Active Thermal Control System Development for Exploration

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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 been actively developing technologies that will enable future missions or will provide significant improvements over the state of the art technologies. These technologies have are targeted for application on the Crew Exploration Vehicle (CEV), or Orion, 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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45th AIAA Aerospace Sciences Meeting and Exhibit
Reno, NV
January 8-11, 2007

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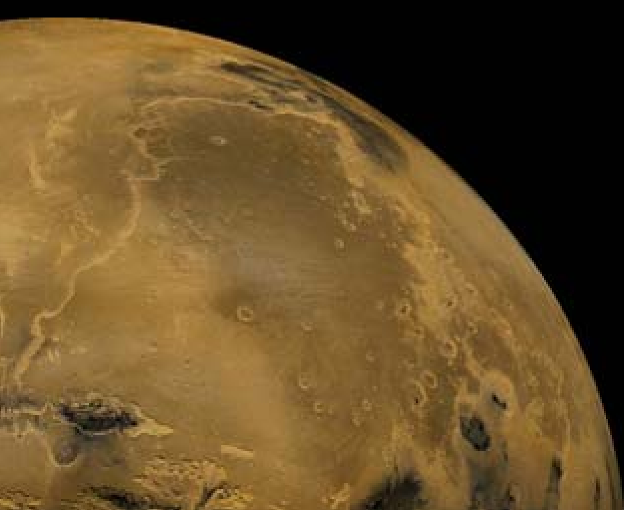
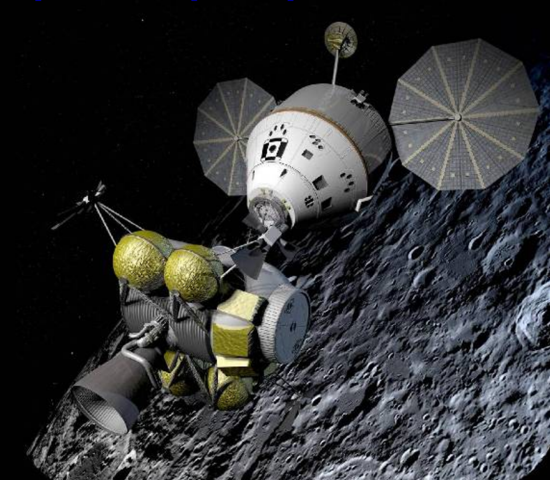


Active Thermal Control Systems (ATCS)

- 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
    - Jacobs-Sverdrup
    - Mainstream
    - Oceaneering Space Systems
    - 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

- Recent Activities
  - Evaluations have been performed on aqueous Dowfrost HD (inhibited propylene-glycol) solutions with respect to the follow:
    - Low temperature performance
    - Compatibility with life support equipment
    - Flammability
    - High temperature decomposition by-products
    - Materials compatibility
      - Especially critical for aluminum tubing and heat exchangers
    - Potential for microbial activity
  - Potential Research Areas
    - Identify or develop new fluids
    - Methods to minimize corrosion in systems with multiple metals (aluminum, SS, nickel) and propylene glycol

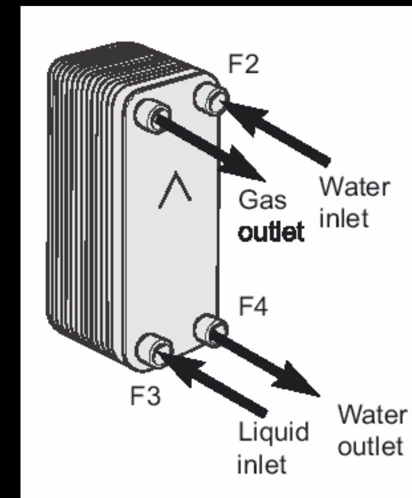
Sparks Generated When Ethylene Glycol Drips on Silver Clad Wiring

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 Lunar Lander and Lunar Outpost
    - Hot environments during Lunar day

Vapor Compression Cycle Heat Pump

- Recent Activities
  - Evaluating Fairchild 54 mm Helirotor Compressor for performance in different gravity environments
  - Trading compact plate-fin versus tube-in-tube heat exchangers
    - Performed tilt tests on plate fin heat exchangers
    - Performance decreased as a function of tilt angle
- 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 for performance in different gravity environments
  - Compressors that can operate in different gravity environments or orientations
    - Lubrication and bearing design
  - Effects of gravity on system performance
    - Start up and shutdown
    - System oil management



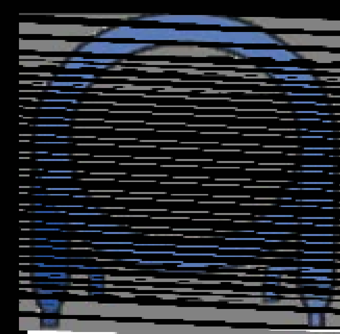
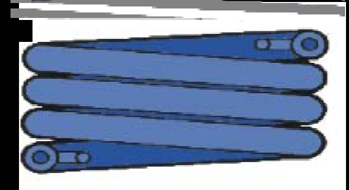


Plate Fin HX



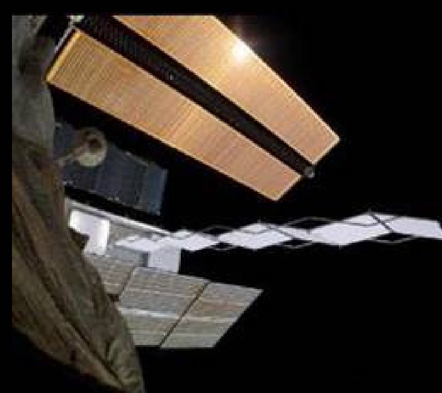
Tube-in-Tube HX

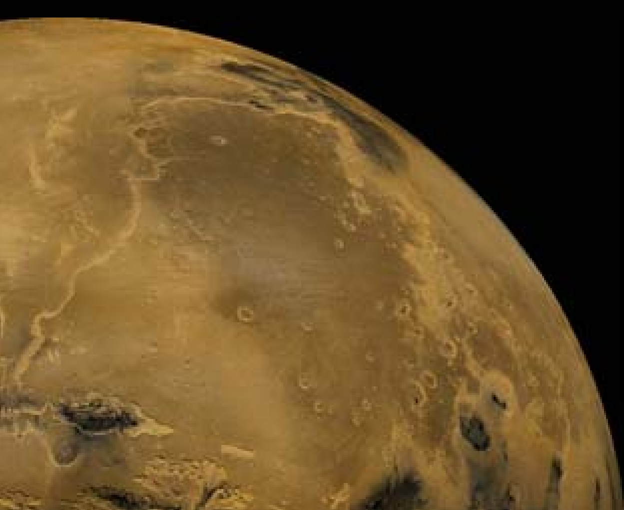
Heat Rejection

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



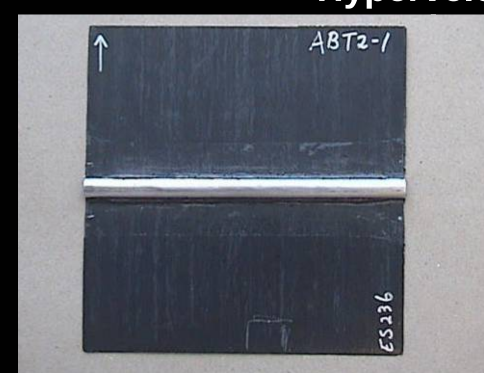


Advanced Radiator Developments

- 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
    - MMOD impacts on composite radiators
  - Structurally Integrated Radiator – Paragon Space Development Corp
  - Stagnation flow radiator designs
  - Applicable to all spacecraft

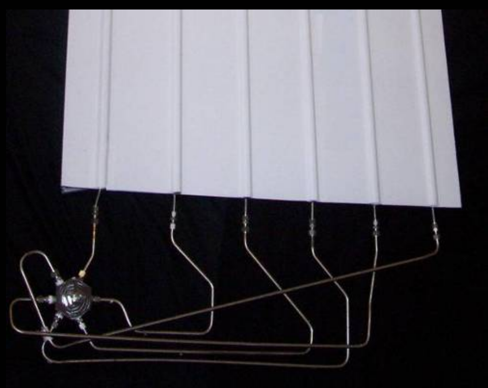
Shuttle Radiator MMOD Damage

JPL/Cal Tech Hypervelocity Test [illegible]ber



Tube Bonding Test Coupon

Advanced Radiator Developments



Stagnation Radiator Manifold

Coating Tests at KSC Corrosion Test Facility

- Recent Activities
  - Environmental testing numerous coating coupons
    - Application on carbon composite and aluminum substrates
    - Coatings include Lithium based white paints, OSRs, Electrochromic thin films, Z93, Z93 with different overcoats, Silver Teflon, and S13
    - Environments include thermal cycling, combined UV and Solar Wind, and launch pad weathering
  - Analysis and testing of stagnation radiator concept
  - Testing of tube to panel bond coupons
  - Design and analysis of composite, sandwich panel radiator
  - 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
  - Flow control methods for multiple radiator systems that use propylene glycol based fluids
    - Low temperature viscosity driven stagnation

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:

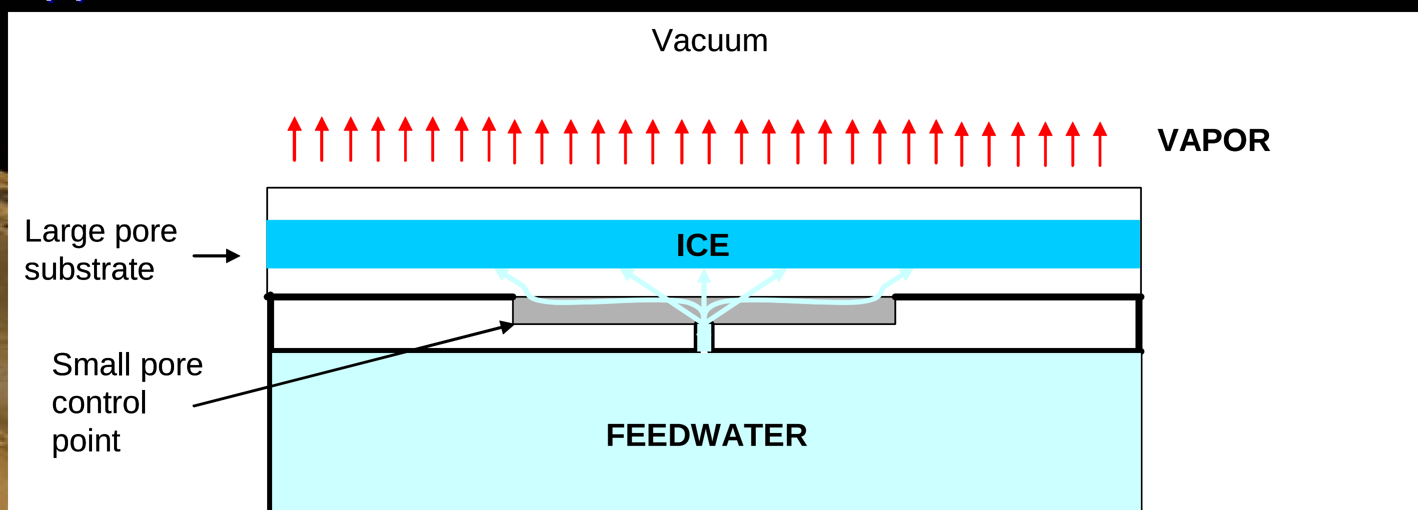
- Sublimators
  - Used on Extravehicular Mobility Unit (EMU) and Apollo Lunar Module
  - Self regulating
  - Sensitive to contamination of porous sublimation region
- Fluid Evaporators
  - Previous designs have used water, ammonia, and other fluids
  - Shuttle Flash Evaporator System (FES) sprays water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

Apollo LM Sublimator

Shuttle FES

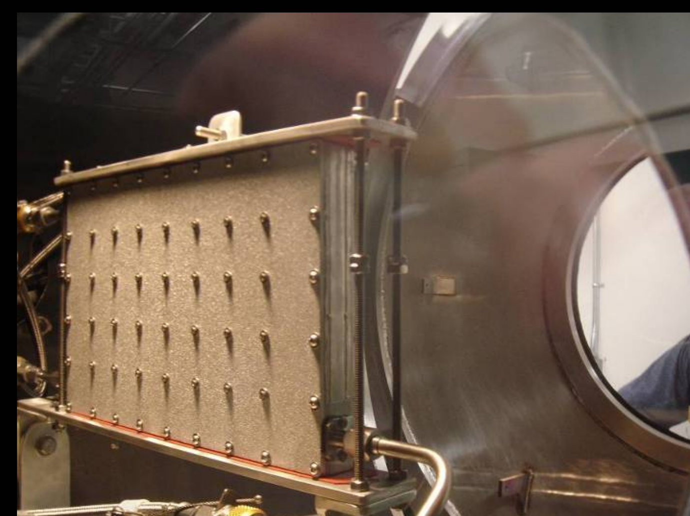
Contaminant Insensitive Sublimator

- 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 Lunar Lander



Contaminant Insensitive Sublimator

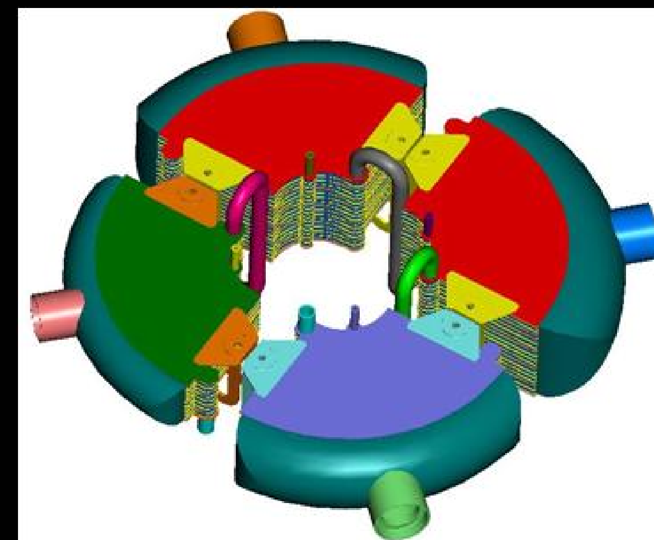
- Recent Activities:
  - Fabricated and tested mini-sublimator
  - Oceaneering Space Systems fabricated a representative scale sublimator engineering unit
  - Tested at JSC
- Research Areas:
  - Flow and phase change in porous media
    - Multiple pore sizes
    - Flow distribution between porous disks and porous plate
    - Evaporation, freezing, and sublimation



Sublimator Testing

Multi-environment Evaporative Heat Sink

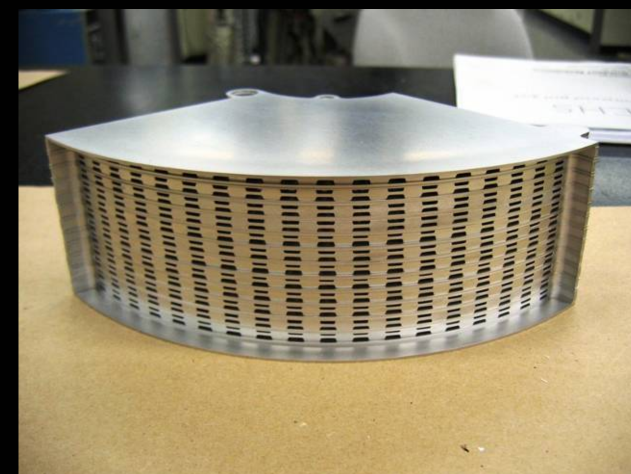
- Objective: Develop evaporative heat sinks that can operate both in space vacuum and in the Earth's atmosphere post-landing
- Technology Under Development
  - Multi-Fluid Evaporator – uses different fluids for evaporant during different mission phases
  - Flow boiling device
  - Under development by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



Multi-Fluid Evaporator Concept

Multi-environment Evaporative Heat Sink

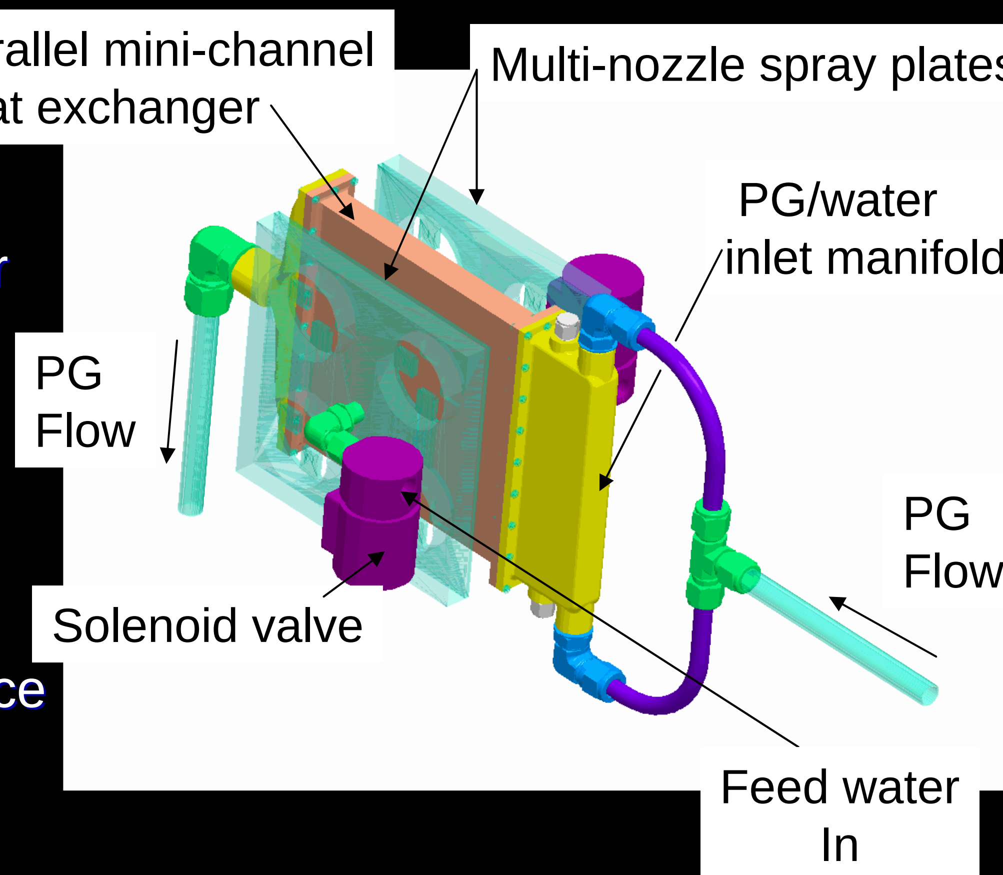
- Recent Activities
  - Completed flow testing to select fin materials
  - Completed testing of engineering unit to map thermal performance
  - Fabricating a prototype
- Potential Research Areas
  - Evaporating flow through heat transfer fins and porous foams
  - Heat exchanger manufacturing with composites



MFE Engineering Unit

Compact Flash Evaporator System

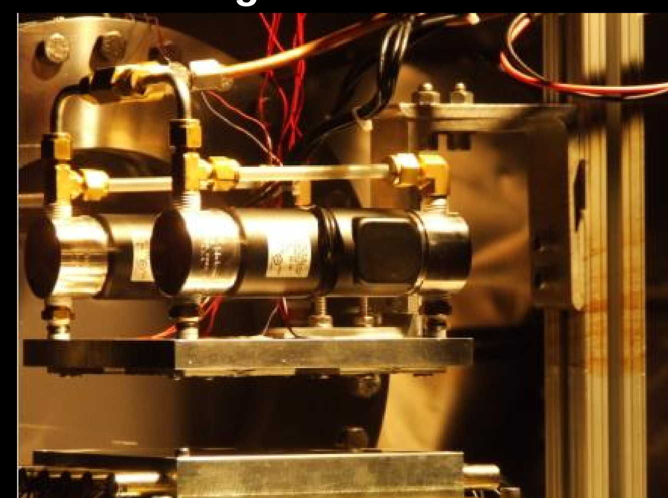
- Objective: Provide the maximum heat flux per mass for an evaporative heat sink by spraying evaporant onto a heated surface.
- Technology Under Development
  - Compact Flash Evaporator System (CFES)
  - Sprays onto a flat micro channel heat exchanger
  - Utilizes both sides
  - Can spray multiple evaporants for both in space and post landing cooling



Compact Flash Evaporator System

- Recent Activities
  - Single nozzle and nozzle array spray tests in vaccum
  - Single nozzle R 134a spray tests
  - CFES design
- Potential Research Areas
  - Spray optimization over a rectangular surface
  - Control methods for evaporant
  - Correlations for heat transfer of sprays in reduced gravity

Single Nozzle Test



Multi-nozzle Array Testing

Forward Work

- Complete fabrication of prototype technologies under development that are applicable to CEV
- Thermal vacuum test of integrated Active Thermal Control System made up of prototype technologies
- Evaluate technologies needed for a Lunar lander and Lunar outpost
  - Dust
  - Hot Lunar surface and environments
  - Longer duration technologies
  - Partial gravity
- Evaluate secondary system components
  - valves, instrumentation, fluid connecters and Quick Disconnects