National Aeronautics and Space Administration

Drop Tower Workshop

29th American Society for Gravitational and Space Research

November 4, 2013

Orlando, Florida, USA

Agenda

- **Background-Workshop Goals**
- **Currently operating drop towers (partial list) and other ground-based facilities**
- **Partial Gravity Facilities**
- **Future ground-based test capability needs**
  - Combustion science
  - Spacecraft fire safety
  - In-situ Resource utilization
  - Complex Fluids
  - Interfacial phenomena
  - Fluid Physics
  - Materials
  - Fundamental Physics
- **Other Programs (Zarm-Bremen)(JAXA)**
- **Discussion**

Agenda

- Background-Workshop Goals
- Currently operating drop towers (partial list) and other ground-based facilities
- Partial Gravity Facilities
- Future ground-based test capability needs
  - Combustion science
  - Spacecraft fire safety
  - In-situ Resource utilization
  - Complex Fluids
  - Interfacial phenomena
  - Fluid Physics
  - Materials
  - Fundamental Physics
- Other Programs (Zarm-Bremen)(JAXA)
- Discussion

Background

- **Current Drop Tower capability is little changed in decades despite major technology growth**
  - exceptions
    - Bremen ---- launch capability
    - Portland State University – rapid turnaround
- **Planetary exploration plans raise new research needs in partial gravity that cannot be satisfied on aircraft alone**
- **Partial gravity research largely ignored despite substantial technical importance**
- **The research discipline areas of emphasis have changed have our ground-based capabilities kept up?**

Goals

Goals (for this workshop and beyond)

- Expand ground based capabilities
  - optimize flight research
  - maximize science and technology development
- Explore interest in the research and exploration communities for ground-based capabilities
- Identify best practices and ideas from other facilities
- Identify most important capabilities for improvement
- Identify new potential users
- Develop a plan to evaluate facility upgrades

Agenda

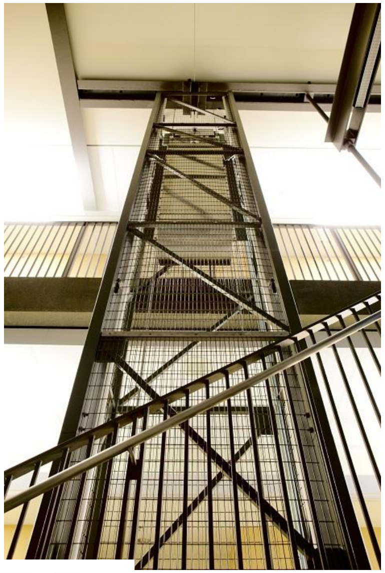
- **Background-Workshop Goals**
- **Currently operating drop towers (partial list) and other ground-based facilities**
- **Partial Gravity Facilities**
- **Future ground-based test capability needs**
  - Combustion science
  - Spacecraft fire safety
  - In-situ Resource utilization
  - Complex Fluids
  - Interfacial phenomena
  - Fluid Physics
  - Materials
  - Fundamental Physics
  - Biological Systems
- **Other Programs (Zarm-Bremen)(JAXA)**
- **Discussion**

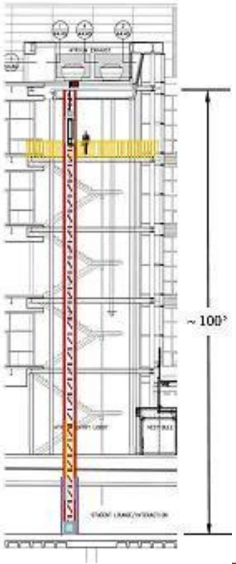
Operational Drop towers (t > 1 s)

- NASA zero-g: 5.2 seconds, 10^{-5} g, 7 drops / week
- NASA 2-second: 2.2 seconds, 10^{-3} g, 15 drops / day
- Queensland University (Australia) 2. seconds, 10^{-4} g, 15 drops / day
- Portland State Univ.: 2.1 seconds, 10^{-3} g, 20+ drops / day
- Fallturm Bremen (Germany): 4.7 seconds, 10^{-5} g, 9 seconds with catapult
- Purdue University: 2 seconds
- Hokkaido University (Japan): 3 seconds, 10^{-3} g
- Others?

PSU Dryden Drop Tower

- **Tower height: 31.1m (102ft)**
- **Free fall distance: 22.2m (73ft)**
- **Low-g time: 2.13 sec.**
- **g-level: < $10^{-3}g_o$**
- **Deceleration distance: ~ 3.5m**
- **Drag Shield mass: 115kg**
- **Experiment mass: < 50kg**
- **Peak deceleration: $15g_o$**
- **Average deceleration: $8.5g_o$**
- **Automated Retrieval: 5 min.**

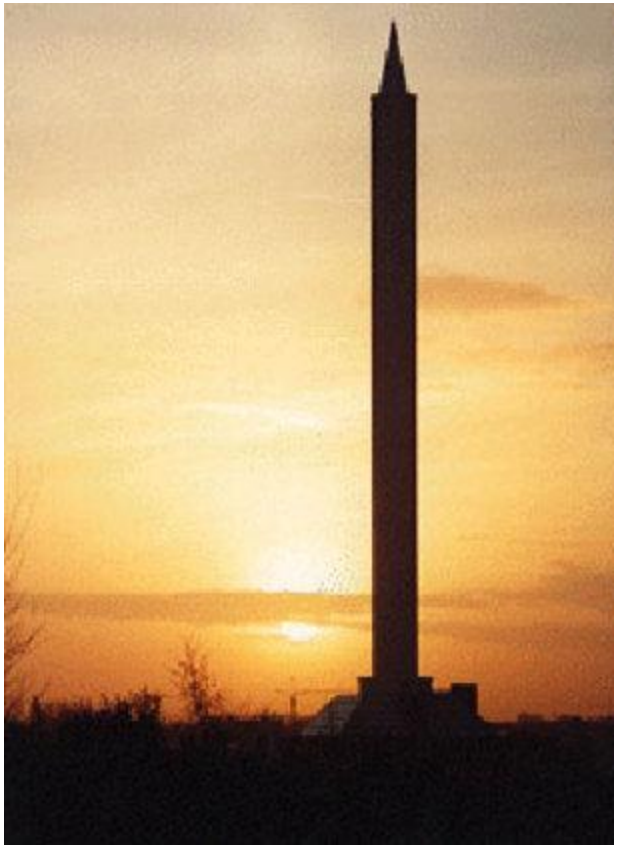




PSU Dryden Drop Tower

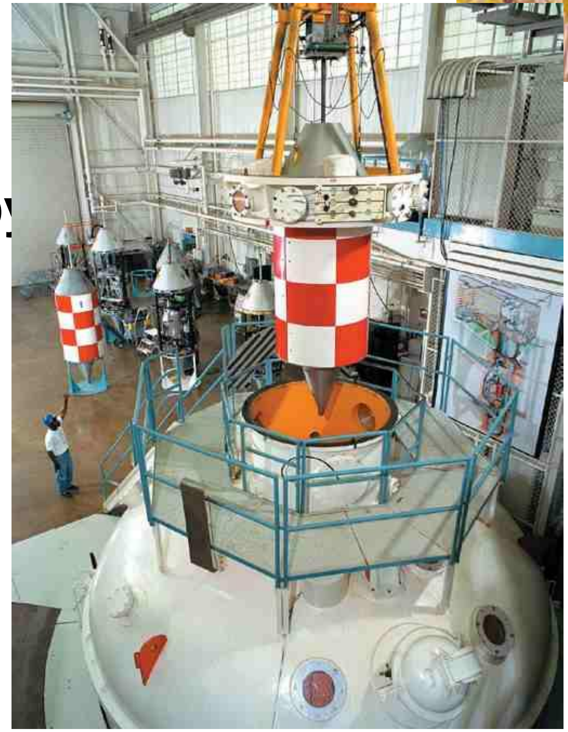
Bremen

- **Free fall distance: 110 m**
- **Low-g time: 4.5 sec.**
- **g-level: < 10^{-6} g_o**
- **Deceleration distance: ~ 3.5m**
- **Deceleration: 50 g_o**



NASA Zero-g facility

- **Microgravity Duration: 5.18 seconds**
- **Free Fall Distance: 432 feet (132 m)**
- **Gravitational Acceleration: <0.00001 g**
- **Mean Deceleration: 35 g**
- **Peak Deceleration: 65 g**
- **Cylindrical, 42 in. (1 m) diameter by 13 ft. (4 m) tall**
- **Gross Vehicle Weight: 2500 lbs. (1130 kg)**
- **Experimental Payload Weight: up to 1000 lbs. (455 kg)**



Hokkaido Drop Tower

- micro-g time: 3 s
- Drop Height: 50 m
- micro-g quality: 10^{-3} G
- Payload Size: 0.5 m Diam x 0.8 m
- Total Weight: 400kg

Agenda

- **Background-Workshop Goals**
- **Currently operating drop towers (partial list) and other ground-based facilities**
- **Partial Gravity Facilities**
- **Future ground-based test capability needs**
  - Combustion science
  - Spacecraft fire safety
  - In-situ Resource utilization
  - Complex Fluids
  - Interfacial phenomena
  - Fluid Physics
  - Materials
  - Fundamental Physics
- **Other Programs (Zarm-Bremen)(JAXA)**
- **Discussion**

Partial Gravity: Centrifuge in NASA Zero-g facility

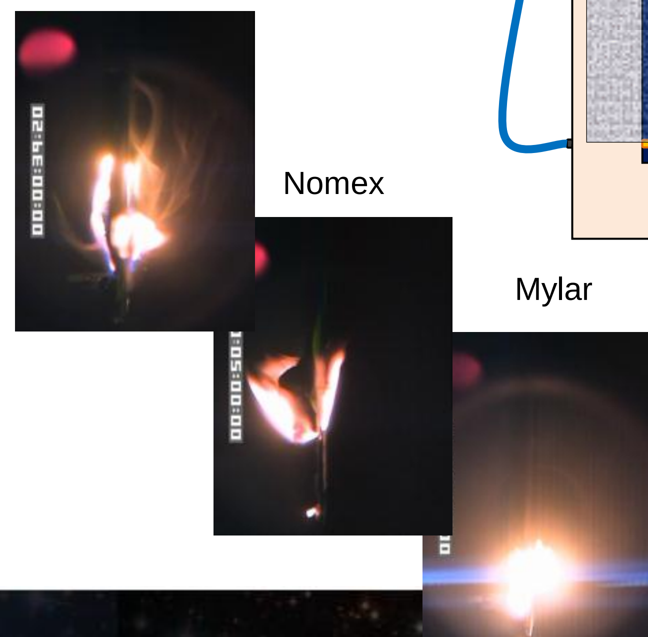
Recent work using a centrifuge in the drop tower demonstrated real promise for exploring partial gravity conditions.

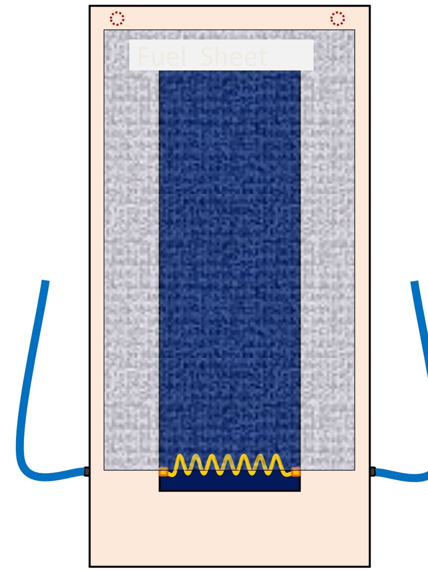
- Fuel sample is 5 cm wide by 6 cm long.

Dome

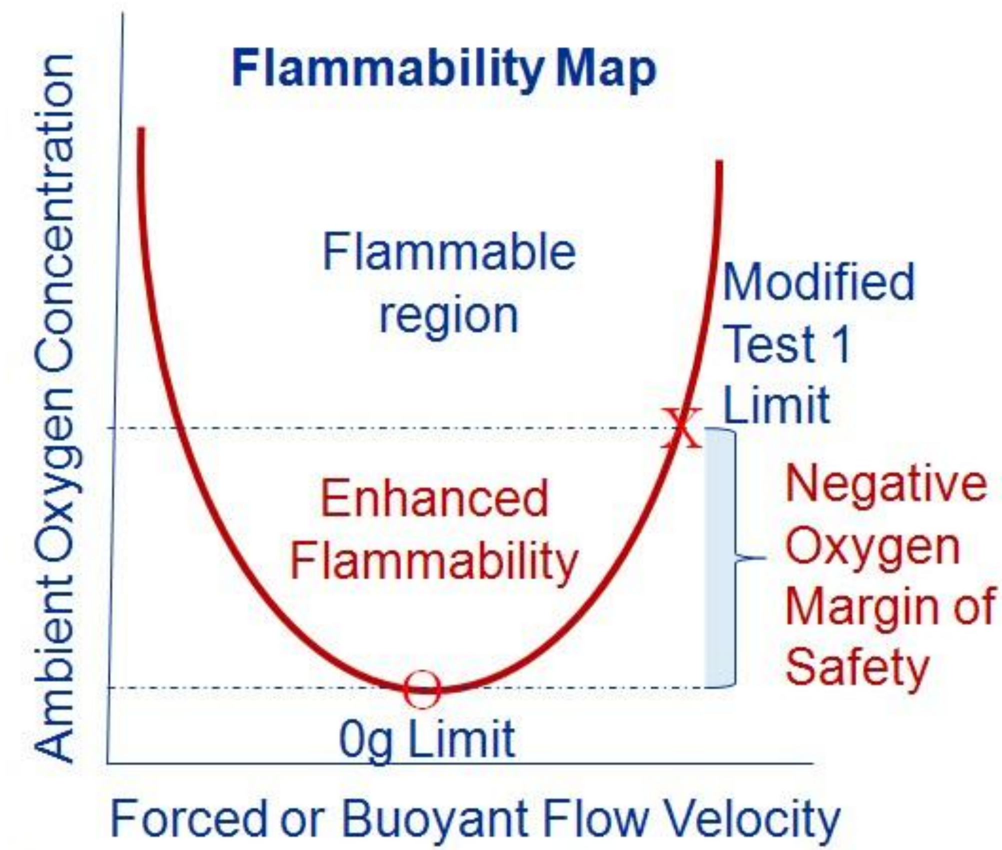
Experiment support plate

Control hardware and electronics





Centrifuge Results



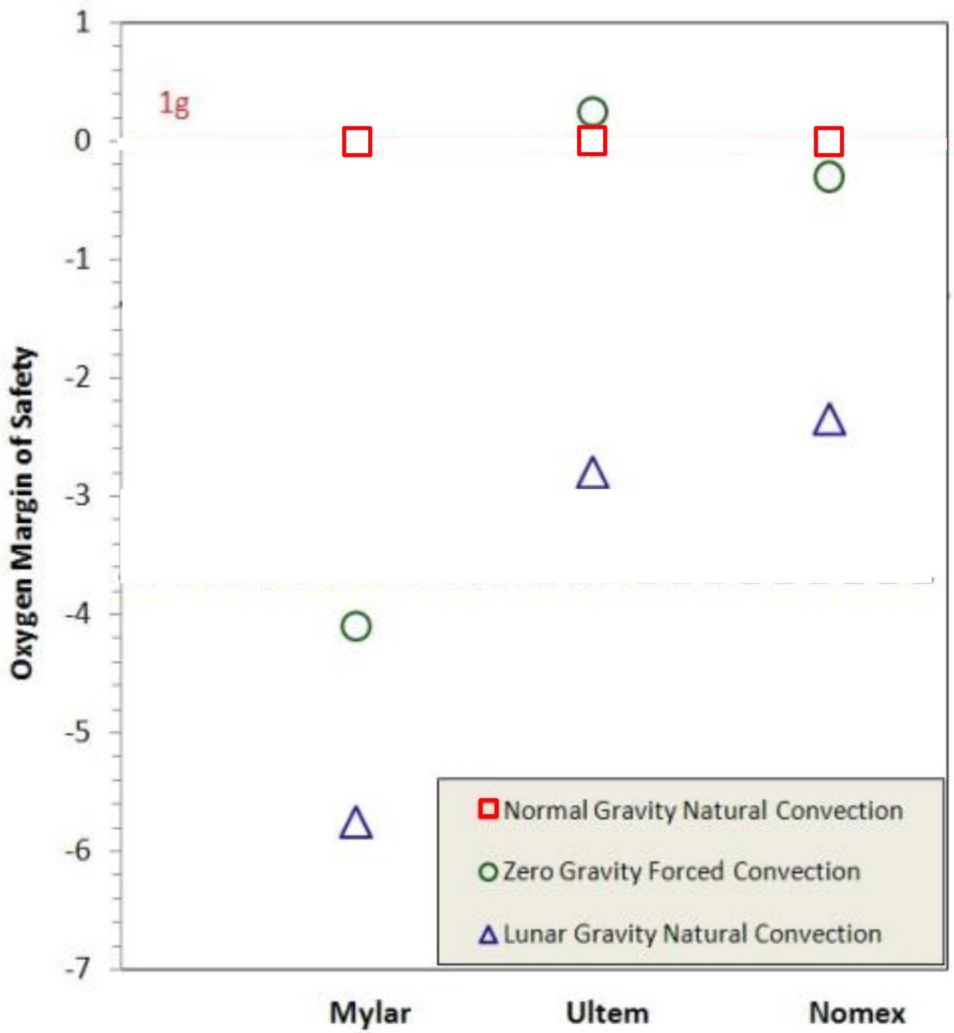
- The Oxygen Margin of Safety is *positive* if materials are *less flammable in 0g*.
- However, microgravity drop tower testing shows that mylar film has a negative margin of safety.

  Lunar ΔO_2 %= -5.75,

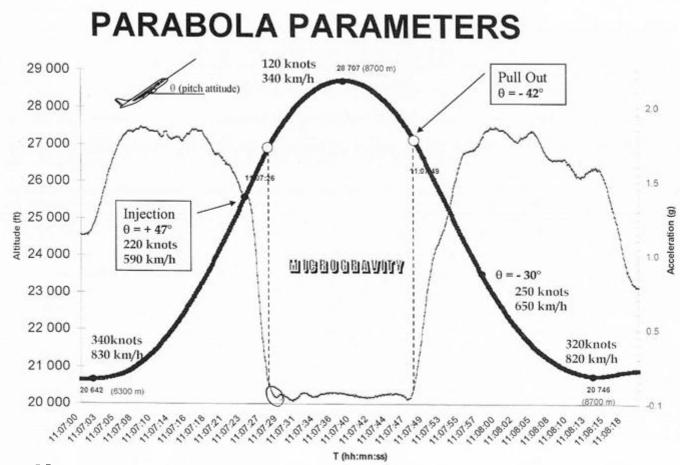
  0g ΔO_2 % = -4.1

Centrifuge Results

- Tests were conducted at WSTF (normal-g) and GRC (Lunar-g) to quantify changes in the MOC for Nomex, Mylar, and Ultem
- Conditions run in Lunar-g burned at both the *normal gravity MOC* and at the *zero-g convective MOC*
  - Lunar-g flammability appears more like zero-g rather than 1-g
  - Cessation of ventilation flow is not effective
- Significant impact on a fire safety strategy, especially if the need for fire detection and suppression is dictated by the difference between the MOC and atmosphere of use.



Zero-g aircraft



- Partial-g flights on aircraft have been flown repeatedly
- G-jitter typically ~ 0.1 to 0.02 g has less impact on partial-g tests than zero-g tests but is still substantial
- Reproducibility of g-levels difficult
- Cost is high
- Schedule opportunities and number of tests are limited

Agenda

- **Background-Workshop Goals**
- **Currently operating drop towers (partial list) and other ground-based facilities**
- **Partial Gravity Facilities**
- **Future ground-based test capability needs**
  - Combustion science
  - Spacecraft fire safety
  - In-situ Resource utilization
  - Complex Fluids
  - Interfacial phenomena
  - Fluid Physics
  - Materials
  - Fundamental Physics
- **Other Programs (Zarm-Bremen)(JAXA)**
- **Discussion**

Spacecraft Fire Safety

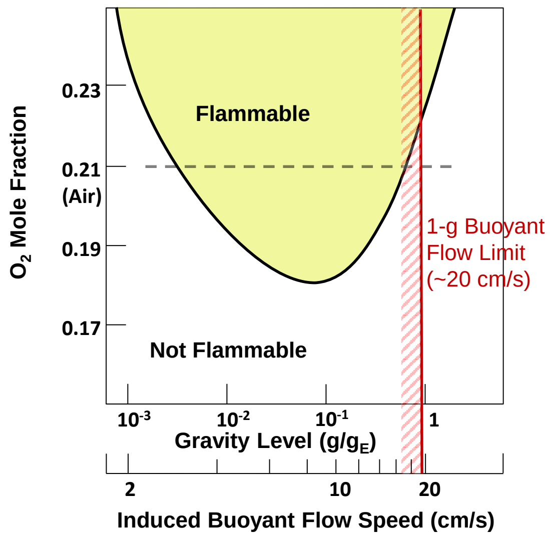
Scientific Basis for Study of Gravitational Effects:

Buoyancy influences fire and flammability through both providing oxygen to the flame and removing heat from (quenching) the flame.

- **Fundamentally non-linear g-impact**
- **Other terrestrial conditions (pressure and oxygen concentration) add further nonlinear effects.**

Characteristic Times of Phenomena:

Gas phase flame: flow residence time (v/l) ~ s, diffusion (r^2/D) ~ 5 s; spread rate and material heating times limit testing to thin materials.



New Areas for Research/ Technology Development

Material flammability assessment, fire suppression

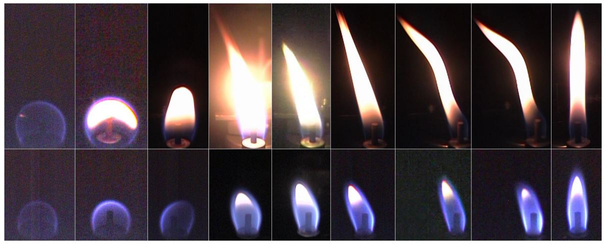
Capability needs:

Reduced cost access to low-gravity : 5 to 10 seconds

Access to lunar and Martian gravity levels 5 seconds minimum

Application:

Extra terrestrial habitats will require effective fire safety methods to protect crew members and the habitat from fires. Fire prevention, detection and suppression are all influenced by gravity.



National Aeronautics and Space Administration

Heptane and Ethanol Flames as a Function of Gravity (Centripetal acceleration) Top View

Heptane Flames

Heptane flames flicker

Ethanol Flames

Ethanol flames sway

Ethanol flames flicker

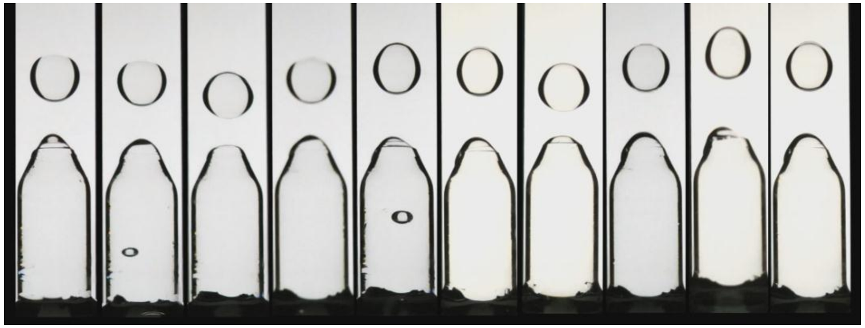
1 cm

Capillary Phenomena

Scientific Basis for Study of Gravitational Effects:
The near absence of gravitational acceleration permits the study of large length scale capillary phenomena for applications in space, but also serves as a tool to observe complex geometric capillary behavior not readily observable at microscales

Characteristic Times of Phenomena:

Recent and ample design tools are in hand to construct scale systems such that as little as a 2s duration can demonstrate process dynamics and/or even system performance (increasing TRL!)



High rate tower allows easy access to statistical data. Lowers effort threshold to consider more traditional approach to experiment plan and execution. Marked increase in creative exploration due to significant increase in trial and error approach due to reduce effort per drop.

New Areas for Research/ Technology Development

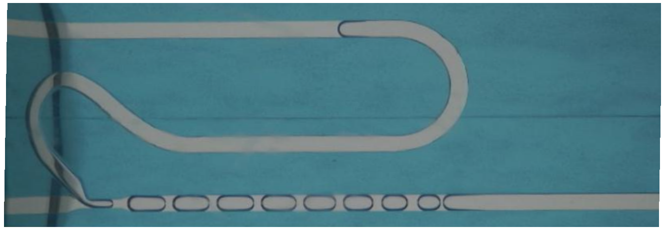
Rapid prototyped experiments with a high rate drop tower **completely(!)** change the environment and productivity for such research. Data transfer and reduction become bottleneck, not experiment fabrication or data collection.

Capability needs:

Always desire longer times which could be exploited with ease provided access to drop capsule allows easy test cell alteration or changeout.

Application:

e.g. Design and development of new passive multi-phase control/separation devices and systems (clear terrestrial and exploration applications)



Value of increased numbers of tests and g-variation

Variable-g, High rate tower benefits

- **Total change in psychological approach to DT testing** **(this has happened at PSU but is difficult to communicate to DT folks outside of PSU and PSU personnel know no different so it is kind of like no big deal. But over 100 drops a day? Come on)**
- **Variable g permits unique studies in sedimentation, bubble migration, and droplet interactions**
- **Variable g allows all capillary stability analyses to be conducted, increasing TRL when needed, and dramatically increasing user exposure to critical low-phenomena.**
- **Variable g allows unique tests with important control of initial conditions: i.e., transitions from partial to zero g, zero to partial g.**
- **Tests varying g by decades say 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, provide excellent breadth to studies and combined with high rate will completely change impact of DT as a low-g research tool**

Gas – Liquid Flows

Scientific Basis for Study of Gravitational Effects:

Buoyancy affects both the shape of the gas-liquid interface and the relative motion at the interface.

Effects of gravity are highly non-linear due to the competing effects of inertia, viscosity and surface tension

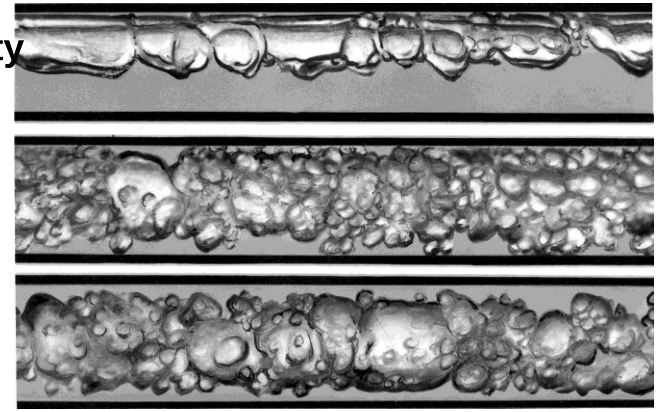
Characteristic Times of Phenomena:

Some interface relationships (i.e. droplets to gas phase, waves on films) can be readily studied in 5 s

Normal Gravity (1.0 G)

Lunar Gravity (0.17 G)

Microgravity (0.00 G)



Horizontal Gas-Liquid Bubble-Slug Flow Regime

New Areas for Research/ Technology Development

Sprays (droplet formation and impact)

Wave formation/film stability

Bubble Coalescence

Capability needs:

Gas supply, high rate (200 to 4000 Hz) video and data acquisition

Variable gravity

Large numbers of drops

Application:

Space-based:

- Water Reclamation
- Thermal Management
- Propellant Management

Terrestrial:

- Petroleum
- Chemical Process Industry

Hydrodynamic Simulation of Boiling Phenomena

Scientific Basis for Study of Gravitational Effects:

- **Boiling process is profoundly affected by the gravitational environment**
- **Governing phenomena (surface tension and buoyancy yield non-linear effects**

Characteristic Times of Phenomena:

Via hydrodynamic analogy time scales can be reduced to 2 to 6 seconds

Fig. A Flow boiling of FC-72 in a narrow channel from nucleate to critical heat flux.
Fig. B Hydrodynamic simulation of flow boiling in an identical channel using air –water system.

Hydrodynamic simulation of flow boiling leading up to onset of simulated CHF can be performed in short duration drop tower tests.

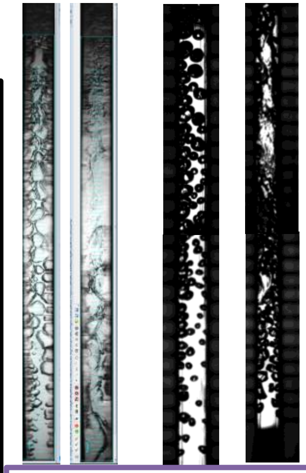


Fig. A Fig. B

New Areas for Research/ Technology Development

Boiling and Interfacial Phenomenon in Low gravity

Applications include:

- **Two Phase Flow Thermal Control Systems and Advanced Life Support Systems**
- **Gravity Insensitive Vapor Compression Heat Pump, Rankine Cycle Power System for Future Space Vehicles and Planetary Bases**

Capability needs:

Cost reduction and accessibility to low gravity environment of 5-10 seconds

- Short duration hydrodynamic analogy test results can be used to identify and determine quantitative criteria for the gravity independent flow boiling regimes.
- Such criteria provide a rational basis to employ with confidence existing data, correlations, and models developed from Earth gravity studies to design reduced gravity thermal management systems

Flight Experiment Risk Mitigation

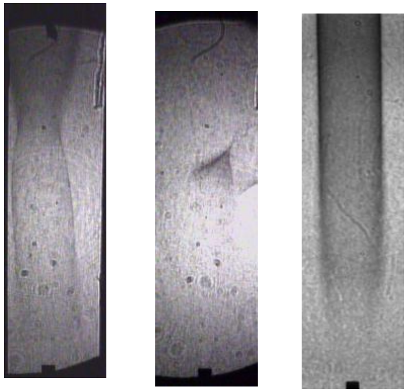
Technical Basis Testing:

Flight hardware selection, hardware settings, test matrix conditions are all areas o substantial risk for flight experiments, increased access to ground based facilities are essential to ensure success

Characteristic Times of Phenomena:

Variable, reliability generally increases with increased time.

Laminar Flame experiment identified engineering flaw through 5 second test but still underestimated inflight soot levels



New Areas for Research/ Technology Development

Most ISS experiments could benefit by risk reducttion experiments

Capability needs:

Extended time (10 s preferred)

Reduced cost

Liquid spread experiment fooled by g-jitter effects

Fuel tray did not fill in flight, loss of data.

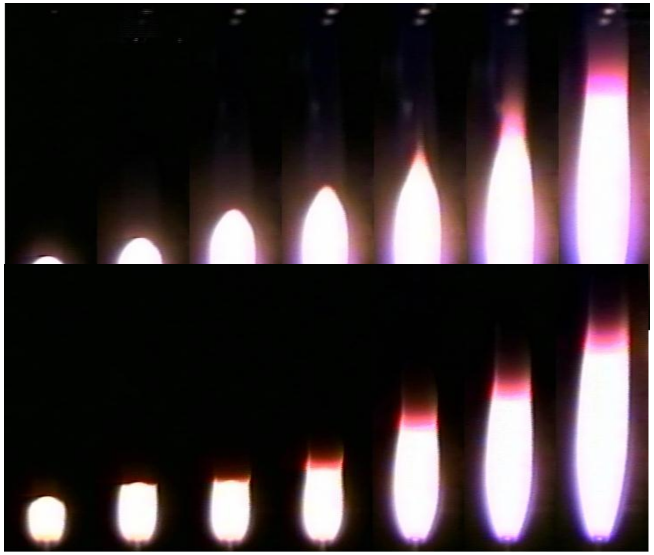
Fundamental Combustion Science

<u>Scientific Basis for Study of Gravitational Effects:</u>
Buoyant flows influence combustion processes through providing oxygen to the flame, reducing residence times and transporting energy (heat) from the flame.

- Fundamentally non-linear g-impact
- Other test conditions (pressure and oxygen concentration) add further nonlinear effects.

<u>Characteristic Times of Phenomena:</u>

Gas phase flame: flow residence time (v/l) ~ s, diffusion (r^2/D) ~ 5 s;



<u>New Areas for Research/ Technology Development</u>

Variation of the g-level, combined with detailed modeling provides opportunities more extensive testing of numerical models and theoretical formulations

<u>Capability needs:</u>

Reduced cost access to low-gravity : 5 to 10 seconds

Access to lunar and Martian gravity levels 5 seconds minimum

<u>Application:</u>

Improved combustion control

Reduced pollution

Increased efficiency

In Situ Resource Utilization

Scientific Basis for Study of Gravitational Effects:

ISRU systems contain numerous systems that are griavyt dependent:

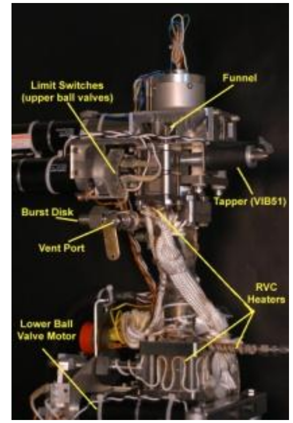
Granular flow

Multiphase reactors

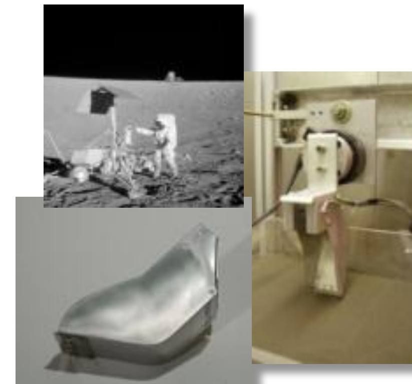
Liquid / slurry transport

Characteristic Times of Phenomena:

Process deconstruction to underlying flow, diffusion, and granular media mechanisms can yield rate information in typical 5 second increments



Lunar Regolith Volatile and Oxygen Extraction reactor at GRC



Surveyor 3 shovel replica testing at GRC

New Areas for Research/ Technology Development

Thermal and Chemical reaction/reactor behavior in lunar and Martian conditions

Flow of granular media in partial gravity

Packed and Fluidized Bed thermal and chemical mechanisms for processing granular planetary soils for volatile extraction, bound water liberation, or metallurgical processes

Capability needs:

Up to 10 seconds of lunar and Martian gravity.

Application:

Extraction and purification of water resources from lunar polar cold traps

Extraction and processing of Martian atmospheric CO_2 to produce oxygen.

Combined processing of Martian atmospheric CO_2 and ground-source water to produce methane (CH_4) and higher HCs.

Production of metallic feedstock for in space additive manufacturing processes.

Conclusions

- **Recent improvements in drop tower systems/technology raise the potential for enhanced capability:**
  - Increased duration
  - Increased throughput
  - Reduced cost
  - Partial Gravity
  - Variable Gravity
- **These offer exciting opportunities for science and critical technology development**
- **But we can’t get it all, to justify further improvements in drop tower capabilities, it is critical to quantify the impact and utilization of these capabilities**

Survey

- **What capabilities would be important?**
  - –Increased throughput
  - –Variable g-level
  - –Variable g-level within the drop
  - –Reduced deceleration impact
  - –High quality zero-gravity
  - –Greater than 6 s zero-gravity drops

Comments & Suggestions