Low-Cost Radiator for Fission Power
Thermal Control

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Overview

- Background
- Motivation
- Objectives
- Feasibility Demonstration
  - Radiator Trade Study
  - Preliminary Design
  - Proof-of-Concept Fabrication and Testing
- Full Scale Low Cost Radiator Development – Up to Date
- Future Steps Considerations
Background

- NASA Glenn Research Center (GRC) is developing fission power system technology for future space transportation and surface power applications
  - A nuclear reactor supplies thermal energy to electrical convertors and uses a heat pipe radiator to reject the waste heat
  - Heat pipes are vertical thermosyphons due to the need to reject heat from both sides for optimum efficiency
- The surface systems were envisioned in the 10 to 100\(kW_e\) range and have an anticipated design life of 8 to 15 years with no maintenance
- Goals for the surface systems are light weight, high reliability and long life
Background

- NASA GRC is developing a Fission Power System Technology Demonstration Unit (TDU)
  - Non-nuclear unit that will be tested in thermal vacuum to demonstrate integrated system performance
- Radiator Requirements for TDU
  - Nominal heat load: 36kW
  - Nominal sink temp.: 250K
  - Coolant inlet temp: 400K
  - Max. panel area: 55m²
  - Radiator will experience temperature and power cycling
    - CTE mismatch must be minimized
  - Specific power must be maximized to reduce associated mass and cost
Motivation

- An improved VCHP radiator for fission power applications will help achieve the OCT goals of reduced mass, improved specific power and reduced cost

- ACT previously developed a dual-facesheet VCHP radiator for a similar Phase I and Phase II program

- Mechanical stress testing of a dual-facesheet radiator under the Phase II program demonstrated that direct bonding may be possible

- A single direct-bond facesheet radiator reduces the overall cost and mass of the assembly
Considerations

- The VCHP radiator needs to do the following:
  - Operate in the temperature range from 370 to 400 K
    - Too hot for ammonia
  - Minimize mass
  - Survive multiple freeze/thaw cycles.
  - Accommodate the Coefficient of Thermal Expansion (CTE) mismatch between the titanium heat exchanger and the Graphite Fiber Reinforced Composite (GFRC) panel face sheets
- Titanium CTE: 8.6 μm/m-K
  - GFRC CTE must be matched along heat pipe axis
- Negative CTE in GFRC perpendicular to heat pipes
  - Coiled adiabatic section to accommodate CTE mismatch
Objectives

- **Overall Objective:** Develop low-cost radiator panels that are suitable for integration in NASA’s TDU.

- **Phase I Objective:** Demonstrate that a single facesheet radiator is feasible.

- **Specifically,**
  - Demonstrate that the GFRC facesheet can be directly bonded to titanium heat pipes, with no problems from the C.T.E. mismatch.
    * Verify through thermal cycle testing of prototype
  - Modify the VCHP radiator design to incorporate new flooding data.
  - Conduct a trade study to determine the effect of various geometrical parameters on the performance of a single-facesheet radiator.
  - Develop a complete preliminary design for a single-facesheet radiator, including estimates of panel performance and weight.
Preliminary Design: Sub-Panel vs. Modular Radiator Design

Continuous Sub-Panel Design
(More efficient if a heat pipe fails)

Modular Sub-Panel Design
(Cheaper to fabricate and no CTE mismatch issues)

Helical adiabatic bends used to compensate for CTE mismatch between facesheet and manifold

Minimal gap between adjacent modules
Advantages of Modular Sub-Panel Design

- **Thermal/Structural Advantages**
  - CTE mismatch in the horizontal direction (along the manifold) is no longer a concern
  - The adiabatic section can be straight (no helical bends) and the length can be minimized or eliminated
  - Modular units are easier to test and validate proper VCHP operation, since there is no thermal influence from adjacent modules

- **Fabrication, Cost, and Logistical Advantages**
  - Eliminates cost of helical bends
    - No alignment issues
  - Minimizes risk of damaging the radiator when installing into TDU
    - Avoids stresses in large continuous sections of facesheet
    - If a module is damaged, it is easier and cheaper to replace
  - During lamination and bonding, waste of GFRC is minimized
  - Modular units are easier to ship
Disadvantages of Modular Sub-Panel Design

◆ Disadvantages
  – If one pipe/fin module fails, the fins are useless since they don’t offer a heat conduction path to the neighboring pipe/fin modules
    ✴ As a consequence, the level of redundancy must be increased

◆ Solution
  – Since the elimination of the adiabatic sections would increase the specific power beyond the original (continuous sub-panel) design, there is potential to add redundancy to the system by adding more heat pipe/radiator modules
Full Scale Design

<table>
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<tr>
<th>Geometry</th>
<th>Value</th>
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<tr>
<td>Evaporator Length (cm)</td>
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<tr>
<td>Adiabatic Section Length (cm)</td>
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<tr>
<td>Condenser Length (cm)</td>
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<td>Fin Width Overhang (cm)</td>
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<tr>
<td>Total GFRC Area (m²)</td>
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<tr>
<td>Total Number of Heat Pipe Modules</td>
<td>108</td>
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<td>Total Number of Heat Pipe Clusters</td>
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<td>Number of Redundant Heat Pipes</td>
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<table>
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<th>Thermal Performance and Mass</th>
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<td>Total Power Output (kW)</td>
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<td>Specific Power (W/kg)</td>
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<td>Mass of Single Heat Pipe/Fin Module (kg)</td>
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<td>Total System Mass (kg)</td>
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<td>Total Temperature Drop from Coolant to GFRC Root (°C)</td>
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Summary of the Feasibility Study

- Overall, the Phase I program was considered a success
  - Single Facesheet Radiator Design
    - Studied the effect of various geometry parameters on thermal performance and mass
    - Examined modular design vs. continuous panel
    - Developed preliminary design based on modular geometry
    - Reduced mass of radiator by ~65%, compared to previous dual-facesheet design
    - Reduces costs and simplifies fabrication – POCO is difficult to machine and expensive
  - Experiments
    - Demonstrated the titanium heat pipes could be directly bonded to the GFRC facesheet
    - Tested the thermal performance of the sub-scale radiator
    - Verified that the sub-scale radiator could withstand the CTE mismatch for several thermal cycle tests
Full Scale Low Cost Radiator Development
- Status -

- Material procurement (ACT) - **done**
  - The entire amount of GFRC is currently purchased and is with Vanguard
  - The entire amount of titanium tubing is purchased and is with ACT
  - The entire amount of titanium screen is also purchased and is with ACT

- Direct Bond Development (VCS and ACT)
  - Adhesive selection (Lap Shear Testing) - **done**
  - Larger condenser OD (or D-shaped pipe geometry) - **done**
  - Wrapping Angle Trial - **ongoing**
  - Testing at ACT and Wrapping Angle Selection

- Module Development (ACT and VSC)
  - Heat Pipe Fabrication (ACT) - **done**
  - Heat Pipe Testing Setup (ACT) - **done**
  - Heat Pipe Testing (ACT) - **done**
  - Module Test setup Design and Fabrication (ACT) - **done**
  - GFRC bonding (VSC)
  - Module Testing (ACT)
Direct Bond Development (VCS and ACT)
Lap shear stress (Direct Bond R&D)

- Flat sample direct-bond lap shear testing
  - Lap shear coupon materials
    - Titanium with Br-127 primer
    - Tencate K13D2U (pitch fiber) composite
    - Film adhesive (varied)
  - Room temperature lap shear testing used to down-select film adhesive
    - FM300-2U film adhesive had superior shear strength compared to BF5622
    - All failures observed were interlaminar (i.e. within composite)

- Elevated temperature (130°C) lap shear testing was carried only for the selected adhesive (FM300-2U)
  - Testing was successful in general
  - Few coupons that showed lower performance
    - Excessive temperature ….146 °C
    - Better priming is under investigation

<table>
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<tr>
<th>Specimen #</th>
<th>Width (in.)</th>
<th>Length (in.)</th>
<th>Bondline Thickness (in.)</th>
<th>Peak Load (lbf)</th>
<th>Peak Stress (psi)</th>
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Room Temperature Lap Shear Results for BF522 Film Adhesive

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<th>Specimen #</th>
<th>Width (in.)</th>
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Vangard process optimization focus is to maximize the bond contact area and minimize composite fiber breakage. They will evaluate three designs by fabricating one short pipe-radiator section of each design. This requires tooling the plate used for module and cluster assembly.
Direct Bond Development (VCS and ACT)  
Wrapping Angle Testing

Short Heat pipe-Radiator test sections will be fabricated at Vanguard
Direct Bond Development (VCS and ACT)
Wrapping Angle Testing

Short heat pipe/radiator test fixture for thermal conductivity uniformity testing at ACT.
Module Development (ACT and VSC)  
Heat Pipe Module Test Setup
Module Development (ACT and VSC)
Fabricated Heat Pipe Module Test Setup

- LN Outlet
- LN Inlet Manifold
- Hot Water Supply Source
- Water Outlet
- Water Inlet
- Bypass Valves
- Flow Meter
- RTDs
Heat Pipe Module Performance Testing for Constant Inlet Temperature (127°C) and Various Sink Temperatures
Cold wall temperature was reduced to maintain evaporator below freezing
Heat pipe demonstrated successful start-up
Next Steps

- Finish the wrap angle selection
  - ACT will test three pipes bonded with three different angles (by mid March)

- Module fabrication and vacuum testing (by mid April)

- Review heat pipe assembly tooling and process
  - Improve heat pipe assembly process

- Design welding fixture for Heat pipe cluster assembly

- Assemble/weld first cluster
  - Cluster scheduled to be at VSC by mid-May
  - ACT prefabs the heat pipes into clusters
  - Vanguard assembles radiators to heat pipe clusters

- Test start date is scheduled for July 27, 2015 (ACT in ambient and GRC in vacuum)
Acknowledgements

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