Thermal Control System Development to Support the Crew Exploration Vehicle and Lunar Surface Access Module

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Abstract. All space vehicles or habitats require thermal management to maintain a safe and operational environment for both crew and hardware. Active Thermal Control Systems (ATCS) perform the functions of acquiring heat from both crew and hardware within a vehicle, transporting that heat throughout the vehicle, and finally rejecting that energy into space. Almost all of the energy used in a space vehicle eventually turns into heat, which must be rejected in order to maintain an energy balance and temperature control of the vehicle. For crewed vehicles, Active Thermal Control Systems are pumped fluid loops that are made up of components designed to perform these functions. NASA has recently evaluated all of the agency's technology development work and identified key areas that must be addressed to aid in the successful development of a Crew Exploration Vehicle (CEV) and a Lunar Surface Access Module (LSAM). The technologies that have been selected and are currently under development include: fluids that enable single loop ATCS architectures, a gravity insensitive vapor compression cycle heat pump, a sublimator with reduced sensitivity to feedwater contamination, an evaporative heat sink that can operate in multiple ambient pressure environments, a compact spray evaporator, and lightweight radiators that take advantage of carbon composites and advanced optical coatings.

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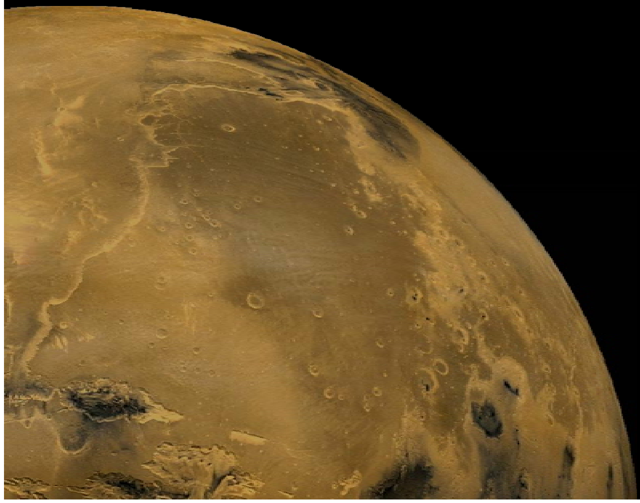


Active Thermal Control Systems (ATCS)

- Control and maintain a suitable and comfortable environment for the crew and vehicle hardware
  - Has been on every human rated space vehicle
- Historically have utilized single-phase (liquid), pumped fluid loops
- Technologies under development have been targeted for the Crew Exploration Vehicle (CEV), Lunar Surface Access Module (LSAM), and a Lunar Outpost (LO)
- Three main functions
  - Heat Acquisition
  - Heat Transfer
  - Heat Rejection

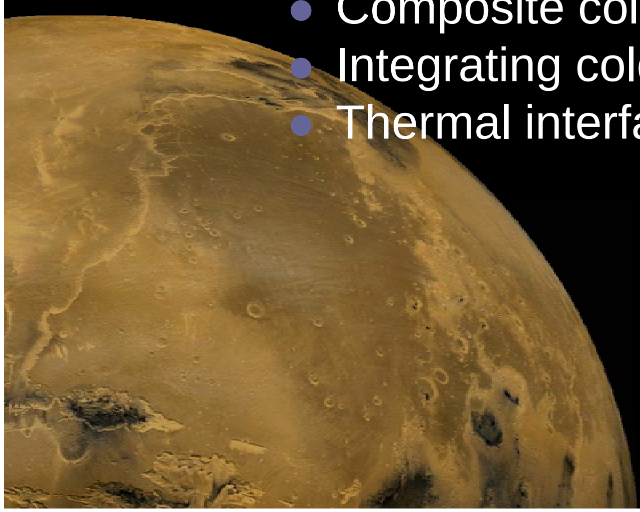
Advanced Hardware Research and Development

- Support NASA's Exploration Systems Mission Directorate
- Collaborations
  - Johnson Space Center, Glenn Research Center, Goddard Space Flight Center, and the Jet Propulsion Laboratory
  - Industry Partners
    - Hamilton Sundstrand
    - Mainstream
    - Paragon Space Development Corporation
    - Sundanzer, Inc.

Heat Acquisition

Collect waste heat from sources such as Crew life support, avionics, motors, and refrigeration systems

- Liquid cooled coldplates
  - Used on every human rated vehicle that has flown
  - More efficient to transfer heat directly into fluid loop with out heating cabin air
  - More important for CEV due to requirement to depressurize the cabin
  - Provide cooling for electronics
  - Potential Research Areas:
    - Composite coldplates
    - Integrating coldplates into vehicle structure,
    - Thermal interface materials



Heat Acquisition

Collect waste heat from sources such as Crew life support, avionics, motors, and refrigeration systems

- Air to liquid heat exchangers
  - Control cabin air temperature and humidity
  - Condensate removal and phase separation with either porous material (Apollo) or rotary separator (Shuttle, ISS)
- Liquid to liquid heat exchangers
  - Transfers energy from one fluid loop to another without mixing of fluids
    - Internal to external fluid loops on Shuttle and ISS
  - Scrutinized as a potential failure source
    - A single failure could allow fluids to mix
  - Potential Research Areas:
    - Heat exchangers with two barriers to prevent fluids from mixing

Heat Transport

Transport heat from heat acquisition hardware to heat rejection hardware

Current state of the art includes:

- Shuttle and ISS use two fluid loops connected by a liquid to liquid heat exchanger
  - Internal water loops
  - External refrigerant loop (Freon 21 or Ammonia)
- Turbine pumps
- Metal bellows accumulators (Shuttle and ISS)
- Teflon flex hoses on ISS
  - Gas permeation into fluid loop changes the properties of the fluid
- EVA Fluid Quick Disconnects (ISS)
  - Required for connections external to the vehicle
  - Complex and prone to operational problems

Metal Bellows Accumulators

EVA Fluid QD

Thermal Control System Fluids

- Objective: Identify fluids that enable single loop ATCS designs
- Technologies Under Development
  - NASA JSC has selected propylene glycol and water mixtures (Dowfrost HD) for more detailed investigations
  - Mainstream is developing new fluids under a SBIR contract with JSC
  - Other commercially available heat transfer fluids are under evaluation by industry
  - Applicable for all future human rated vehicles

Thermal Control System Fluids

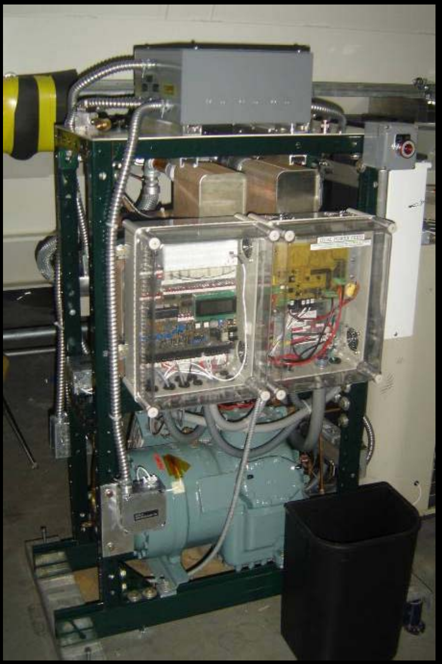
- Current Tasks
  - Investigating compatibility with materials and Life Support Systems
  - Investigating safety issues such as toxicity and flammability
  - Evaluating low temperature fluid characteristics (-100 to 0 °C) via testing for 35, 50, and 60% glycol concentrations
    - Volumetric expansion and
    - Low temperature viscosity
    - Freezing characteristics
  - Potential Research Areas
    - Identify or develop new fluids

Burst Tests

Volumetric Expansion

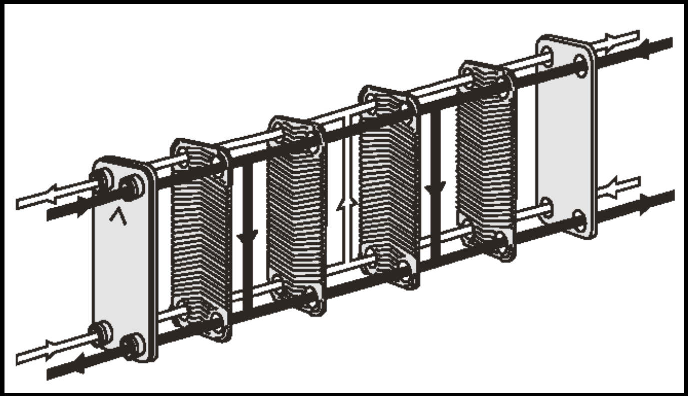
Vapor Compression Cycle Heat Pump

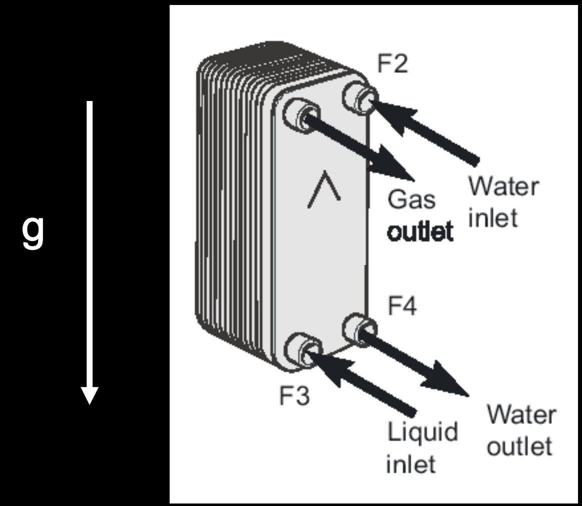
- Objective: Demonstrate gravity independent performance of 50°C lift to a heat sink above 300 K
- Technologies Under Development
  - Vapor compression heat pump system
    - 15 kW capacity
    - COP ~3.0
    - Can operate in low to microgravity environments
  - Applicable to LSAM and Lunar Outpost
    - Hot environments during Lunar day



Vapor Compression Cycle Heat Pump

- Current Tasks
  - Testing a baseline system
  - Evaluating evaporator and condenser for gravity dependence
    - Plate fin heat exchangers
    - Two-phase flow analysis
    - Testing in multiple orientations
  - System Modeling
  - Compressor selection
- Potential Research Areas
  - Evaporators, condensers, and two-phase mixing devices for use in low to microgravity environments
  - Analysis and testing techniques to evaluate system components and complete systems



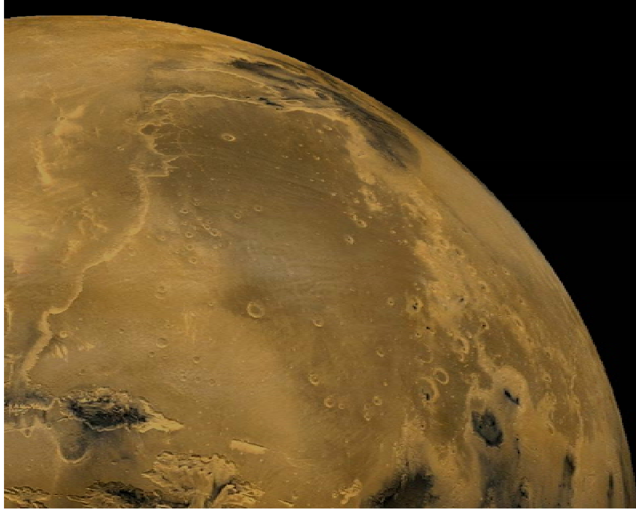


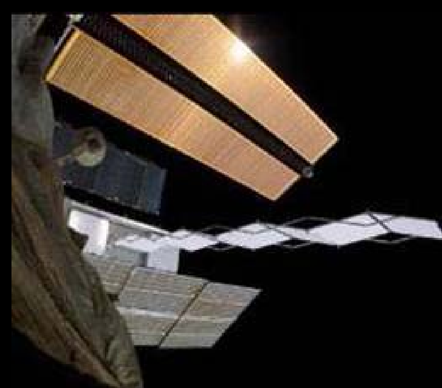
Heat Rejection

Radiators use heat transfer via radiation to reject energy to space

Current state of the art:

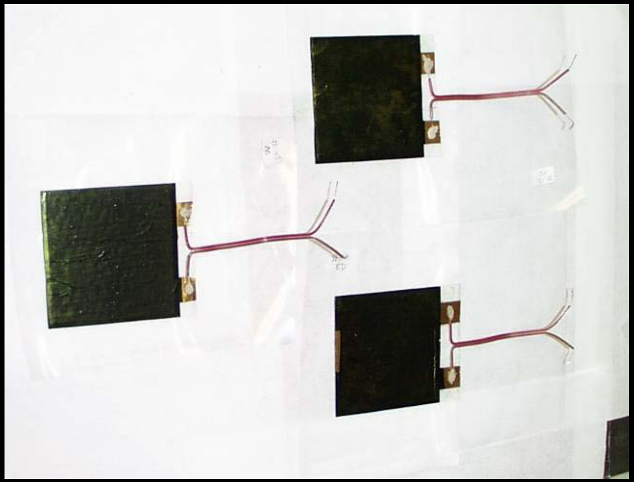
- Aluminum radiators
  - Shuttle and ISS use deployable radiators
  - Gemini and Apollo used body mounted radiators
  - Silver Teflon or Z-93 coating



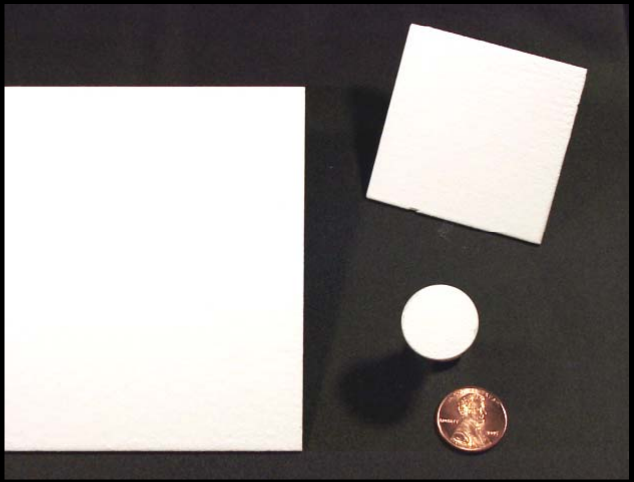


Advanced Radiator Developments

- Objectives: Decrease radiator mass and operate during mission transients
- Technologies Under Development
  - Carbon composite radiators
    - Coatings and coating application for composite radiators
    - Integrating flow channels into composite panels
  - Structurally Integrated Radiator – Paragon Space Development Corp
  - Variable emissivity coatings
  - Stagnation flow radiator designs
  - Applicable to all spacecraft



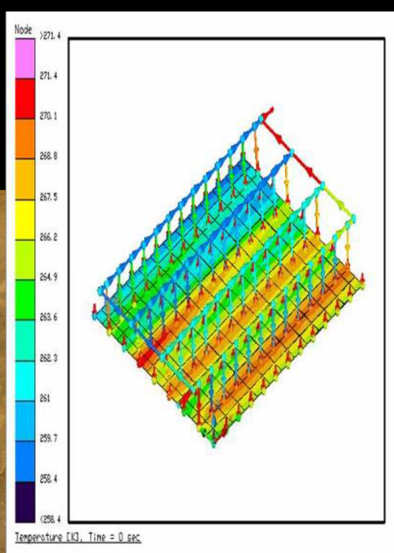
Coupons with Electrochromic Thin films



Coupons with Lithium Based White Paint

Advanced Radiator Developments

Proof of Concept Stagnation Radiator Test Article



Stagnation Radiator Thermal Desktop Model

- Current Tasks
  - Environmental testing of composite and coating coupons
    - K1100 fiber based composites
    - Coatings include Lithium based white paint, OSRs, and Electrochromic thin films
    - Environments include thermal cycling, combined UV and Solar Wind, and launch pad weathering
  - Analysis and testing of stagnation radiator concept
  - Thermal and structural testing for Structural Radiators
- Potential Research Areas
  - Applying coatings to composites
  - Integrating flow channels with composites
  - Coating degradation in anticipated environments, including Lunar dust

Heat Rejection

Evaporative heat rejection transfers energy into a fluid, causing the fluid to evaporate and the vapor is vented to space

Current state of the art:

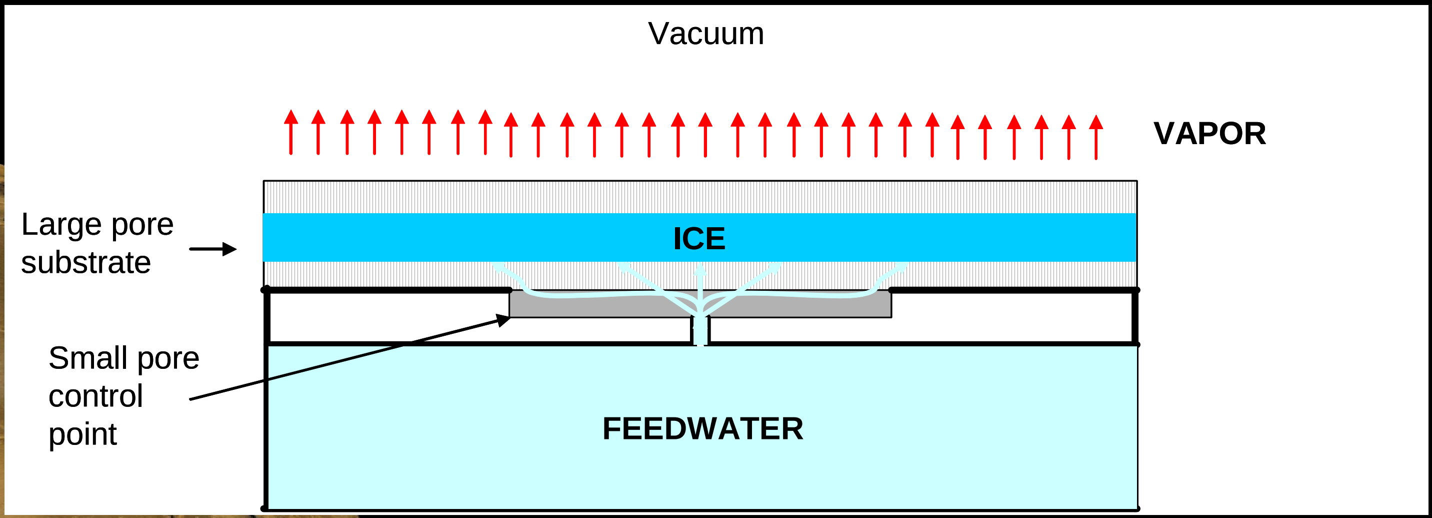
- Sublimators
  - Used on Extravehicular Mobility Unit (EMU) and Apollo Lunar Module
  - Self regulating
  - Sensitive to contamination of porous sublimation region
- Fluid Evaporators
  - Previous designs have used water, ammonia, and other fluids
  - Shuttle Flash Evaporator System (FES) sprays water onto a heated surface
  - Shuttle Ammonia boiler is used below 120,000 ft during re-entry and post landing

Apollo LM Sublimator

Shuttle FES

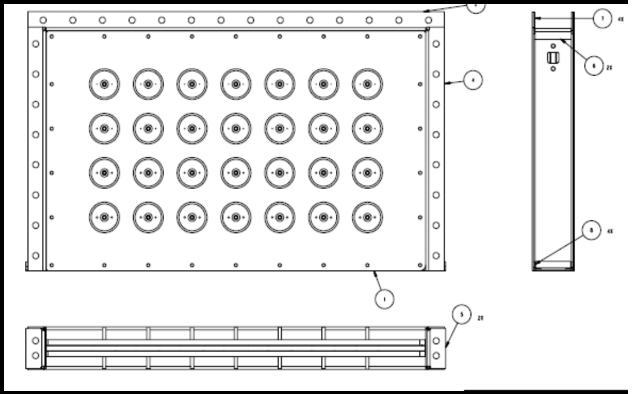
Contaminant Insensitive Sublimator

- Objective: Improve sublimator reliability by decreasing sensitivity to contamination in feedwater
- Technology Under Development
  - Developing design of a sublimator with a two stage feedwater distribution
  - Small pore sized material controls the water distribution
  - Freezing and sublimation occur in material with larger pore size
  - Applicable to CEV and LSAM



Contaminant Insensitive Sublimator

- Current Tasks:
  - Fabricated Mini-sublimator
  - Testing Mini-sublimator
  - Revising drawing for large engineering unit
- Research Areas:
  - Flow and phase change in porous media
    - Multiple pore sizes
    - Flow distribution between porous disks and porous plate
    - Evaporation, freezing, and sublimation

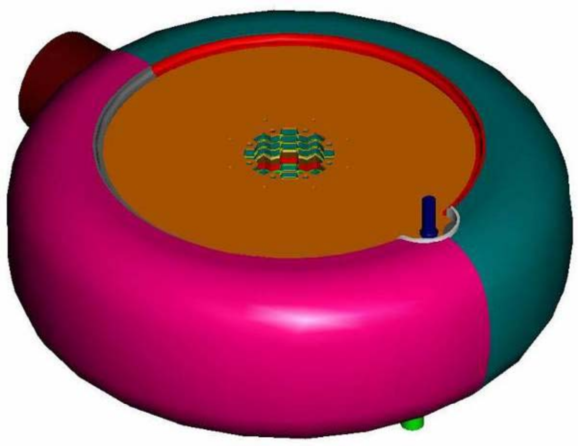


Multi-environment Evaporative Heat Sink

- Objective: Develop evaporative heat sinks that can operate both in space vacuum and in the Earth's atmosphere post-landing
- Technology Under Development
  - Multi-Fluid Evaporator – uses different fluids for evaporant during different mission phases
  - Flow boiling device
  - Under development by Hamilton Sundstrand
  - Applicable to CEV and LSAM

Multi-environment Evaporative Heat Sink

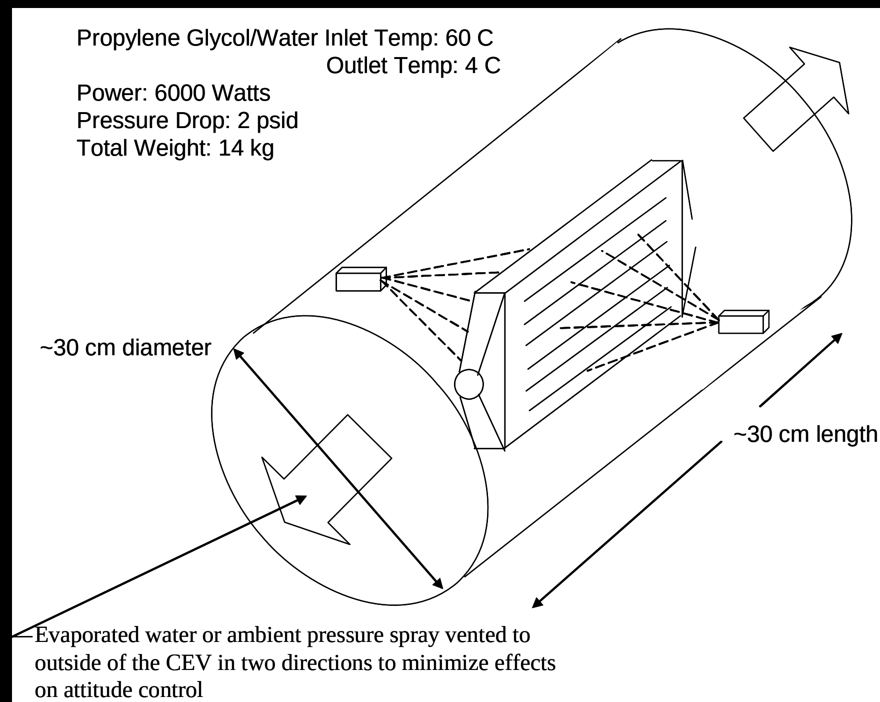
- Current Tasks
  - Recently completed testing of small scale units to map thermal performance, evaluate different heat transfer fins, and evaporant flow control methods
  - Designed full scale unit
  - Fabricating an engineering unit for testing
  - Fabricating a prototype
- Potential Research Areas
  - Evaporating flow through heat transfer fins and porous foams
  - Heat exchanger manufacturing with composites



Compact Flash Evaporator System

- Objective: Provide the maximum heat flux per mass for an evaporative heat sink by spraying evaporant onto a heated surface.

- Technology Under Development
  - Compact Flash Evaporator System (CFES)
  - Sprays onto a flat micro channel heat exchanger
  - Utilizes both sides
  - Can spray multiple evaporants for both in space and post landing cooling



Compact Flash Evaporator System

- Current Tasks
  - Developing micro channel heat exchanger
  - Building subscale test units
  - Testing single nozzle and multiple nozzle arrays
  - Drop tower tests
- Potential Research Areas
  - Spray optimization over a rectangular surface
  - Control methods for evaporant
  - Correlations for heat transfer of sprays in reduced gravity

Conclusion

- In order to support NASA's current Vision for Space Exploration, focused advanced thermal control system hardware development is necessary

- In addition to design, analysis, and testing; integrated testing and long term life testing needs to be performed on future systems