DEVELOPMENT AND CAPABILITIES OF ISS FLOW BOILING AND CONDENSATION EXPERIMENT

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Agenda

- Experiment Objective
- Top Level Science Requirements and Constraints
  - ISS Constraints
    - Mass, Volume, Power, Cooling Constraints
- Test Sections
- Fluid System
  - Engineering Schematic
    - Fluid System nPFH Module
    - Fluid System Cooling Module
    - Fluid System Preheater
- Breadboard Testing
  - Pressure data and Inlet conditions for Condensation Experiment
  - Pressure data and Inlet conditions for Flow Boiling Experiment
  - Video Imaging and Capabilities
- 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
Flow Boiling and Condensation Experiment

Flow Boiling and Condensation Fluid Systems

Diagram of the Flow Boiling Module (FBM) and Condensation Module (CM) for Visualization. The system includes:
- Electrical Heater
- Flow Boiling Module (FBM)
- Condensation Module for Visualization (CM-FV)
- Condenser
- Accumulator
- Coriolis Flow Meter
- Gear Pump
- Filter
- Degassing Contactor
- VES

Details of the system components and flow paths are shown, including flow rates, pressures, and temperatures. The diagram also includes legends for different components and flow directions.

Legend:
- DC: Direct Current
- P: Pressure
- T: Temperature
- F: Flow

The system is designed to study the behavior of fluids under microgravity conditions, focusing on the interaction between flow boiling and condensation processes.
Requirements - Fluid System

- Deliver flow rates between 2 and 14 g/s of nPFH for Condensation Experiments and 2 to 40 g/s for Flow Boiling Experiments
- Deliver the required power up to 1660 W to the fluid
- Deliver the required system pressure of 100 and 150 kPa
- Volume increase is accommodated with an accumulator
- Deliver the required thermodynamic conditions of the fluid at the entrance of the test modules (subcooled, saturated and two-phase mixture)
- Provide the fluid cooling function

Constraints

- Limitation on the available power (~1660 W total available for heating) and available heat dissipation (~1600 W)
- ITCS cooling water flow rate up ~50 g/s to and returning stream temperature requirement of 40-49 °C
- Volume constraint 91.44x121.92x48.28 cm³ (36x48x19 in³)
- Mass constraint (~200 kg max)
Flow Boiling and Condensation Experiment

Flow Boiling and Condensation Test Modules

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

- **Condensation Module**
  - Flow Visualization
    - Saturated vapor Inlet condition
      - Mass Flow Rate 2 to 14 g/s

- **Condensation Module**
  - Heat Transfer
    - Saturated vapor Inlet condition
      - Mass Flow Rate 2 to 14 g/s

- Flow Boiling Module Assembled

- CM-FV Test Module

- CM-HT Test Module

- Resistive Heater
- Oxygen-Free Copper Slab
- Transparent Walls
- Oxygen-Free Copper Slab

- Water
- Stainless Steel Tube
- Condensation Film
- Transparent, Low Thermal Conductivity Wall

- Inner diameter of water tube
- Outer diameter of water tube
- Width of FC-72 channel

- L, D1, D2, S1

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- Science Concept Review Presentation, December 2011
FBCE Fluid System Architecture

Test Modules
FS-BHM
FS-CM
FS-nPFHM
Fluid System (FS) nPFH Module
- Consists of:
  - Pump
  - Filter
  - Coriolis flow meter
  - Degassing

FS Cooling Module
- Consists of:
  - Condenser
  - Accumulator
  - Coriolis flow meters

FS Preheater Module
- Consists of:
  - Preheater
  - Electronics and Control
Breadboard/Brassboard Model

- CM-FV
- High Speed Cameras
- Data Acquisition and Control

- nPFH Module
- Cooling Module
- Bulk Heater Module

- High Speed Video Recording and Observation
Similar Conditions used for Split and Solid Sheath:

- **Low Flow Test (2 g/s), 100 kPa**
  - Average FC-72 into Bulk Heater:
    - $1.98 \pm 0.11$ g/s, 23.6± 0.9 C
  - Average Water into Condenser:
    - $20 \pm 0.1$ g/s, 20.4± 0.1 C
  - Average Water into CM-FV:
    - $5.07 \pm 0.01$ g/s, 21.2± 0.2 C

- **High Flow Test (40 g/s), 100 kPa**
  - Average FC-72 into Bulk Heater:
    - $40 \pm 0.2$ g/s, 32.7± 0.2 C
  - Average Water into Condenser:
    - $15.04 (\pm 0.02)$ g/s, 20.4 (± 0.1) C
  - Average Water into CM-FV:
    - $15.1 (\pm 0.1)$ g/s, 20.4 (± 0.1) C

Solid sheath heating elements seem to heat quicker

- Cartridge heaters pressed into the aluminum holes (typical installation) should provide even quicker heating
- Pressed in cartridge heaters are less likely to fall out

The solid sheath cartridge heaters were run at a lower voltage than the split sheath cartridge heaters

- Electrical tests indicated that the solid sheath had lower electrical resistance than the split sheath cartridge heaters
- Even with less voltage, the solid sheath heated quicker
Solid sheath cartridge heaters
- Faster heating, better fit and lower contact resistance, operates at lower voltage
- Bulk heater manufacturer makes solid sheath cartridge heaters
  - Could have the manufacturer build this as COTS

Split sheath cartridge heaters
- Typically used for ease of removal to facilitate replacement
  - FBCE does not require this feature
- Allows a TC in the hole with the cartridge heaters
- Bulk heater manufacturer does not make solid sheath cartridge heaters
  - GRC assembly of cartridge heaters into bulk heater
System pressure increases steadily with flow rates.

Heater power averaged over periods of time where FC-72 flow rate is constant.

Heat gained by FC-72 in bulk heater was calculated from thermodynamic measurements.

An average of 54 W lost from heater at 14 g/s of FC and slightly lower heat loss of 45 W at 10 g/s.

Similar analysis on CMFV showed a loss of 65 W to ambient.
Flow loop along with selected test modules is capable of obtaining full transient to steady state data along with high speed imaging.

Example of Transient Test Run with CM-FV

- FC-72 vapor with specified inlet conditions (flow rate and temperature) introduced into the condensation module with no cooling water flow and allowed sufficient time for steady state.
- Cooling water flow rate started simultaneously with high speed video recording.
  - High speed video recorded at 1000 fps for 29 seconds to capture the condensation transient.
- Relevant data (water and surface temperature, FC-72 and water flow rates, pressure) continuously recorded at 1 Hz.
- At the end of 10 minutes time interval, two seconds of high speed video is recorded to provide a comparison between the steady state and the transient.

![Graphs showing temperature and flow rate transitions over time.](image-url)
Experiments... Transients in Flow Condensation

- Transient of 10 seconds observed upon turning on water flow rate
- A time scale of about 25 seconds observed upon turning off cooling water to CMFV
Flow Boiling and Condensation Experiment

Experiments... Transients in Flow Condensation

- High speed imaging (1000 fps) of condensation in CM-FV in the horizontal configuration for 0.2 s, 1.5 s, 10 s and 29 s.
- Imaging started simultaneously with water flow rate as designated by the white vertical line in the graph on the left.
Flow condensation with increasing FC-72 flow rate and constant water flow rate
Flow Boiling and Condensation Experiment

Summary
Concluding Remarks

- Flow Boiling and Condensation engineering team preparing for the Critical Design Review
- Design of flight hardware for FBCE
- Design of Engineering Models (EM) for CM-HT and Fluid system modules
- Development of Brassboard/EM hardware for future engineering testing of fluid system, software and avionics

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Questions??