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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ISS Flight Experiment

FBCE Science Objectives

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
Test Modules

• Flow Boiling Module
  – Subcooled, saturated and 2-phase Inlet condition at:
    • 2.5 < Mass Flow Rate < 40 g/s
    • Heat Flux < 60 W/cm²

• Condensation Module – Flow Visualization
  – Saturated vapor Inlet condition
    • 2 < Mass Flow Rate < 14 g/s

• Condensation Module – Heat Transfer
  – Saturated vapor Inlet condition
    • 2 < Mass Flow Rate < 14 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

FIR layout on optical bench with pump, CM-FV vapor and collinear flow tube

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

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
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- $\dot{m} = 2.5 \, g/s$

% of CHF achieved in each of the 5 low gravity paraboli performed at 2.5 g/s

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- 36%
- 57%
- 79%
- 92%
- 100%
Testing Results - $m = 2.5 \text{ g/s}, 2$ Heaters
Testing Results - $\dot{m} = 40 \text{ g/s}, 2 \text{ Heaters}$
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?