforts, and has several publications and NASA group and individual achievement awards, including the Space Flight Awareness Award and the NASA Exceptional Service Medal.

Wednesday Lunch Speaker: Joe Gasbarre

Deputy Director for Flight Programs, LaRC Science Directorate (SD)



Joe Gasbarre is a senior systems engineer and manager with over 20 years of experience specializing in flight and concept systems development for space-based missions and atmospheric flight vehicles. He currently serves as the Deputy Director for Flight Programs in NASA Langley Research Center's (LaRC) Science Directorate and in this position has responsibility for project execution and development of NASA LaRC's flight projects funded by NASA's Science Mission Directorate (SMD). This portfolio consists of over $400M in total value and represents contributions to SMD's Earth Science, Planetary Science, and Heliophysics Divisions as well as external partnerships with NOAA, USAF/DOD, and commercial entities. Prior to this assignment, Mr. Gasbarre was assigned to NASA's Office of Chief Engineer (OCE) where he was the Acting Chief Engineer for the Science Mission Directorate (SMD) from October 2017 to April 2019. In this capacity, Mr. Gasbarre served as the embedded engineering technical authority for the Agency responsible for all SMD missions, providing guidance to the SMD Associate Administrator and other senior staff on adherence to Agency engineering policies and procedures. Before joining NASA Headquarters in October 2017, Mr. Gasbarre served as the SAGE III/ISS Project Manager during the project's launch and commissioning phase after having served as the Project's Chief Engineer since project inception. Mr. Gasbarre received his BS degree in Aerospace Engineering from Pennsylvania State University and his MS degree in Aerospace Systems from the University of Maryland. He was a founding member of the NASA Thermal and Fluid Analysis Workshop (TFAWS) Steering Committee and a past workshop chair (2003).

Banquet Keynote Speaker: Kunio M. Sayanagi, Ph.D.

Associate Professor of Planetary Science
Department of Atmospheric and Planetary Sciences, Hampton University

Kunio Sayanagi is an associate professor in the Atmospheric and Planetary Sciences Department at Hampton University. He received his Ph.D. in Physics from the University of Arizona. His core expertise is on the atmospheric dynamics of planets in our solar system.

His current projects fall under the following four general categories:

(1) Computational fluid dynamics modeling of Jetstreams and Vortices in planetary atmospheres
(2) Spacecraft-based Remote-sensing measurements of planetary atmospheres -- He was part of the Imaging Science Team of NASA's Cassini Mission to Saturn that ended in 2017. He is currently involved in analyzing data returned from ESA's Venus Express and JAXA's Akatsuki mission to Venus.
(3) Telescopic observation of solar system planets. He uses various telescopes to observe solar system planets including the Hubble Space Telescope. He is currently building an observatory on Hampton University campus -- his observations generally focus on the temporal evolution of clouds in the atmospheres of Venus, Jupiter, Saturn, Uranus and Neptune.
(4) Planning and designing future planetary missions. He is the PI of the "Small Nexg-generation Atmospheric Probe" concept to explore Uranus (topic of the talk today). To date, he has also led or participated in proposing and/or developing 13 planetary mission concepts.

In addition to above research activities, Kunio is also very active in planetary science priority formulation. He was a member of the 2013 National Academy Planetary Science Decadal Survey's Giant Planets Panel. Today, as a member of the Steering Committee of NASA's Outer Planets Assessment Group, he also evaluates NASA's exploration priorities in the outer solar system.

Thursday Lunch Speaker: Jeanne Willoz-Egnor

Director of Collections Management and Curator of Scientific Instruments, The Mariner's Museum and Park

Jeanne Willoz-Egnor has served as the Director of Collections Management and Curator of Scientific Instruments at The Mariners' Museum and Park in Newport News, Virginia since 1994. Spending nearly thirty-five years in cultural institutions has given Jeanne a broad range of historical knowledge and experiences. Working closely with Oracle Racing, Inc. in recent years, Jeanne helped coordinate the donation of two hydrofoiling catamarans to the Museum and led a small team in the assembly of the AC72 USA-17, winner of the 2013 America's Cup, for the Museum's current exhibition Speed and Innovation in the America's Cup. Since 2017, she has worked with Oracle Racing's boat builders and designers to develop a unique understanding of hydrofoiling and other technologies developed and employed in the most recent America's Cup campaigns.

Forum Participant Biographies

Thermal Properties – Do We Trust Them?

Moderator: Dr. Sandra Walker

Dr. Sandra Walker has been a Research Aerospace Engineer at NASA Langley for over 30 years. She received her PhD in Aerospace and Mechanical Engineering from the University of Virginia in 2001. She is currently serving as Assistant Branch Head for SMCB.

Callie McKelvey

Callie McKelvey has served as the Thermal Sub-Discipline Engineer (SDLE) for the Space Launch System (SLS) Program for the past 6 years. In this role, she led the MSFC team producing thermal analyses to derive cross-program vehicle thermal interface design environments. Ms. McKelvey will discuss her experience in obtaining thermo-physical and thermo-optical properties for MSFC's in-house analysis products and her desire for an agency supported thermal materials database.

Kamran Daryabeigi

Dr. Daryabeigi works in the Structural Mechanics and Concepts Branch at NASA Langley Research Center. His main concentration is in the area of thermal testing, high-fidelity physics based thermal modeling, and developing efficient high-temperature insulations for thermal protection systems for aerospace applications. He also has experience in thermal property (thermal conductivity and specific heat) measurements for high temperature insulations and other materials.

Donald Ellerby

Don Ellerby has been working on thermal protection systems at NASA Ames Research Center for ~18 years. He has worked on a variety of materials from Ultra High Temperature Ceramics to ablative TPS materials. Most recently he was the project manager for the Heatshield for Extreme Entry Environment Technology (HEEET) in collaboration with NASA LaRC and JSC. Don will discuss his experience in measuring thermal properties of ablative materials including work on PICA during the Orion program and more recently on HEEET.

Evan Racine

Evan Racine has been with NASA GRC for 3 years. He has a Bachelors in Mechanical Engineering from Michigan State University and a Masters in Aerospace Engineering from the University of Dayton. His current work activities are for the Gateway program's Power and Propulsion Element, Plasma Diagnostics Package, and AMPS for Gateway. Evan has experience testing and modeling the effects of ion propulsion systems on the optical properties of thermal control surfaces. Evan will discuss his research in measuring thermal optical properties of common and uncommon materials and using experimental data in the design of flight hardware.

Additive Manufacturing, Building Our Future Layer by Layer

Moderator: Karen Taminger

Ms. Karen Taminger is a Senior Materials Research Engineer at NASA Langley Research Center in the Advanced Materials and Processing Branch. She currently serves as a technical lead for structures in transport aircraft, and for several in-space and for-space manufacturing projects. Over the past 15 years, she has also led development of the Electron Beam Freeform Fabrication (EBF^3) technology for high performance, low cost fabrication of metallic structures for aircraft, launch vehicles, and spacecraft. She has spent 3 hours in zero-gravity (in 15-second increments!) while parabolic flight testing EBF^3 for compatibility with the space environment. She is the co-inventor on five issued patents and four other patent disclosures, and co-author on more than 35 papers and 100 presentations. She was awarded a NASA Exceptional Technology Achievement Medal in 2014, a NASA Exceptional Achievement Medal in 2007, and her team was selected for the runner-up NASA Patent of the Year in 2016 and Langley's Whitcomb-Holloway Technology Transfer Award in 2008, all related to her work in metal additive manufacturing. Karen earned her BS in Honors from Virginia Tech in 1989, majoring in Materials Engineering, and her MS degree from Virginia Tech in 1999 in Materials Science and Engineering. She has been employed at NASA Langley Research Center as a co-operative education student from 1986-1989, and full-time since graduating with her BS in 1989.

Joshua Fody

Josh Fody has been at NASA Langley for 6 years working mostly on high temperature insulations and hot structures. He transferred from Engineering to Research Directorate over a year ago where he has focused primarily on additive manufacturing. His work in additive is on continuum scale finite element process models designed to predict melt pool dimensions and temperature histories for metallic powder bed and blown powder applications. He has also done some work with reduced order models for part scale residual stress predictions, as well as some optimization coding using Python.

Saikumar Yeratapally

Dr. Saikumar Yeratapally has been working in the field of Additive Manufacturing at NASA Langley Research Center for over 2 years. He is working towards developing an ICME-based framework to establish Process-Structure-Property (PSP) relations in additively manufactured materials. In this regard, he has automated the linkage between SPPARKS, a process simulation package from Sandia, with ScIFEN, an in-house performance modeling finite element software. Additionally, he is looking at modeling the effect-of-defects on the performance of additive materials. He has developed a 3D framework to model explicitly model lack of fusion pores that are notoriously known to degrade the mechanical properties of the material.

Travis Belcher

Travis Belcher has been working with Additive Manufacturing (AM) for 3 years. His primary focus has been heat transfer through AM Lattice Structures and how to incorporate these structures in design for passive thermal control. During the forum, Mr. Belcher will present his findings on the thermal characterization of AM Lattice Structures and the ongoing research into these structures at Marshall Spaceflight Center.

Jean-Michel HUGO

Jean-Michel HUGO has created the company TEMISTh in 2012 after his Ph.D on the use of cellular materials, such as metal foams, applied to heat exchangers conception. The PhD study focused on the understanding of relationship between geometry of cellular materials and their thermal and fluid properties in a first part. On a second part, a methodology was developed in order to be able to design heat exchanger using these materials. With the development of additive manufacturing and the use of lattice structures, a huge potential appears for customizing thermal solution. During the forum, Mr. Hugo will present advantages and inconvenient of additive manufacturing for heat exchangers and an example of cold plate conception and optimization using lattice structures and numerical methodology.

NASA-LaRC Tour Descriptions

Two tours of the NASA Langley Research Center will offered during TFAWS 2019. Each tour will visit three sites, including the National Transonic Facility, 31-Inch Mach 10 Air Tunnel and the Integrated Structural Assembly of Advanced Composites/ISAAC (tour stops are subject to change and will depend on the size of the tour group). Information about each stop is included below.

Tours are limited to the first 50 people for each tour date and preference will be given on a first-come, first-serve basis. Tour reservations should be made when registering for TFAWS, at least 3 weeks prior to the workshop (in order to arrange badging). Personnel with NASA badges will be able to sign up for the tours at later dates, if space is still available.

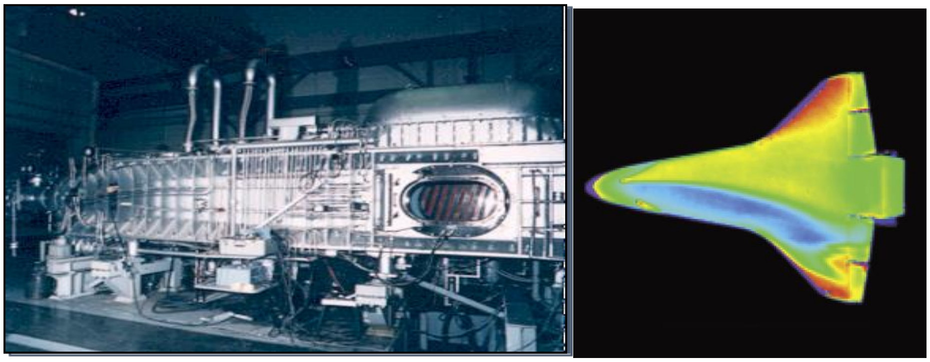
Both tours will depart from the lobby of the hotel and transportation will be provided.

National Transonic Facility (NTF)

Arial view of NTF and Boeing 777 model in tunnel (credit: NASA)

The Langley National Transonic Facility (NTF) is a high pressure, cryogenic, closed circuit wind tunnel with a thermally insulated pressure shell and is capable of Mach 0.1 to 1.2 with a Reynolds number range of 4x106 to 145x106 per foot. The tunnel has two modes of cooling. In the variable temperature cryogenic mode, nitrogen is the test gas and liquid nitrogen is sprayed into the circuit. The heat of vaporization and latent heat cools the tunnel structure while removing the fan heat. In this mode, the NTF provides full-scale flight Reynolds numbers without an increase in model size. In the ambient temperature air mode, air is the test gas. Water flows through the cooling coil to remove fan heat.

Langley Aerothermodynamics Laboratory – 31-Inch Mach 10 Air Tunnel



31-Inch Mach 10 Tunnel and Space Shuttle heating data from the tunnel (credit: NASA)

The Langley Aerothermodynamics Laboratory (LAL) has three hypersonic wind tunnels utilized for aerodynamic performance and aeroheating assessment of hypersonic vehicles. Collectively, they provide a wide range of conditions and are suited for fast-paced screening, assessing, optimizing, and bench-marking (when combined with computational fluid dynamics) advanced aerospace vehicle concepts and fundamental flow physics research. The LAL has contributed to many programs including Apollo, Viking, Space Shuttle Orbiter, National Aero-Space Plane, Pegasus XL, DC-X, X-33, X-34, X-38, Kistler and X-43/HyperX, as well as the Columbia Accident Investigation and Shuttle Return To Flight Programs. The LAL was also involved in the development of the Mars Microprobe, Stardust Sample Return Capsule, Genesis, Mars Science Laboratory, Orion and HYTHIRM.

Integrated Structural Assembly of Advanced Composites (ISAAC)

ISAAC (Credit NASA)

Integrated Structural Assembly of Advanced Composites (ISAAC) is a state of the art composite manufacturing robot. ISAAC was purchased from Electroimpact and installed in 2015. NASA Langley was the first NASA Center to receive this technology and the third manufacturing facility in the world to receive an ISAAC. The robot has 8 degrees of freedom and an accuracy rate of +/- .05". ISAAC also has several detachable end effectors, making it a versatile machine. Similar robots have become very popular in the automotive and commercial flight industries. At NASA Langley Research Center, ISAAC supports research on the design and manufacturing of composite parts.

Vendor Display Booths

The following vendor display booths will be present at TFAWS 2019:

Hardware

- Advanced Cooling Technologies
- Aerothreads
- Arieca, LLC
- Dunmore Aerospace
- DuPont
- Fralock
- Temisth

Software

- BETA CAE Systems USA, Inc.
- COMSOL, Inc.
- CRTech
- Gamma Technologies
- Loadpath
- Maya Heat Transfer Technologies
- MSC
- Siemens Digital Industries
- Spacedesign Corporation
- Tecplot
- TERMA B.V.
- ThermoAnalytics

Acknowledgments

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Passive Thermal Control and Protection – Steve Rickman (JSC)
Active Thermal Technical Fellow – Henry Rotter (JSC)
Aerothermal Technical Fellow– Dave Schuster (LaRC)

Organization Committee Chairs (LaRC)

Shelly Mason	Michelle Rodio

Organization Committee (LaRC)

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Karen Berger (Session Chair)	Elora Kurz	Tory Scola
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Warren Davis	Kim Martin	Bill Wood

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Special Thanks!

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Notes

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