Discussion of Priorities
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.
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
    - \( \mu g \), Martian, and Lunar
    - Variable gravity – sloshing
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)
Critical

• Scale-up
  – Do other scales (same idea)
  – Components
Severely Limiting Phase Separation

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

- Noncondensibles
Enhancements

Passive Phase Separation
- Inertial Driven
  - Cyclonic devices
  - Tees/manifolds

Phase Change
- Surface Enhancements
- Surfactants & Engineered Fluids
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
Phase Separation

• Bubble removal from rotating tanks through Needle suction

Flow Through Components

• Valves
• Pumps
  – Single phase – avoid cavitation
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
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*
Multiphase Flow in Power and Propulsion Workshop
Fluid Stability and Dynamics Workshop

Microgravity Science Division
Space Directorate

Two-Phase Flow Facility (TFFy)

- Heater power supply
- Flow meter
- Pump
- ~90 cm High-speed video camera – moveable
- Pressure & Temperature sensors on Test section
- Preheater and cooler for temperature control
- Pump for forced convection
- Liquid/vapor separator

Multiple test sections to investigate various geometries and flow regimes

13-May-2003
2008
Space Flight

- Parallel flow channels with multiple evaporators.
  - 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*
2003 – 2008
Ground – Based μG 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)
• 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
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)
2009 – 2015

Ground – Based $\mu$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
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.
2016 ++

Space Flight

• Phase change and heat transfer with exotic materials
• High and low pressure and temperature experiments
• Large scale system demonstrations
2016 ++
Ground – Based $\mu$G Facilities

- Detailed verification of the comprehensive computation package.
2016 ++

Other

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