



Multiphase Flow in Power and Propulsion Workshop
Fluid Stability and Dynamics Workshop
Microgravity Science Division

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Space Directorate



Discussion of Priorities



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Prioritization Scheme

Priority Ratings

- **Critical:** enabling technology if not solved, don't or can't go.
- **Severely Limiting:** enabling technology but other systems can be used, but a steep price
- **Enhancements**
 - safety and reliability
 - weight savings
 - cost savings
- **Communication:** Analysis, modeling, existing resource awareness can overcome difficulties.

Method of Testing

- space-flight experiment (SF)
- ground-based reduced gravity testing (GB)
- normal gravity testing,
- analysis/modeling
- review of existing space-flight / ground-based data for its appropriateness.



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Critical Issues

Reduced Gravity Instabilities

- Flow/phase splitting through Parallel flow paths (system level)
- Phase Accumulation and release within Flow System Components
Transient Operations
 - Startup/Shutdown
 - Changes in Set Point Operation
 - Variable gravity over sustained time periods
 - 1 – g prior to launch & after landing
 - 1g during launch / landing
 - μ g, Martian, and Lunar
 - Variable gravity – sloshing



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Critical

- Phase separation, distribution and control
 - Control-- pick components, get in game
 - (not phase change part)
 - Take **best** tool, **best** data, design experiment to test (evaporator/condenser system) (one really **pertinent** example!)
- Critical heat flux in transient and oscillating flows (recovery)
 - Take **best** tool, **best** data, design experiment to test) (one really **pertinent** example!) Run transients Evaporator/(not a system)
 - Density wave oscillations in multiphase systems
 - Take **best** tool, **best** data, design experiment to test (evaporator/condenser system) (one really **pertinent** example!)
- Gravitationally insensitive evaporators/condensers
 - (same system)



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Critical

- Scale-up
 - Do other scales (same idea)
 - Components



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Severely Limiting Phase Separation

- Active Separators based on Centrifugal concept. Unstable operations at flooding conditions
- *Multiphase (gas-liquid ?) pump*



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Severely-Limiting Phase Change

- CHF is not a problem unless some other instability initiates a flow interruption.
 - Recovery from dryout by quenching hot surface because of
 - Exceeding CHF due to other flow instability
 - Hydrodynamic rupture of liquid film at slow slugging/wave frequencies
 - High power density: Spray cooling.



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Severely Limiting Flow Through Components

- Flow Splitting and Combining
- Packed Beds
 - Mass and Heat transfer coefficients
 - Phase Distribution and accumulation
- *Mass transfer in various systems*



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Severely Limiting

- *Noncondensibles*



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Enhancements

Passive Phase Separation

- Inertial Driven
 - Cyclonic devices
 - Tees/manifolds

Phase Change

- Surface Enhancements
- Surfactants & Engineered Fluids



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Awareness Instabilities

Likely Problems in reduced gravity – Solve through Analysis and Awareness. Maybe look at existing data

- Ledinegg/Pumped Loop Instability
- Pressure Drop Oscillations
- Density Wave Oscillations



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Awareness

Phase Separation

- Bubble removal from rotating tanks through Needle suction

Flow Through Components

- Valves
- Pumps
 - Single phase – avoid cavitation



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Methods of Resolution

- ISS
 - Fluids Integrated Rack
 - Microgravity Science Glovebox
 - Express rack
 - other
- Ground-based Reduced Gravity Facilities
- Normal Gravity Testing and Modeling
- *Long duration partial/micro gravity*



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Comment: Elements of ANY Two Phase Flow Experiment

- Liquid Supply
- Means of supplying vapor or gas
- Plumbing consisting of valves, tubing, accumulators, etc.
- Test article (s)
- Sensors – pressure, temperature, flowrate, *flow regime*
- Data Acquisition and Control System
- Ability to remotely change operational settings.
- Highly desired are Flow Visualization Sections, preferably high speed camera
- *Power, heat sink*
- *Ground control*



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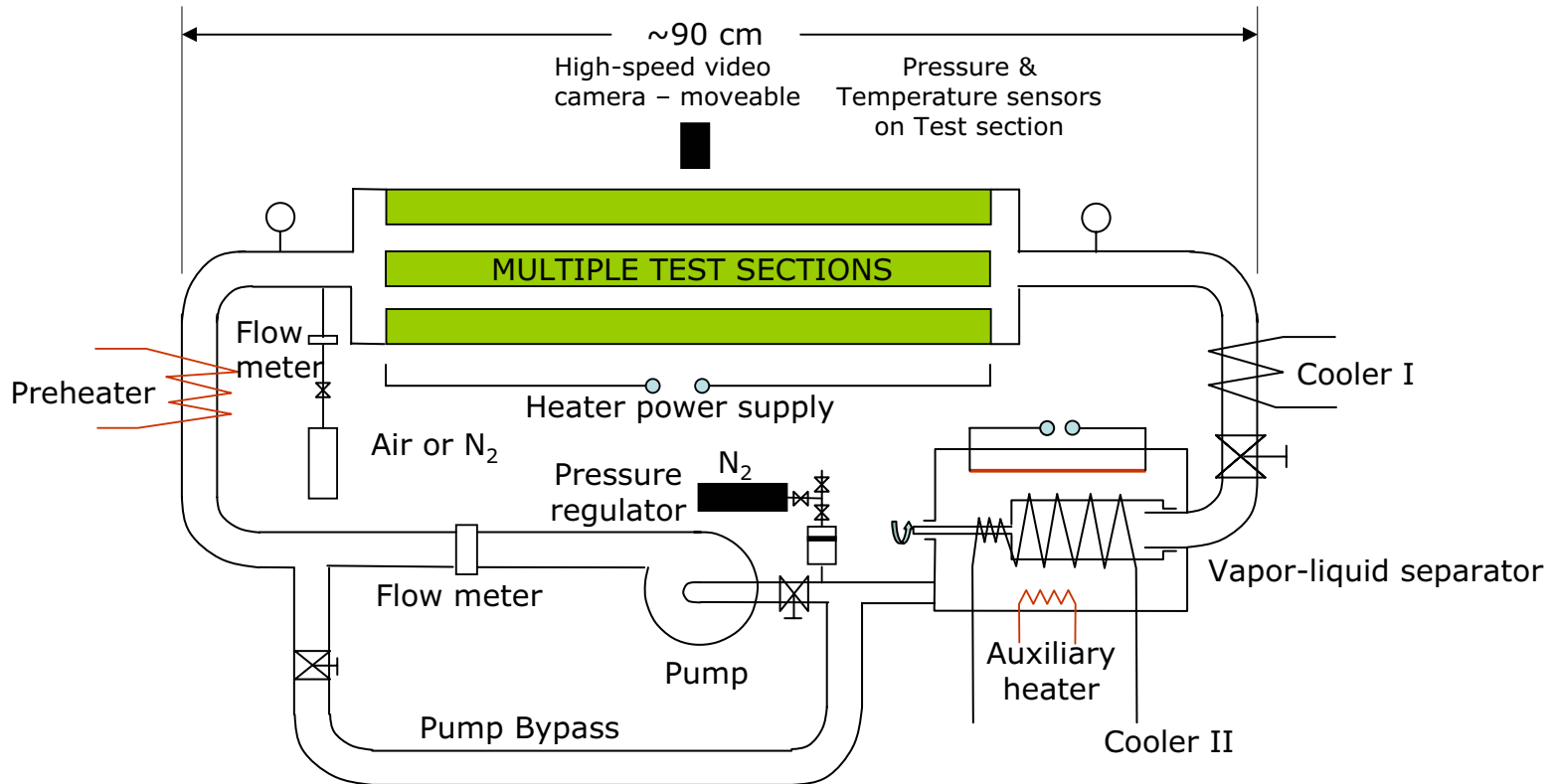
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Two-Phase Flow Facility (T₂FF₂)



Multiple test sections to investigate various geometries and flow regimes

- Preheater and cooler for temperature control
- Pump for forced convection
- Liquid/vapor separator



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2008 Space Flight

- Parallel flow channels with multiple evaporaters.
 - Flow through splitting manifold into the parallel channels
 - Parallel channels could focus on different aspects of boiling, namely critical heat flux and quenching,
- Assess slugging phenomena on active separation device(s)
- *Packed Bed hydrodynamic characterization*



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2003 – 2008

Ground – Based μ G Facilities

- Flow splitting and mixing tees and manifolds (airplane)
- Component separation (air-water, e.g., fuel cells)
- Cryogenic (??)
- Phase Change
 - determine wetting characteristics of solid-liquid combinations and strategies (additives) to modify/control the wetting and spreading.
 - Conduct testing for rewetting/quenching of hot surfaces
 - Investigate the effects of wetting characteristics of a condensing surface
- Passive two phase flow separation techniques
 - Drainage of condensate with refrigerators from their "cold plates."
 - drainage of waste water, including urine from rat cages
 - continue bubble removal schemes for bioreactor
 - Propellants
- Initiate investigations of the effectiveness of techniques using acoustic, electric field, surfactants and surface enhancement for 1-g and low-g
 - (To alleviate CHF problems)



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**2003 – 2008****Other**

- Evaluate current two-phase system designs for known and appropriate normal gravity instability mechanisms.
- Continue and complete development of mechanistic models for nucleate pool boiling
- **Design tools/handbook**
- **Flow boiling**



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2009 – 2015

Space Flight

- Continue parallel channel instability tests
- Demonstration/validation of scaling
- Conduct phase change experiments for CHF, Quenching & Spray cooling
- Conduct phase change experiments on condensation to determine condensation heat transfer coefficient in microgravity
- Conduct ISS experiments on liquid-gas flows in packed beds (mass transfer, reactions)



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2009 – 2015

Ground – Based μ G Facilities

- Conduct experiments for pool and flow boiling for the effect of boiling enhancement techniques.
- Conduct advanced phase separator tests for a wide variety of concepts, including passive methods.
- Exotic materials and fluids,
- Nuclear power components
- Setting up for the next grand and glorious project
- Electrical and electroacoustic manipulation of interfaces and fluids



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**2009 – 2015****Other**

- Bio power sources
- Nano-scale prototypes for power/etc
- Designed surfaces for heat transfer
- Combined comprehensive modeling effort for multiphase heat transfer and flow leading to user design code.



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2016 ++
Space Flight

- Phase change and heat transfer with exotic materials
- High and low pressure and temperature experiments
- Large scale system demonstrations



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2016 ++
Ground – Based μ G Facilities

- Detailed verification of the comprehensive computation package.



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2016 ++
Other

- two phase design and operations manuals
- software package development?.