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

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**ISS Flight Experiment**

- **Science Objectives**
  - 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:
    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

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**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:
    - $2.5 < \text{Mass Flow Rate} < 40$ g/s
    - Heat Flux $< 60$ W/cm$^2$

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

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

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*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
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

FIR layout on optical bench with pump, CM-FV vapor and collinear flow tube
Ground Testing-Pre-Heater Characterization

- Pre-heater studies of time constant to achieve steady state
- Steady state achieved within 6 minutes

3 heater surface TCs spaced 120 degrees circumferentially apart
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
- Accumulator Pressure Control
- Heater
- Condenser
- Accumulator
- Pump
- 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 - $m = 2.5 \text{ g/s}$

% 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 Heaters
Testing Results- $\dot{m} = 40 \text{ g/s}, \ 2 \text{ Heaters}$

- **$\Delta T_{\text{Inlet/Subcooling}}$**
  - Units: °C
  - Time: 0 to 250 s

- **Heat Flux (W/cm²)**
  - Units: W/cm²
  - Time: 0 to 50 s

- **$\Delta T_{\text{Wall Max}} - T_{\text{Sat in}}$ (°C)**
  - Blue $\rightarrow P_{\text{FBM In}}$
  - Red $\rightarrow P_{\text{FBM Out}}$
  - Time: 0 to 250 s

- **FBM Inlet/Outlet Pressure (psia)**
  - Time: 0 to 250 s
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?