Active Thermal Paper Session

Active Thermal Paper Session #1 (Monday 9:00 AM to 11:30 PM)

ID	Title	Author(s)	Affiliation	Email
TFAWS-AT-001	Development of a Cryogenic Analysis Tool for the Scaling of Cryogenic Boil-Off Reduction Systems	Monica Guzik	NASA Glenn Research Center	monica.c.guzik@nasa.gov
TFAWS-AT-002	Ammonia and Propylene Loop Heat Pipes with Thermal Control Valves for Variable Thermal Conductance	Kara Walker John Hartenstine Calin Tarau William Anderson	Advanced Cooling Technologies, Inc.	Kara.Walker@l-ACT.com
TFAWS-AT-003	Variable Conductance Heat Pipe Back-Up Cooling for a Stirling Converter	Calin Tarau Carl Schwendeman William Anderson Peggy Cornell	Advanced Cooling Technologies, Inc.	Calin.Tarau@l-ACT.com
TFAWS-AT-004	Variable Conductance Thermal Management System for Ballon Payloads	Calin Tarau William Anderson	Advanced Cooling Technologies, Inc.	calin.tarau@1-ACT.com
TFAWS-AT-005	Variable Conductance Heat Pipe Radiator for Lunar Fission Power Systems	Bryan J. Muzykal Christopher Peters William Anderson	Advanced Cooling Technologies, Inc.	Bill.Anderson@l-ACT.com

Active Thermal Paper Session #2 (Wednesday 1:00 PM to 3:00 PM)

TFAWS-AT-006	Study of Thermal Transport in Highly Anisotropic Materials for Space Recuperator Applications	Louis Chow	UCF	Louis.chow@ucf.edu
TFAWS-AT-007	Simulating Fluid Networks Containing Reacting Flow Using GFSSP Linked with CEA	Richard Schulman	NASA KSC AI Solutions	richard.e.schulman@nasa.gov
TFAWS-AT-008	No Vent Fill and Transfer Line Chilldown Analysis by GFSSP	Alok Majumdar	NASA MSFC	Alok.K.Majumdar@nasa.gov
TFAWS-AT-009	Integration of a Reverse Turbo-Brayton Cryocooler with a Broad Area Cooling Shield and a Heat Pipe Radiator	R. J. Christie	NASA Glenn Research Center	Robert.j.christie@nasa.gov

TFAWS-AT-001

Development of a Cryogenic Analysis Tool for the Scaling of Cryogenic Boil-off Reduction Systems

Monica C. Guzik, NASA Glenn Research Center, OH

ABSTRACT

Considering that future projected NASA missions vary widely in both scope and duration, there is a clear need for the development of analytical tools that are capable of applying the current state of technology to the wider array of applications that are planned in the years to come. One such example is the scaling of cryogenic propellant thermal control systems from the present, small-scale applications to the larger launch vehicles and storage depots of the future. Recent developments in the areas of both active and passive thermal control, such as the Reverse Turbo-Brayton Cycle cryocooler and Self-Supporting Multi-Layer Insulation, show a great deal of promise in the reduction of overall system mass and power as compared to the cryogenic storage strategies of past missions. These advancements require a reinvention of the current analytical tools in order to realign with the anticipated technologies of the future. This paper discusses such an effort, as applied to the Cryogenic Analysis Tool. This tool leverages component-level scaling equations with data generated from the recent Cryogenic Boil-Off Reduction Systems Reduced Boil-Off testing in order to provide an integrated, system-level model that addresses a wide array of applications within the accessible and convenient Excel/VBA environment. The tool design, approach, and interface is configured to enable the performance of multiple parametric studies for a given mission concept, in order to investigate the application of active and passive thermal control strategies for the broad range of future NASA mission concepts.

TFAWS-AT-002

Ammonia and Propylene Loop Heat Pipes with Thermal Control Valves for Variable Thermal Conductance

Kara Walker, *Advanced Cooling Technologies, Inc.*

ABSTRACT

It is often desirable to partially or completely shut down a Loop Heat Pipe (LHP), for example, to maintain the temperature of electronics connected to the LHP on a satellite during an eclipse. The standard way to control the LHP is apply electric power to heat the compensation chamber, reducing the pressure differential across the system and decreasing LHP flow. The amount of electrical power to shut down an LHP during an eclipse on orbit is generally reasonable.

On the other hand, for LHPs on lunar and Martian landers and rovers, the electrical power requirements can be excessive. For example, the Anchor Node Mission for the International Lunar Network (ILN) has a Warm Electronics Box (WEB) and a battery, both of which must be maintained in a fairly narrow temperature range using a variable thermal conductance link. During the lunar day, heat must be transferred from the WEB to a radiator as efficiently as possible; see Figure 1. During the night, heat transfer from the WEB must be minimized to keep the electronics and batteries warm with minimal power, even with a very low (100 K) heat sink; see Figure 2. A mini-LHP has the highest Technology Readiness Level, but requires electrical power to shut-down during the 14-day lunar night, with a significant penalty in battery mass: 1 watt of electrical power translates into 5kg of battery mass.

Two mini-LHPs with a Thermal Control Valve (TCV) were developed to provide variable thermal conductance without electrical power: one with ammonia, and the second with propylene as the working fluid. . The TCV could route vapor to the condenser, or bypass the condenser and route back to the compensation chamber, depending upon the environmental temperature conditions. For lunar applications, the sink temperature during lunar night could reach as low as -223°C. A propylene LHP has an advantage over an ammonia LHP, since it can withstand these reduced sink conditions without the concern of freezing.

The presentation will describe the ammonia and propylene LHP and TCV designs, fabrication and testing results.

TFAWS-AT-003

Variable Conductance Heat Pipe Back-Up Cooling for a Stirling Convertor

Calin Tarau, Carl Schwendeman, William G. Anderson, and Peggy A. Cornell, *Advanced Cooling Technologies, Inc., PA*

ABSTRACT

In a Stirling Radioisotope Power System (RPS), heat must be continuously removed from the General Purpose Heat Source (GPHS) modules to maintain the modules and surrounding insulation at acceptable temperatures. The Stirling convertor normally provides this cooling. If the Stirling convertor stops in the current system, the insulation is designed to spoil, preventing damage to the GPHS at the cost of an early termination of the mission. An alkali-metal Variable Conductance Heat Pipe (VCHP) can be used to passively allow multiple stops and restarts of the Stirling convertor. In a previous NASA SBIR Program, Advanced Cooling Technologies, Inc. (ACT) developed a series of sodium VCHPs as backup cooling systems for Stirling RPS. The operation of these VCHPs was demonstrated using Stirling heater head simulators and GPHS simulators. In the most recent effort, a sodium VCHP with a stainless steel envelope was designed, fabricated and tested at NASA Glenn Research Center (GRC) with a Stirling convertor for two concepts; one for the Advanced Stirling Radioisotope Generator (ASRG) back up cooling system and one for the Long-lived Venus Lander thermal management system. The VCHP is designed to activate and remove heat from the stopped convertor at a 19°C temperature increase from the nominal vapor temperature. The 19°C temperature increase from nominal is low enough to avoid risking standard ASRG operation and spoiling of the Multi-Layer Insulation (MLI). In addition, the same backup cooling system can be applied to the Stirling convertor used for the refrigeration system of the Long-lived Venus Lander. The VCHP will allow the refrigeration system to: 1) rest during transit at a lower temperature than nominal; 2) pre-cool the modules to an even lower temperature before the entry in Venus atmosphere; 3) work at nominal temperature on Venus surface; 4) briefly stop multiple times on the Venus surface to allow scientific measurements. This paper presents the experimental results from integrating the VCHP with an operating Stirling convertor and describes the methodology used to achieve their successful combined operation.

TFAWS-AT-004

Variable Conductance Thermal Management System for Balloon Payloads

Calin Tarau, William G. Anderson, *Advanced Cooling Technologies, Inc., PA*

ABSTRACT

While continuously increasing in complexity, the payloads of terrestrial high altitude balloons need a thermal management system to reject their waste heat and to maintain a stable temperature as the air (sink) temperature swings from as cold as -90°C to as hot as +40°C. A current solution consists of copper-methanol Constant Conductance Heat Pipes (CCHPs). The problem with these devices is that the conductance cannot effectively be reduced under cold operating or cold survival environment conditions without expending significant energy in an active heater to maintain the instruments in their normal operating range. This presentation will cover the development of a low cost Variable Conductance Heat Pipe (VCHP) that allows the thermal resistance to increase passively under cold operating or cold survival environment conditions, keeping the instrument section warm without minimal electric heating. This VCHP is based on smooth-bore, thin-wall stainless steel tubing, with methanol, toluene or pentane as working fluids, and is capable of passively maintaining a relatively constant evaporator (payload) temperature while the sink temperature varies between -90°C and +40°C. Two configurations were developed, a cold reservoir one (reservoir is attached to the condenser) and a hot reservoir one (reservoir is attached to the evaporator). Both configurations were tested with methanol, pentane and toluene as working fluids and the experimental results were consistent with the modeling results. In all experimental cases, the evaporator temperature was maintained within the required interval while the sink temperature varied between -90°C and +40°C. The hot reservoir configuration showed a very tight temperature control. For example, the pentane charged hot reservoir VCHP allowed the evaporator temperature to change with only 3.7ºC. The largest temperature variation was 32.6ºC and it was shown by the pentane charged cold reservoir VCHP. This variation was still within the required interval of 60ºC. Survival tests were carried out for the toluene charged cold reservoir VCHP. A duration of 13,000 seconds was needed by the evaporator to cool from 49ºC down to 20ºC while power was shut down and the sink was continuously -90ºC.

TFAWS-AT-005

Variable Conductance Heat Pipe Radiator for Lunar Fission Power Systems

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ABSTRACT

Nuclear power systems for long-term Lunar and Martian missions present many challenges to thermal management systems, such as variable thermal loads, large temperature swings between day and night, and freezing of the working fluid. The radiator to reject the waste heat must be sized for the maximum power at the highest sink temperature. This radiator is then oversized for other conditions, such as the Lunar/Martian night, or periods when the power to be rejected is low. A Variable Conductance Heat Pipe (VCHP) radiator can passively accommodate changing thermal loads and environments. In a VCHP, a non-condensable gas (NCG) is added that blocks a portion of the condenser. The NCG permits passive control of the thermal load and allows for freezing of the working fluid in a controlled fashion during shutdown. Heat is supplied to the variable conductance heat pipes by a single-phase pumped loop.

A variable conductance thermosyphon radiator with an attached heat exchanger was developed and tested. The radiator is designed to operate in the 370 to 400 K temperature range, which is above the operating range of standard aluminum/ammonia radiator panels. To operate at these higher temperatures, the radiator has a titanium heat exchanger, titanium/water thermosyphons, and graphite fiber reinforced composite radiator panels. The radiator is capable of: 1) Accommodating changes in power and sink temperature, 2) Successfully starting up from an initially frozen state with excess water frozen in an arbitrary location, and 3) Shutting down, freezing, and then successfully restarting. A low mass design was developed that accommodates the coefficient of thermal expansion (CTE) mismatch between the titanium heat exchanger and the graphite radiator panel. A small-scale prototype of the radiator system was built to verify various aspects of the design, including the heat exchanger, CTE matching of components, freeze/thaw survivability, etc. A full-scale VCHP radiator was fabricated and tested in order to demonstrate functionally at a larger, more representative size and determine maximum heat rejection.

Figure 1 shows a plot of the steady-state temperatures of the radiating surface during nominal operation. The condensing sections of the embedded VCHPs are indicated by the linear higher temperature regions. Overall, the panel shows good isothermality with a ΔT of 26 °C from the centermost VCHP condenser to one of its symmetry planes. The temperature of each evaporator was lowered to 35 °C to allow the panel to shut down. This state of shutdown is evident in Figure 2. Note that the panel is completely isothermal and has equilibrated to the temperature of the ambient (Figure 2). There is an evaporator to condenser ΔT of 12 °C since non-condensable gas has filled all of the condenser and adiabatic section and blocks the flow of vapor to these portions of the heat pipe.

TFAWS-AT-006

Study of Thermal Transport in Highly Anisotropic Materials for Space Recuperator Applications

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W. Notardonato, Kennedy Space Center, FL

ABSTRACT

A high-effectiveness, low-pressure-drop recuperator is one of the critical components of energy-efficient, high-capacity cryocoolers for long-term storage of cryogens including hydrogen. This paper presents the results of an investigation of the thermal transport mechanisms in highly anisotropic materials. These materials enable the development of compact, lightweight recuperative heat exchangers for high-capacity, energy-efficient, low-temperature cryocoolers. The high in-plane thermal conductivity allows effective heat transfer from the warm stream to the cold stream, while the low out-of-plane thermal conductivity keeps undesirable axial conduction from one end of the recuperator to the other to a minimum. It is expected the concept suggested in this paper could lead to a disruptive technology and affect how future space heat exchangers are designed and built.

This is the first time an investigation is carried out to exploit the unique thermophysical properties of lightweight, highly anisotropic materials to enable the development of high-effectiveness, compact and lightweight recuperator for cryocoolers. A very attractive feature is that the recuperator design is modular, so high gas flow rates (i.e. >20W of heat removal at hydrogen temperature) can be obtained by simply increasing the number of modules. NASA Space Technology Roadmap indicates 20K compact cryocoolers capable of removing 20W of heat from liquid hydrogen could offer significant mass savings of cryogenic propellants through zero boil-off (ZBO), and thus enables long duration space missions.

TFAWS-AT-007

Simulating Fluid Networks Containing Reacting Flow Using GFSSP Linked with CEA

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ABSTRACT

Generalized Fluid System Simulation Program (GFSSP) and NASA Chemical Equilibrium with Applications (CEA) are, on their own, powerful analysis tools for studying complex flow networks and combustion equilibrium chemistry, respectively. In order to extend the capability of GFSSP to include reacting flow, a reacting flow module that is linked to CEA is created. Using user subroutines provided with GFSSP, an interface is constructed to pass information between the two programs. The temperature and pressure of each reactant is calculated by GFSSP at each node designated as combustion. CEA then determines the equilibrium composition of the mixture, new temperature due to the reaction and averaged fluid properties of the mixture. The properties calculated by CEA are then integrated back into the GFSSP solver. To demonstrate the new capability, several example models are created that include the new combustion node. The model focused on determining a relation between oxidizer and fuel line diameters to temperature of combustion. A parametric was run on the model over a range of fuel line diameters. It was found that for a line pressure of 100 Psia and a line temperature of -160 Fahrenheit, the ratio of oxidizer to fuel line diameter that results in hottest combustion temperature is 2/3.

TFAWS-AT-008

No Vent Tank and Transfer Line Chilldown Analysis by GFSSP

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ABSTRACT

The current interest in pressurized transfer of cryogenic fluids stems in part from NASA's plans for an ambitious human Space Exploration Initiative including manned voyages to the Moon and Mars. These activities will require enormous amounts of propellant stored as cryogenic liquids. The ability to efficiently transfer these cryogens between earth-to-orbit tanker vehicles, orbiting depots, and space transportation vehicles is required for mission success.

One of the objectives of Cryogenic Propellant Storage and Transfer (CPST) Analytical Tool Development Task is to provide to designers and analysts the capability to model the system operation with reasonable accuracy. It is also desirable that computation time for modeling events is not excessively large. The analytical capability to model no-vent chill and fill and transfer line chilldown was very limited primarily due to complexities of modeling unsteady two phase flows with phase change. In recent years there have been some progress in modeling tank [1] and transfer line chilldown [2] using NASA-developed GFSSP [3]. This paper describes the progress of modeling no-vent chill and fill of cryogenic tanks and provides the status of modeling transfer line chilldown using GFSSP.

TFAWS-AT-009

Integration of a Reverse Turbo-Brayton Cryocooler with a Broad Area Cooling Shield and a Heat Pipe Radiator

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ABSTRACT

A unique cryogenic propellant tank cooling and heat rejection system was developed by integrating a reverse turbo-Brayton cycle cryocooler with a broad area cooling shield and a constant-conductance heat-pipe radiator. This system is being used to demonstrate the feasibility of reducing the boil-off of cryogenic propellant from spacecraft storage tanks. This cooling system demonstrated the ability to remove 13W of heat at 80K from a very large area while rejecting up to 400W at 300K through the heat-pipe radiator. The broad area cooling shield was imbedded within the multilayer insulation surrounding a liquid hydrogen tank. By extracting heat from this shield at 80K, the heat leak into liquid hydrogen was expected to be reduced by 2/3rds. The broad area cooling shield uniquely used the process flow of the cryocooler to provide distributed cryogenic cooling over an unprecedented area of $8m^2$. Discrete cooling was also provided to the tank support struts and tank piping that penetrated through the multilayer insulation. Testing was performed with both conventional insulation and Self Supporting Multilayer Insulation. This cooling system is also being integrated with a liquid oxygen tank. In that design, instead of having a cooled shield within the insulation, the cooling tubes are bonded directly to the tank wall. With cooling at 80K, the boil-off rate from the liquid oxygen tank is expected to be reduced to zero. This paper describes the system design and how the hardware was physically integrated. The performance results will be documented by the Principal Investigator in a separate paper. The reduced boil-off testing of this system with liquid hydrogen propellant tanks has been completed and zero boil-off testing with liquid oxygen is currently in progress.