Table of Contents

Overview of TFAWS

Welcome to the 2018 Thermal and Fluids Analysis Workshop (TFAWS) in Galveston, Texas! TFAWS is an annual workshop sponsored by the NASA Engineering and Safety Center (NESC), and hosted by a NASA center. Johnson Space Center is honored to host this year's workshop.

The goal of TFAWS is to promote a strong thermal & fluids engineering community through knowledge sharing, professional development, and networking across NASA, academia, and the greater aerospace industry. TFAWS focus area spans across the disciplines of Active Thermal Control, Aerothermal, CryoThermal and Passive Thermal Control. To maintain expertise in these disciplines over time, TFAWS provides content useful to engineers at all levels of experience.

TFAWS 2018 has a number of parallel tracks, providing attendees opportunities for:

- Hands on instruction on relevant state-of-the art analysis tools.
- Short courses taught by experts on hardware selection, thermal analysis methods, and thermal control techniques.
- Participation in presentations and discussion regarding recent and future work.
- Networking at paper sessions, training courses, lunches, and evening events.

Over the years, TFAWS has been a great platform for engineers to stay current on engineering lessons learned, analysis tools, and thermal design and modeling approaches. TFAWS has helped strengthen relationships between NASA centers, international partners, government agencies, academia, and commercial companies. It is our goal for this year's workshop to continue this tradition.

TFAWS 2018 Host Center – Lyndon B. Johnson Space Center

Aerial view of Manned Spacecraft Center, Site 1, looking north. September 1965

The Lyndon B. Johnson Space Center (JSC) has focused on furthering human space exploration since its establishment as the Manned Spaceflight Center in 1961. JSC has played a pivotal role in the success of the Mercury, Gemini, Apollo, Space Shuttle, and International Space Station (ISS) Programs. JSC is home to the Christopher C. Kraft Jr. Mission Control Center, the Lunar Sample Laboratory Facility, NASA's astronaut corps, and the Sonny Carter Training Facility – which houses the Neutral Buoyancy Laboratory. Today, JSC's nearly 10,000 person workforce conducts a wide range of activities, including ISS maintenance and utilization, commercial crew vehicle development support, Orion engineering and program management, Gateway planning, and research and development for future deep space missions.

In 2017, the James Webb Space Telescope underwent over 90 days of testing in JSC's historic Chamber A, through Hurricane Harvey. The 120-foot tall by 65-foot diameter thermal vacuum chamber is known for testing the Apollo vehicles, in both manned and unmanned configurations. Chamber A was also used for a variety of ISS thermal control system tests in the 1980s and 1990s. These included evaluation of candidate two phase external control systems, system level testing of the selected single phase thermal control system, and radiator beam valve module ammonia vent testing.

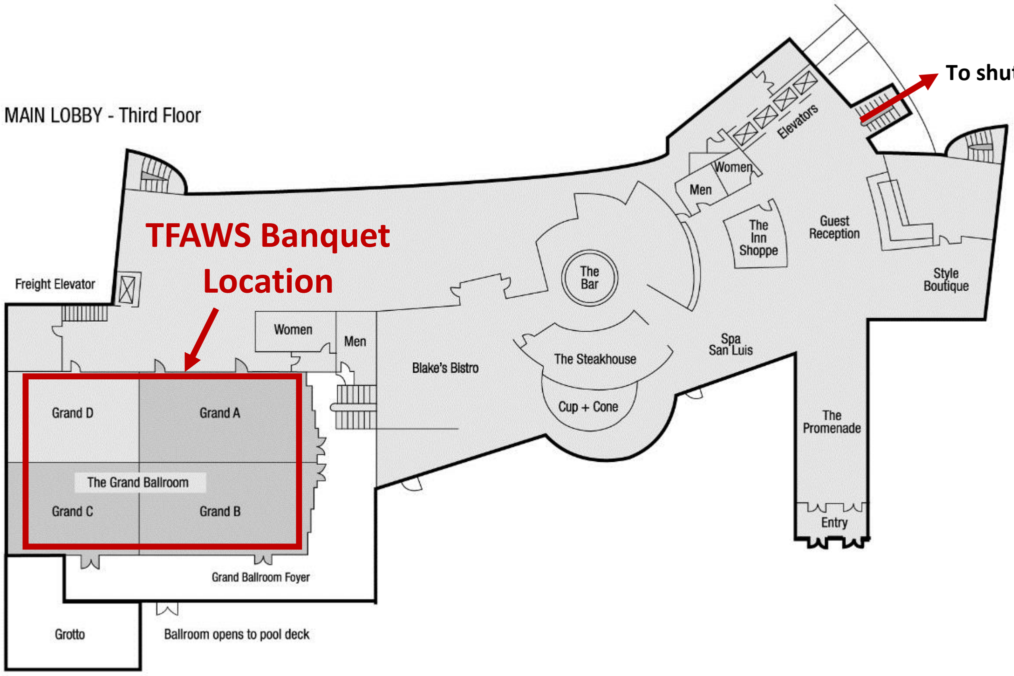
Hotel and Convention Center Information

The San Luis Resort
5222 Seawall Blvd, Galveston, Texas, 77551

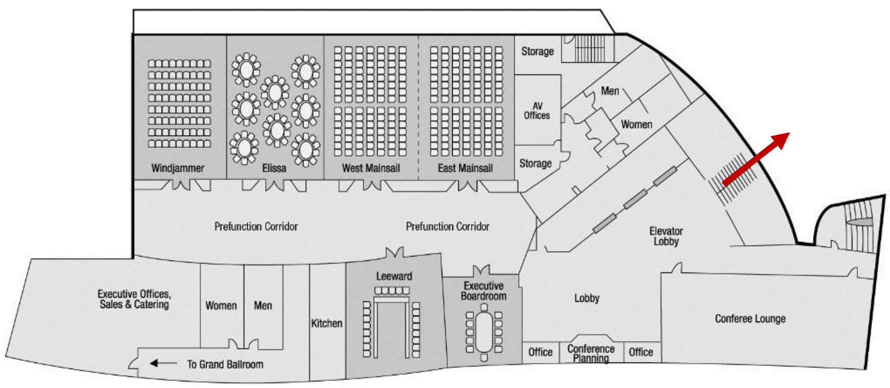
- Will host many non-local attendees as well as Monday's welcome reception and the TFAWS Banquet.
- Located 0.3 miles from the convention center (roughly a 5 minute walk).
- To walk to the convention center head southwest, past the IHOP, on Seawall Blvd.
- A shuttle will provide transportation between the hotel and convention center roughly every 15 minutes from 7 AM to 6 PM Monday-Thursday.
  - The shuttle will park outside the 1st floor rear door of the hotel, down the main lobby stairs.

THE SAN LUIS Hotel
SPA & CONFERENCE CENTER

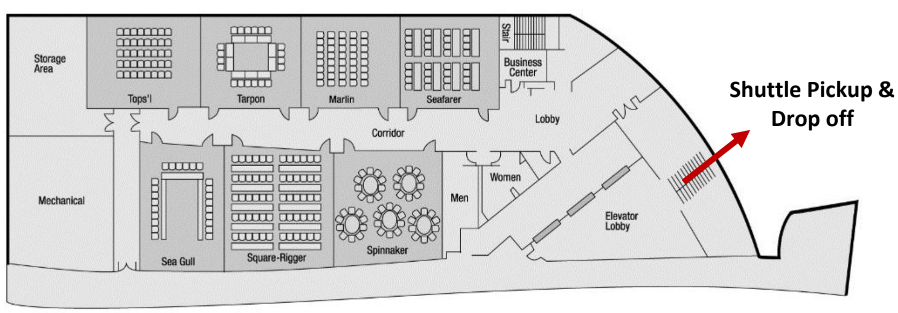
MAIN LOBBY - Third Floor



CONFERENCE CENTER - Second Floor

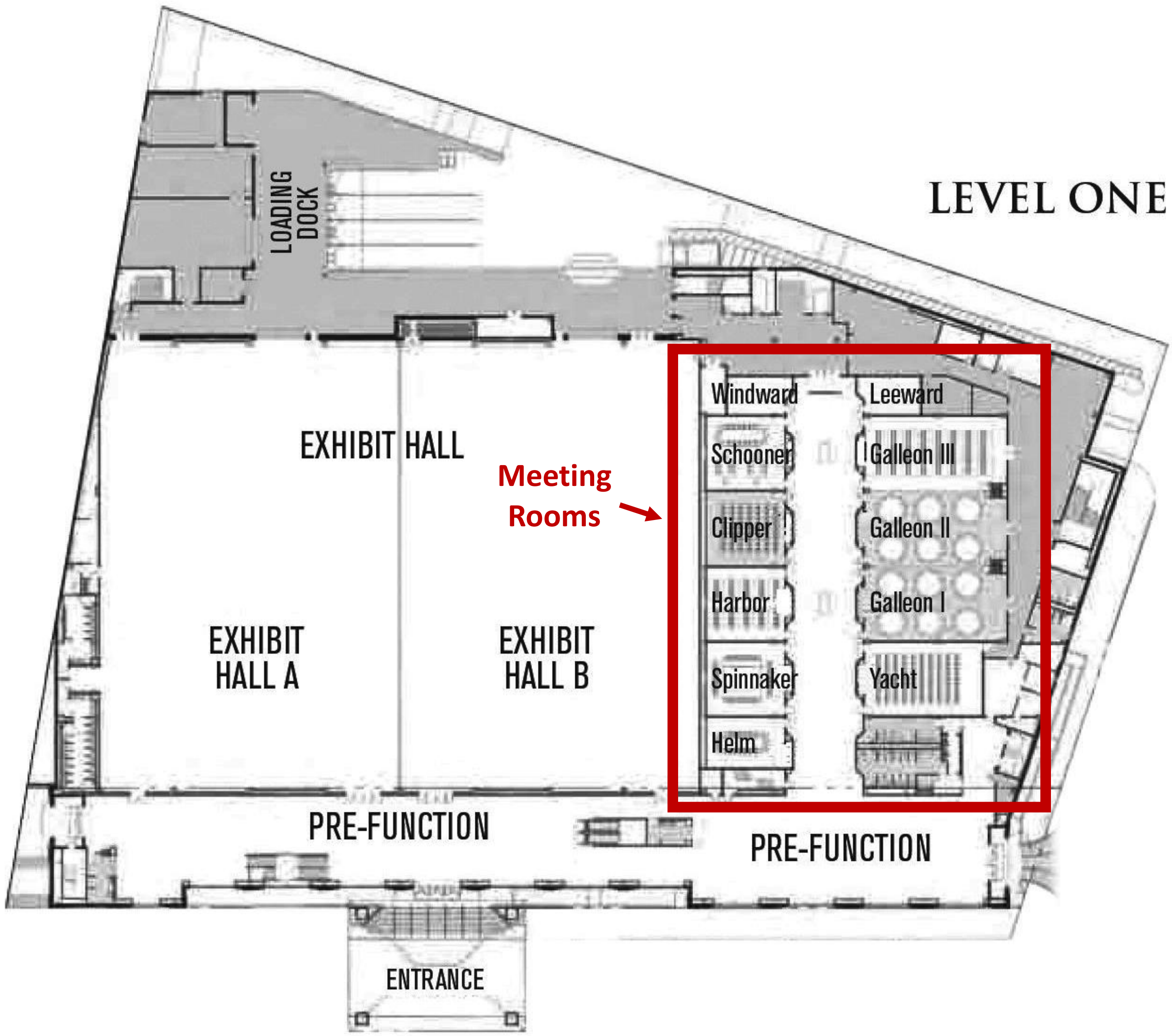


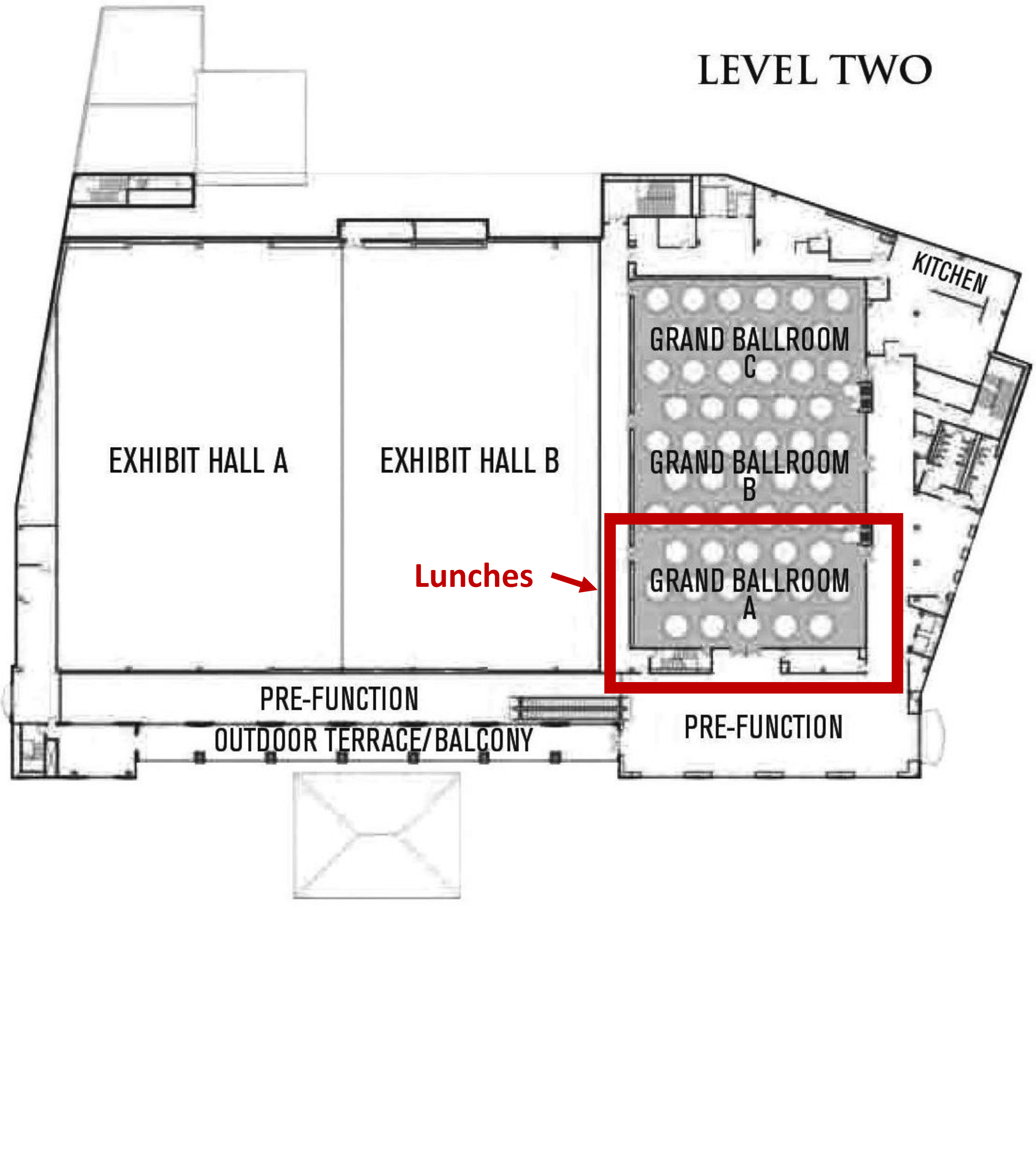
CONFERENCE CENTER - First Floor



Galveston Island Convention Center
5600 Seawall Blvd, Galveston, Texas, 77551

- Sessions will be in the 1st floor meeting rooms.
- Lunches will be in the 2nd floor Grand Ballroom.
- A registration and information booth will be in the 1st floor prefunction area will be staffed 7am-4pm Monday-Thursday.
- Parking is free and open to the public.




LEVEL TWO
KITCHEN
GRAND BALLROOM C
GRAND BALLROOM B
GRAND BALLROOM A
EXHIBIT HALL A
EXHIBIT HALL B
Lunches
PRE-FUNCTION
OUTDOOR TERRACE/BALCONY
PRE-FUNCTION

Monday, August 20th: Agenda Summary

<table>
<tr><th>Time</th><th>Galleon 1</th><th>Galleon 2</th><th>Galleon 3</th><th>Clipper</th><th>Spinnaker</th><th>Yacht</th></tr>
<tr><td>8:00 AM</td><td rowspan="4">Generalized Fluid System Simulation Program</td><td rowspan="4"></td><td></td><td></td><td rowspan="4">Active Thermal Paper Session I</td><td></td></tr>
<tr><td>9:00 AM</td><td></td><td>Marlow: TEC Demo</td><td></td></tr>
<tr><td>10:00 AM</td><td rowspan="2">CONVERGE CFD for Thermal Fluid Modeling</td><td rowspan="2">ITAR Paper Session (10:30 Start)</td><td></td></tr>
<tr><td>11:00 AM</td><td></td></tr>
<tr><td>12:00 PM</td><td colspan="6">Lunchtime Speaker: John Lienhard, Ph.D.
Professor Emeritus University of Houston & host of NPR's The Engines of Our Ingenuity
2nd Floor Banquet Hall, Convention Center</td></tr>
<tr><td>1:00 PM</td><td rowspan="2">New & Advanced Features in Thermal Desktop Demo</td><td rowspan="4">ACT: Heat Pipe Tutorial</td><td>GT-Suite Case Studies</td><td rowspan="2">Maya HTT Presentation</td><td rowspan="4">Interdisciplinary Paper Session I</td><td></td></tr>
<tr><td>2:00 PM</td><td>MLI Standards & Best Practices</td><td></td></tr>
<tr><td>3:00 PM</td><td rowspan="2">Simcenter Space Systems Thermal Modeling Environment (Maya HTT)</td><td>TSS Demo</td><td></td><td></td></tr>
<tr><td>4:00 PM</td><td></td><td>Pump Design & Selection</td><td rowspan="3">TFAWS Delegates Meeting (Invite Only)</td></tr>
<tr><td>5:00 PM</td><td colspan="5">Adjourn</td></tr>
<tr><td>5:00-6:00</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Evening</td><td colspan="6">TFAWS 2018 Welcome Reception – Cove Bar at The San Luis Resort at 6:00 PM</td></tr>
</table>

Tuesday, August 21st: Agenda Summary

<table>
<tr><th>Time</th><th>Galleon 1</th><th>Galleon 2</th><th>Galleon 3</th><th>Clipper</th><th>Spinnaker</th><th>Yacht</th></tr>
<tr><td>8:00 AM</td><td rowspan="4">Intro to Thermal Desktop & FloCad (Hands-On)</td><td rowspan="4">Thermal Analysis Results Processor (TARP)</td><td>Veritrek</td><td></td><td rowspan="4">Passive Thermal Paper Session I</td><td rowspan="4">NASA In-Situ Resource Utilization Thermal Technical Discussion</td></tr>
<tr><td>9:00 AM</td><td>BETA CAE Systems Demo</td><td>Pump Design & Selection</td></tr>
<tr><td>10:00 AM</td><td rowspan="2">Cryogenic Systems for IR Sensor Cooling Short Course</td><td rowspan="2">Thermal Modeling Methods of Li-Ion Batteries</td></tr>
<tr><td>11:00 AM</td></tr>
<tr><td>12:00 PM</td><td colspan="6">Lunchtime JSC Public Affairs Office Event: NASA’s Driven to Explore Trailer
Front of Convention Center
JSC Tour (Start 12:30PM – End: 5:30pm) Meet: Side Entrance of Convention Center</td></tr>
<tr><td>1:00 PM</td><td rowspan="4">Into to RadCAD (Hands-On)</td><td rowspan="4">GT-SUITE Thermal Fluids/Multi-Physics Training (Hands On)</td><td rowspan="2">BETA CAE Systems Demo</td><td rowspan="4">Active Thermal Paper Session II</td><td rowspan="4">Interdisciplinary Paper Session II</td><td rowspan="4">Passive Thermal TDT (NASA Civil Servant Only)</td></tr>
<tr><td>2:00 PM</td></tr>
<tr><td>3:00 PM</td><td>Mentor</td></tr>
<tr><td>4:00 PM</td><td></td></tr>
<tr><td>5:00 PM</td><td colspan="6">Adjourn</td></tr>
<tr><td>Evening</td><td colspan="6">Evening Social Event - The Spot, Galveston Island – 6PM
3204 Seawall Blvd, Galveston, TX 77550</td></tr>
</table>

Wednesday, August 22nd: Agenda Summary

<table>
<tr><th>Time</th><th>Galleon 1</th><th>Galleon 2</th><th>Galleon 3</th><th>Clipper</th><th>Spinnaker</th><th>Yacht</th></tr>
<tr><td>8:00 AM</td><td rowspan="4">Intro to TD Direct (Hands-on)</td><td rowspan="4">Intro to TSS</td><td>Ansys Presentation</td><td rowspan="3">History of ATCS of Manned US Spacecraft (US Citizens Only)</td><td rowspan="4">Passive Thermal Paper Session II</td><td></td></tr>
<tr><td>9:00 AM</td><td></td><td></td></tr>
<tr><td>10:00 AM</td><td>Ansys Discovery Live Demo</td><td></td></tr>
<tr><td>11:00 AM</td><td></td><td>Future of 2-ϕ Thermal Control</td><td></td></tr>
<tr><td>12:00 PM</td><td colspan="6">Lunchtime Speaker: Karen Nyberg, Ph.D. – Current Astronaut and Former Thermal Analyst
2nd Floor Banquet Hall, Convention Center</td></tr>
<tr><td>1:00 PM</td><td rowspan="4">TAITherm Human Thermal Hands-On Training Course</td><td rowspan="4">Intro to TSS</td><td></td><td rowspan="4">Aero/Cryo Paper Session</td><td rowspan="4">Interdisciplinary Paper Session III</td><td rowspan="4">Active Thermal TDT (NASA Civil Servant Only)</td></tr>
<tr><td>2:00 PM</td><td rowspan="2">Ansys Discovery Live Demo</td></tr>
<tr><td>3:00 PM</td></tr>
<tr><td>4:00 PM</td><td></td></tr>
<tr><td>5:00 PM</td><td colspan="6">Adjourn</td></tr>
<tr><td>6:00 PM</td><td colspan="6">Cocktail Hour: San Luis Resort Grand Ballroom Foyer (cash bar)</td></tr>
<tr><td>7:00 PM</td><td colspan="6">TFAWS 2018 Banquet – Keynote Speaker: Donald Roy Pettit, Ph.D., Astronaut
San Luis Resort Grand Ballroom</td></tr>
</table>

Thursday, August 23rd: Agenda Summary

Time	Galleon 1	Galleon 2	Galleon 3	Clipper	Spinnaker	Yacht
8:00 AM	Capture Output & Verify Results (COVeR) Presentation	Advanced TSS		Form Factors, Grey Bodies, and Radiation Conductances	Active Thermal Paper Session III	
9:00 AM			Intro to KeyShot 3D Rendering			Thermal Desktop Modeling of Cryogenic Tanks
10:00 AM						
11:00 AM						
12:00 PM	**Lunchtime Speaker: Kevin Window – Director of Engineering at Johnson Space Center 2nd Floor Banquet Hall, Convention Center**					
1:00 PM	CRTech: Bring Your Own Model	Advanced TSS		JWST Thermal Analysis and Thermal Vacuum Discussion	Passive Thermal Paper Session III	
2:00 PM			KeyShot Advanced Features			
3:00 PM						
4:00 PM						
5:00 PM	Adjourn					
Evening	**Evening Social Event - Stuttgarden Tavern, Galveston 6PM 111 23rd St, Galveston, TX 77550**					

Friday, August 24th: Agenda Summary

Time	Galleon 1	Galleon 2	Galleon 3	Clipper	Spinnaker	Yacht
8:00 AM						JSC Tour Start 7:30AM End 1PM Meet: Side Entrance of Convention Center
9:00 AM						
10:00 AM						
11:00 AM						
12:00 PM	**Adjourn: Thank You For Being Part of TFAWS 2018!**					

Active Thermal & Fluids Paper Session I

Location: Spinnaker Conference Room, Time: 8:00AM-12:00PM

Session Chair: Brian Motil (GRC) & Ryan Edwards (GRC)

8:00 – 8:30	**Numerical and Experimental Investigation of River Hydrokinetic Turbine for Water Pumping Application** TFAWS18-AT-02 *Muzammil Ejaz, Mohammad Fozan ur Rab, Fahad Qureshi, Hassan, and Wajiha Rehman*
8:30 – 9:00	**Demonstration of Copper-Water Heat Pipes and HiK Plates on the International Space Station** TFAWS18-AT-03 *Mohammed Ababneh, Calin Tarau, William Anderson, Angel Alvarez-Hernandez, Stephania Ortega, Jeffery Farmer, and Robert Hawkins*
9:00 – 9:30	**Ammonia Vent of the External Thermal Control System (EATCS) Radiator #3 Flow Path #2 on the International Space Station (ISS)** TFAWS18-AT-01 *Darnell Cowan*
9:30 – 10:00	**Next Generation of High-Heat-Flux Heat Pipes for Space Thermal Control Applications** TFAWS18-AT-04 *Mohammed Ababneh, Calin Tarau, William Anderson, and Jesse Fisher*
10:00 – 10:15	**Break**
10:15 – 10:45	
10:45 – 11:15	**Technology Development of Shape Memory Alloy Morphing Radiators: Analysis, Design, and Testing** TFAWS18-AT-20 *Christopher Bertagne*
11:15 – 11:45	**Mitigation of Orion Ammonia Boiler Outlet Coolant Thermal Stratification** TFAWS18-AT-15 *Eugene Ungar and Lauren Foley*

Generalized Fluid System Simulation Program

Location: Galleon 1 Conference Room, Time: 8:00AM-12:00PM

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 (waterhammer). GFSSP has been developed at MSFC for flow analysis of rocket engine turbopumps and propulsion systems. The class will show how the user can quickly develop a system-level thermo-fluid model, discuss the capabilities of the software, and present model examples. GFSSP's new Graphical User Interface, MIG (Modeling Interface for GFSSP) will be introduced in this class. Students will build two models as a group activity, and have the opportunity to work one or more hands-on tutorials.

Marlow: TEC Demo

Location: Clipper Conference Room, Time: 9:00AM-10:00AM

Company: II-VI Marlow

An introductory presentation on thermoelectric devices used for cooling, heating, & power generation projects. Course covers a high level overview of Thermoelectric devices, primary uses, cooler selection, system installation nuances, standard vs. custom module designs, & II-VI Marlow's process with concept to completion for customer assistance. Come join the II-VI Marlow team to learn more about the interesting world of thermoelectric devices and how your next project could benefit from this technology.

Converge CFD for Thermal Fluid Modeling

Location: Galleon 3 Conference Room, Time: 10:00AM-12:00PM

Company: Converge CFD

Convergent Science specializes in modeling fluid flow, conjugate heat transfer, spray, combustion and optimization using our CONVERGE CFD software. CONVERGE automatically generates a mesh at runtime, this eliminating all user meshing time even for moving boundary problems. CONVERGE is widely used to simulate the flow, spray, combustion and conjugate heat transfer for a variety of applications. In this seminar, an overview of CONVERGE CFD will be given and numerous thermal fluid examples will be shown.

ITAR Paper Session

Location: Clipper Conference Room, Time: 10:30AM-11:00AM

Session Chair: Christopher Massina (JSC)
Location: Clipper Conference Room

Attendance limited to participants that have been badged by the US government.
Badges will be check prior to conference room entry.

10:30 – 11:00 **Modeling on Clearing Liquid Blockage in the Helium Pressure Line of a Propellant Tank**
TFAWS18-ITAR-03
Xiao-Yen Wang, Glenn Research Center

Lunchtime Speaker: Monday, August 20th

Dr. John Leinhard

Location: Ballroom A (take escalator to 2nd floor), Time: 12:00PM-1:00PM

John H. Lienhard, Ph.D. author and voice of NPR's *The Engines of Our Ingenuity*, is Professor Emeritus of Mechanical Engineering and History at the University of Houston. He received BS and MS degrees from Oregon State College and the University of Washington, his PhD from the University of California at Berkeley, and he holds two honorary doctorates. He is known for his research in the thermal sciences as well as in cultural history. He is an Honorary Member of the American Society of Mechanical Engineers and a member of the National Academy of Engineering.

In addition to many awards for his technical contributions, Dr. Lienhard has received, for his work on *Engines*, the ASME Ralph Coates Roe Medal for contributions to the public understanding of technology, the 1991 Portrait Division Award from the American Women in Radio and Television, and the 1998 American Society of Mechanical Engineers Engineer-Historian Award, other ASME honors, and two 2005 Crystal Microphone Awards.

Session Descriptions: Monday, August 20th (Afternoon)

Interdisciplinary Paper Session I

Location: Spinnaker Conference Room, Time: 1:15PM-4:30PM

Session Chair: Chris Evans (MSFC)

13:15 – 13:45 **Thermal & Fluids Analysis and the NASA Launch Services Program**
TFAWS18-IN-22
Paul Schallhorn and Gary O'Neil

13:45 – 14:15 **Two-Phase Flow System Design Status of the Flow Boiling and Condensation Experiment (FBCE)**
TFAWS18-IN-14
Jesse deFiebre and Monica Guzik

14:15 – 14:45 **Proof of Concept Design and Analysis of heat Reutilization of a Solid Oxide Electrolyzer Cell for Oxygen Supply on Mars**
TFAWS18-IN-06
Samuel Ogletree, Shan Mohammed, and M. A. Rafe Biswas

14:45 – 15:15 **Temperature Controller Design of a High Temperature Ceramic Transport Membrane System for Oxygen Production using a Lumped Thermal Modeling Approach**
TFAWS18-IN-11
Kevin Fuentes, Samuel Ogltree, Shan Mohammed and M. A. Rafe Biswas

15:15 – 15:30 **Break**

15:30 – 16:00 **Validating Electrochemical, Thermal, and Fluidic Performance of a PEM Fuel Cell System Using GT SUITE**
TFAWS18-IN-16
Ryan Gilligan, Monica Guzik, Ian Jakupca, and Phillip Smith

16:00 – 16:30 **Identification of the Physical Orientation of Drones to Obtain the Optimum Performance During Flight**
TFAWS18-IN-13
Md. Abu Saleh

New & Advanced Features in Thermal Desktop Demo

Location: Galleon 1 Conference Room, Time: 1:00PM-3:00PM

Company: 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.

ACT: Heat Pipe Tutorial

Location: Galleon 2 Conference Room, Time: 1:00PM-5:00PM

Company: Advanced Cooling Technologies

This Heat Pipe Short Course by Advanced Cooling Technologies, Inc. will provide a broad overview of heat pipes including operating principles, limitations, design considerations, applications, and testing. 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 applications in space.

GT-SUITE Case Studies (Thermal Fluids and Multi-Physics Overview)

Location: Galleon 3 Conference Room, Time: 1:00PM-2:00PM

Company: 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? If so, come 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 one hour software demonstration. About

Gamma Technologies: GT-SUITE is a unique transformational all-in-one CAE tool. 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 (with in-situ meshers), 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 HTT Simcenter Space Systems Thermal Presentation

Location: Clipper Conference Room, Time: 1:00PM-3:00PM

Company: Maya HTT

This presentation will introduce users to Simcenter Space Systems Thermal, a thermal analysis tool fully integrated with CAD. We will be creating a thermal model of an articulated space manipulator, building it block by block by creating FEM models for each component of the manipulator and at the end combining them into one assembly. This "Assembly of FEMs" model will then be used to obtain orbital temperatures and seeing the effect of varying the optical properties of the manipulator surfaces.

MLI Standards & Best Practices

Location: Galleon 3 Conference Room, Time: 2:00PM-3:00PM

Company: Aerothreads Inc.

Where do you begin when you need Multi-layer Insulation (MLI)? We will review standard material options, their best applications, and how these choices influence our design process, fabrication techniques, and handling considerations.

Simcenter Space Systems Thermal Modeling Environment (Maya HTT)

Location: Galleon 1 Conference Room, Time: 3:00PM-5:00PM

Company: Maya HTT

This 2-hour hands-on training session will take you through access and use of 3D assembly CAD geometry, geometry preparation (idealization), and preparation of a coupled thermal/flow simulation model, followed by solution and post-processing. At that point, you will address significant design changes and see how those changes flow down through the entire simulation process with minimal analysis re-work. You will leave this session with a better understanding of the advantages of the CAD-based approach to thermal/flow simulation.

TSS Demo

Location: Galleon 3 Conference Room, Time: 3:00PM-4:00PM

Company: Spacedesign

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

Pump Design & Selection

Location: Clipper Conference Room, Time: 3:00PM-4:00PM

Company: Texas Processing Equipment

In this class attendees will learn how to select a pump including fluid characteristics and data required that determines the size & pump style best for the application. Performance curves, how NPSH is key to a reliable pump installation, and discussion of various pump styles and drives will also take place.

Evening Activities: Monday, August 20th

TFAWS 2018 Welcome Reception

Location: Cove Bar at the San Luis Resort, Time: 6:00PM

Come mingle and network with fellow attendees while taking in the beautiful views of the beach and relaxing on the pool deck. Rain location: The San Luis Lobby Bar

Passive Thermal Paper Session I

Location: Spinnaker Conference Room, Time: 8:00AM-12:00PM

Session Chair: Ruth Amundsen (LaRC) & Kaitlin Liles (LaRC)

8:00 – 8:30	**Influence of Lunar Rover on Lunar Surface Temperature** TFAWS18-PT-01 *Christopher Pye, Jean-Frederic Ruel, and Josh Newman*
8:30 – 9:00	**Analysis of On-Orbit Thermal Performance of the Bigelow Expandable Activity Module (BEAM)** TFAWS18-PT-03 *Zaida Hernandez*
9:00 – 9:30	**Thermal Systems Modeling of a Variable Emittance Coating for Human Spacecraft Applications** TFAWS18-PT-10 *Sydney Taylor, Christopher Massina, and Liping Wang*
9:30 – 10:00	**LHP Wick Fabrication via Additive Manufacturing** TFAWS18-PT-04 *Bradley Richard*
10:00 – 10:15	**Break**
10:15 – 10:45	**A Review of SAGE III on ISS Flight Thermal Data** TFAWS18-PT-07 *Kaitlin Liles, Ruth Amundsen, and Warren Davis*
10:45 – 11:15	**Thermal Analysis of Propulsion Components for Europa Clipper Mission** TFAWS18-PT-19 *Heather Bradshaw*
11:15 – 11:45	**Challenging Louver Design Modification for Europa Clipper Interplanetary Mission** TFAWS18-PT-15 *Scott Christiansen*

Intro to Thermal Desktop & FloCad (Hands-On)

Location: Galleon 1 Conference Room, Time: 8:00AM-12:00PM

Company: CRTech

This session will provide an introduction to 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. Experienced users are welcome but are requested to allow new users to have priority at the workstations.

Thermal Analysis Results Processor (TARP)

Location: Galleon 2 Conference Room, Time: 8:00AM-12:00PM

Company: Thermal Modeling Solutions

Post Processing of Thermal Model output using TARP. TARP is a dedicated post processor with a variety of Post Processing object types (DataSets, Plots, Tables, Graphical Tables, Backloads, etc.) available to the user which results in an Excel workbook with the requested objects.

Veritrek (Reduced-Order Modeling for Thermal Desktop)

Location: Galleon 3 Conference Room, Time: 8:00AM-9:00AM

Company: Veritrek

An automated software tool for generating Reduced Order Models (ROMs) was developed for Thermal Desktop. Called Veritrek, it provides users the ability to develop ROMs based on Thermal Desktop models with minimal user intervention. An overview of Veritrek will be provided along with case studies of this new approach.

NASA In-Situ Resource Utilization Thermal Technical Discussion

Location: Yacht Conference Room, Time: 8:00AM-12:00PM

This meeting will cover an overview of NASA's ISRU project, and the thermal challenges associated with developing an ISRU fuel production plant. Informal presentations will be given on various processes for Mars soil water extraction, CO2 capture, methane production, oxygen production, separation, and liquefaction. Open discussion on potential solutions to system and/or component level thermal challenges related to ISRU technologies will follow.

BETA CAE SYSTEMS DEMO (ANSA for Geometry Handling)

Location: Galleon 3 Conference Room, Time: 9:00AM-10:00AM

Company: BETA CAE

Implementation of ANSA software for preparation, clean-up and healing of geometries. Surface mesh generation for complicated geometries, generation of layers for CFD applications and volume mesh including any type of elements. Preparation and set-up of files needed for OpenFOAM and other solvers.

Pump Design & Selection

Location: Clipper Conference Room, Time: 9:00AM-10:00AM

Company: Texas Processing Equipment

In this class attendees will learn how to select a pump including fluid characteristics and data required that determines the size & pump style best for the application. Performance curves, how NPSH is key to a reliable pump installation, and discussion of various pump styles and drives will also take place.

Cryogenic Systems for IR Sensor Cooling Short Course

Location: Galleon 3 Conference Room, Time: 10:00AM-12:00PM

Instructor: Bill Fischer, Aerospace Corporation

Abstract located under *Agenda* on tfaws.nasa.gov

Thermal Modeling Methods of Li-Ion Batteries

Location: Clipper Conference Room, Time: 10:00AM-12:00PM

Instructor: William Walker, Ph.D.

This short course provides participants with an in-depth discussion on three aspects of lithium-ion (Li-ion) batteries that are relevant to the TFAWS community. First an understanding of Li-ion battery fundamentals is provided through a brief discussion centered around (a) the aerospace industry's choice to use Li-ion batteries, (b) general performance characteristics and (c) electrochemical reaction basics. Secondly, Li-ion battery heat generation is discussed with respect to (a) Ohmic heating that occurs during nominal charge-discharge operations and (b) the heating mechanisms associated with a thermal runaway event. Understanding both heating mechanisms is critical to the development of effective thermal management systems. Lastly, this course will lead the participants through the basic construction process of a thermal model of a Li-ion battery assembly that is capable of simulating nominal heating and thermal runaway heating. The overall goal of the course is to provide participants with an in-depth understanding of both the fundamental and thermal aspects of Li-ion batteries.

Lunchtime PAO Event: Tuesday, August 21st

NASA's Driven to Explore Trailer

Location: Front of Convention Center

NASA's Driven to Explore (DTE) mobile, multi-media exhibit immerses visitors in the story of NASA. Guests will learn why we explore, discover the challenges of human space exploration and how NASA provides critical technological advances to improve life on Earth. The exhibit includes imagery and audio and visual technology to connect visitors with the space program, highlighting advanced human research that will ensure safe and sustainable future missions, and next-generation vehicles and surface systems destined for use exploring beyond low Earth orbit.

Note: The Tuesday afternoon tour departs the Galveston Convention Center no later than 12:40PM. If not attending the tour, we encourage you to check out the JSC Public Affairs Office trailer prior to eating, to give tour attendees time to purchase food before departing.

Interdisciplinary Paper Session II

Location: Spinnaker Conference Room, Time 1:15PM-3:15PM

Session Chair: Chris Evans (MSFC)

13:15 – 13:45 **Numerical and Theoretical Investigations of Compressible Boundary Layers**
TFAWS18-IN-09
Frederick Ferguson, Tasmin Hossain, and Julio Mendez

13:45 – 14:15 **Measurement of the Effective Radial Thermal Conductivities of 18650 and 26650 Lithium-Ion Battery Cells**
TFAWS18-IN-08
Harsh Bhundiya, Melany Hunt, and Bruce Drolen

14:15 – 14:45 **Thermal Modeling and Correlation of the Space Environments complex Vacuum Chamber and Cryoshroud**
TFAWS18-IN-17
Erik Stalcup

14:45 – 15:15 **Characterization of a 50kW Inductively Coupled Plasma Torch for Testing of Ablative Thermal Protection Material**
TFAWS18-IN-21
Benton Greene, Noel Clemens, Philip Varghese, Stanley Bouslog, and Steven Del Papa

Into to RadCAD (Hands-On)

Location: Galleon 1 Conference Room, Time: 12:00PM-5:00PM

Company: CRTech

This session will provide an introduction to 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. Experienced users are welcome but are requested to allow new users to have priority at the workstations.

GT-SUITE Thermal Fluids/Multi-Physics Training (Hands On)

Location: Galleon 2 Conference Room, Time: 12:00PM-5:00PM

Company: Gamma Technologies

This hands-on class will demonstrate the multi-physics capabilities in GT-SUITE simulation software by building a handful of examples of thermal fluid models of propulsion systems, including transient water hammer, line chilldown, tank charging and thermal stratification, 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. About Gamma Technologies: GT-SUITE is a unique transformational all-in-one CAE tool. 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 (with in-situ meshers), 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.

BETA CAE Systems Demo (ANSA for Mesh Generation)

Location: Galleon 1 Conference Room, Time: 12:00PM-5:00PM

Company: BETA CAE

Details on geometry clean-up, automatic identification of errors in geometry and correction. Parameterization of the domain using morphing boxes and deformation of geometry. Set-up of design of experiments for optimization based on iterative execution of ANSA-solver-META software.

Mentor

Location: Galleon 3 Conference Room, Time: 3:00PM-4:00PM

An introduction to FloEFD, the fully CAD-Embedded fluid dynamics software, that supports frontloading of CFD analysis earlier in design processes. FloEFD for Siemens NX, Solid Edge, PTC Creo, and CATIA V5 is designed to eliminate the significant CFD process time overheads and provide an accurate simulation tool suited for design engineer use. The presentation will describe how to how to perform fluid flow and heat transfer analysis directly within familiar CAD environments using several example models for aerospace and electronics cooling applications. These will cover enabling FloEFD technology that supports: quick handling and preparation of CAD geometry for CFD; fast, robust automated meshing directly on CAD geometry; guided simulation set up; and visualizing/analyzing results through to performing parametric studies and comparing results for earlier decision making.

Active Thermal & Fluids Paper Session II

Location: Clipper Conference Room, Time: 1:15PM-4:00PM

Session Chair: Brian Motil (GRC) & Ryan Edwards (GRC)

13:15 – 13:45	**Overview of the Thermal Control System on the Europa Clipper Spacecraft** TFAWS18-AT-19 *Christopher Bertagne, Pradeep Bhandari, Jenny Hua, Raymond Lee, Arthur Mastropietro, Hared Ochoa, Anthony Paris, and Bruce Williams*
13:45 – 14:15	**Thermal and Hydraulic Analysis of Europa Clipper Heat Rejection System Thermal Control Valves** TFAWS18-AT-14 *Razmig Kandilian, Pradeep Bhandari, and Arthur Mastropietro*
14:15 – 14:45	**Multi-Objective Optimization of Thermal Properties for Direct Contact Membrane Distillation** TFAWS18-AT-16 *Dani Perdue*

14:45 – 15:15 **Thermal Modeling of Zero Boil Off Tank Experiment**
TFAWS18-AT-17
Erin Tesny and Daniel Hauser

15:15 – 15:30 **Break**

15:30 – 16:00 **CFD Analysis of NACA-0018 and NACA-0021 Blade Profile of Darrieus-Type Hydro Rotor Performance in Vortex**
TFAWS18-AT-08
Wajiha Rehman and Mohammad Fozan ur Rab

Evening Activities: Tuesday, August 21st

Social Outing – The Spot, 6pm

Location: 3204 Seawall Blvd, Galveston, TX 77550
Phone: (409)621-5237, Website: http://www.islandfamous.com/venues

The Spot has 5 venues in 1 spot, offering gourmet hamburgers, fresh seafood, ice cream, fresh-baked desserts and bread, an arcade, and Tiki Bar. The Spot is outdoor dining at its best, featuring one of Galveston's largest open air decks overlooking the beautiful Gulf of Mexico. Tuesdays feature Happy Hour until 7pm and each of the 5 establishments has their own Tuesday Specials.

Directions: The Spot is 1.4miles Northeast up Seawall Blvd from the San Luis Resort. To take the 28min walk or 3minute drive from the San Luis, head up Seawall Blvd opposite the direction of the IHOP and Galveston Convention Center.

For transportation in Galveston, we recommend Lyft. New customers get a $10 credit by signing up at lyft.com/invite/TFAWS

Passive Thermal Paper Session II

Location: Spinnaker Conference Room, Time: 8:00AM-11:15AM

Session Chair: Ruth Amundsen (LaRC) & Kaitlin Liles (LaRC)

8:00 – 8:30	**Optimization of Thin-Film Solar Cells for Lunar Surface Operations** TFAWS18-PT-18 *William Johnson*
8:30 – 9:00	**Thermal Design, Analysis, and Thermal Vacuum Testing of a 3U CubeSat, CeREs** TFAWS18-PT-17 *Sergio Guerrero*
9:00 – 9:30	**Verification of the In-House Developed Simulator Software for Communication Satellite** TFAWS18-PT-16 *Anil Aksu and Hilmi Sundu*
9:30 – 10:00	**Thermal Analysis and Design of an S-Band Helical Antenna for LEO Satellites** TFAWS18-PT-13 *Sonia Botta, Nahuel Castello, Juan Andres Breme, and Cristobal Gerez*
10:00 – 10:15	**Break**
10:15 – 10:45	**Characterization of Radiation Heat Transfer in High Temperature Structural Test Fixtures** TFAWS18-PT-14 *Larry Hudson, Gus Kendrick, Jessica Kenny, Chris Kostyk, Shelby Pfeifer, Tim Risch, and Megan Waller*
10:45 – 11:15	**International Space Station Passive Thermal Control System, Top Ten Lessons-Learned** TFAWS18-PT-08 *John Iovine*

Intro to TD Direct (Hands-on)

Location: Galleon 1 Conference Room, Time: 8:00AM-12:00PM

Company: CRTech

This session will provide an introduction to 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. Experienced users are welcome but are requested to allow new users to have priority at the workstations.

Intro to TSS

Location: Galleon 2 Conference Room, Time: 8:00AM-12:00PM

Company: Spacedesign

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.

Ansys Presentation

Location: Galleon 3 Conference Room, Time: 8:00AM-12:00PM

Company: Ansys

Come join ANSYS as we show off and discuss our entire platform, the ability to integrate multiple physics and share information between various groups. Learn about the latest innovation in simulation and how you can leverage capabilities to for thermal and fluids analysis and beyond. The ANSYS platform integrates fluids, structural, electromagnetics, and full systems into a platform with tools that any designer or analyst can leverage to understand and deliver products with more confidence.

History of ATCS of Manned US Spacecraft

Location: Galleon 1 Conference Room, Time: 8:00AM-10:30AM

Instructor: Eugene Ungar, Ph.D.

Attendance limited to US Citizens.
Proof of US Citizenship will be check prior to conference room entry.

The short course traces the evolution of active thermal control systems on US human spacecraft from Mercury to Orion. Design parameters, limitations, and details will be presented.

Ansys Discovery Live

Location: Galleon 3 Conference Room, Time: 10:00AM-11:00AM

Company: Ansys

Come join ANSYS as we show off our latest and most innovative technology, we spent the last 6 years developing a tool that provides instantaneous 3D simulation, tightly coupled with direct geometry modeling, to enable interactive design exploration and rapid product innovation. It is an interactive experience in which you can manipulate geometry, materials types or physics inputs, then instantaneously see changes in performance. Capable of multiple physics Discovery Live will allow testing of more design iterations in a shorter amount of time, perform feasibility studies on new concepts and bring products to market faster.

Future of 2 Phase Thermal Control (Panel Discussion)

Location: Clipper Conference Room, Time: 10:30AM-12:00PM

Panel Members: Rubik Sheth (JSC), Eric Sunada (JPL), Brian Motil (GRC)

Two-phase thermal control systems in microgravity, with significant density differences between phases, pose challenges for many current and proposed spacecraft systems. Because of the lack of understanding of these effects and the inability to scale multiphase systems in low gravity, NASA generally opts to avoid using two-phase systems for spacecraft despite the significant performance increases and lower mass. The goal of this panel discussion will be to identify key technology gaps and challenges that thermal engineers face today when considering a two-phase thermal management system.

The panel discussion will begin with a brief overview of recent and on-going NASA projects designed to elicit a fundamental understanding of gas-liquid two phase behavior as it applies to thermal control systems in the Space environment. The projects/experiments discussed will range from boiling/condensation fundamentals, heat pipes, and cryogenic storage systems. We will identify what fundamental question or questions are being addressed in each case.

An overview will be also be presented to address future mission needs and the specific advantages multi-phase systems offer, in particular for low cost planetary science missions and enabling missions in extreme environments. The need for efficient heat transfer with concurrent spatial and temporal temperature stability to reduce thermally-induced noise drives a serious look at multi-phase systems as a solution. Furthermore, missions to environments such as the Venus surface or penetration of ice layers in ocean worlds will likely require them.

Time will be allocated at the end of this session to allow comments and questions from attendees. The intent is to use this session as a starting point to advocate for a coordinated technology development effort in this area.

Lunchtime Speaker: Wednesday, August 22nd

Dr. Karen Nyberg

Location: Ballroom A (take escalator to 2nd floor), Time: 12:00PM-1:00PM

Karen L. Nyberg, Ph.D. was selected as a Mission Specialist by NASA in 2000. The Vining, Minnesota native holds a Bachelor of Science in Mechanical Engineering from the University of North Dakota; a Master of Science in Mechanical Engineering from the University of Texas at Austin, and a Doctorate in Mechanical Engineering also from the University of Texas at Austin. She began as a Co-op in 1991 and worked for NASA in a variety of areas. She received a patent for work done in 1991 on the Robot Friendly Probe and Socket Assembly. In 1998, upon completing her doctorate, she accepted a position with the Crew and Thermal Systems Division, working as an Environmental Control Systems Engineer. Nyberg has served on two spaceflights, STS-124 and Expedition 36/37, and has accumulated 180 days in space. She has since served in the Space Shuttle branch, the Exploration branch, and as Chief of the Robotics branch.

Interdisciplinary Paper Session III

Location: Spinnaker Conference Room, Time: 1:15PM-5:00PM

Session Chair: Chris Evans (MSFC)

13:15 – 13:45	**Experimental Study of the Effects of Xenon Plasma Erosion on Spacecraft Thermal Control Surfaces** TFAWS18-IN-20 *Evan Racine*
13:45 – 14:15	**Modeling a Rapid Cycle Adsorption Pump for CO2 Compression** TFAWS18-IN-12 *Lisa Erickson and Anthony Iannetti*
14:15 – 14:45	**Automatic creation of reduced-order models using Thermal Desktop** TFAWS18-IN-07 *Derek Hengeveld*
14:45 – 15:15	**Modeling Multi-Parameters Radiation in Porous metal Via Machine Learning** TFAWS18-IN-15 *Hyun Hee Kang and Shima Hajimirza*
15:15 – 15:30	**Break**
15:30 – 16:00	**Thermal Fluid Model Development of Steam Methane Reformer using Artificial Neural Network** TFAWS18-IN-01 *M. A. Rafe Biswas and Kamwana Mwara*
16:00 – 16:30	**Integrated Thermal Vacuum Testing of the Solar Array Cooling System for Parker Solar Probe** TFAWS18-IN-05 *Carl Ercol, Elisabeth Abel, Allan Holtzman, and Eric Wallis*
16:30 – 17:00	**Candidate Benchmark Problems for Active and Passive Thermal Software** TFAWS18-IN-18 *Douglas Bell*

Aerothermal/Cryothermal Combined Paper Session

Location: Clipper Conference Room, Time: 1:15PM-4:30PM

Session Chair: Monica Guzik (GRC)

13:15 – 13:45	**The Design and Aero Thermodynamic Analysis of Inversely Derived Scramjet Configurations** TFAWS18-AE-01 *Frederick Ferguson, Dehua Feng, and Julio Mendez*
13:45 – 14:15	**Shock-Capturing using a Radial Basis Function Blended Interpolation Scheme** TFAWS18-AE-02 *Michael Harris, Alain Kassab, Eduardo Divo*
14:15 – 14:45	**CO2 Cryofreezer Coldhead and Cycle Design Insights for Mars ISRU** TFAWS18-CT-01 *Jared Berg and Malay Shah*
14:45 – 15:15	**Cryogenic thermophysical properties measurements of materials at the cryogenics and fluids branch, Goddard Space Flight Center** TFAWS18-CT-02 *Amir E. Jahromi, James G. Tuttle, Edgar R. Canavan*
15:15 – 15:30	**Break**
15:30 – 16:00	**Numerical Modeling of Thermal Stratification in Cryogenic Propellant Tanks** TFAWS18-CT-04 *Xiao-Yen Wang, Jonathan Harrison, Andy Noonan, Pooja Desai*
16:00 – 16:30	**Cryogenic Multilayer Insulation Theory and an Analysis of Seams under a Variety of Assumptions** TFAWS18-CT-05 *Justin Elchert*

TAITherm Human Thermal Hands-On Training Course

Location: Galleon 1 Conference Room, Time: 1:00PM-5:00PM

Company: ThermoAnalytics

ThermoAnalytics will lead a hands-on class that will teach users about human thermal simulation by setting up and analyzing transient human thermal models, building a cabin with environmental loads, applying clothing systems, and understand localized comfort for design evaluation. The TAITherm Human Thermal model can simulate humans with different genders, height, and weight operating in a wide range of environments. The class will be relevant for anyone interested in human thermal design for cabins, HVAC/ECS systems, protective suits, personal cooling devices, moisture management, microclimates, wearable sensors, performance materials, or human safety. ThermoAnalytics is a global leader in thermal and infrared simulation and testing. TAITherm is our advanced thermal analysis software with a powerful GUI to enable rapid setup and analysis of complex thermal systems. TAITherm can also perform coupled thermal-electrical simulation of battery cells and packs under realistic transient conditions, predict thermal runaway, and evaluate battery lifetime performance. TAITherm and Human Thermal models can be readily coupled with other CAE tools, including 1D, CFD, FEA, Thermal, and Optimization tools. Our CoTherm tool provides a flexible and user-friendly way of implementing co-simulation processes with different simulation codes.

Intro to TSS

Location: Galleon 2 Conference Room, Time: 1:00PM-5:00PM

Company: Spacedesign

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.

Ansys Discovery Live Demo

Location: Galleon 3 Conference Room, Time: 2:00PM-4:00PM

Company: Ansys

Come join ANSYS as we show off our latest and most innovative technology, we spent the last 6 years developing a tool that provides instantaneous 3D simulation, tightly coupled with direct geometry modeling, to enable interactive design exploration and rapid product innovation. It is an interactive experience in which you can manipulate geometry, materials types or physics inputs, then instantaneously see changes in performance. Capable of multiple physics Discovery Live will allow testing of more design iterations in a shorter amount of time, perform feasibility studies on new concepts and bring products to market faster.

Cocktail Hour & TFAWS Banquet

Location: San Luis Resort Grand Ballroom, Time: 6:00PM

Keynote Speaker: Dr. Donald Roy Pettit

Donald R. Pettit, Ph.D was selected by NASA in 1996. The Silverton, Oregon native holds a Bachelor of Science in Chemical Engineering from Oregon State University and a Doctorate in Chemical Engineering from the University of Arizona. Prior to becoming an astronaut, he worked as a staff scientist at the Los Alamos National Laboratory, New Mexico. A veteran of three spaceflights, Pettit served as NASA Science Officer for Expedition 6 in 2003, operated the robotic arm for STS-126 in 2008 and served as a Flight Engineer for Expedition 30/31 in 2012, where he lived aboard the International Space Station for more than 6 months.

Experience:
Staff scientist at Los Alamos National Laboratory, Los Alamos, New Mexico from 1984 to 1996. Projects included reduced gravity fluid flow and materials processing experiments onboard the NASA KC-135 airplane, atmospheric spectroscopy on noctilucent clouds seeded from sounding rockets, fumarole gas sampling from volcanoes and problems in detonation physics. He was a member of the Synthesis Group, a presidential commission lead by Lt. Gen. (Ret.) Tom Stafford tasked with assembling the technology to return to the Moon and explore Mars (1990) and the Space Station Freedom Redesign Team (1993).

NASA Experience:
Selected by NASA to be an astronaut in April 1996, Dr. Pettit reported to the Johnson Space Center in August 1996. A veteran of three spaceflights, Dr. Pettit has logged more than 370 days in space and over 13 spacewalk hours. He lived aboard the International Space Station for 5 1/2 months during Expedition 6, was a member of the STS-126 crew, and again lived aboard the station for 6 1/2 months as part of the Expedition 30/31 crew.

Spaceflight Experience:
Expedition 6 (November 23, 2002 to May 3, 2003). Dr. Pettit completed his first spaceflight as NASA Science Officer aboard the International Space Station with Mission Commander Ken Bowersox, and Flight Engineer Nikolai Budarin, logging more than 161 days in space. During their mission, the crew performed science experiments while continuing space station construction. Dr. Pettit and Ken Bowersox performed two spacewalks. The Expedition 6 crew launched on STS-113 Space Shuttle Endeavour expecting to return on STS-114 Space Shuttle Discovery after a 2 1/2-month mission. Following the Columbia Space Shuttle disaster that grounded the Space Shuttle fleet, they returned to Earth after 5 1/2 months on Soyuz TMA-1, landing in Kazakhstan with a malfunction-caused ballistic entry. This off-nominal entry resulted in the crew being lost for a number of hours until recovered by ground rescue teams.

STS-126 (November 14 to November 30, 2008). The Space Shuttle Endeavour launched from the Kennedy Space Center, Florida, and due to bad weather, returned to land at Edwards Air Force Base, California. Eventually, the vehicle was relaunched and the 16-day mission included expanding the living quarters of the International Space Station and a regenerative life support system that reclaims potable water from urine. During the mission, Dr. Pettit operated the robotic arm for four spacewalks.

Expedition 30/31 (December 21, 2011 to July 1, 2012). Pettit launched to the International Space Station aboard the Soyuz TMA-03M spacecraft from Kazakhstan. NASA Flight Engineer Don Pettit, Russian Soyuz Commander Oleg Kononenko and European Space Agency Flight Engineer Andre Kuipers of the Netherlands docked to the station on December 23, 2011. Dr. Pettit did scientific research and captured the first commercial cargo spacecraft, the SpaceX Dragon D1 using the robotic arm. They landed in Kazakhstan after 193 days in space.

Active Thermal & Fluids Paper Session III

Location: Spinnaker Conference Room, Time: 8:00AM-11:15PM

Session Chair: Brian Motil (GRC) & Ryan Edwards (GRC)

8:00 – 8:30	**A Volume of Fluid Based Numerical Algorithm for Simulating Multiphase Incompressible Flows with Large Density Discontinuities** TFAWS18-AT-12 *Joshua Wagner and C. Fred Higgs III*
8:30 – 9:00	**Photovoltaic Thermal Control System Flow Control Valve Actuator Duty Cycle after Addition of Lithium-Ion Batteries** TFAWS18-AT-11 *Matthew Jurick, Garry Livesay, and Keyla Robles*
9:00 – 9:30	**Increased Control of Squeeze-Film Performance with Magnetohydrodynamics and Surface Roughness: Theory and Modelling** TFAWS18-AT-10 *Jordan Wagner and C. Fred Higgs III*
9:30 – 10:00	**Nucleate Boiling Heat Transfer Enhancement with Electrowetting** TFAWS18-AT-07 *Aritra Sur, Yi Lu, Carmen Pascente, Paul Ruchhoeft, Vishal Talari, and Dong Liu*
10:00 – 10:15	**Break**
10:15 – 10:45	**Suppression of Leidenfrost State Using Electrically Induced Interfacial Instabilities** TFAWS18-AT-06 *Yi Lu, Vishal Talari, Jiming Bao, Dong Liu*
10:45 – 11:15	**Heat Transfer Augmentation via In-Situ Nanofluids Synthesis and Regenerative Nanofin Coatins** TFAWS18-AT-22 *Brandon Dooley and Debjyoti Banerjee*

Capture Output & Verify Results (COVeR)

Location: Galleon 1 Conference Room, Time: 8:00AM-12:00PM

Company: Thermal Modeling Solutions

Post Processing of Thermal Model output using TARP. COVeR is a standalone post processing environment that specializes in showing heat flows within a model in a block diagram format. Both codes strongly leverage the concept of Groups to combine related nodes into representations of actual hardware thereby removing the abstraction associated with nodal level results.

Advanced TSS

Location: Galleon 2 Conference Room, Time: 8:00AM-12:00PM

Company: Spacedesign

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.

KeyShot 3D Rendering

Location: Galleon 3 Conference Room, Time: 9:00AM-10:00AM

Company: KeyShot

KeyShot is a standalone 3D rendering software program known for its ease-of use, speed, and high quality image output. You can bring in your native CREO, SpaceClaim, or other 3D CAD data and render out amazing images or animations within minutes. In this workshop, you'll learn the basics of KeyShot. Topics covered include import options, assigning and editing materials, applying textures and labels, HDRI and physical lighting, cameras, and more. Learn about new improvements with KeyShot 7 such as new materials, improved texture mapping, new procedural textures, and workspaces. You'll also walk away with tips and tricks to make your rendering workflow more efficient. This is not a hands-on session so no previous experience with KeyShot is required.

Form Factors, Grey Bodies, and Radiation Conductances

Location: Clipper Conference Room, Time: 8:00AM-12:00AM

Instructor: Steve Rickman

Students are introduced to basic thermal radiation analysis in undergraduate heat transfer courses but little focus is given to techniques employed for thermal radiation analysis in the real world. This theory-based short course provides an introduction to thermal radiation form factors, grey bodies and radiation conductances. Various techniques for form factor calculation are explored and demonstrated. Radiation interchange using, both, monte carlo and radiosity techniques is demonstrated.

Thermal Desktop Modeling Cryogenic Tanks (Panel Discussion)

Location: Yacht Conference Room, Time: 9:00AM-11:00AM

Abstract located under *Agenda* at tfaws.nasa.gov

Lunchtime Speaker: Thursday, August 23rd

Kevin Window

Location: Ballroom A (take escalator to 2nd floor), Time: 12:00PM-1:00PM

As Director of John Space Center's Engineering Directorate, Kevin Window provides executive guidance and institutional support to programs, projects, and technology activities in support of the U.S. space policy and NASA identified strategic goals. He provides organizational leadership for overall technical engineering support and system management of the International Space Station (ISS), Orion, and technical insight into the Commercial Crew Program (CCP). His organization is also responsible for developing technology and engineering domains necessary for human space flight for lunar and Mars exploration and numerous unique NASA hardware and software developments across all human space flight programs.

Session Descriptions: Thursday, August 23rd (Afternoon)

Passive Thermal Paper Session III

Location: Spinnaker Conference Room, Time: 1:15PM-3:15PM

Session Chair: Ruth Amundsen (LaRC) & Kaitlin Liles (LaRC)
Location: Spinnaker Conference Room

13:15 – 13:45 **Constant Conductance Heat Pipe Modeling in Siemens Simcenter and Correlation with JPL SWOT Mission Two-Phase Testbed**
TFAWS18-PT-05
Lina Maricic, Louis Tse, and Ruwan Somawardhana

13:45 – 14:15 **MLI Blanket Performance: Analytical Predictions and Quantitative Trends Measured in Testing**
TFAWS18-PT-06
Tyler Schmidt, Pradeep Bhandari, and Hared Ochoa

14:15 – 14:45 **Infrared Microscopy-Based Thermal Characterization of Lithium-Ion Battery Electrodes**
TFAWS18-PT-11
Rajath Kantharaj, Yexin Sun, and Amy Marconnet

14:45 – 15:15 **Assessment of the Mars Helicopter Thermal Design Sensitivities Using the Veritrek Software**
TFAWS18-PT-12
Stefano Cappucci, Michael T. Pauken, Jacob Moulton, and Derek Hengeveld

CRTech: Bring Your Own Model

Location: Galleon 1 Conference Room, Time: 1:00PM-5:00PM

Company: CRTech

This session is a great opportunity receive feedback on your own models from the folks at CRTech.

Advanced TSS

Location: Galleon 2 Conference Room, Time: 1:00PM-5:00PM

Company: Spacedesign

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.

JWST Thermal Analysis and Thermal Vacuum Discussion

Location: Clipper Conference Room, Time: 1:15PM-4:30PM

Moderator: Daniel Nguyen (GSFC)

Overview of Test Planning, Preparations, and Conduct of the James Webb Space Telescope Combined Optical Telescope Element and Integrated Science Instrument Module (OTIS) Thermal Vacuum/Thermal Balance Test in the JSC Chamber A

Topic List

13:15 – 14:00 **OTIS description and test objectives, ISIM and OTE precursor testing.**

14:00 – 14:45 **Chamber A capabilities and modifications to complete thermal vacuum testing.**

14:45 – 15:00 **Break**

15:00 – 15:45 **Highly specialized GSE required for JWST verification testing.**

15:45 – 16:30 **Test result, hurricane Harvey impacts, and lessons learned.**

The cryogenic thermal vacuum/thermal balance test of the James Webb Space Telescope (JWST) combined Optical Telescope Element (OTE)/Integrated Science Instrument Module (ISIM), known as the OTIS, at the Johnson Space Center (JSC) Chamber A in 2017 was an extremely complex test due to the size and intricacies of the telescope, complex test objectives, and cryogenic temperatures required for test. The final thermal vacuum test of the combined flight OTE and ISIM elements was prefaced by years of modifications to chamber facilities and development of highly specialized Ground Support Equipment (GSE), and included three extensive precursor tests of non-flight and flight hardware in the JSC Chamber

A to establish safe and optimal test operational procedures. Extensive efforts were expended prior to the test to assure safety of personnel and flight hardware during off-nominal events. Much of the planning was based in part on experiences during the ISIM element testing in the GSFC Space Environment Simulator (SES) and the OTE precursor testing in JSC Chamber A. This planning for off-nominal events proved especially prescient for the OTIS test, as Hurricane Harvey struck the Houston area during the test in August 2017, and consequences for the precious payload could have been severe.

This combined presentation from the OTIS payload thermal, JSC facilities, and OTIS GSE test groups, defines the JWST observatory and mission in general, and the ISIM and OTE elements in more detail. It lists the OTIS test thermal objectives, critical constraints and limitations, and test planning. JSC Chamber A facility capabilites, and the extensive modifications performed to ready it for the OTIS test, are described. The highly specialized GSE developed for the test, including thermal boundaries, optical equipment, and data system development, are also described. Planned versus actual thermal profiles, general thermal model predictions versus test results, consequences of Hurricane Harvey, and lessons learned from the test are shown.

KeyShot Advanced Features

Location: Galleon 3 Conference Room, Time: 2:00PM-3:00PM

Company: KeyShot

Looking to get the most out of KeyShot? In this session, you will learn how to use the Pro features of KeyShot 7. You'll be able to create high-quality visuals even faster after learning about multi-materials, the material graph, geometry editor, model sets, studios, the configurator, and viewer. Animation, KeyShotXR, and VR will also be covered. No previous experience with KeyShot required.

Evening Activities: Thursday, August 23rd

Social Outing – Stuttgarden Tavern, 6pm

Location: 111 23rd St Galveston, Galveston, TX 77550
Phone: (409)497-4972, Website: https://www.stuttgardentavern.com/galveston-2/

Enjoy delicious German and American food and relax at Stuttgarden on 'The Strand' – a historic district in Galveston with lots of shopping and sightseeing. Thursdays at Stuttgarden feature $8 pork schnitzel and $6 craft flights.

After your dinner feel free to explore The Strand, we recommend grabbing dessert at La Kings Confectionary (Open until 9pm, 2323 Strand St) or checking out the Tall Ship Elissa, built in 1877 (Open til 5, but you can see it at the dock anytime - 2100 Harborside Dr). 'The Strand' has lots of shopping and nightlife - on Strand St. between 20th St. and 25th St.

Directions: Stuttgarden Tavern is 3.7miles (roughly a 10 minute drive from the San Luis Resort)

- Head northeast on Seawall Blvd
- Turn left onto 37th St
- Turn right onto 23rd St/23rd Street Rear
- Stuttgarden Tavern is on the right side of the road

For transportation in Galveston, we recommend Lyft. New customers get a $10 credit by signing up at lyft.com/invite/TFAWS

Active Thermal & Fluids I

Ammonia Vent of the External Thermal Control System (EATCS) Radiator #3 Flow Path #2 on the International Space Station (ISS)
TFAWS18-AT-01
Darnell Cowan, Johnson Space Center

The External Active Thermal Control System (EATCS) provides cooling for all pressurized modules and the main Power Distribution Electronics (PDE) on the International Space Station (ISS). There are 2 EATCS loops (Loop A and Loop B) which includes 3 deployable radiators. Each deployable radiator contains 2 flow paths to provide heat rejection.

Telemetry monitoring identified a coolant (liquid ammonia) leak in EATCS Loop B. Robotic External Leak Locator (RELL) scans found higher concentrations of vaporous ammonia near the EATCS Loop B Radiator #3 Flow Path #2. On May 3, 2017, the EATCS Loop B Radiator #3 Flow Path #2 was isolated and vented. As of the data to date, the ammonia leak has ceased.

The purpose of this presentation is to discuss the analysis for venting the EATCS Loop B Radiator #3 Flow Path #2. Venting analysis is performed to determine the worst case time to empty the flow path and maximum thrusts imposed on the ISS. Flight controllers and engineers in the Mission Control Center (MCC) uses this data to develop operational procedures and perform the vent safely. It was predicted that the worst case time to empty the EATCS Loop B Radiator #3 Flow Path #2 was ~ 60 minutes. The predicted maximum thrusts were ~ 22 lbf (98 N) at the start of the vent and 20 lbf (89 N) after the system reaches saturation.

The vent was successfully performed and took ~ 20 minutes to empty the EATCS Loop B Radiator #3 Flow Path #2. Using telemetry from the day of the vent, analysis determined the time to empty the EATCS Loop B Radiator #3 Flow Path #2 would be ~15 minutes. The predictive analysis used worst case inputs and assumptions which bounded the actual results. Telemetry is not available to correlate actual thrust with the predicted maximum thrusts. However, by using Russian Thrusters for ISS attitude control, attitude control telemetry indicated the flight attitude was maintained.

Numerical and Experimental Investigation of River Hydrokinetic Turbine for Water Pumping Application
TFAWS18-AT-02
Muzammil Ejaz, Mohammad Fozan ur Rab, Fahad Qureshi, Hassan, NED University of Eng and Tech, Karachi, Pakistan
Wajiha Rehman, University of Engineering and Technology, Lahore, Pakistan

This study is carried out to utilize the kinetic energy of flowing river stream to drive the turbine through which a pump shaft would be coupled. The turbine will rotate water pump to pump the water to the desired altitude and distance. This system does not require any external power and heavy construction work. Axial flow Hydro-kinetic turbine design is chosen because it has high efficiency and fabrication ease. The scaled prototype is fabricated first and tested in a water tunnel at 0.7 m/sec flow velocity. Then, same prototype model is analyzed using Computational Fluid Dynamics (CFD) tool at same inlet flow velocity and numerical results would be validated. The computational grid contains approximately 8.5 million cells with average y+ value of less than 5 and the k-omega SST turbulence model is utilized. The full-scale turbine which is needed to be installed in the river stream has 5 feet tip diameter. The actual minimum river flow velocity is measured and is found to be 2 m/sec. So, its numerical analysis is also carried out at

2 m/s flow inlet velocity in a fully submerged condition to replicate the actual flow conditions. The results show that the turbine can produce about 310-320 N-m of torque while running at 65-70 rpm in this condition. Hence, the turbine can produce about 2.1KW output shaft power. The turbine will be directly coupled to the pump shaft by utilizing belt-pulley mechanism that can increase the rpm up to 300. Progressive cavity pump would be suitable as they have ability to operate at low rpm and are capable for delivering continuous flow. Thus, making the overall process simple and cost efficient.

Demonstration of Copper-Water Heat Pipes and HiK Plates on the International Space Station

TFAWS18-AT-03

Mohammed Ababneh, Calin Tarau, and William Anderson, Advanced Cooling Technologies, Inc.
Angel Alvarez-Hernandez and Stephania Ortega, Johnson Space Center
Jeffery Farmer, and Robert Hawkins, Marshall Space Flight Center

Copper-water heat pipes are commonly used for thermal management of electronics systems on earth and aircraft, but have not been used in spacecraft thermal control applications to date, due to the satellite industry's requirement that any device or system be successfully tested in a microgravity environment prior to adoption. Recently, Advanced Cooling Technologies Inc., (ACT), in coordination with engineers from NASA's Marshall Space Flight Center (MSFC) and Johnson Space Center (JSC) demonstrated successful flight operation of these heat pipes in low-Earth orbit. The testing was conducted aboard the International Space Station (ISS) under the Advanced Passive Thermal eXperiment (APTx) project, a project to test a suite of passive thermal control devices 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 freeze-thaw cycles during the ISS testing. The following was demonstrated during 10 days of testing on the ISS:

1. Successful operation of the copper-water heat pipes and HiK™ plate
2. Ability of the copper-water heat pipes and HiK™ plate to survive multiple freeze/thaw cycles
3. As-designed heat transport via copper-water heat pipes.
4. Reliable, repeatable start up of copper-water heat pipes and HiK™ plate from a frozen state.

This presentation describes the test hardware, ground and flight test campaign, and discusses the results and conclusions of the testing.

Next Generation of High-Heat-Flux Heat Pipes for Space Thermal Control Applications

TFAWS18-AT-04

Mohammed Ababneh, Calin Tarau, and William Anderson, Advanced Cooling Technologies, Inc.
Jesse Fisher, Lockheed Martin Coherent Technologies

Novel hybrid wick aluminum-ammonia constant conductance heat pipes (CCHPs) are developed to handle heat flux requirements for spacecraft thermal control applications. The 5-10 W/cm2 heat density limitation of aluminum-ammonia grooved heat pipes has been a fundamental limitation in the current design for space applications. The recently demonstrated >50W/cm2 capability of the hybrid high heat flux heat pipes provides a realistic means of managing the high heat density anticipated for the next generation space designs. The hybrid wick high heat flux aluminum-ammonia CCHP transported a heat load of 275 Watts with heat flux input of > 50 W/cm2 and with a thermal resistance of 0.015 ºC/W at 0.1 inch adverse elevation. This demonstrates an improvement in heat flux capability of more than 3 times over the standard axial groove aluminum-ammonia CCHP design.

Mitigation of Orion Ammonia Boiler Outlet Coolant Thermal Stratification
TFAWS18-AT-15
Eugene Ungar and Lauren Foley, Johnson Space Center

Part of NASA's Orion Multi-Purpose Crew Vehicle active thermal control system (ATCS) is the Ammonia Boiler Heat Exchanger (ABHX). The ABHX is used as a topper when the Orion radiators cannot provide sufficient cooling and is the sole method of cooling the spacecraft after separation of the command and service modules prior to reentry. Ammonia and an inhibited propylene glycol/water mixture (PGW) flow through the ammonia boiler in a counter-flow fashion, allowing the evaporating ammonia to cool the PGW. After exiting the boiler, the PGW travels through a 10.9 mm internal diameter tube with three bends to a temperature sensor block containing two thermistors. Development testing showed that the flow at the sensor block was not well mixed - the two PGW temperature sensors registered temperature differences of up to 5°C.

A scaled gravity-fed water test stand was constructed of 1 inch clear PVC pipe to investigate the stratification of the flow downstream of the boiler. Dye injection was used to visually assess the flow and mixing. Baseline testing confirmed that the flow was poorly mixed at the thermistor location. Static mixers of different types and lengths were assessed in the test stand. In the end, a configuration was chosen that resulted in well-mixed flow while adding minimal pressure drop.
In the present work, the stratification issue is discussed, the test stand configuration and scaling is detailed, and the test is described. The chosen mixer configuration is detailed and its effect on the performance of the Orion ATCS is discussed.

Technology Development of Shape Memory Alloy Morphing Radiators: Analysis, Design, and Testing
TFAWS18-AT-20
Christopher Bertagne, Jet Propulsion Laboratory

Thermal control is an important aspect of spacecraft design, particularly in the case of crewed vehicles that must maintain a precise internal temperature at all times, in spite of significant variations in the external thermal environment and internal heat loads. Future missions beyond low Earth orbit will require radiator systems with high turndown ratios, defined as the ratio between the maximum and minimum heat rejection rates achievable by the radiator system. Current radiators are only able to achieve turndown ratios of 3:1, far less than the 12:1 turndown ratio requirement expected for future missions. An innovative morphing radiator concept uses the temperature-induced phase transformation of shape memory alloy (SMA) materials to achieve turndown ratios that are predicted to exceed 12:1 via substantial geometric reconfiguration. Developing mathematical and computational models of these morphing radiators is challenging due to the strong two-way thermomechanical coupling not present in traditional fixed-geometry radiators and not widely considered in the literature. Although existing simulation tools are capable of analyzing the behavior of some thermomechanically coupled structures, general problems involving radiation and deformation cannot be modeled using publicly available codes due to the complexity of modeling spatially evolving boundary fields. This presentation discusses the development of new computational tools to provide important insight into the operational response of SMA-based morphing. Several example problems are used to demonstrate the novel radiator concept. Additionally, a prototype morphing radiator was designed, fabricated, and tested in a thermal environment compatible with mission operations. An associated finite element model of the prototype was developed and executed. Model predictions of radiator performance generally agree with the experimental data, giving confidence that the tools developed are able to accurately represent the thermomechanical coupling present in morphing radiators and that such tools will be useful in future designs.

Active Thermal & Fluids II

CFD Analysis of NACA-0018 and NACA-0021 Blade Profile of Darrieus-Type Hydro Rotor Performance in Vortex
TFAWS18-AT-08
Wajiha Rehman, University of Engineering and Technology, Lahore
Mohammad Fozan ur Rab, NED University of Engineering and Technology

Darrieus-Type hydro rotor (DHR) is analogous to Darrieus vertical axis wind turbine, the difference is working fluid is water instead of air. The rotor is independent of flow direction and it generates power at low head regions while having little environmental effect. This research work aims to test the performance of two vertical axis rotors of different NACA profiles i.e. NACA-0018 and NACA-0021 in a conical water vortex pool.). Numerically, the relation of the coefficient of performance with the blade pitch angle and tip speed ratio will be shown for both profiles. The transient turbulent model with sliding mesh technique is used for simulation. This data will be helpful in forming the characteristic curves of both profiles in water which will be used in future research of low head water turbines.

Thermal and Hydraulic Analysis of Europa Clipper Heat Rejection System Thermal Control Valves
TFAWS18-AT-14
Razmig Kandilian, Pradeep Bhandari, and Arthur Mastropietro, Jet Propulsion Laboratory

This study presents simultaneous thermal and hydraulic analysis of the Europa Clipper heat rejection system (ECHRS). The spacecraft employs a mechanically pumped fluid loop to control component temperatures by harvesting the heat rejected by electronic components and utilizing it to maintain propulsion module component allowable flight temperatures (AFTs). The ECHRS utilizes two thermal control valves (TCVs) to modulate the heat rejection rate from the radiator based on the HRS fluid temperature to prevent exceeding AFTs at ECHRS controlled interfaces during the cruise to Jupiter and to minimize heater power in the cold Jupiter environment. In worst-case hot conditions (WCH), the TCVs direct flow to the radiator to reject heat and cool the fluid. In worst-case cold conditions (WCC), the TCVs bypass the radiator to minimize heat loss from the system. Each TCV has a hot and cold inlet and an outlet where the mixed fluid exits. The flow impedance of each inlet port depends on the temperature of the mixed fluid, which depends on the flow split between hot and cold flows. Therefore, hydraulic and thermal analysis must be performed simultaneously to determine the steady-state flow split and fluid and interface temperatures. First, the hydraulic analysis identified several leak paths between the primary and backup pairs of mixing valves resulting in 10% reduction in flow to the radiator in WCH conditions. Therefore, the design included a check valve upstream of the first TCV to prevent leakage between the two sets of TCVs. In addition, minimum and maximum flow fractions of 0.0016 and 0.86 to the radiator can be achieved in WCC and WCH conditions, respectively using two TCVs in series. This control scheme along with the use of louvers on the radiator presents a simple method to modulate the overall spacecraft heat rejection rate ratio of 35:1. This paper presents a simple method using pre-existing and commonly used analysis tools to perform coupled hydraulic and thermal analysis to design mechanically pumped fluid loop thermal control systems.

Multi-Objective Optimization of Thermal Properties for Direct Contact Membrane Distillation
TFAWS18-AT-16
Dani Perdue, Rice University

Direct contact membrane distillation (DCMD) is a process that has shown promise within the field of desalination due to its less energy intensive methods and widespread applications. DCMD is a thermally driven microfiltration separation process that operates on the principle of vapor-liquid equilibrium conditions where heat and mass transfer occur simultaneously. Fundamentally, DCMD is a based on a porous hydrophobic membrane separating the hot solution (feed) from the cold solution (permeate) where desalinated water condenses. The temperatures at the membrane interface determine the vapor pressure difference across the membrane. Molecular simulation has been used to identify trends between the various parameters of the distillation process by holding one property constant to study the effect on the other components of the system. However, DCMD still requires more concentrated research to determine what is required of all vital system components to produce an ideal and maximized output.
In this work, direct simulation Monte Carlo is employed to simultaneously optimize the relationships between key thermal properties: the Nusselt number, thermal boundary layer, heat transfer coefficient, and temperature polarization coefficient. Through molecular simulation, phase equilibrium was reached by calculating the chemical potential at the membrane interface and the entropy of the system was found. A wide array of configurations was executed within the model to pinpoint the Pareto frontier. We demonstrate that with these optimized parameters, the limitations of flux can be bounded, which will highlight the probabilistic range for improved future experimental work.

Thermal Modeling of Zero Boil Off Tank Experiment
TFAWS18-AT-17
Erin Tesny and Daniel Hauser, Glenn Research Center

Understanding fluid behavior in microgravity environments is essential to further development of cryogenic storage in space environments. The Zero Boil Off Tank (ZBOT) experiment was designed to investigate two-phase pressurization and depressurization of a tank in a microgravity environment. The test fluid was the refrigerant Perfluoro-normal-Pentane (PNP). Thermal modeling for the ZBOT model was conducted using Thermal Desktop and SINDA/FLUINT. The temperature distribution within the fluid of the tank is of particular interest. This particular work is centered on ascertaining the thermal behavior of the refrigerant in order to build more complete models of fluid in microgravity. Separate cases were run modeling experiments that were conducted both on the ground and on the International Space Station (ISS) to compare 1g and microgravity environments. The microgravity modeling cases consisted of a fluid lump representing the vapor ullage suspended in a solid to represent the liquid. Mass flow between the liquid and vapor was modeled using the Schrage equation for mass flow. Initial results indicate that the pressure rise and temperature increase within the fluid closely align with the experimental data by matching initial conditions of the experiment. This work is ongoing and will yield further insights into the thermal behavior of fluid mixing in microgravity.

Overview of the Thermal Control System on the Europa Clipper Spacecraft
TFAWS18-AT-19
Christopher Bertagne, Pradeep Bhandari, Jenny Hua, Raymond Lee, Arthur Mastropietro, Hared Ochoa, and Anthony Paris, Jet Propulsion Laboratory
Bruce Williams, Johns Hopkins University

This presentation will provide a detailed overview of the ongoing design and development of the thermal control system on the Europa Clipper spacecraft. Europa Clipper is currently being co-developed by the

NASA Jet Propulsion Laboratory (JPL) and the Applied Physics Laboratory (APL) at Johns Hopkins University to study the Jovian moon Europa in far greater detail than previous missions. The mission seeks to characterize the ice shell, subsurface ocean, surface topography, and magnetic environment of Europa using a suite of nine scientific instruments. The spacecraft faces several important challenges that affect its overall thermal design. The first of these is the need to support a range of different launch vehicles, including Delta IV Heavy, Falcon Heavy, and NASA's upcoming SLS. Launching on either the Delta IV Heavy or Falcon Heavy would require the spacecraft to perform a gravity-assist flyby of Venus in order to achieve a sufficiently high velocity to reach Jupiter, which requires that the spacecraft be designed to operate in a very warm thermal environment near Venus as well as very cold thermal environments during its science tour. An additional challenge is that the spacecraft is very power-limited, as a result of using solar panels for primary electrical power in lieu of radioisotope thermoelectric generators (RTGs). These challenges, as well as several others, have driven the architecture of the thermal control system toward an active architecture with a pumped fluid loop to harvest waste heat from warm electronics boxes and redistribute it in order to warm propulsion components. The design of this "heat redistribution system" (HRS) draws on heritage from the Mars Science Laboratory (MSL) mission, which uses a pumped fluid loop with CFC-11 as the working fluid. The result is a robust and reliable thermal design capable of meeting the unique requirements facing the Europa Clipper mission.

Active Thermal & Fluids III

Numerical Simulation of a Generic Scramjet Combustor with Cavity Flame Holder and Jet Injection using an Integro Differential Scheme to Solve the Navier Stokes Equations Numerically
TFAWS18-AT-05
Julio Mendez and Frederick Ferguson, North Carolina A&T State University

High Performance Computing (HPC) has made high-resolution fluid dynamic computations practical, and it has contributed to the design of high fidelity fluid systems. Accessing thousands of processors is not a technical barrier anymore, although efficient numerical implementations are mandatory. On the other hand, high fidelity numerical schemes such as Essentially Non-Oscillatory schemes (ENO) and Large Eddy Simulations (LES) with flux limiters have become the norm in supersonic flows studies where discontinuities due to shocks make computations unstable. However, the aforementioned schemes rely on flux reconstructions that are computationally expensive and they add uncertainty errors that are difficult to quantify. This technical effort focuses on the capabilities of a promising computational approach called The *Integro Differential Scheme* (IDS). Preliminary results demonstrated the IDS is second-order accurate and its built on a consistent averaging procedure which reconstructs the spatial fluxes based on the local information. The uniqueness of this method comes from combining the finite volume and finite difference methods. More importantly, the IDS solves the Navier Stokes Equations (NSE) without numerical models. This property highlights the advantage of the IDS since there is no uncertainty connected to semi-empirical models. As a validation test case, this work solves the flow field in a generic Scramjet with a single and double cavity flame holder and jet injection. The latter representing the fuel injection, although the solution does not consider chemical reaction. The computational model of the Scramjet will include the isolator, fuel injectors and the exhaust duct. The main objective of this study is to evaluate the flow structure near the injector, the role of the injection pressure, shock pattern as well as the effect of the cavity on the shock wave structures. This work does not evaluate the effect of the cavity geometry on the overall performance. Preliminary results demonstrate that the IDS recover the shock structure as it is expected and the static pressure recovery inside the Isolator is underpredicted compared to the diffusion model presented by Matsuo et al.. This discrepancy is not surprising since the shock structure is not symmetric because of the strong reflected shock emanating from the upper lip of the Scramjet.

Suppression of Leidenfrost State Using Electrically Induced Interfacial Instabilities
TFAWS18-AT-06
Yi Lu, Vishal Talari, Jiming Bao, Dong Liu

Leidenfrost phenomenon is closely related to the critical heat flux (CHF) limit in boiling heat transfer. When it happens, the formation of an insulating vapor layer between the liquid and the heating surface will significantly deteriorate heat transfer and lead to dryout crisis. Thus, understanding the mechanisms of and devising effective ways to suppress Leidenfrost phenomenon will provide insight for boiling heat transfer enhancement. In this work, a synchronized high-speed optical imaging and infrared (IR) thermography approach is taken to simultaneously measure the shape evolution of a Leidenfrost droplet and the instantaneous temperature and heat flux distributions on the heating surface. Both direct-current (DC) and alternating-current (AC) electric fields are applied to induce the electrowetting (EW) effect to suppress the Leidenfrost state. The impact of the applied voltage and driving frequency on the droplet dynamics, the instability of the liquid-vapor interface and the phase change heat transfer is investigated with the spatiotemporally resolved optimal and IR images. A theoretical model is also developed to predict the vapor film thickness and the elevated Leidenfrost point under the influence of the electric field.

Nucleate Boiling Heat Transfer Enhancement with Electrowetting
TFAWS18-AT-07
Aritra Sur, Yi Lu, Carmen Pascente, Paul Ruchhoeft, Vishal Talari, and Dong Liu, University of Houston

Electrowetting (EW) has drawn significant research interests in droplet-based microfluidics, and most applications focus on electronic displays, lab-on-a-chip devices and electro-optical switches, etc. In this paper, we report a novel application of EW in enhancing nucleate boiling heat transfer. The working approach capitalizes on the complimentary roles of hydrophobicity and hydrophilicity in the fundamental processes of nucleate boiling, and takes advantage of the ability of EW to dynamically alter the surface wettability at different thermal loads. In this work, we demonstrate the creation of tunable adaptive boiling surfaces, and examine the effects of EW on the overall boiling heat transfer characteristics. A synchronized high-speed optical imaging and infrared thermography approach is taken to obtain simultaneous measurements of the bubble dynamics, the temperature and heat flux distributions on the boiling surface. Boiling curves are constructed and the boiling heat transfer coefficients are computed for an EW-modulated surface, and the comparison with those for hydrophilic and hydrophobic surfaces shows clearly the efficacy of using EW to drastically improve the boiling heat transfer performance. Some insights are also offered on the boiling heat transfer mechanisms under the influence of EW.

Increased Control of Squeeze-Film Performance with Magnetohydrodynamics and Surface Roughness: Theory and Modelling
TFAWS18-AT-10
Jordan Wagner and C. Fred Higgs III, Rice University

Hydrodynamic squeeze-films are leveraged ubiquitously in engineering systems to damp vibrations of sensitive mechanical components. In these classical, purely-hydrodynamic bearings, damping is provided solely by the viscosity of the interfacial fluid, for which may be drastically diminished in high-temperature environments, potentially rendering the damper ineffective. Consequently, there has been interest in using fluids that maintain their viscosity at high-temperatures—for example, liquid metals like mercury and gallium—as the lubricating fluid in such dampers. Since these fluids are often good conductors of electrical current, we propose that electric and magnetic fields applied in specific orientations to such dampers may offer additional performance in extreme environments and enable in-situ control via the magnetohydrodynamic (MHD) forces induced in the flow.

Electrically-conducting fluids are subject to the same forces that act on current-carrying wires situated amongst a magnetic field; however, the resulting dynamics of the conducting fluid is significantly more complex than that of the wire. A thorough physical-mathematical analysis is required to leverage the potential benefits of this phenomenon. In this work, we develop a computational framework to analyze this problem, which is based on coupling the governing systems of electro and fluid dynamics—namely, the Maxwell and Navier-Stokes equations, respectively. The resulting partial differential equation system that emerges from introducing the Lorentz force into the fluid momentum equation governs generalized MHD flow. This system is extremely complex, and its solution is impossible to obtain analytically (at worst) and presents a formidable challenge numerically (at best). To make the problem more tractable, we follow a scaling-technique popular for analyzing thin-film flows, which was proposed by Osbourne Reynolds in 1886. The treatment is based on enforcing a low-Reynolds number assumption and integrating the mass-continuity constraint over depth. From this technique, we obtain a single, variable-coefficient Poisson equation for the fluid pressure that is invariant along the fluid depth; its solution can be used to form a potential function for the depth-averaged velocity field. We consider this the governing equation for MHD squeeze-film flows and refer to it as the MHD Reynolds equation. In the limit of vanishing Hartmann

number, which is a dimensionless parameter characterizing the relative strength of MHD and viscous forces, this equation reduces to the famous, purely-hydrodynamic Reynolds equation.

In squeeze-films, the roughness of the boundaries is often on the same order as the characteristic length-scale of the flow and may significantly influence the performance of the device. Hence, we incorporate the ability to input deterministic surface profiles into our analysis framework. These surfaces may be produced in-silico with various numerical techniques or directly measured using profilometry of real-world samples. In this work, we demonstrate the use of a generalized Weierstrass-Mandelbrot fractal to digitally generate very realistic, scale-invariant surface profiles for our analyses.

The spatially-varying coefficients of the governing equation may be thought of as the flow conductivities and are a function of the applied magnetic field and surface topography. Since discrete representations of real surface profiles often possess poor smoothness properties, we avoid numerically differentiating this function by solving the weak form of the MHD Reynolds equation. The weak formulation employs Green's theorem to shift the differential operator from the coefficient function onto a better-behaved test function. As a result, the continuity requirement of the coefficient function that is inherently imposed in the strong form becomes relaxed, allowing the function to be chosen from a significantly richer space. The Galerkin finite element method (FEM) is then applied for solution of the governing equation. Among several advantages, the FEM allows a wide-range of domain geometries to be considered naturally, as well as the ability to use unstructured mesh refinement in parts of the domain where increased accuracy is required.

This work presents a novel derivation of the MHD Reynolds equation, which is more general than previous forms, as it captures the effect of simultaneously imposed electric currents and magnetic fields. Furthermore, our FEM implementation enables a domain with arbitrary surface topography—as well as geometry and topology—to be simulated, which has not been investigated in previous works. We employ the model to show that the load-carrying capacity (i.e. damping) of realistic squeeze-films may be significantly enhanced as magnetic field strength is increased, even in cases of diminished fluid viscosity. A similar effect is also observed when an electrical eddy-current is generated within the fluid. We propose and analyze a method for real-time control of the damper that makes use of these effects. Finally, the influence of surface roughness on the squeeze-film flow is presented, which suggests that performance may either benefit or suffer depending on a specific roughness structure.

Photovoltaic Thermal Control System Flow Control Valve Actuator Duty Cycle after Addition of Lithium-Ion Batteries

TFAWS18-AT-11

Matthew Jurick, Garry Livesay, and Keyla Robles, Boeing

The International Space Station (ISS) Program developed Lithium-Ion (LI) batteries to replace its original Nickel-Hydrogen (Ni-H2) batteries in order to enhance the long term sustainability of the orbital complex. Thermal conditioning is provided for the batteries by the Photovoltaic Thermal Control System (PVTCS) working in concert with heaters within the batteries.

The PVTCS is a pumped fluid loop using liquid ammonia, radiant fin heat exchangers for equipment heat transfer, a deployable radiator for heat rejection, gas-charged bellows accumulators to maintain pump inlet pressure and accommodate fluid volume change, and a Flow Control Valve (FCV) to modulate the flow through the radiator.

The FCV and the heater systems operate under closed-loop control, each commanded by a dedicated software algorithm, and work together to keep battery temperatures within limits. The FCV is driven by an actuator containing an electric stepper motor and a drivetrain assembly. Included in the requirements of the PVTCS are limits for the cumulative motion of the FCV and its actuator.

The thermal limits of the new LI batteries differ from the limits of the baseline Ni-H2 batteries, and the PVTCS control algorithms were modified to accommodate the new limits. Integrated thermal analysis was performed to define and verify the updated algorithms against FCV motion requirements. Observations over the first year of on-orbit Li-ion operations indicate the FCV motion is within the specified limits.

A Volume of Fluid Based Numerical Algorithm for Simulating Multiphase Incompressible Flows with Large Density Discontinuities
TFAWS18-AT-12
Joshua Wagner and C. Fred Higgs III, Rice University

Flows comprised of multiple fluid phases separated by sharp interfaces exist in many engineering applications, a large number of which involve gas-liquid flows. Examples of such flows include liquid jet atomization in rocket combustors, lubrication delivery systems, liquid sloshing in fuel tanks, and inkjet printheads. Predicting the behavior of gas-liquid flows is critical to the design and operation of many engineering systems; therefore, much research effort has been expended in developing computational fluid dynamics (CFD) algorithms capable of simulating multiphase flows. Gas-liquid flows are accompanied by large, discontinuous variations in fluid properties, e.g., density and viscosity, which greatly increase the difficulty of the numerical implementation. In this work, a new strategy for overcoming the challenges of modeling gas-liquid flows is presented in the context of the volume of fluid (VOF) method. The state of the work is currently in the development stage but will soon proceed to testing.

The Navier-Stokes (N-S) equations of incompressible flow can be employed to predict the behavior of a fluid given a set of appropriate boundary and initial conditions. The numerical procedure used to solve the N-S equations must be augmented with the capability to track or capture the various phases in a multifluid domain. The VOF method is among the most popular CFD techniques for modeling multiphase and free-surface flows. In this method, a scalar field is distributed among an Eulerian grid indicating the volume fraction of a particular fluid phase in each computational cell. The fluid density and viscosity in each cell is calculated from the volume fraction field by weighted averaging (the scalar volume fractions are used to construct weight coefficients). With the density and viscosity fields known, the unsteady N-S equations are numerically integrated using a time-marching algorithm, i.e., the unknown variables (velocity and pressure) are solved at each node on the computational grid at discrete time steps. Additionally for each time step, the volume fraction field must be updated with the newly computed velocity values using the scalar advection equation. Special care must be taken to solve the volume fraction advection equation so that the interface remains sharp and is not smeared by artificial diffusion common to the numerical methods typically used to solve this type of PDE. For this reason, we use the piecewise linear interface calculation (PLIC) to advect the sharp interface. In PLIC, the interface is first reconstructed in each cell using a line segment, the orientation of which is based on the volume fractions of the cell in question and its neighboring cells. Next, the volume fraction fluxed through each cell face is calculated geometrically; these fluxes are used to solve the advection equation in a sharp interface-preserving manner.

The solution algorithm described above performs well when the density ratio between the fluids is small, such as with water and oil; however, when the density ratio becomes large (e.g., liquid propellant and air), many VOF codes are plagued by unphysical flow behavior and stability issues. This is often due to an inconsistency between mass and momentum advection that occurs at the interface. When the density ratio is large, the mass contained within an interface cell may vary drastically over a time step. While the PLIC method computes the mass advected through cell faces over each time step, the density in the momentum equation is simply the density obtained from the volume fraction field after advection; thus, the mass fluxed through the cell faces is not consistent with the mass contained in the momentum fluxes. The primary solution to this issue is to use the mass fluxes found by the PLIC method (mass is easily obtained from volume fraction fluxes) in the advective term of the conservation form of the N-S momentum equation.

It is common in incompressible flow codes to stagger the unknown variable nodes to avoid velocity-pressure decoupling. This results in the PLIC flux faces to occur at different locations than the momentum control volume faces. This problem is commonly resolved by using a two grid approach where the N-S equations are solved on the coarser grid and the volume fraction is advected using PLIC on a grid twice as fine. This allows for volume fraction fluxes to be found on the momentum control volume faces; however, this approach severely reduces the efficiency of the code and can be complicated to implement.

In this work, we are developing a methodology that ensures consistent mass-momentum coupling using PLIC fluxes as previously described but does not require the use of a twice-fine grid. The new method is shown to be free of artifices arising from inconsistent mass-momentum coupling without the computational burden demanded by the twice-fine grid approach. The new approach is directly compared to the twice-fine grid method to investigate the differences in accuracy and performance. The new methodology is further assessed by simulating several test problems pertaining to gas-liquid flows.

Heat Transfer Augmentation via In-Situ Nanofluids Synthesis and Regenerative Nanofin Coatins
TFAWS18-AT-22
Brandon Dooley and Debjyoti Banerjee, Thermascape Technologies, Inc.

Increasing demand for higher energy and power densities in modern thermal systems continues to spur the development of enhanced heat transfer fluids and surfaces. Interest in using colloidal suspensions of nanoparticles - more commonly known as "nanofluids" - as enhanced heat transfer and thermal energy storage mediums has gained considerable traction in recent years owing to their unique thermophysical properties. Likewise, developing and optimizing specialized heat transfer surfaces for passively improving thermal performance in devices has long been a virtuous technical pursuit driven by industrial significance.

When adapted for real thermal platforms, both nanofluids and enhanced surfaces are met with a number of challenges. For example, the raw nanoparticle stock traditionally blended with carrier fluids to produce nanofluids is not only prohibitively expensive, but once placed into solution, the nanoparticles tend to destabilize and agglomerate over time. Unfortunately, this generally renders conventional nanofluids too costly and ineffective for long-term use in most thermal engineering applications. Similarly, performance improvements offered by most augmented heat transfer surfaces tend to decrease with increasing substrate fouling and corrosion. This severely limits the application of most enhanced surface technologies to very clean or highly-specialized services.

In this presentation, we address the aforementioned roadblocks with a new technique for generating nanofluids and nanofin coatings in-situ. By doping a conventional working fluid with low concentrations of inexpensive liquid precursors, conditions can be made favorable for the precipitation of nanoparticles within the actual working fluid stream during operation. This process generates stable, self-sustaining nanofluids that can be customized as enhanced heat transfer fluids for applications ranging from compact aerospace and electronics cooling systems to solar-thermal energy storage and power generation. Furthermore, a notable byproduct of this nanofluid synthesis process can be used to deposit nanoscopic fin-like protrusions on active heat transfer surfaces during operation. These "nanofins" have been found to generate a continuously-regenerating coating that lowers interfacial convective resistance while providing protection from fouling and corrosion.

For the range of fluids, surfaces, and conditions studied to date, results show that the heat capacity of the nanofluids synthesized in-situ by the reported technique can be up to 100% greater than that of the base working fluid alone.

The results also indicate that for a given pumping power, the nanofin coatings can increase heat transfer by as much as 50% in single-phase liquid systems and up to 300% in two-phase boiling and condensing applications. Under the conditions studied, the nanofin coatings were observed to reduce corrosion by as much as 35% compared to the substrate materials in isolation. The data also suggest that the heat transfer enhancements provided by the nanofin coatings are the result of unique surface phenomena and are independent of the working fluid used.

Aerothermal

The Design and Aero Thermodynamic Analysis of Inversely Derived Scramjet Configurations
TFAWS18-AE-01
Frederick Ferguson, Dehua Feng, and Julio Mendez
Mechanical Engineering Department, NCAT, Greensboro, NC

Air-breathing access to space using combined-cycle engines concepts are currently being investigated as a possible future replacement for conventional chemical rockets. The niche for the development of high-speed air-breathing engines lies in the fact that an air-breathing engine uses the oxygen present in the atmosphere. As such, there is no need for the engine to carry its oxidizer supply. This fact will significantly increase the effective specific impulse of the launch vehicle and consequently result in the ability to place larger payloads into orbit for the same amount of fuel as in a conventional vehicle. However, spacecraft designers are experiencing a multitude of technical challenges as they seriously explore air-breathing propulsion concepts as viable options for access to space.

Among the available air-breathing propulsion concepts, the literature survey conducted as part of this research effort revealed that the scramjet is an attractive alternative. The scramjet has many attractive engineering characteristics and is worthy of a realistic engineering evaluation. The objective of this effort is to inversely derive scramjet configurations at selected design points along the scramjet engine flight corridor. In addition, the proposed design process allows for the derivation of realistic scramjet geometries by incorporating real-world effects into the design process. Once constructed, the goal is to identify the scramjet design parameters and evaluate their relationship to the scramjet overall performance. In accomplishing this goal, a quasi-one-dimensional flow field solver with capabilities of modeling the real-world effects was developed. The quasi-one-dimensional flow field solver is based on the Runge-Kutta 4th order scheme for solving systems of differential equations. In principle, the solver allows for the flow field evaluation within arbitrarily shaped ducts in which the influences of ‘varying Mach numbers’, ‘area change’, ‘friction’, ‘heating’ and ‘chemistry’ may be of importance.

Plans are to conduct the overall scramjet configuration performance evaluation in the flight Mach number range of 4 through 15. In addition, plans are underway to compare the performance of this new class of scramjets with existing scramjet models, report on any new findings and suggest recommendations for possible future improvements.

Shock-Capturing using a Radial Basis Function Blended Interpolation Scheme
TFAWS18-AE-02
Michael Harris, Kennedy Space Center
Alain Kassab, University of Central Florida
Eduardo Divo, Embry-Riddle Aeronautical University

In fluid and thermal analysis, the governing equations are presented as partial differential equations. Solutions of these equations for linear simple geometry problems exist, but for non-linear and complex geometry numerical methods must be used. The methods used today are finite difference methods (FDM), finite volume methods (FVM), and finite element methods (FEM). These methods require a mesh which the governing equations are discretized and solved. Meshless methods have recently become a research interest and can reduce the pre-processing by only requiring a point cloud and no connectivity between points. This work will focus on a method using radial basis function (RBF) interpolation using the Hardy multiquadrics RBF. The Hardy multiquadrics is dependent on a shape parameter that must be chosen properly for accurate interpolation. In literature, the shape parameter is chosen to be an arbitrarily high value to render the RBF flat and the condition number of the matrix high below the limit of ill-condition. This approach works very well for smooth functions, but for steep gradients, shocks, and discontinuities this approach fails. Instabilities could occur due to oscillations produced by the interpolation. Instead, the shape parameter should be reduced in the presence of steep gradients rendering the RBF steep. This approach, labeled as RBF blended interpolation, is presented here with examples.

Cryothermal

CO2 Cryofreezer Coldhead and Cycle Design Insights for Mars ISRU

TFAWS18-CT-01

Jared Berg, Glenn Research Center
Malay Shah, Kennedy Space Center

Feasible frameworks for human Mars exploration incorporate in situ resource utilization (ISRU) to generate commodities like rocket propellant. An important resource is atmospheric carbon dioxide (CO2), which may be isolated for further processing by various means including cryofreezing. A practical cryofreezer requires a coldhead which serves as a heat exchanger and solid phase CO2 collection surface. Due to the radical difference in thermal conductivity between the coldhead material and accreted CO2 ice, coldhead geometry is a plausible target for optimization. This problem presents a unique and complex mix of interacting heat transfer modes and design trades. The work detailed in this presentation includes design, analysis, and testing of multiple cryofreezer coldheads with novel geometries and conceptual insights into efficient approaches to physical design and cycle operation. It is demonstrated that cycles shorter than those utilized in previous experiments offer superior production rates, implying both specific design priorities and practical limits to performance. The cryofreezer is a subsystem of the Atmospheric Processing Module (APM), a part of the MARCO POLO project at Kennedy Space Center.

Cryogenic thermophysical properties measurements of materials at the cryogenics and fluids branch, Goddard Space Flight Center

TFAWS18-CT-02

Amir E. Jahromi, James G. Tuttle, Edgar R. Canavan
Goddard Space Flight Center

Several projects through different phases have needed characterization of various properties of materials such as thermal conductivity, heat capacity, emissivity, absorptivity, and most recently thermal contraction/expansion for a wide variety of carefully-chosen materials or coatings where applicable. The cryogenics and fluids branch at NASA's Goddard Space Flight Center has been in a unique position to carefully design and implement test facilities that would enable such measurements given its longstanding experience in cryogenic measurements and its well-equipped facilities. Typical temperature range measurements include those from room temperature down to 4 K, with the exception of radiation related properties being limited to temperatures slightly higher than 4 K (i.e. 20 K). Particularly proper care to details of the setup, data acquisition, and data reduction is necessary for high precision and accuracy. So far we have provided measurements and characterizations for many missions/projects including the James Webb Space Telescope (JWST), Wide-Field InfraRed Survey Telescope (WFIRST), Visible Infrared Imaging Radiometer Suite (VIIRS), investigations for NASA's Engineering and Safety Center (NESC), etc. . We describe our capabilities to provide thermophysical properties measurements for other entities within the NASA family as well as other government agencies that require such high precision measurements.

Numerical Modeling of Thermal Stratification in Cryogenic Propellant Tanks

TFAWS18-CT-04

Xiao-Yen Wang, Glenn Research Center
Jonathan Harrison and Andy Noonan, Gamma Technologies
Pooja Desai, Johnson Space Center

The boiling-off rate of cryogenic propellant inside the tank is always one of the major factors to be considered for the design of thermal insulation around the propellant tank and space launch system.

Thermal stratification inside the propellant tank is important to be included in the model for an accurate prediction of the boiling-off rate for different thermal insulation systems of propellant tanks.

In this work, two types of commercial software, Thermal Desktop SINDA/FLUINT and GT-SUITE, are used to model the cryogenic propellant tank boiling-off. The model results are compared to each other for validation. Thermal Desktop SINDA/FLUINT uses twin lumps (one node for the vapor region and one node for the liquid region) to model the cryogenic fluids inside the tank, and the phase change, heat transfer and mass transfer between the liquid and vapor. GT-SUITE uses similar approaches and allows users to utilize multiple nodes to model both vapor and liquid regions, which is important for modeling stratification inside the tank.

A few problems of a cryogenic tank are modeled by using these two software programs. Numerical results are compared with each other for validation. The stratification effects on the accuracy of the boiling-off rate of the propellant are being investigated. Details of the comparison and problem description will be provided in the final paper.

Cryogenic Multilayer Insulation Theory and an Analysis of Seams under a Variety of Assumptions
TFAWS18-CT-05
Justin Elchert, Glenn Research Center

The theory of thermal radiation as applied to multilayer insulation was researched and explored, and validation cases were solved in Thermal Desktop. Some results are compared to previously published research, and new results are published regarding cracks in both spherical and cylindrical cryogenic insulations with a cold boundary of 90 K to 220 K for ten layer blankets under a variety of assumptions and scenarios, such as the effect of including contact resistance between layers. It was found that enabling either directional emission or specular, mirrorlike reflections had little impact on the results.

Interdisciplinary I

Proof of Concept Design and Analysis of heat Reutilization of a Solid Oxide Electrolyzer Cell for Oxygen Supply on Mars
TFAWS18-IN-06
Samuel Ogletree, Shan Mohammed, and M. A. Rafe Biswas, University of Texas at Tyler

As NASA seeks to lay the groundwork required for human exploration of Mars, new and innovative life support systems need to be developed. A major component of these life support systems is the reliable supply of oxygen to revitalize cabin air. Current methods of oxygen supply rely purely on resources stored from launch. While these methods work for near-Earth orbit, planned missions that extend beyond this region require large resource storage and bloated launch costs. A technology that shows promise in addressing these concerns is a Solid Oxide Electrolyzer Cell (SOEC) system involving carbon dioxide electrolysis. This technology is unique in its ability to utilize resources produced and gathered from the Martian surface and atmosphere (consists of 96% carbon dioxide) during a manned mission. However, in its current form, the system is unable to meet power consumption requirements due to the heating elements necessary to meet the high operating temperature of 800°C. To consider the Mars environment, we developed a proof of concept design of a thermal reutilization device to analyze and test on Earth. To determine the feasibility of this design, we tested in a NASA affiliated experimental facility to mimic the system operation using air as the testing gas. A customized shell and tube heat exchanger (HX) was designed and analyzed to reutilize the hot exhaust air from the system to preheat the inlet air. The HX consists of a carbon steel shell with six rectangular passes. Four carbon steel tubes make a single pass through each shell pass creating a pure counter-flow orientation. To reduce heat loss to the environment during testing, the HX was covered with two inches of ceramic fiber insulation. Air flow was controlled through a single fan at the shell inlet. For testing, air at 25°C was introduced to the shell structure at a flow rate of 20 SLPM while the tube structure was provided with 520°C air at the same flow rate. The resulting shell outlet temperature of the HX was 207.3°C giving a shell side ΔT of 182.3°C. The tube outlet temperature was 89.4°C giving a tube side ΔT of 429.6°C. The HX had a calculated effectiveness of 0.102 and reduced the required heating element power by 75 W (36.6% reduction). As a first iteration proof of concept, the HX design showed promise in addressing the SOEC system's concerns.

Measurement of the Effective Radial Thermal Conductivities of 18650 and 26650 Lithium-Ion Battery Cells
TFAWS18-IN-08
Harsh Bhundiya, Melany Hunt, Caltech
Bruce Drolen, Engineering Consultant

In recent years there has been increased scrutiny of lithium-ion batteries, partly because of incidents in which they have caused harmful fires. One such incident occurred in September of 2010, when the lithium batteries inside a Boeing B747-400F cargo aircraft near Dubai caught on fire, killing both of the crewmembers inside the airplane. Since 2006, there have been numerous mobile phone fires caused by their small lithium-ion batteries. The much-publicized incidents of the 2016 Samsung Galaxy S7 phones catching fire serve as a recent example. The cause of these fires is thermal runaway, a term that describes the rapid increase in temperature caused when the energy generated within a cell is larger than what can be dissipated by the cell[1-3]. Another problem with thermal runaway is that it can easily propagate from one cell to the next. This means that thermal runaway in one cell can proliferate to all of the cells in the battery, leading to a much more energetic and potentially catastrophic event. It is therefore important to understand the thermal pathway from cell-to-cell to develop the means to prevent propagation of a cell failure.

To gain further understanding of thermal runaway, researchers have developed analytical thermal models of individual lithium-ion cells and the batteries they comprise. A key consideration in these models is the effective radial thermal conductivity of the cell. The electrochemical portion of the cell is comprised of a many-layered "winding" which makes estimation of the effective radial thermal conductivity of the device difficult. Recently, Tanaka[4] used an effective radial conductivity of 1.02 W m^{-1} K^{-1} and Coman, et al.[5] used a radial thermal conductivity of 3.4 W m^{-1} K^{-1}. In each of these cases, the value accounts for the conductivities of the various layers of the winding of the cell but ignores the thermal contact resistance from layer to layer. Drake et al.[6] used an analytical model for the expected temperature curve as a function of time when a cylindrical Li-ion cell is subjected to radial heating on one of its outer surfaces, and theoretically determined the radial thermal conductivities of 18650 and 26650 lithium-ion cells: 0.20 ± 0.01 and 0.15 ± 0.01 W m^{-1} K^{-1}, respectively. Vishwakarma, et al.[7] present measured results from a flat 1-D layered geometry that indicate an effective conductivity of 0.24 W m^{-1} K^{-1} stating that the majority of the thermal resistance is in the contact from the cathode layer to the plastic separator layer.

In this paper, we directly measure the radial thermal conductivities of both 18650 and 22650 lithium-ion cells and compare the measured results to a thermal model for the layered radial geometry including the contact resistance from the winding of the cell to the outer wall of the cell as reported by Gaitonde, et al.[8]. Cells were disassembled to determine the dimensions of the various layers and to count the number of layers. Using these data as well as contact resistances between the winding and case of the cell, anode and plastic separator, and cathode and plastic separator calculated by previous researchers, we predicted an effective radial thermal conductivity of 0.27 W m^{-1} K^{-1} for the 18650 cell and 0.22 W m^{-1} K^{-1} for the 22650 cell.

We designed and assembled an experiment to measure the effective radial thermal conductivity. Nichrome wire was inserted into the gap at the center of each cell's winding and heated the wire using a DC power supply at varying currents. Type K thermocouples were placed inside the center of the winding as well as outside the case of the cell. These thermocouples enabled us to measure the temperature difference between the center of the winding and the case of the cell when it was heated from inside. We used this temperature difference and the one-dimensional cylindrical heat conduction equation to calculate the effective radial thermal conductivity of the cell.

Following the above approach for the 18650 cell, we measured a thermal conductivity of 0.43 ± 0.07 W m^{-1} K^{-1}, while for the 22650 cell, we measured 0.20 ± 0.04 W m^{-1} K^{-1}. Both of our measured values are larger than Drake's reported values and they are significantly smaller than the values reported with perfect thermal contact between the layers. This latter finding suggests that including realistic, non-ideal, contact coefficients from layer-to-layer is important when modeling the radial transport of heat in cylindrical lithium ion battery cells.

Temperature Controller Design of a High Temperature Ceramic Transport Membrane System for Oxygen Production using a Lumped Thermal Modeling Approach

TFAWS18-IN-11

Kevin Fuentes, Samuel Ogltree, Shan Mohammed and M. A. Rafe Biswas, University of Texas at Tyler

Solid oxide electrolyzer cell (SOEC) system have the potential to create oxygen efficiently for manned missions on Mars, but the current concern with the system is high operating temperatures and high power consumption. A significant amount of energy is devoted to heating up inlet gas before entering the SOEC operating at temperature of around 800oC. To better understand and study the issue, a proof-of-concept heat recovery of the SOEC system was developed by University of Texas at Tyler student design team in the form of a heat exchanger through the Texas Space Grant Consortium design challenge with support from NASA JSC. To improve the efficiency of the system through heat recovery, the inlet ambient gas is heated prior to the entrance of the SOEC by heat exchange with the hot exhaust SOEC gas, which would be vented out otherwise. This shell and tube heat exchanger design would help reduce the energy consumption of the system due to pre-heating. The heat exchanger was built and tested for initial analysis at a NASA affiliated facility. However, a temperature controller needed to be designed to ensure stable and consistent performance. To design the controller, the dynamic modeling analysis consisted of a first-principles lumped-approach model of the heat exchanger by making assumptions such as well-insulated heat exchanger, the fully developed, steady state flow, negligible conduction resistance, and uniform fluid properties on each side. Experimental data was gathered from the heat exchanger to establish the initial conditions of dynamic model of the outlet temperatures including the shell outlet temperature, which should be the pre-heated gas before entering the SOEC system. The model was used to develop the initial control parameters and further tuned using MATLAB and Simulink®. Various classical controllers including a proportional only (P) controller, a proportional-integral only (PI) controller, and a proportional-integral-derivative (PID) controller were developed, tuned and evaluated. A particularly conservative PID (P = 3, I = 0.003, D= 0.001) controller integrated into the dynamic system was found to be well-suited for this application with no overshoot and a steady state error of less than 2%. Through this initial analysis, the controller designed shows promise, but experimental testing is needed to evaluate the stability and consistency of the performance based on the controller for the proof-of-concept heat exchanger.

Identification of the Physical Orientation of Drones to Obtain the Optimum Performance During Flight
TFAWS18-IN-13
Md. Abu Saleh

Lately, drones are highly preferred in access to the remote areas and notably for the emergency uses. Aerodynamics is a vital topic while a drone is in a flight operation. The movement of drones is largely dependent on the air density, wind velocity, weather conditions and so forth. This study is focused on the aerodynamic simulation of drones during flight in order to find out the optimum orientation of a specific drone at which it may perform the best as its capacity. The optimum orientation includes the inclination and speed of wings in different weather conditions and atmospheric pressure is considered in this study. The drone that is undertaken for this study is the phantom 4 pro manufactured by the Dà-Jiāng Innovations (DJI) Science and Technology Co., Ltd. The simulation has been carried out in the ANSYS software with the proper specifications of this drone provided by the manufacturing company. The result of this research might help the drone manufacturing companies to add an extra facility while the drone is in an emergency condition or the power is not sufficient for the duration of the normal flight. Primarily, this study is at the beginning state with creating the drone according to the specifications. This work can be designated by a development in drone research for the flight operations.

Two-Phase Flow System Design Status of the Flow Boiling and Condensation Experiment (FBCE)
TFAWS18-IN-14
Jesse deFiebre and Monica Guzik, Glenn Research Center

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 goal of the FBCE is to obtain heat transfer data, as well as general flow data, for two-phase flow systems in micro-gravity. This will help in the design of thermal management systems that are able to utilize latent heat transfer more efficiently. The FBCE has two Test Module Assemblies (TMAs): the Flow Boiling Module (FBM), which collects thermal and visual data of the test fluid as it is boiling, and the Condensation Module – Heat Transfer (CM-HT), which collects thermal data of the test fluid as it is condensing. Two-phase fluid systems provide some unique design challenges. Unlike single-phase systems, two-phase systems cannot be controlled by simply setting pressure or temperature. As the quality of the system changes, pressure can change drastically. This in-turn affects the quality. To properly condition the test fluid over the range of test conditions for each TMA, fluid service modules were designed to control pressure, temperature, and quality. In order to test out the experiment design and control concepts prior to fabrication of the flight hardware, the FBCE fluid system engineers began with a breadboard design that evolved over time as design deficiencies were found. This was then used to inform the flight design. As flight components were selected, critical flight-like components were installed in the breadboard model to upgrade it to a light engineering (brassboard) model. The FBCE passed its Critical Design Review (CDR) in January 2018, and has moved into the fabrication phase at the NASA Glenn Research Center. This paper discusses the current status of the FBCE, as well as some of the critical design changes that were implemented as the project evolved.

Validating Electrochemical, Thermal, and Fluidic Performance of a PEM Fuel Cell System Using GT SUITE
TFAWS18-IN-16
Ryan Gilligan, Monica Guzik, Ian Jakupca, and Phillip Smith

The AES Modular Power Systems (AMPS) Fuel Cell team at the NASA Glenn Research Center (GRC) has created a Microsoft Excel model of a regenerative fuel cell (RFC) system for potential lunar and Martian applications. Due to some limitations of this model, including the ability to predict transient effects in the thermal and fluidic performance of the system, a system-level transient thermal/fluids model was desired. GT-SUITE is a transient multi-physics simulation tool that is popular in the automotive industry and has a built in template for proton exchange membrane (PEM) fuel cells. However, terrestrial fuel cells used in the automotive industry vary significantly from aerospace fuel cells. A validation effort was undertaken to compare GT SUITE model results to actual data collected during the 2015 AMPS Power Module Demonstration in which the AMPS team used a PEM fuel cell system to power a 478 kg rover assembly at the Dunes test site located at GRC. The purpose of the model was to evaluate the efficacy of using GT SUITE to model a non-flow through PEM fuel cell system. The validation effort examined electrochemical performance including fuel cell stack voltage and power supplied, the thermal performance of the stack namely stack temperature and heat rejection rates, and the fluidic performance of the system including pressures, reactant consumption, and water production rates.

Thermal & Fluids Analysis and the NASA Launch Services Program
TFAWS18-IN-22
Paul Schallhorn and Gary O'Neil, Kennedy Space Center

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.

Measurement of the Effective Radial Thermal Conductivities of 18650 and 26650 Lithium-Ion Battery Cells

TFAWS18-IN-08

Harsh Bhundiya, Melany Hunt, Caltech

Bruce Drolen, Engineering Consultant

In recent years there has been increased scrutiny of lithium-ion batteries, partly because of incidents in which they have caused harmful fires. One such incident occurred in September of 2010, when the lithium batteries inside a Boeing B747-400F cargo aircraft near Dubai caught on fire, killing both of the crewmembers inside the airplane. Since 2006, there have been numerous mobile phone fires caused by their small lithium-ion batteries. The much-publicized incidents of the 2016 Samsung Galaxy S7 phones catching fire serve as a recent example. The cause of these fires is thermal runaway, a term that describes the rapid increase in temperature caused when the energy generated within a cell is larger than what can be dissipated by the cell[1-3]. Another problem with thermal runaway is that it can easily propagate from one cell to the next. This means that thermal runaway in one cell can proliferate to all of the cells in the battery, leading to a much more energetic and potentially catastrophic event. It is therefore important to understand the thermal pathway from cell-to-cell to develop the means to prevent propagation of a cell failure.

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Numerical and Theoretical Investigations of Compressible Boundary Layers

TFAWS18-IN-09

Frederick Ferguson, Tasmin Hossain, and Julio Mendez, NCAT

The motivation of this research is to evaluate the capability of current turbulence models to predict the velocity, the temperature and the heat transfer rates in compressible turbulent boundary layers. Experimentally, the challenges behind measuring both the velocity and temperature variables independently are mainly due to the close coupling of the two variables with compressible boundary layers. It is a well-established fact, once the Mach number exceeds 0.3, compressibility effects in the flow cannot be overlooked. Further, under compressibility conditions, the density variations become very significant, resulting in the heat transfer rate playing an even more substantial role. The net result is an altering of the dynamics within the boundary layer that is significantly different from its laminar counterpart. Physical properties, such as the specific heat capacities, the viscosity and the thermal conductivity, which are often considered as being constant, now vary with respect to temperature, creating the aforementioned strong coupling between the velocity and the temperature fields.

Numerous researchers have attempted to characterize turbulent boundary layers at supersonic speeds. The Reynolds analogy was first introduced to relate the heat transfer to the momentum transfer occurring in the flow. However, this analogy contains two weaknesses: it first assumes that both the temperature and the velocity have the same distribution and secondly it requires for the Prandtl number to be equal to unity. In light of these shortcomings, Young provided an extensive discussion about the effect of compressibility on the boundary layer, concluding that for Mach numbers less than 2.5 the velocity profile will have slight differences from that with an incompressible fluid on the same Reynolds number. Additionally, Crocco derived an equation to relate the velocity to the temperature in both laminar and turbulent flows. However, experiments showed that this assumption only holds true for boundary layer flows with adiabatic walls. In addition, researchers have also tried to derive a law of the wall in a coupled turbulent boundary layer. Notably, Van Driest scaled the velocity gradient with density and extracted a transformed velocity with which the logarithmic law holds true. Following this widely accepted breakthrough, scientists extended the Van Driest transformation to characterize the velocity in the entire boundary layer with limited success.

Despite the progress made in this field of research, a common issue frequently expressed in the literature is the difficulty in acquiring high quality time-resolved velocity and temperature data in compressible flows, especially near the walls. The effort proposed herein plans to address the aforementioned challenges. The major objective of this study is to demonstrate the capabilities of the Integro-Differential Scheme (IDS) by solving the flow field challenges in compressible boundary layers.

Thermal Modeling and Correlation of the Space Environments complex Vacuum Chamber and Cryoshroud
TFAWS18-IN-17
Erik Stalcup, Glenn Research Center

A thermal model of the Space Environments Complex (SEC) vacuum chamber and cryoshroud has been developed in support of upcoming thermal vacuum/thermal balance testing for Orion EM-1. The model was developed in Thermal Desktop and includes the vacuum chamber itself, a fluid model of the gaseous nitrogen flowing through the cryoshroud and the chamber piping, the Heat Flux System (HFS) within the cryoshroud, and the mechanical ground support equipment (MGSE) that interfaces with the vehicle. Results are shown for model correlation which was completed using test data from multiple integrated system tests at various operating conditions in transient and steady states. This correlated model has been used in various analyses to make informed decisions about the testing configuration. These results are also presented, including an assessment the heat load on the cryoshroud to predict nitrogen consumption, an investigation of the optimal multi-layer insulation (MLI) configuration, and temperature predictions for the MGSE to use as input for structural analysis. An additional model was created to include the environment directly outside the vacuum chamber, in order to better predict the chamber temperatures. Results from this analysis are briefly discussed and are detailed in a companion presentation. In the future, this model will be integrated with a fluid model of the facility gaseous nitrogen recirculation system to predict system-level performance.

Characterization of a 50kW Inductively Coupled Plasma Torch for Testing of Ablative Thermal Protection Material
TFAWS18-IN-21
Benton Greene, Noel Clemens, Philip Varghese, University of Texas at Austin
Stanley Bouslog and Steven Del Papa, Johnson Space Center

With the development of new manned spaceflight capabilities including NASA's Orion capsule and the Space-X Dragon capsule, there is a renewed importance of understanding the dynamics of ablative thermal protection systems. To this end, a new inductively coupled plasma torch facility is being developed at UT-Austin. The torch operates on argon and/or air at plasma powers up to 25 kW for input power up to 50 kW. In the present configuration the flow exits from a low-speed subsonic nozzle and the hot plume is characterized using slug calorimetry and emission spectroscopy. Measurements using emission spectroscopy have indicated that the torch is capable of producing an air plasma with a temperature between 5,000 K and 8,000 K depending on the power and flow settings and an argon plasma with a temperature of approximately 12,000 K. The temperature falls off from the central peak value by approximately 1,000 K at a radius of 8 mm. The facility operation envelope was determined, and heat flux was measured for selected points within the envelope using both a slug calorimeter and a Gardon gauge heat flux sensor. The torch was found to induce a stagnation point heat flux of between 90 and 225 W/cm^2. A small asymmetry of unknown cause which increases with increasing mass flow rate was found in the radial variation of heat flux.

Interdisciplinary III

Thermal Fluid Model Development of Steam Methane Reformer using Artificial Neural Network
TFAWS18-IN-01
M. A. Rafe Biswas, University of Texas at Tyler
Kamwana Mwara, Johnson Space Center

NASA's Johnson Space Center has recently begun efforts to eventually integrate air-independent Solid Oxide Fuel Cell systems, with landers that can be propelled by LOX-CH4, for long duration missions. Using landers that utilize such propellants, provides the opportunity to use such systems as a power option, especially since they are able to process methane into a reactant through fuel reformation. To ensure fuel reformation in the systems, Steam Methane Reformation (SMR) are being employed. Various lead-up activities, such as hardware testing and computational modelling, have been initiated to assist with this developmental effort.

One modeling approach, currently being explored to predict SMR thermal fluid dynamic behavior, involves the usage of artificial neural networks (ANN). Since SMR thermal fluid performance characteristics are inherently complex, ANN can account for such nonlinear characteristics of multiple input and output variables to better predict its performance. There are minimal to no studies on the development of dynamic ANN to predict the transient behavior of SMR in the way that this modeling work investigates. The work to be presented involves prediction of the dynamic performance of a SMR tube reactor at operating conditions including temperatures around 600-700oC and pressures around 5 psig. In this work, six input variables being considered consist of steam and methane inlet temperatures, pressures, and flow rates. The output variables that represent the thermal fluid behavior are SMR outlet temperature and pressure. The compositions in the inlet and outlet flow rates of SMR will be considered in a future presentation. The dynamic temperature and pressure models of two different ANN structures (time delay only, and time delay and NARX) are judged based on accuracy and consistency. To develop an optimal ANN model, the number of hidden layer neurons is varied from 1 to 25. The model responses (> 10 hidden neurons) were demonstrated to predict the experimental data very well. The coefficient of determinations of all models ranged from 0.97 to 1. For temperature response, the ANN models with NARX and time delay predicts better with MSE from 0.1 to 0.4 than the ANN models with time delay only with lowest MSE of 22. For pressure, the ANN models with NARX and time delay predict slightly to almost negligibly better with MSE from 0.03 to 0.07 than the ANN models with time delay only, which also has similar MSE from 0.03 to 0.08. This could be due to the higher fluctuations in the SMR pressure data. The results show promise of ANN modeling approaches for offline and real-time prediction of transient thermal fluid behavior to assist in the system integration of SMR into the power source of the lander.

Integrated Thermal Vacuum Testing of the Solar Array Cooling System for Parker Solar Probe
TFAWS18-IN-05
Carl Ercol, Elisabeth Abel, Allan Holtzman, and Eric Wallis, Johns Hopkins University

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 in order to obtain repeated coronal magnetic field and plasma measurements in the region of the sun that generates the solar wind. The baseline mission will entail 7 years from launch in 2018 until the completion of the 24th orbit; if delays necessitate, a backup 8-year, 26-orbit mission will be flown, with launch in 2019. 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, which produces a perihelion solar constant in excess of 480 suns. Spacecraft power is generated using photovoltaic solar arrays that are actively cooled by the solar array cooling system (SACS), manufactured by Hamilton Sundstrand, Windsor Locks, CT. This paper will describe the equivalent "test-like-you-fly" environments that were simulated and the results achieved during the SACS integrated thermal vacuum test (ITVT) that took place at Goddard Space Flight Center between 1 March and 16 March 2017.

Automatic creation of reduced-order models using Thermal Desktop
TFAWS18-IN-07
Derek Hengeveld, LoadPath

There is a need in the Thermal Desktop community for creating and using reduced order models (ROMs). ROMs can provide an efficient surrogate to more computationally expensive high-fidelity representations. Properly developed, ROMs provide near real-time simulations with accurate results and enable new analyses previously impractical using traditional modeling approaches. A method for creating and using ROMs for Thermal Desktop was developed based on Latin Hypercube sampling and Gaussian-Process data fitting. Testing showed that 1,000s of thermal simulations could be completed in seconds. However, the initial approach was not automated and required significant user-interaction to develop surrogate models.

An automated software tool for generating ROMs was developed for Thermal Desktop. Called Veritrek, it provides users the ability to develop ROMs with minimal user intervention. Based on a recently released Thermal Desktop API, the tool allows users to select continuous/categorical input factors and a broad range of output responses that define the ROM. Smart sampling and data fitting approaches are then enabled allowing automatic creation of a ROM. Case studies of this new approach will be presented along with a discussion of advantages/disadvantages. In addition, Veritrek visualization capabilities will be presented including: screening studies, factor sweeps, 3-D plotting, point analyses, and optimization studies.

Modeling a Rapid Cycle Adsorption Pump for CO2 Compression
TFAWS18-IN-12
Lisa Erickson, Johnson Space Center
Anthony Iannetti, Glenn Research Center

A Rapid Cycle Adsorption Pump (RCAP) is a competitive technology for capturing and pressuring CO2 within a Martian In-Situ Resource Utilization (ISRU) system. In an ISRU plant, CO2 from the Martian atmosphere at ~0.69-0.925kPa must first be pressured to ~101-500kPa to produce O2 and/or CH4. A RCAP pressurizes CO2 by imposing fast temperature swings on an adsorbent bed – low pressure CO2 is adsorbed onto the cooled bed, and higher pressure CO2 is desorbed from the heated bed. To aid the design of a RCAP for NASA's Advanced Exploration Systems (AES) ISRU project, a finite difference thermal model of a single stack RCAP was developed in Thermal Desktop. The stack consists of one gas passage sandwiched between two sorbent beds and two cold plates (for heating/cooling each bed). The model implements adsorption/desorption physics via a linear driving force approximation in order to predict both temperature and pressure swings in the pump. The modeling approach is presented along with a discussion of its results and the current design. The model was also used to trade cooling speed when constructing the RCAP with 3D printed high thermal conductivity copper (GRCop-84) verses 3D printed aluminum (AlSi10mg). A wide assembly was modeled to predict the performance of multiple stacks in parallel. Major performance drivers were identified to be 1) the contact heat transfer to the sorbent bed, and 2) the pump's thermal mass.

Modeling Multi-Parameters Radiation in Porous Metal Via Machine Learning
TFAWS18-IN-15
Hyun Hee Kang and Shima Hajimirza
Texas A&M University

Porous metal components used in aerospace applications should function in a predictable and consistent manner over extensive periods of time at elevated temperatures. The characterization of radiative properties serves as critical function in advancing design and manufacturing of porous metal parts. However, efficient and accurate prediction of radiative heat transfer in porous media remains a challenge. Current approaches struggle with expensive computation and imperfect physical modeling. This study demonstrates that machine learning methods can be reliably used to predict radiative properties of dispersed media, i.e. packed beds, as a function of packed bed geometry and material properties. The computationally expensive ray tracing Monte Carlo (RTMC) method, which is widely used in this context, is replaced by Neural Networks (NN). The data-driven surrogate prediction works generally well. The output trends of both RTMC and NN models agree well with each other and with previously measured literature results. The surrogate model allows fast approximation of the radiative properties within extensive design space with little training. The uncertainty of the NN results is measured by using statistical methods. Further development is required to reduce error gaps among experiment, RTMC, and NN model. The developed model will be used for efficient optimizations in design and manufacturing of porous metal components. Considering multi-functionality of porous metals, the NN model can also be the foundation for further multi-objective optimization.

Candidate Benchmark Problems for Active and Passive Thermal Software
TFAWS18-IN-18
Douglas Bell, C&R Technologies

Benchmark problems have been established for computational fluid dynamics to test the solution of various conditions and solution types. These problems can be solved to evaluate the accuracy or simply the capabilities of CFD applications. A set of benchmark problems focusing on active and passive thermal solutions is likewise needed. An established set of benchmark problems can make comparing software easier and can provide a means to certify software for use on programs where safety is a key concern. As established by numerous groups, benchmark problems should be simple, easy to model, quick to solve, and preferably have a closed-form or known and generally accepted solution. As a set, they should explore a wide range of capabilities.
This paper explores candidate benchmark models for active and passive thermal software. While some models have already been established, such as those documented by NAFEMS, more are needed and recommendations are provided. The candidate models presented in this paper will hopefully initiate the standardization of a set of benchmark problems for active and passive thermal software. In the end, a set of benchmark problems should be established by a governing body such as NESC with input from the community, such as those attending TFAWS. This established set of problems should address capabilities required within the active and passive thermal communities.

Experimental Study of the Effects of Xenon Plasma Erosion on Spacecraft Thermal Control Surfaces
TFAWS18-IN-20
Evan Racine, Glenn Research Center

The effects of long duration exposure of various spacecraft thermal control materials and coatings to a xenon plasma thruster plume is studied experimentally. The use of electric propulsion to carryout NASA in-space propulsion demands has been increasing. One such mission is the Power and Propulsion Element (PPE) for NASA Gateway Mission. The PPE will have the largest electric thruster suite of any spacecraft to date. The environment created during on-orbit operation of the thrusters has been shown to be different than the environment created during operation within ground vacuum facilities. Understanding the on-orbit environment created by the thrusters and its impacts on the spacecraft is the goal of the sensor package that NASA GRC is developing to fly on the PPE. The Plasma Diagnostic Package (PDP) will measure different aspects of the thruster plume and the impacts on the spacecraft surface. Among them will be the changes to emissivity and absorptivity of predetermined thermal control materials through the use of Radiometers. The goal of this experiment is to quantify the changes in emissivity and absorptivity due to xenon plasma erosion and develop criteria for designing Radiometers for the PDP. The experiment exposed ten different materials to the ion plume during a long duration Hall Effect Thruster test inside a vacuum chamber and measured the changes in the emissivity and absorptivity over time.

Passive Thermal I

Influence of Lunar Rover on Lunar Surface Temperature
TFAWS18-PT-01
Christopher Pye and Jean-Frederic Ruel, Maya HTT Ltd.
Josh Newman, Canadensys Aerospace Corp.

The lunar regolith is a very poor thermal conductor. As a result, the temperature of the surface can fluctuate quickly as the environment changes. For terrestrial applications it is common to assume that the planet's surface is fixed at an appropriate temperature. The properties of the lunar regolith indicate that this approach may not be valid for a lunar rover which will experience a varying radiative environment resulting from the presence of the rover itself.
This paper demonstrates the implementation of a published lunar regolith model (Christie, Plachta and Hassan) in NX SST and investigates the influence of a simplified lunar rover on the surface temperature and the impact of these changes on rover thermal performance.

Analysis of On-Orbit Thermal Performance of the Bigelow Expandable Activity Module (BEAM)
TFAWS18-PT-03
Zaida Hernandez, Johnson Space Center

The Bigelow Expandable Activity Module (BEAM) was berthed to Node 3 of the International Space Station (ISS) on April 16, 2016 and expanded in May 2016. The International Space Station (ISS) program extended BEAM life from its original two year certification to help alleviate some of the stowage issues onboard. A thermal model was created to further evaluate acceptable ventilation rates to maintain adequate thermal control for the planned stowage configurations within BEAM. This presentation will cover the thermal analysis results as well as discuss the current status of BEAM and any notable thermal events in FY18.

LHP Wick Fabrication via Additive Manufacturing
TFAWS18-PT-04
Bradley Richard, Advanced Cooling Technologies, Inc.

As the capabilities of CubeSats and SmallSats increase so do the heat rejection requirements. While loop heat pipes (LHPs) are capable of transporting heat across deployable radiators they are currently too expensive for most applications. The largest cost comes from the fabrication of the primary wick which requires multiple machining steps as well as a knife-edge seal. The focus of this work is the development of a 3D printed LHP evaporator using a direct metal laser sintering (DMLS) process to fabricate the primary wick. 3D printing LHP wicks offers several advantages. The overall cost can be significantly reduced by eliminating multiple machining steps, and the risk of failure can be reduced by eliminating the knife-edge seal. The challenge with 3D printing of LHP primary wicks is that a very small pore radius is required to supply sufficient capillary pumping power. A pore radius and permeability study was conducted for optimization of DMLS methods and parameters for fabricating primary wicks. The result of this study is DMLS parameters for wicks with pore radii less than 10 μm. In addition, a DMLS parameter optimization study was performed for fabrication of the coarser secondary wick. Experimental testing was completed on a complete LHP prototype with a 3D printed primary wick. Steady state operation with a heat input of up to 125W was achieved.

A Review of SAGE III on ISS Flight Thermal Data
TFAWS18-PT-07
Kaitlin Liles, Ruth Amundsen, and Warren Davis, Langley Research Center

The Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument is the fifth in a series of instruments developed for monitoring aerosols and gaseous constituents in the stratosphere and troposphere. SAGE

III was launched in February 2017 and mounted to the International Space Station (ISS) to begin its three-year mission. This paper will present noteworthy thermal data from the payload's first 16 months of flight, including the payload's thermal response to ISS maneuvers, definition of flight rules to prevent limit violations, and comparisons to predictions. Correlation efforts to date, as well as potential future objectives, will be discussed.

Thermal Systems Modeling of a Variable Emittance Coating for Human Spacecraft Applications
TFAWS18-PT-10
Sydney Taylor and Liping Wang, Arizona State University
Christopher Massina, Johnson Space Center

Considerable research effort has recently been invested in thermochromic variable emittance radiators, which can vary their heat rejection in response to changing thermal environments or spacecraft heat loads to provide passive thermal control. Vanadium Dioxide (VO_2) is a thermochromic insulator-to-metal transition material which exhibits a dramatic change in optical properties upon transition at 341 K. Given this optical property shift, VO_2 can be integrated into nanostructured coatings to yield variable emittance coatings for use in a wide range of thermal control applications. The most significant challenge currently with VO_2-based coatings is reducing the transition temperature so that it is suitable for spacecraft thermal control applications. Many techniques exist to achieve this, such as impurity doping, rapid cooling, and introducing mechanical strain, however the reduction in transition temperature is typically accompanied by a degradation of the optical property shift. Considering these difficulties, it is therefore important to determine the transition temperature range and emittance change needed for the coating to be useful for a given application.

The objective of this work is to determine the transition temperature and emittance change required for a VO_2-based variable emittance coating to be effective for a representative human spacecraft. To assist with this effort, a MATLAB model is constructed to determine the optimal transition range of the variable emissivity coating and to illustrate the benefit of a variable coating over a static emissivity coating. The MATLAB model is also used to investigate the minimum required emittance change for the spacecraft to be useful for a representative human spacecraft mission. A cylindrical spacecraft is considered with radiator panels mounted on the lateral surface of the cylinder and a diameter based on Orion. The radiator was discretized into 360 radiator panels. Nominal values were identified for the spacecraft heat load, crew heat load, and radiator inlet temperature. The heat transfer characteristics of the transport fluid were assumed to be consistent with propylene glycol water (PGW). The input parameters for the variable model are the high temperature emittance, low temperature emittance, transition start temperature, and transition end temperature. The output is the temperature at the exit of each radiator panel and the average temperature once the flows from all radiator panel lines are combined.

The first level of analysis compares the performance of several variable emittance coatings with a static coating ($\varepsilon = 0.9$) for both a hot and cold case. The hot case occurs when the cylinder is oriented with its lateral side towards the sun, while the cold case occurs when the base of the cylinder is oriented towards the sun. Radiation from other bodies is neglected. In the second level of analysis, an optimal transition range of 7-13 °C is determined by minimizing the total percentage of the full load that the spacecraft heat load could be turned down to before the averaged radiator outlet temperature went outside the allowable range. An additional requirement imposed in the model is that the outlet temperature of each radiator panel must remain above -10 °C, which is where the performance of the PGW will start to decline. The next level of analysis will consider alternative thermal environments, in particular radiation from IR sources and albedo effects, as well as transient cases.

Challenging Louver Design Modification for Europa Clipper Interplanetary Mission
TFAWS18-PT-15
Scott Christiansen, Sierra Nevada Corporation

SNC's louver product is a passive thermal control device designed to be mounted to a thermal radiator. The device is to be open at a desired temperature to allow maximum heat rejection from the radiator. In addition, and at a desired lower temperature the louver needs to be closed to minimize radiator heat loss. Typically, the higher full open set point is in the 10C to 35C range. SNC's louver blades are passively operated by bimetal coil actuators, which are thermally coupled to the radiator. Because the louver blades rotate only 90 degrees and are controlled by hard stops at the ends of travel, the bimetal coil stresses increase as temperatures change above or below the set point temperatures. To minimize the possibility of permanently damaging (deforming) the actuators the minimum to maximum temperature range for the standard louver is a total of 100C.

The Europa Clipper mission presents some uniquely challenging environments and resulting requirements for thermal control. Prior to launch, all components must undergo planetary protection protocols, the most effective being a vacuum-bakeout at 125 C or greater. After launch, one of the mission scenarios may involve a Venus gravity assist maneuver. The closer proximity to the sun will result in a warmer spacecraft, which leads to the need for radiators large enough for the increased heat load. Once at the destination near Jupiter, the situation is significantly different. During the highly elliptical orbit around Jupiter, the spacecraft will get quite cold, requiring the louvers to close and restrict heat loss. Extremely limited power due to the large distance from the sun precludes the use of heaters to maintain the radiator and louvers at an acceptably high temperature. The extreme radiation environment also makes reliable monitoring and control with active electronics and/or mechanisms very difficult. Ultimately, these requirements result in the need for passively controlled louvers with a mission temperature range from -110C to +125C minimum. This requirement is much greater than the range capability of the standard, heritage product.

This presentation will discuss the efforts to modify the louver design to meet the 235C temperature range required for this mission and still maximize product flight heritage. A brief trade study summary and selection of the best solution approach will be presented. We will include a summary of analysis results used to validate the potential solution. We will also present initial development-level test results that verify the proposed change can meet the new requirements. Additional assembly level development test results may also be presented.

Thermal Analysis of Propulsion Components for Europa Clipper Mission
TFAWS18-PT-19
Heather Bradshaw, Goddard Space Flight Center

This presentation describes the thermal analysis and model development that occurred for selected components on the propulsion module subsystem of the Europa Clipper mission, which will fly to Jupiter's icy moon Europa and collect science data from orbit. An overview of a bipropellant system is given, as well as a description of a typical thermal propulsion design. A comparison is also provided, describing the unique Europa Clipper thermal design, which is atypical in many respects. The engine thermal model development is also discussed, including hot-firing tests with nozzle convection correlation, as well as thermal vacuum tests to measure and correlate the emissivity of critical nozzle surfaces. A description of engine firing, as well as valve soak back, is also provided, including temperature maps and results of engine cases. A summary is also provided, of lessons learned regarding thermal propulsion considerations.

Passive Thermal II

International Space Station Passive Thermal Control System, Top Ten Lessons-Learned
TFAWS18-PT-08
John Iovine, Johnson Space Center

The International Space Station (ISS) has been on-orbit for nearly twenty years, and there have been numerous technical challenges along the way from design to assembly to on-orbit anomalies and repairs. The Passive Thermal Control System (PTCS) management team has been a key player in successfully dealing with these challenges. The PTCS team performs thermal analysis in support of design and verification, launch and assembly constraints, integration, sustaining engineering, anomaly and failure response, and model validation. This effort is a significant body of work and provides a unique opportunity to compile a wealth of real world engineering and analysis knowledge and the corresponding lessons-learned. The PTCS lessons encompass the full life cycle of flight hardware from design to on-orbit performance and sustaining engineering. These lessons can provide significant insight for new projects and programs. Key areas to be presented include thermal model fidelity, verification methods, analysis uncertainty, and operations support.

Thermal Analysis and Design of an S-Band Helical Antenna for LEO Satellites
TFAWS18-PT-13
Nahuel Castello, Comisión Nacional de Actividades Espaciales (CONAE)
Sonia Botta, Juan Andres Breme, and Cristobal Gerez, Universidad Nacional de La Plata

The two SAOCOM satellites are part of the Argentine and Italian Emergency Management System, SIASGE. The SIASGE constellation is made up by four Italian satellites, Cosmo Skymed, and two Argentinian Space Agency satellites, SAOCOM 1A and 1B. The systems under study are two pairs of S-Band frequency helical antennas mounted on the service platform and SAR antenna of CONAE's SAOCOM 1A and 1B satellites. These antennas are part of the command data handling subsystem and are responsible for the communications of the satellite with the ground control station for telemetry and telecommand operations.

The S-band antennas have to be able to operate during all of the stages of the satellite's life, including the launch trajectory; therefore, the operation conditions can become extreme. Starting from the location and the environment they are subjected to (solar radiation, albedo, Earth IR and aerodynamic heating flux) a set of critical study cases is defined for each of the pairs. Given that the location of each of these pairs is different, it is expected that the thermal design will be unique for each group. Due to the need to solve the thermal design with passive thermal control, many cases of thermal analysis and many configurations of thermal coating have been simulated in order to verify that the thermal design meets the thermal requirements with sufficient margin. A series of thermo-optical properties corresponding to a white thermal coating type and to the brass surface termination have been measured with a portable spectrum reflectometer.

Due to the nature of the operation of these antennas, there are limitations on the thermal control methods that can be used. For instance, standard multi-layer insulation (Kapton/aluminized Mylar MLI) and active thermal control are forbidden on most of the antenna surface in order to prevent radio frequency interference.

In the complete paper, the study cases selection criteria and analysis will be detailed, followed by a brief description of the Thermal Mathematical Model (TMM), the expected results and the available thermal control methods. Next, the results obtained for the original configuration will be shown and analyzed, describing the original thermal behavior of the system. The different thermal design configurations proposed will be simulated and their results evaluated.

Characterization of Radiation Heat Transfer in High Temperature Structural Test Fixtures

TFAWS18-PT-14

Larry Hudson, Gus Kendrick, Jessica Kenny, Chris Kostyk, Shelby Pfeifer, Tim Risch, and Megan Waller, Armstrong Flight Research Center

High-temperature ground testing of high-speed flight vehicles and associated heated components is often done using radiant heaters that consist of arrays of quartz lamps or graphite elements. These lamps are typically around 3-in wide by 12-in long and produce non-uniform heating in the region below the lamps. In an actual, large-scale ground test, arrays of multiple lamps are assembled to provide the required heating over the test article. Some overall variation in the heat flux is obtained by varying the power to each of the lamps in separate thermal control zones, but this still results in areas of discretized heating. This discretization of heating relative to a desired continuous, flight-like heating profile demands accurate understanding of the heating distribution on the test article so that proper interpretation of the test data can be realized.

A facility characterization effort has been undertaken at the AFRC Flight Loads Laboratory to understand the behavior of radiant heating systems. The effort has utilized a thermal measurement system consisting of several radiant heaters, heat flux gages, and a scanning table to measure the light output as a function of position below the lamps. Testing includes variations in the lamp configuration including height, spacing, configuration of thermal barriers, and power output. These measurements have supported the analysis of various test fixtures, interpretation of test data, and optimization of heater designs. This presentation will outline the planned effort and summarize the progress made to date based upon initial measurement and analytical results. Further discussion on future planned work will also be included.

Verification of the In-House Developed Simulator Software for Communication Satellite

TFAWS18-PT-16

Anil Aksu and Hilmi Sundu, TUBITAK Space Technologies Research Institute

During the mission in orbit around the Earth, spacecraft get exposed to several sources of thermal loads which can be classified as external and internal. The external heat loads include solar flux, albedo, and the Earth IR radiation depending on orbital parameters whereas the internal loads are the heat dissipation caused by the electrical and mechanical inefficiency of equipment composing the spacecraft during its mission.

Even though the spacecraft gets exposed to periodic heating, the temperature of the spacecraft equipment have to stay within certain temperature limits. Regarding a communication satellite in geo-stationary orbit, while payload and external equipment would cool via the thermal radiation, temperature limits should be set within appropriate conduction and radiation links including the assistance of active heaters.

The physical process and the configuration described above needs to be introduced appropriately to the computer to get a reasonable estimate of thermal cycle in the satellite. The physical model includes a continuous satellite components and the discrete radiative connection between them. The discretization of the physical processes, conduction, and radiation, leads to two separate thermal connectivity matrices. The non-linearity radiative heat transfer mode must be linearized around the temperature distribution vector which represents the temperature at each node of the discretized satellite. Furthermore, because of the non-linearity, most of the explicit time integration schemes are unstable. Therefore this type of problem requires implicit time integration method. In the present study, Crank-Nicholson algorithm is preferred. It takes information from both the next time step and the current time step. It both increases the accuracy and the stability of the time integration. The implicit part of the time integration is also a root finding problem in higher dimensions. It is solved via multi-dimensional Newton-Raphson algorithm. Additionally, time step selection also plays an important role in both accuracy and more importantly stability. Differing from linear problems, a stable time step should be determined for every time step because of non-linear radiative heat transfer.

In this study, an in-house thermal code is developed for satellite simulator for simulating the thermal behavior of the spacecraft. The model is set on a newly developed communication satellite thermal mathematical model. Although the thermal model of the satellite would be verified after thermal balance tests, the simulator aims to obtain same temperatures of the ones acquired by commercial software within temperature margins.

Thermal Design, Analysis, and Thermal Vacuum Testing of a 3U CubeSat, CeREs

TFAWS18-PT-17

Sergio Guerrero, Goddard Space Flight Center

This paper describes the particular thermal design methods and thermal vacuum (TVac) testing approach used for a low earth orbit (LEO) CubeSat mission. Compact Radiation Belt Explorer (CeREs) is a 3U CubeSat with a deployable antenna and solar arrays, developed by National Aeronautics and Space Administration (NASA) in collaboration with the Southwest research Institute (SWRI). The thermal design approach for CubeSats differs from typical larger LEO observatories. They're design can be limited by factors such as compact size, quick temperature swings, and power budget; also parameters and guidelines used for larger missions have to be adjusted to better suit the CubeSat's mission. A passive thermal design was developed to effectively maintain CeREs and its components within the allowable operational temperatures once in orbit, to do this, a flight and TVac thermal model were developed, using Thermal Desktop, to allow the prediction of temperatures and thermal behavior. Tailorable optical properties coatings along with thermal interface materials were used to establish the sinks and heat paths of the CubeSat, together achieving the desired thermal control. In addition, two flight heaters were used to maintain a suitable temperature zone for the battery, as it was discovered the battery was the pacing component during thermal testing, as it had the narrowest temperature limits. A TVac test, which included a bakeout, three thermal balances, a cold solar array deployment, and four qualification cycles, was conducted in order to validate the thermal design. The data from the test was also used for the correlation of the flight thermal model to obtain more accurate temperature predictions. The passive thermal design allowed CeREs to perform successfully throughout the various stages of the TVac test and the comprehensive functional testing. Uncorrelated thermal model temperature predictions showed 69% of monitored temperatures within ±5°C of TVac results, for both, hot and cold balances. After model correlation, 88% and 94% of monitored temperatures showed to be within ±5°C of TVac results, for hot balance and cold balance, respectively. The CeREs thermal design was effective at maintaining components within their required temperature allowance, employing passive thermal control approaches. A particular thermal vacuum setup and testing approach was developed to best asses the performance of the CubeSat in the worst case environments predicted for its mission. Thermal vacuum testing validated the thermal design and facilitated the thermal model's correlation for more accurate thermal behavior prediction. CeREs is to be launch into orbit from Mahia, New Zealand, in June 2018, on the Electron rocket by RocketLab.

Optimization of Thin-Film Solar Cells for Lunar Surface Operations
TFAWS18-PT-18
William Johnson, Aerodyne ESSCA

Thin-film solar cells have been in production for decades, but technology has only recently advanced enough to allow for comparable efficiencies to traditional rigid cells. Some of the benefits of thin-films, such as lighter weight and being foldable, are particularly advantageous to space applications since mass and volume are key considerations of any flight project. Using these thin-film cells in space, however, is outside of their ground-based design criteria. This requires special care to be taken in designing the power generation system of a spacecraft around a thin-film solar cell, particularly in regards to thermal management. Without the diffusion of an atmosphere to mitigate solar load, the temperature of the panels can rapidly exceed their design specification. In this paper a design solution is presented that allows for thin-film solar cells to be used in a robotic lunar lander. Due to the low thermal mass and in-plane conductivity of thin films, it is difficult to remove waste heat by any other method than radiation. On the lunar surface this means angling the arrays to increase their view factor to space, which has the negative consequence of decreasing their power generation. An optimization was developed to balance the heat rejection and power generation of the cells, using constraints on the maximum cell temperature and minimum spacecraft power requirements. The resulting solar panel angle was then used as an input to the Thermal Desktop model to verify the final panel temperatures.

Passive Thermal III

Constant Conductance Heat Pipe Modeling in Siemens Simcenter and Correlation with JPL SWOT Mission Two-Phase Testbed
TFAWS18-PT-05
Lina Maricic, ATA Engineering Inc.
Louis Tse and Ruwan Somawardhana, Jet Propulsion Laboratory

Jet Propulsion Laboratory's (JPL) Surface Water and Ocean Topography (SWOT) mission is an international mission partnered with Centre National d'Etudes Spatiales (CNES) and Canadian Space Agent (CSA). The SWOT spacecraft will measure both Earth's surface water and the topography of the ocean surface.
In conjunction with JPL, ATA Engineering provided thermal model construction and thermal analysis support of the SWOT mission. Ka-band Radar Interferometer (KaRIn) is SWOT's primary instrument which will dissipate nearly 1,100 watts of power under operational conditions during the science missions. Passive thermal design was used to address stringent temperature and thermal stability requirements of KaRIn. KaRIn electronics were mounted to a total of four thermal pallets which are hogged out aluminum panels with embedded constant conductance heat pipes (CCHPs), which subsequently transport heat from the KaRIn electronics boxes to loop heat pipe evaporators (LHPs), and eventually to radiators. Using two-phase heat transport, the aim of the thermal pallet is to maintain an isothermal platform for the mounted components to meet the thermal stability design requirements as defined by the observatory measurement performance. This paper focuses on the CCHP modeling methodology in Siemens Simcenter and demonstrates a close correlation between the thermal model prediction and the ground thermal bed testing for the Radio Frequency Unit (RFU) thermal pallet under steady state conditions.

MLI Blanket Performance: Analytical Predictions and Quantitative Trends Measured in Testing
TFAWS18-PT-06
Tyler Schmidt, Pradeep Bhandari, and Hared Ochoa, Jet Propulsion Laboratory

Heat loss through multi-layer insulation (MLI) blankets is typically a major driver of the heater power needed for a spacecraft or instrument. A complicating matter is that predictions of MLI performance are often uncertain until after system level thermal testing and thermal model correlation. If performance is worse than expected, it can lead to undesirable modifications to flight hardware late in a project lifecycle or constraints on mission operations. Therefore, there is an advantage to developing higher confidence predictions and models for MLI performance.

A thermal development test was conducted at the Jet Propulsion Laboratory (JPL) to quantify the performance of MLI blankets and compare with analytical predictions. A 1ft x 1ft x 1ft aluminum sheet metal cube was constructed to serve as the test article for all MLI blankets. Various parameters such as blanket layup configurations (e.g. mylar layers and dacron netting vs embossed layers only) and locations/staggering of seams were included. Before the test, analytical predictions were made for the overall effective emittance (ε*) of each blanket design with the test article at temperatures of +20, +35, and +50 °C. Predictions were based on an empirical correlation derived from results of MLI blanket tests at the former Lockheed Corporation. This equation accounts for several influencers, including number of layers and boundary temperatures, of MLI blanket performance.

Overall, the test data showed good correlation with the analytical predictions, which demonstrated the model's ability to predict ε* values of various MLI blanket designs. Most of the pre-test predictions were within ±15% of the test actuals. Trends for ε* in relation to temperature, blanket layup, and blanket seams are each discussed. The implementation and results for using two separated blankets (with the same number of total layers as a single blanket) are also described.

In late 2018 to early 2019, additional development tests that build off this work will investigate blanket performance at several locations on the spacecraft for the planned Europa Clipper mission.

Infrared Microscopy-Based Thermal Characterization of Lithium-Ion Battery Electrodes
TFAWS18-PT-11
Rajath Kantharaj, Yexin Sun, and Amy Marconnet, Purdue University

Lithium-ion batteries provide higher energy and power densities when compared with nickel cadmium, nickel metal hydride, and lead acid batteries. However, abusive usage of such batteries, that is, high discharge/charge rate or operation under extreme ambient temperature leads to excessive heat generation. As the temperature rises to approximately 90 ℃, exothermic side reactions are promoted that generate additional heat. This dramatically increases internal temperature and the release of gases builds up pressure, ultimately leading to a disastrous event known as thermal runaway. Eliminating this threat requires a deeper understanding of the electrochemical heat generation and the prevalent anisotropic thermal transport within the battery that leads to accumulation of heat within the core. Accurate characterization of thermal conductivity will enable a better understanding of transport as well as aid numerical electrochemical-thermal modeling, which will improve thermal management strategies. Currently, thermal conductivity data is lacking for certain cathode materials like $\mathrm{LiMn_2O_4}$ (LMO) and $\mathrm{LiNiCoAlO_2}$ (NCA) at the electrode-level and the cell-level. In this paper, infrared (IR) microscopy is used to characterize and visualize cross-plane thermal conduction in electrode (LMO cathode and graphite anode) and separator materials in the range of $30℃ - 70℃$. Current measurements indicate that dry/wet anode has an effective conductivity of $1.3\ \mathrm{Wm^{-1}K^{-1}}/1.6\ \mathrm{Wm^{-1}K^{-1}}$. For the cathode, we measured conductivities of $0.56\ \mathrm{Wm^{-1}K^{-1}}$ and $1.7\ \mathrm{Wm^{-1}K^{-1}}$ in the dry and wet states, respectively. In this work, IR microscopy is also used to investigate *in situ* spatial distribution of temperature across cathode-separator-anode, with the ultimate goal of characterizing spatio-temporal variation of heat generation. For the purpose, we have built an air-tight set-up that houses the electrodes, separator and the electrolyte with visualization through an infrared-transparent calcium fluoride (CaF_2) window. Temperature and charging/discharging voltages and currents are recorded simultaneously during charging and discharging for further analysis.

Assessment of the Mars Helicopter Thermal Design Sensitivities Using the Veritrek Software
TFAWS18-PT-12
Stefano Cappucci and Michael T. Pauken, Jet Propulsion Laboratory
Jacob Moulton and Derek Hengeveld, Loadpath

The Mars Helicopter will be a technology demonstration conducted during the Mars 2020 mission. The primary mission objective is to achieve several 90-second flights and capture visible light images via forward and nadir mounted cameras. These flights could possibly provide reconnaissance data for sampling site selection for other Mars surface missions. The helicopter is powered by a solar array, which stores energy in secondary batteries for flight operations, imaging, communications, and survival heating. The helicopter thermal design is driven by minimizing survival heater energy while maintaining compliance with allowable flight temperatures in a variable thermal environment. Due to the small size of the helicopter and its complex geometries, and because it operates with very low power and small margins, additional care had to be paid while planning thermal tests and designing the thermal system. A Thermal Desktop® model has been developed to predict the thermal system's performance. A reduced-order model (ROM) created with the Veritrek software has been utilized to explore the sensitivities of the thermal system's drivers, such as electronics dissipations, gas gaps, heat transfer coefficients, etc. This paper presents the performance of the Veritrek software products and the details of the ROM creation process. The results produced by Veritrek have been utilized to study the effect of the major thermal design drivers and the Mars environment on the Mars Helicopter.

JSC Tours Information

Important: completely enclosed, low or flat heeled shoes are required to comply with safety regulations. There will be no stop for food or gift shops either day.

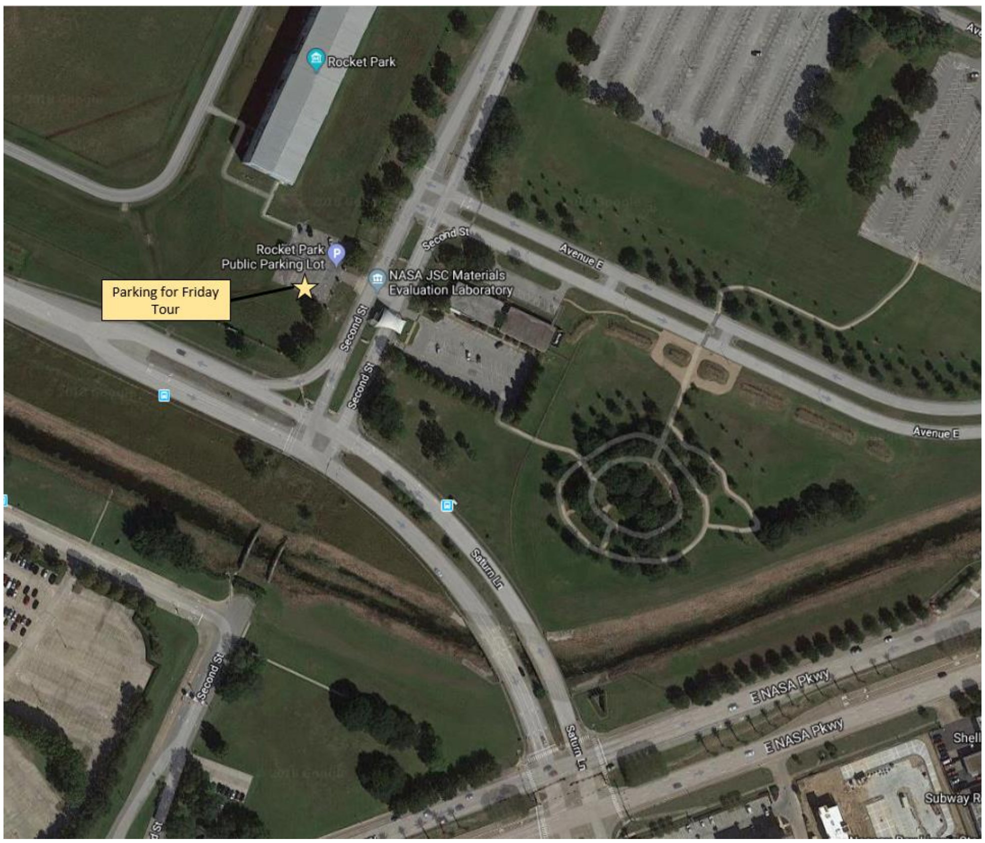
Tuesday, August 21st Tour:

Departs Galveston Convention Center no later than 12:40 pm, returns ~6:00 pm

Friday, August 24th Tour:

Departs Galveston Convention Center no later than 7:30 am, returns ~1:00 pm

If you have registered for the Friday tour, you have the option to drive yourself to JSC and meet the tour group at Rocket Park. To navigate to Rocket Park please put 'Saturn Ln and Second Street 77058' in your GPS. Let security know you need to park your car at Rocket Park, and they will direct you where to go. Please be at Rocket Park on JSC property at 8:00AM. The tour will leave no later than 8:15AM.



Mission Control:

Since 1965, Mission Control has been the helm of America's human spaceflights. Since International Space Station assembly began in 1998, the center has become a focal point for human spaceflight worldwide. The teams that work in Mission Control, Houston, have been vital to every U.S. human spaceflight since the Gemini IV mission in 1965, including the Apollo missions that took humans to the moon and 135 space shuttle flights. It is currently staffed 24/7 365 days a year in support of continuous crewed operations of the International Space Station.

Space Vehicle Mockup Facility:
The mission of the Space Vehicle Mockup Facility (SVMF) is to provide world class training for space flight crews and their support personnel and high-fidelity hardware for real-time mission support. A major task of the SVMF is to support Engineering and Mission Operations evaluations for the International Space Station (ISS) and Orion Programs. All mockups and part-task trainers are available to support troubleshooting on the ground any time problems develop on orbit in real time. Also in the building is Engineering Development areas which include Humanoid Robots (Valkyrie and Robonaut), Hybrid Reality Lab, Human class Rovers, and the Active Response Gravity Offload System (ARGOS)

Neutral Buoyancy Lab:
The mission of the NBL is to prepare for space missions involving spacewalks. NASA team members use the NBL to develop flight procedures, verify hardware compatibility, train astronauts and refine spacewalk procedures during flight that are necessary to ensure mission success. The NBL was sized to perform two activities simultaneously; each uses mockups sufficiently large to produce meaningful training content and duration. It is 202 ft in length, 102 ft in width and 40 ft in depth (20 ft above ground level and 20 ft below) and holds 6.2 million gallons of water.

Chamber A & B:
The Thermal-Vacuum Test Complex consists of the two largest chambers at JSC located in Building 32. The facility provides full scale testing of large systems and human testing/training in a high fidelity simulated space environment. **Chamber A** is the largest of the JSC thermal-vacuum test facilities. Its usable test volume and high-fidelity space simulation capabilities are adaptable for thermal-vacuum testing of a wide variety of test article. The major structural elements of the chamber are the 13.7 m (45 ft) diameter floor, the 12.2 m (40 ft) diameter access door, and the dual crewlocks at the floor level and at the 0.0 m (0.0 ft) and 9.4 m (31 ft) level. Chamber A was most recently used for JWST Mirror assembly testing. **Chamber B**, with roughly one tenth of the internal volume of Chamber A, can handle a variety of smaller scale tests more economically and with faster response. It is a human-rated chamber equipped with a traversing monorail that provides weight relief to one suited crewmember at a time. Major structural elements of the chamber are the removable top head, the fixed chamber floor, dual crewlocks at the floor level, and a load bearing floor area of 6.1 meters (20 ft) in diameter that will support a concentric load of 34,000 kg (75,000 lb).

Acknowledgements

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