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# Gas-Liquid Flows and Phase Separation

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***Strategic Research to Enable NASA's Exploration Missions***

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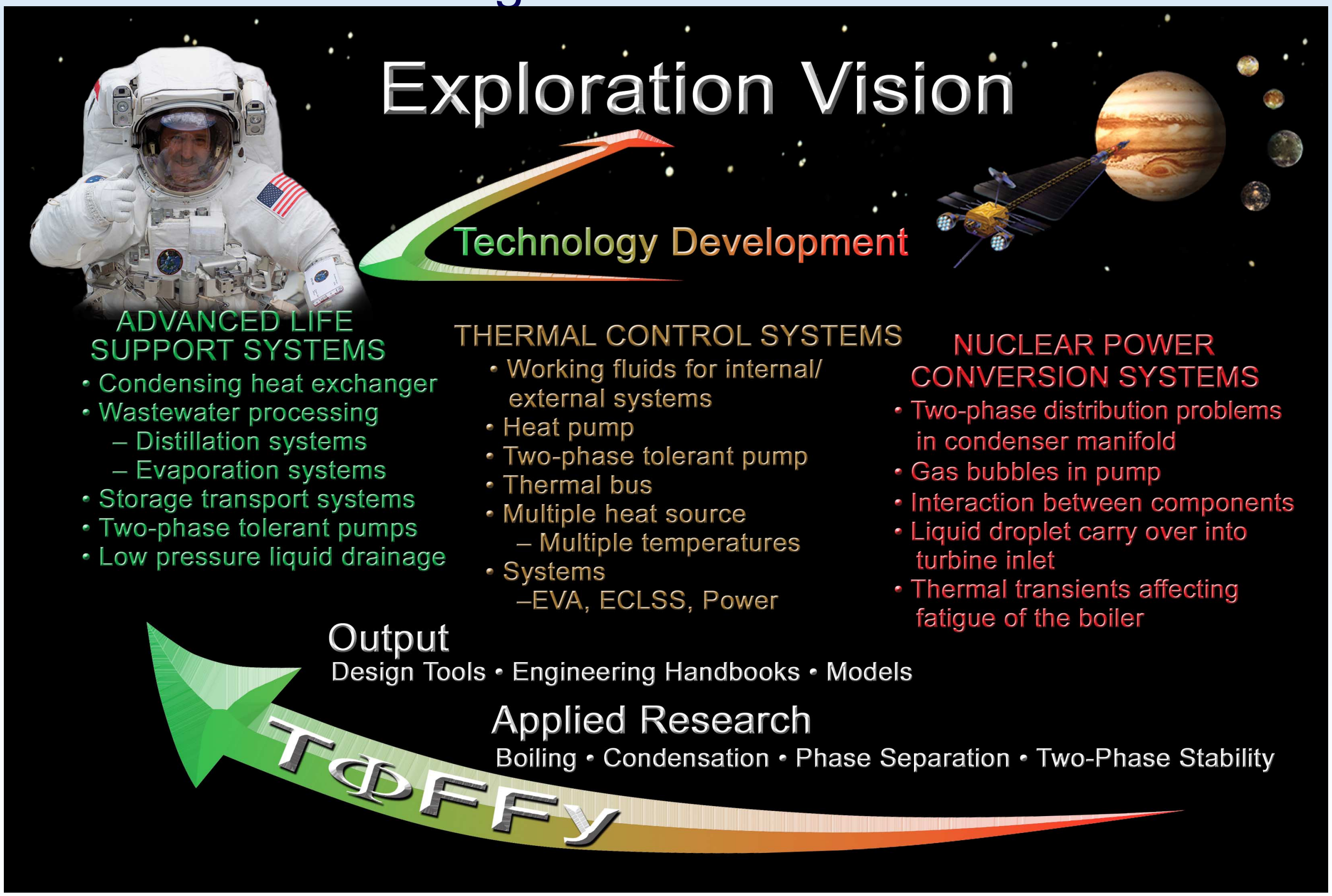
Microgravity Fluid Physics Branch
Glenn Research Center at Lewis Field

# Common Issues for Space System Designers

- Ability to Verify Performance in Normal Gravity prior to Deployment.
- **System Stability***
- Phase Accumulation & Shedding
- **Phase Separation***
- Flow Distribution through Tees & Manifolds
- **Boiling Crisis***
- Heat Transfer Coefficient
- Pressure Drop

* Two Phase Flow Facility

# Space-Based Technologies Using Two Phase Flow



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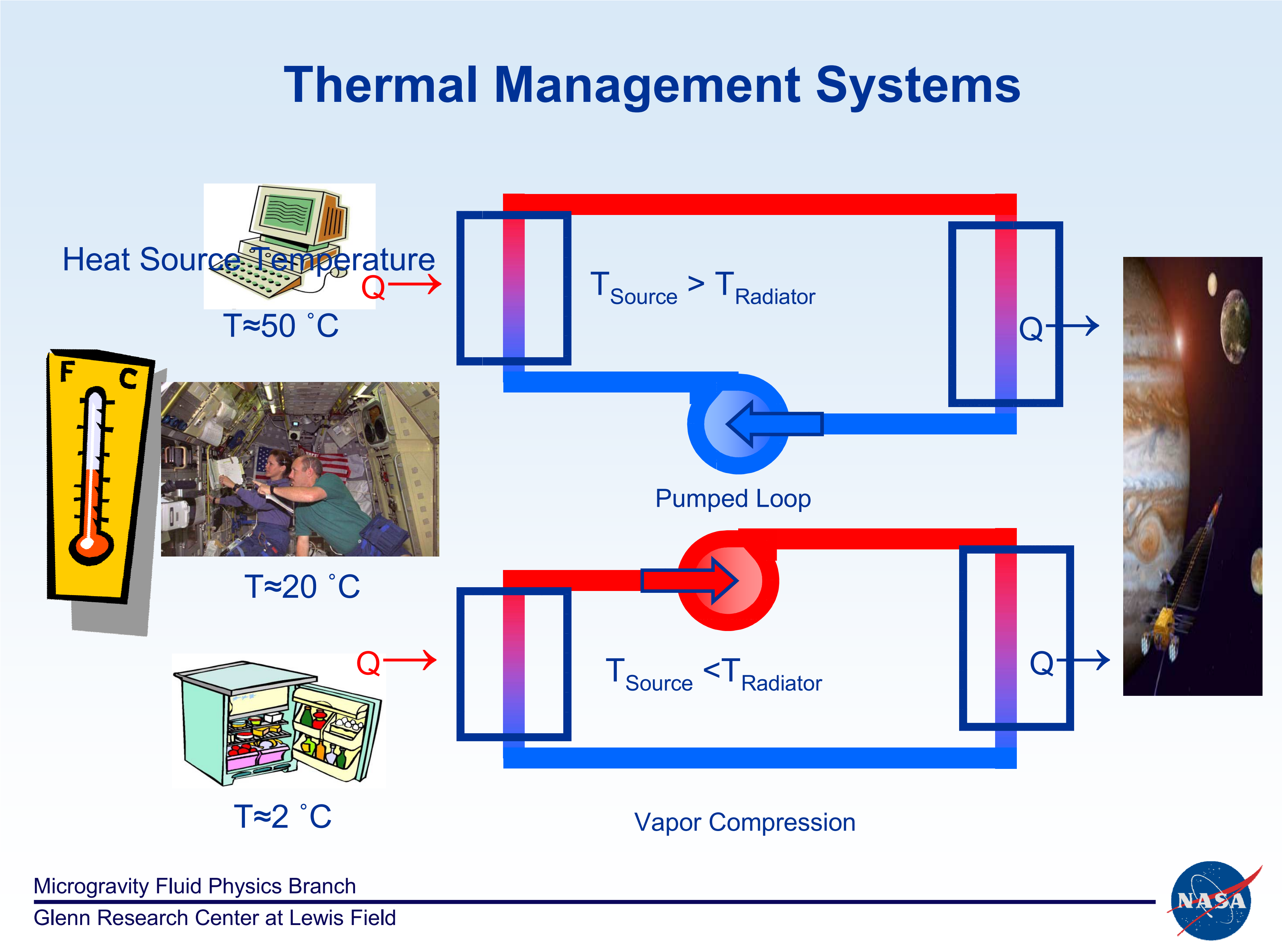
# Partial Listing of Where Gas-Liquid Flows are in Life Support Systems

| Stream Type | Air Revitalization | Water Reclamation | Thermal Management | Solid Waste Management |
|---|---|---|---|---|
| Cabin Humidity Condensate | √ | | √ | |
| Urine | | √ | | |
| Spills | | √ | | √ |
| Dish Washing | | √ | | |
| Laundry | | √ | | |
| Sabatier $CO_2$ Reaction | √ | | | |
| Waste Solids Drying | | | | √ |
| Food Processing | | √ | | √ |

# Life Support Systems

- Commonality of Source Stream
  - Aqueous-based Working Fluid (Water)
  - Into Waste Water Tank
  - Low Pressure Inlet
  - Gas Phase Present
  - Particulate Matter may be Present
- Differences
  - Dissolved Matter → Fluid Property Effects
  - Batch vs. Continuous Input
  - Flow Rates
  - Void Fraction


Thermal Management Systems
Heat Source Temperature
T≈50 ˚C
T≈20 ˚C
T≈2 ˚C
F
C
Q
T Source > T Radiator
Q
Pumped Loop
Q
T Source <T Radiator
Q
Vapor Compression
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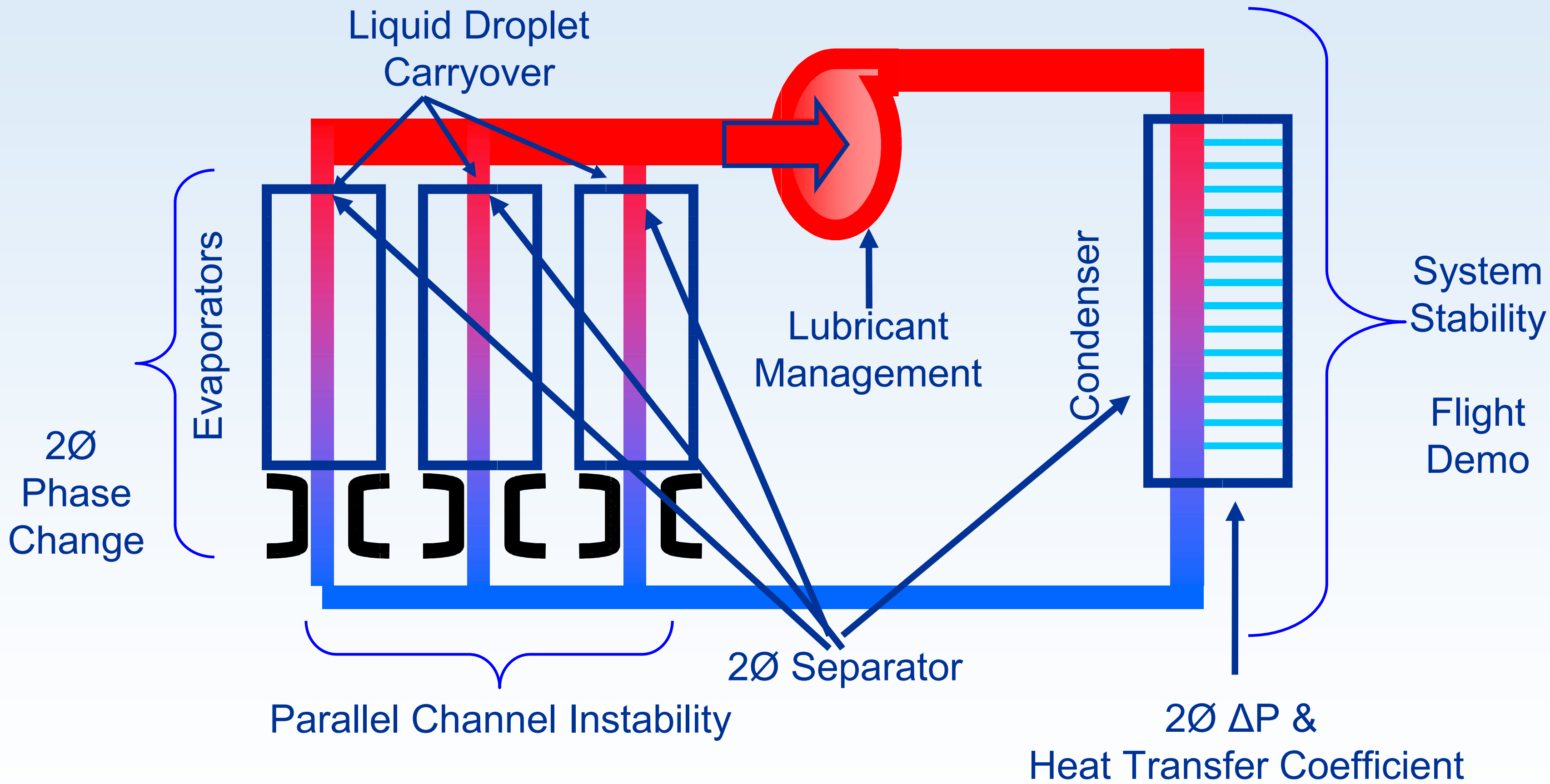
# Vapor Compression Cycle

## Two Phase Issues

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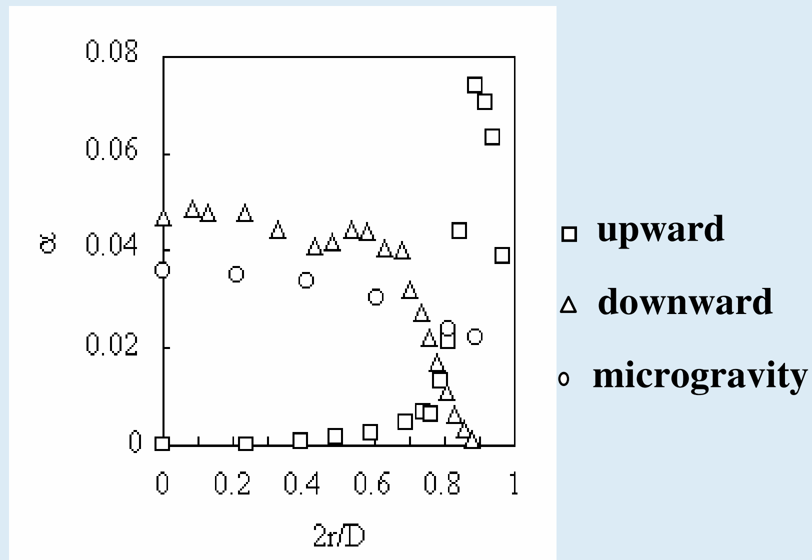
# The Effect of Reduced Gravity on Gas-Liquid Flows

*Negating the Effect of Buoyancy*

- Axisymmetric flows
- Reduced Hydrostatic Pressure
- Spherical Bubbles vs. Ellipsoid
- No Gravity-Induced Shearing:
  - Gas Phase Rising relative to Liquid Falling
- Co-flow of Gas and Liquid Phases.

**Radial void fraction distributions**

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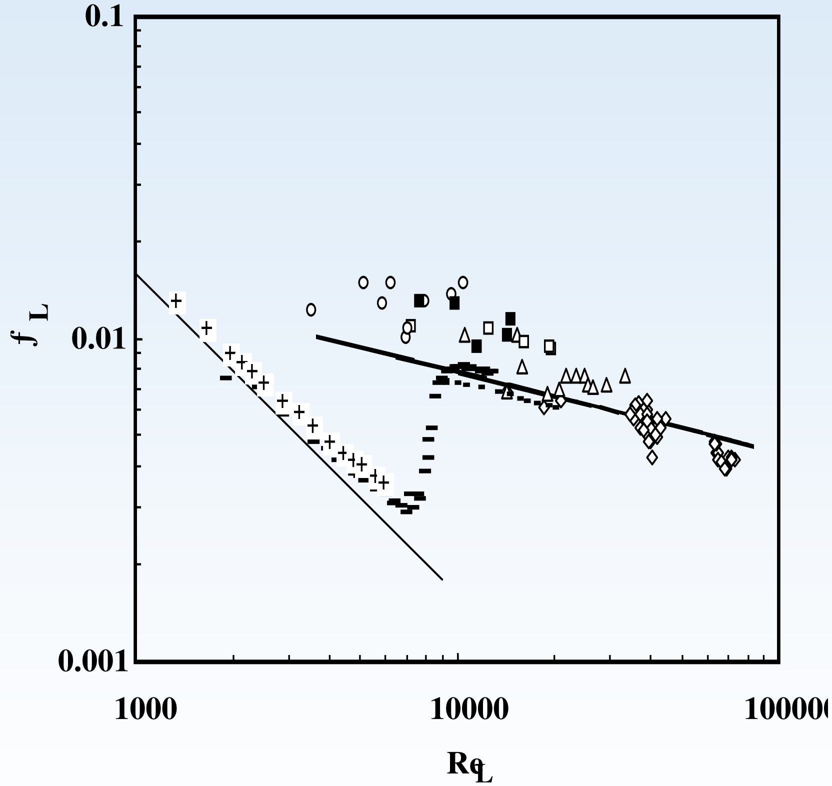
# What Do We Know?
# Flow Regimes

- 3 (½) Flow Regimes: Bubble, Slug, Annular (Transitional Slug Annular)
- Multiple Models that work well
  - Constant Void Fraction
  - Weber Number Model
  - Suratman Number Criteria

# What Do We Know?
# Pressure Drop

- Modified Homogenous Equilibrium Model works well
  - Mixture Density
  - Mixture Velocity
  - Liquid Viscosity

# Wall Friction Factors $f_L$ in Bubbly Flow:




**Reduced Gravity Two Phase Flow:**
○ D=6 mm, □ D=10 mm, △ D=19 mm,
■ D=12.7 mm, ◇ D=40 mm
**Single-Phase Flow:**
+ D=6 mm, _ D=10 mm, - D=19 mm
Blasius, ______ Poiseuille relationship

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# Concerns

- Phase Accumulation and Shedding

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- Liquid Film Rupture and Dryout

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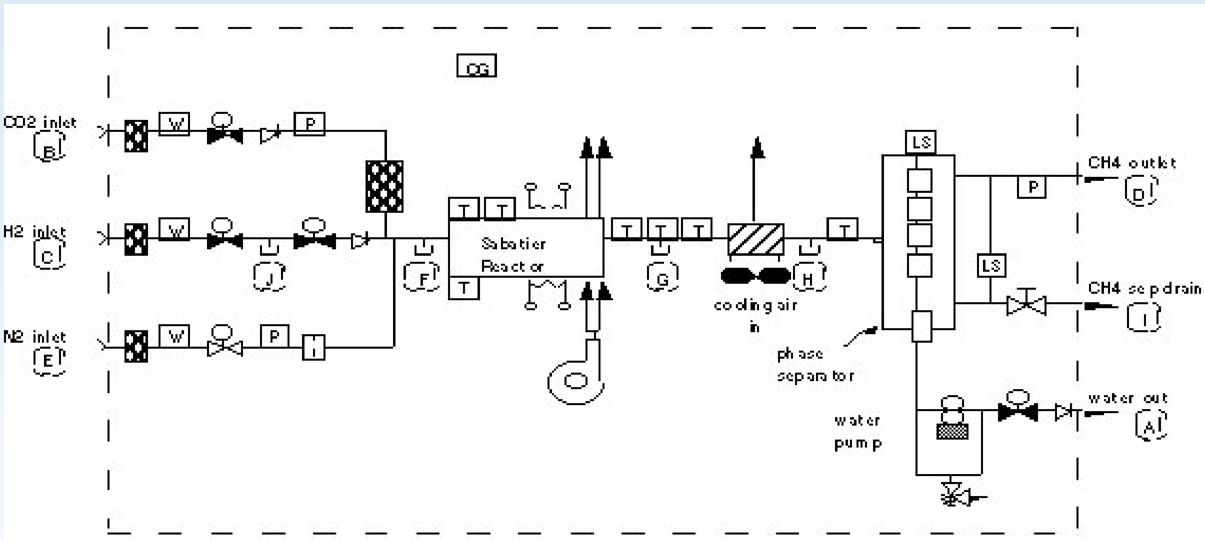
# Example: Sabatier Reactor

$$CO_2 + 4H_2\ 4 \rightarrow CH_4 + 2(H_2O) + heat$$

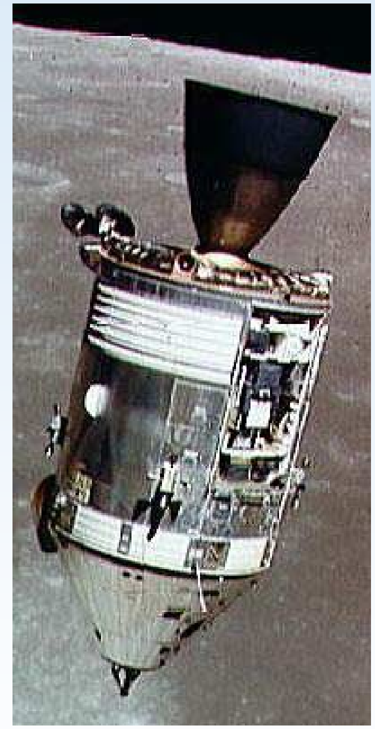



<u>2Ø Issues</u>

- Separator
- Liquid in Gas Outlet Stream
    - Detection
    - Response
- Influence of Fines

# Crew Exploration Vehicle Thermal Management System

- Capsule-type vehicle
- Functional during Orbital, Re-entry, and Post-Landing Phases
- Closed Loop System – Desire No Flash Evaporators
- Heat Load Estimate
  - Fuel Cells: 7 kW at 50 °C
  - Electronics: 3 kW at 40 °C
  - Cabin: 0.5 kW at 7 °C
- Limit Total Radiator Area < 200 $ft^2$
- Body Mounted Radiator
- Working Fluid
  - Non-Toxic
  - Non-Corrosive
  - Low Freezing Point



# Why Separate?

- Critical Process or Component that is intolerant of one Phase
  – Centrifugal pumps with gas bubbles
  – Phase Specific Sensors, i.e., hot wires
  – Biological media negatively impacted by gas
- Better System Performance
  – Condensors Work Better if no liquid present at inlet.
  – Control of Phase Distribution into a manifold

# Requirements to Consider

- Available Power
  - Mars Transfer Vehicle has MW but for propulsion
  - CEV has up to 10 kW
- Vibration
  - Wear & tear
  - Noise
- System Life
  - Most will be Life of Mission or Vehicle
  - Some systems may have cleanliness/sterile concerns
- Separator Life
- Flow Rate range
  - ml/min to l/min

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# Requirements to Consider

- Acceleration Environments
  - Pre Launch 1 G
  - Launch – hi-G's
  - Transit - microgravity
  - De-Orbit – hi-G's
  - Moon (1/6 G) or Mars (3/8 G)
  - Post Landing 1 G
- Degree of Separation Desired
- Contamination Sensitivity
  - Separation process negatively impacted by solids or immiscible 2nd liquid phase
- Tolerance of "Slugging" or "flooding" Events
  - System capacitance
- Startup & Shutdown

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# Range of Separator Requirements

| Stream Type | Near Continous or Batch | Inlet Void Fraction |
|---|---|---|
| Cabin Humidity Condensate | **Continuous** | ? |
| Urine | **Batch** | **Low** |
| Dish Washing | **Batch** | **Low-Initially** |
| Laundry | **Batch** | **Low - Initially** |
| Sabatier $CO_2$ Reaction | **Continuous** | **High** |
| Waste Solids Drying | **Continuous** | **High** |
| Food Processing | **Batch** | **High** |
| Bioreactor | **Continuous** | **Low** |

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# Mechanical Phase Separation

- Centrifuge – Very high G's
  - Spin outside housing
  - Spin internal float
- Use rotational acceleration to also develop "hydrostatic" pressure rise to pump liquid
  - Rotary Fluid Management Device (Sundstrand)
  - Two Phase Pump (Foster-Miller)
  - MOBI

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# Passive Separation: Membranes

- Use of Hydrophilic Membranes and Surfaces to position liquid interface and withdraw liquid.
- Liquid Acquisition Devices (LAD's) are used in upper stage propellant tanks to ensure start of rocket motor.
- Gas Phase Breakthrough based on bubble point or LaPlace Eqn using membrane pore size.
- Prone to contamination.

# Passive Separation: Inertial

- Phase Separation achieved due to inertial differences in liquid and gas phase inertia

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Bubble Flow through Tee

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Gas Accumulation in Vena Contracta

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# Passive Separation: Inertial

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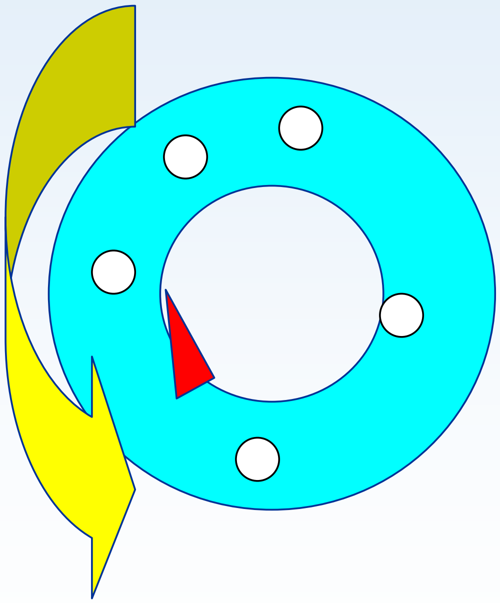

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# Passive Separation: Cyclonic

- Two Phase Flow Injected Tangentially into Cylinder.
- Separation driven by Flow
- Cyclones designed for microgravity will work well in multiple gravity levels

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# Summary

- Guidance similar to "A design that operates in a single phase is less complex than a design that has two-phase flow "[1] is not always true considering the amount of effort spent on pressurizing, subcooling and phase separators to ensure single phase operation.
- While there is still much to learn about two-phase flow in reduced gravity, we have a good start.
- Focus now needs to be directed more towards system level problems.

[1] Graf, J., Finger, B., Daues, K., "**Life Support Systems for the Space Environment: Basic Tenets for Designers Rev. A,** " http://advlifesupport.jsc.nasa.gov/documents/lsstenets.doc, 2003.

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