ENIVRONMENTAL CONTROL AND LIFE SUPPORT FOR HUMAN SPACE VEHICLES - MICRO/PARTIAL-GRAVITY TESTING NEEDS

A Presentation to the

Next Generation Suborbital Researchers Conference

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Overview

- Environmental Control & Life Support Systems (ECLSSs)
- Some Areas of Scientific Interest for Flight Experiments
- The Need for Micro- and/or Partial Gravity
  Flight Experiments
- Examples of Current/Recent ECLSS Flight Experiments
- Suborbital Flight Testing & Other Collaboration

Environmental Control & Life Support Systems (ECLSSs)

- Critical for crewed space missions
- Include air, water, thermal and other associated systems (e.g., data monitoring)
- Can be gravity/acceleration sensitive due to the fluids, gases and/or solids/particulates contained in these systems, their size/capacity, etc.
  - Close ties to fluid physics, heat transfer and other science disciplines
- These systems must be designed to be “gravity-insensitive” and/or be thoroughly analyzed/tested to ensure operation across gravity levels

Some Areas of Scientific Interest for Flight Experiments

- Related flight experiments to understand basic principles under low- or partial-gravity may include:
  - Complex fluids
    - Soft materials where intermolecular forces and interfacial phenomena play a large role
    - Examples: foams, liquid crystals, granular media
  - Interfacial Phenomena
    - Fluid interactions for liquid-gas and solid-liquid-gas systems
    - Examples: capillary phenomena, drops and bubbles, coalescence and aggregation phenomena
  - Biofluids
    - A cross between fluid physics and biology, and a new area of emphasis
    - Examples: cell culture conditions, physiological systems (e.g., redistribution of fluid in the body)

Some Areas of Scientific Interest (cont'd)

- Dynamics and Stability
  - Without gravity, the forces affecting flow instabilities change (e.g., surface tension)
  - Examples: g-jitter induced flows, thermocapillary phenomena
- Multiphase Flow and Heat Transfer
  - Multi-phase flow fluid dynamics is strongly dependent on gravity or lack thereof; typically there are large density differences between the phases
  - Examples: flow regimes, condensation, pool boiling
  - These systems are needed for future power system, thermal management and life support designs
- Future Exploration Systems Design
  - The conduct of research to obtain fundamental understanding and achieve breakthroughs to enable safer, more efficient, more productive, and more affordable human exploration programs
  - Examples: specific gravity-dependent phenomena (flows through packed beds), dust behavior in extraterrestrial environments

The Need for Micro- and/or Partial Gravity Flight Experiments

- Has been defined as when research/testing is required in the space environment, or adequate simulation of this environment (e.g., C-9, suborbital vehicle), to (e.g.),
  - test hypotheses and increase understanding related to basic fluid physics, heat transfer, etc.
  - test/operate a system(s) prior to implementation on-orbit, to verify the system(s) prior to flight, reduce on-orbit anomalies and maintenance/repair, validate planned operations, etc.
  - support technology development for future human and robotic space missions, etc.
- Examples:
  - For multiphase flows, the absence or reduction of gravity provides that surface tension plays a more dominant role
  - For biological water recovery systems, it is unknown what affect the microgravity or reduced gravity environment has on microorganisms

Examples of Current/Recent ECLSS Flight Experiments

- Immobilized Microbe Microgravity Water Processing System (IMMWPS) Flight Experiment
- International Space Station Water Recovery System Conductivity Sensor
- Two-Phase Flows in Partial Gravities

Immobilized Microbe Microgravity Water Processing System (IMMWPS) Flight Experiment

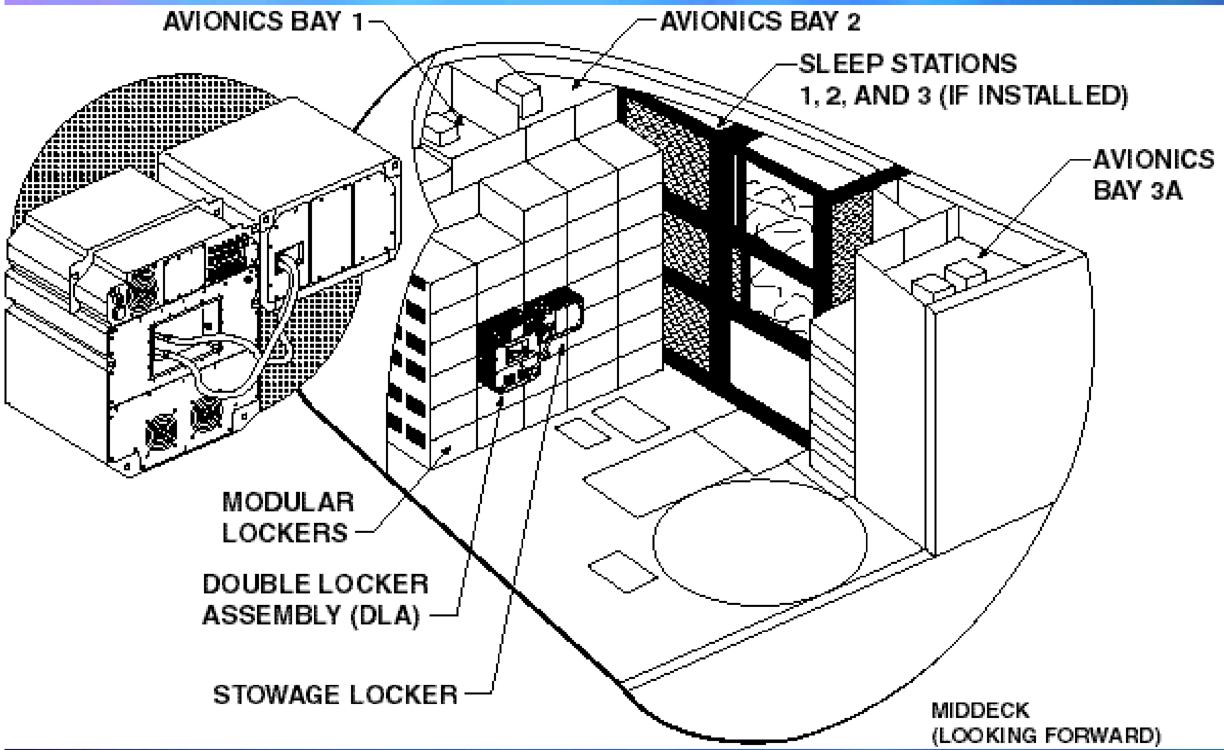
- IMMWPS is a technology demonstration of a primary water processor design proposed for future upgrades to the International Space Station (ISS) and/or other spacecraft

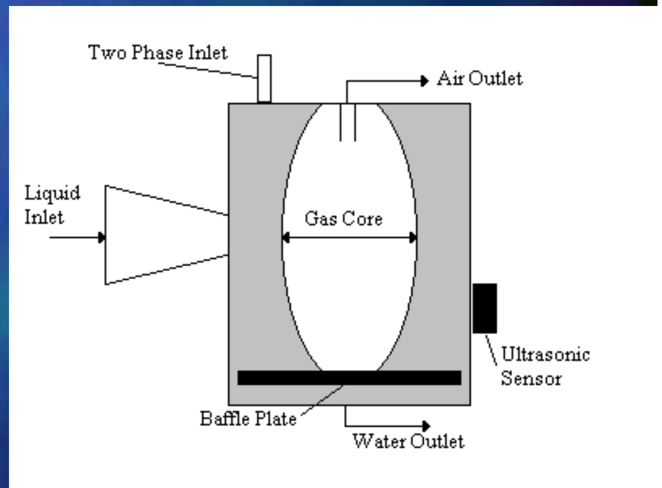
- The overall purpose of IMMWPS is to evaluate the ability of microorganisms to biologically degrade wastewater contaminants in a microgravity environment
  - utilizes a Microbial Processor Assembly (MPA) inoculated with facultative anaerobes to convert organic contaminants in wastewater to carbon dioxide and biomass
  - Also includes a novel vortex separator, fluid bags and hoses, etc.; provides for an interesting fluids management experiment as well

Immobilized Microbe Microgravity Water Processing System (IMMWPS) Flight Experiment (cont'd)

- Steady-state performance of the flight unit was proposed to be compared to that of a ground control experiment
  - NOTE: ground testing conducted to verify the performance and operations pre-flight showed flaws in the design and planned operations that were corrected (see Hurlbert et al. (2002) for full description)
- The biological nature of the experiment results in long time-constants, thus driving the need to eventually complete an orbital flight experiment
- STATUS: IMMWPS is now in bonded store awaiting a flight opportunity (originally designed for testing in the Space Shuttle Mid-Deck)

IMMWPS Images

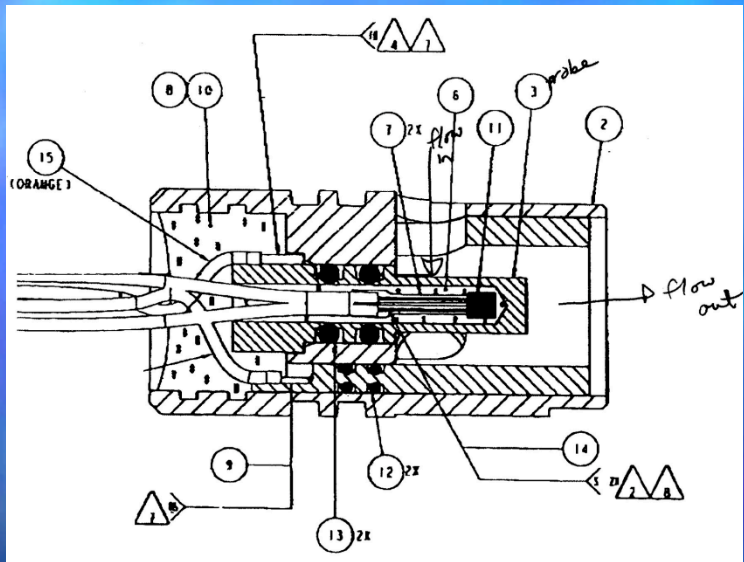


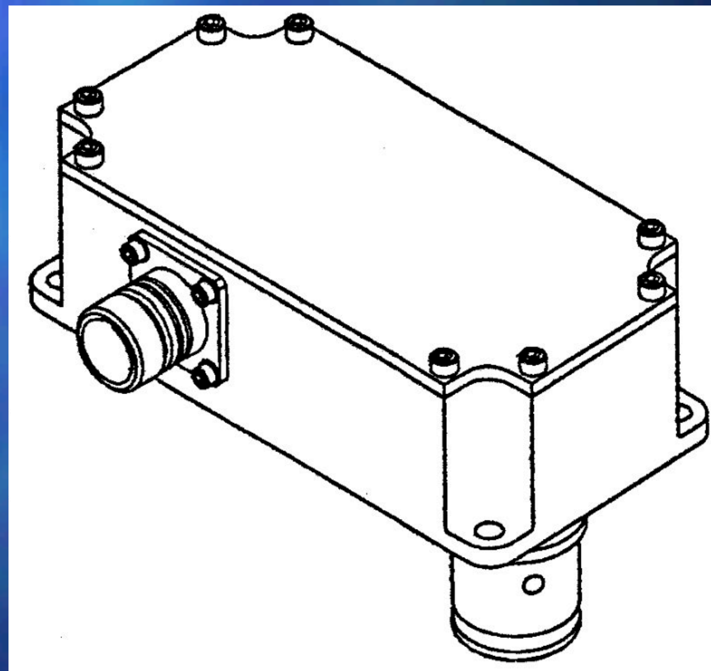


International Space Station Water Recovery System (WRS) Conductivity Sensor

- These sensors were proposed for the Water Processing Assembly (WPA) for Node 3
- The primary purpose for these sensors was to insure the quality of water coming out of the processing system
  - e.g., if "bad" water is detected by the sensor downstream of the ion exchange bed, a 3-way solenoid valve activates and returns it to the processing loop
- Ground testing showed that the sensor did not work in every orientation relative to 1-g
  - Operation of the sensor was assisted by buoyancy (i.e., the tendency of a body to float or rise when submerged in a fluid; resultant upward force equal to the weight of the fluid displaced by the body)
  - Buoyancy is a gravity effect and will not be present in zero-g
- STATUS: the sensor was re-designed for "flow through" to accommodate operations with two-phase flow

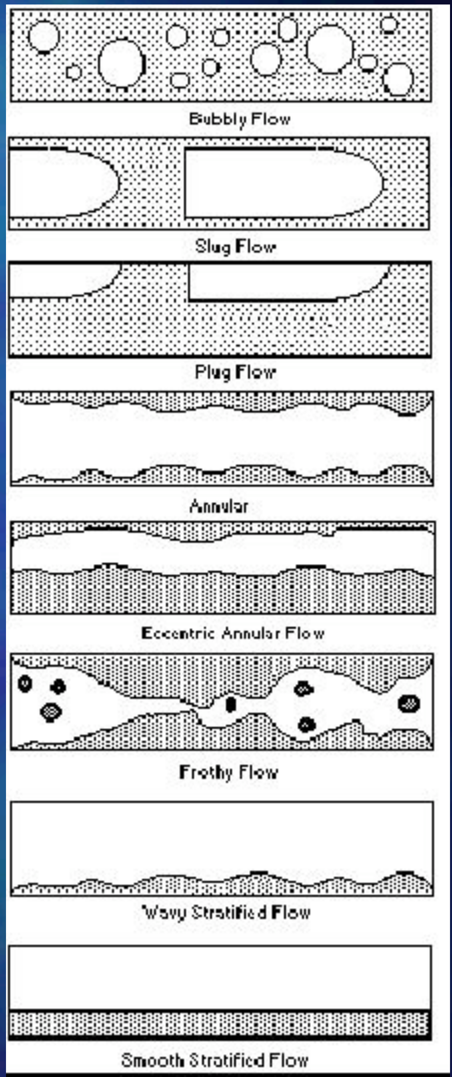
WRS Conductivity Sensor





Two-Phase Flows in Partial Gravities

- Two-Phase Flows are defined as having the liquid and vapor phases of a working fluid flowing together in a system.
- Significant advantages for space systems design can be realized
  - heat can be added or subtracted at a constant temperature
  - up to an 80% savings in system power and mass for thermal control systems (Ungar (1993))
  - use of bioreactor-based water reclamation and recycling system can reduce mass, power, volume and complexity (Hanford (1997))



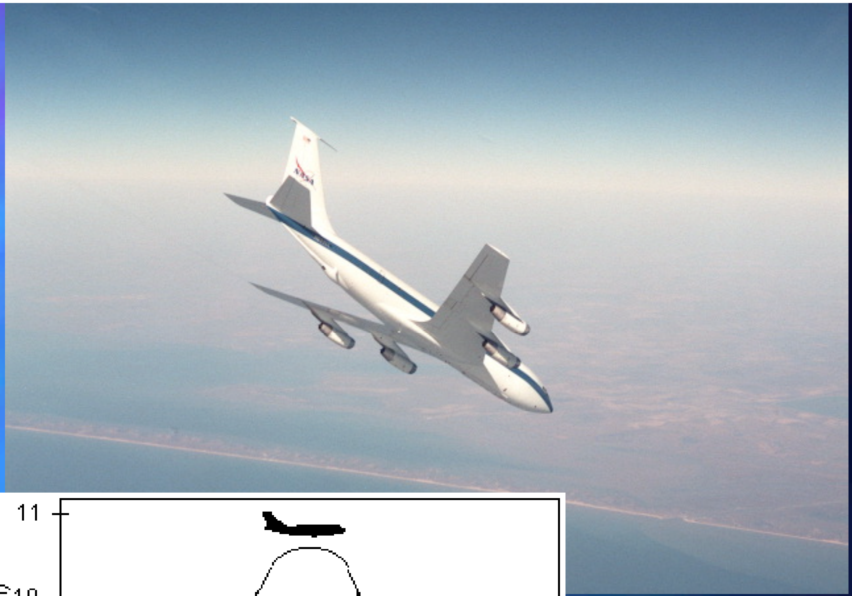
Two-Phase Flows in Partial Gravities (cont'd)

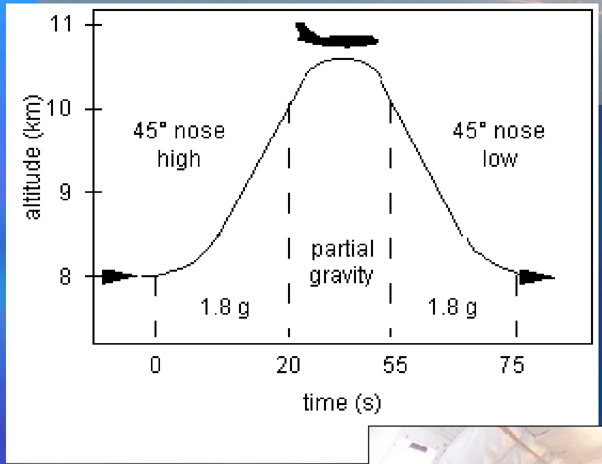
– A ground-based study was funded through a grant with The University of Houston under the Advanced Life Support Program

– This was the first study that investigated two-phase flow dynamics and scaling with validation data across four gravity levels (i.e., Earth, Mars, Moon and Microgravity)

– Data collected in ground testing (i.e., lab) and using the NASA KC-135 aircraft

- A very challenging test environment in the KC-135:
  - Inherent Facility Constraints include
    - size of the cargo door,
    - interior width of the cabin,
    - variation in cabin temperature, and
    - short time duration of the reduced gravity periods.
  - Operations Issues include
    - weather,
    - pilot's skills,
    - aircraft equipment,
    - response of your research equipment, and
    - the well-being of the test crew.





Two-Phase Flow Scaling Across Gravity

- A classical approach was employed using the Buckingham Pi Theorem, based on Delil (1991).
- A simplified scaling approach was realized by using the same working fluid, at the same operating temperature and pressure, and matching the geometry.
- The final scaling relationship for this study was:

$$Eu_f \blacksquare fn(S, Fr_f)$$

or

$$Eu_f \blacksquare fn(Fr_g)$$

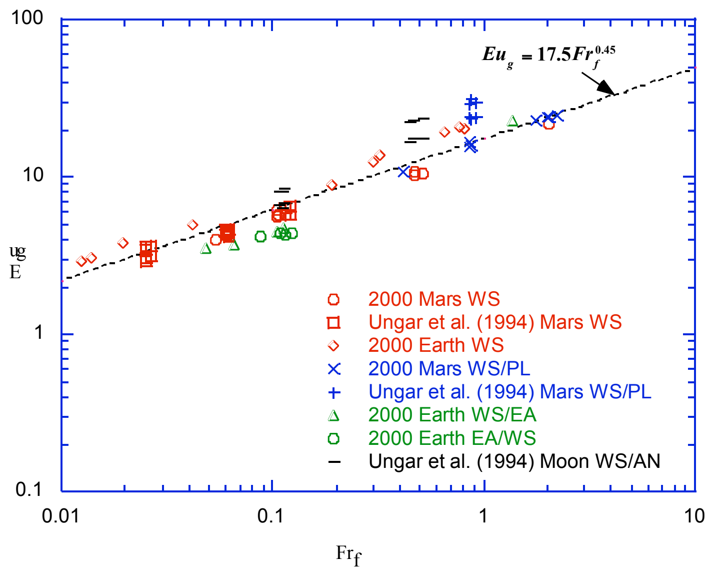


Figure 6.8 Eu_g versus Fr_f for 2000 and Previous Data for WS and WS-Transition Flows with S < 100

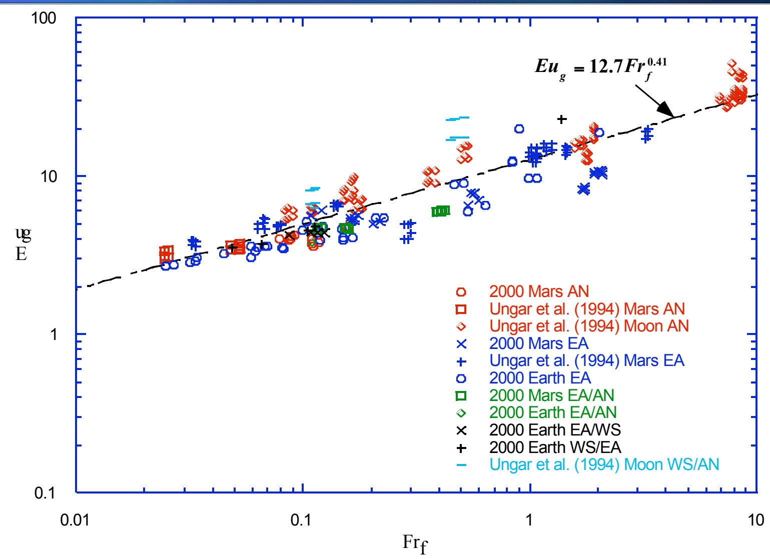


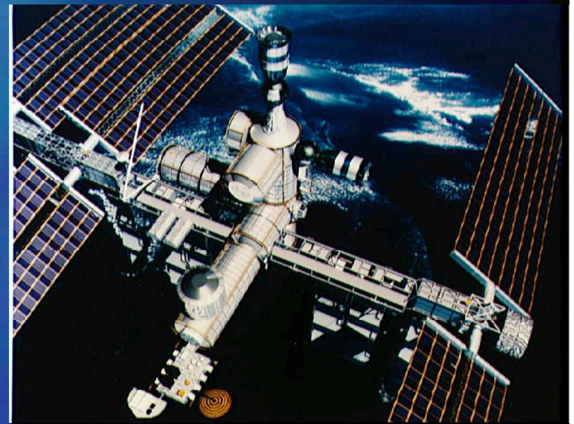
Figure 6.10 Eu_g versus Fr_f for 2000 and Previous Data for AN-Type and AN-Transition Data with S < 100

Suborbital Flight Testing & Other Collaboration?

– YES to Suborbital!!!
  - Minutes of micro- and/or partial-g may be much better suited to pre-test of orbital hardware, studies of fluids (e.g., allows for system stability), etc.
  - Experiments and areas of research are ready for the "next big step", and some require human interaction that can be accommodated on proposed vehicles
  - Early testing can lead to characterization of test environments (e.g., 3-axis accelerations, ops) and development/evaluation of standardized services (e.g., payload rack(s), power conditioning)
  - ETC……

Suborbital Flight Testing & Other Collaboration? (cont'd)

– YES to Collaboration!!!
  - Experiments/support hardware can be readied or easily developed should sponsorship become available
  - Experienced engineers and scientists may be available for consulting and/or provision of services
  - Suborbital experience may support future orbital implementation and ops
  - ETC……



CHECK OUT:

http://www.nasa.gov/centers/johnson/engineering/main/index.html

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