Development of Flow Boiling and Condensation Experiment on the International Space Station - Normal and Low Gravity Flow Boiling Experiment Development and Test Results

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AGENDA

• ISS Flight Experiment Objective
• Fluid System-ISS
• Test Modules
  – Flow Boiling Module
  – Condensation Module - Flow Visualization
  – Condensation Module - Heat Transfer
• Ground Testing
  – Breadboard Development
  – Pre-Heater Characterization
  – Proposed On-Orbit Degassing System Testing
• Flow Boiling Module Performance Assessment-Zero-G Testing
  – Fluid system
  – Diagnostics and Data Acquisition
  – FBM Heater control
• Sample of Testing Results
  – FBM Two Heaters
• Future Work
The proposed research aims to develop an integrated two-phase flow boiling/condensation facility for the International Space Station (ISS) to serve as primary platform for obtaining two-phase flow and heat transfer data in microgravity.

Key objectives are:
1. Obtain flow boiling database in long-duration microgravity environment
2. Obtain flow condensation database in long-duration microgravity environment
3. Develop experimentally validated, mechanistic model for microgravity flow boiling critical heat flux (CHF) and dimensionless criteria to predict minimum flow velocity required to ensure gravity-independent CHF
4. Develop experimentally validated, mechanistic model for microgravity annular condensation and dimensionless criteria to predict minimum flow velocity required to ensure gravity-independent annular condensation; also develop correlations for other condensation regimes in microgravity

Applications include:
1. Rankine Cycle Power Conversion System for Space
2. Two Phase Flow Thermal Control Systems and Advanced Life Support Systems
4. Cryogenic Liquid Storage and Transfer

- Science Requirements Document for FBCE, March, 2013
- Science Concept Review Presentation, December 2011
Preliminary Engineering Fluid System Design (ISS)
Test Modules

- **Flow Boiling Module**
  - Subcooled, saturated and 2-phase Inlet condition at:
    - $2.5 < \text{Mass Flow Rate} < 40 \text{ g/s}$
    - $\text{Heat Flux} < 60 \text{ W/cm}^2$

- **Condensation Module - Flow Visualization**
  - Saturated vapor Inlet condition
    - $2 < \text{Mass Flow Rate} < 14 \text{ g/s}$

- **Condensation Module - Heat Transfer**
  - Saturated vapor Inlet condition
    - $2 < \text{Mass Flow Rate} < 14 \text{ g/s}$

*Science Requirements Document for FBCE, March, 2013*
*Science Concept Review Presentation, December 2011*
Flow Boiling Module Design

- **FBM/Heater Design**
  - Flow Channel 2.5x5x100 mm
  - Both surfaces are heated with resistive heaters
  - Max heating of 300 W from both sides
  - Visualization with high speed camera 2000-4000 fps
CM-FV Design and Challenges

- Science requirements called for TCs on the inner surface of water tube and middle of tube
- Sectional tube design
- Three observation areas coincident with data collection areas
- Easy Access to inner tube

Counterflow of water loop (blue) and FC-72 (red, nPFH for flight) along with thermocouples (T) and pressure transducers (P) location
CM-HT Design and Challenges

- **CM-HT Short Design**
  - Easy access to inner tube
  - TCs are fixed firmly to outer surface of inner tube
  - Eng. Model CM-HT is a longer version of CM-HT Short

Counterflow of water loop (blue) and FC-72 (red, nPFH for flight) along with thermocouples (T) and pressure transducers (P) location
Ground Testing

- Breadboard Development
- Pre-heater Characterization
  - Operation
  - Control
- Testing of potential design for On-Orbit degassing
Ground Testing - Breadboard Development

Fluid System components Integrated with instrumentations for heater evaluation
Ground Testing - Pre-Heater Characterization

- Pre-heater studies of time constant to achieve steady state
- Steady state achieved within 6 minutes
Ground Testing of Proposed On-Orbit Degassing System

• Developed a fluid loop for degassing testing
• Use of membrane contactor
• Testing showed after 50 minutes, partial pressure of non-condensable gases is below 2 kPa
Zero-G Aircraft Testing/FBM Engineering Assessment

Aircraft Rack Features:
• Fluid System
• Diagnostics:
  – Lumenera and Sentech video cameras
• FBM Heater Power Input and Temperature Control
• Data acquisition
Fluid System

- FBM
- Heater
- Pump
- Accumulator
- Pressure Control
- Condenser
- Accumulator
- Drain
Zero-G Aircraft Rack

- Pre-Heater Control
- Air Cooled Condenser
- Pump
- Filter
- Data Acquisition
- FBM Observation
- Instrumentation panel-FBM
- Instrumentation panel-Flow rate, pressure, Temperatures
- Accumulator
- Flow Boiling Module
Data Acquisition $m = 2.5 \text{ g/s}$
Testing Results-High Speed Visualization- $m = 2.5 \, g/s$

36%  57%  79%  92%  100%

% of CHF achieved in each of the 5 low gravity paraboli performed at 2.5 g/s
Testing Results: $m = 2.5 \text{ g/s}, 2 \text{ Heaters}$
Testing Results- \( \dot{m} = 40 \text{ g/s} \), 2 Heaters

- \( \Delta T_{\text{Inlet/Subcooling}} \)
- \( \Delta T_{\text{Wall Max}} - T_{\text{Sat in}} \) (\( ^\circ \text{C} \))
- \( \text{Heat Flux (W/cm}^2 \))
- \( \text{FBM Inlet/Outlet Pressure (psia)} \)
Future Plans

- Ground and Low gravity testing of condensation modules
- Development of engineering model prior to or by PDR planned for January 2015

- Thank you
- Questions?