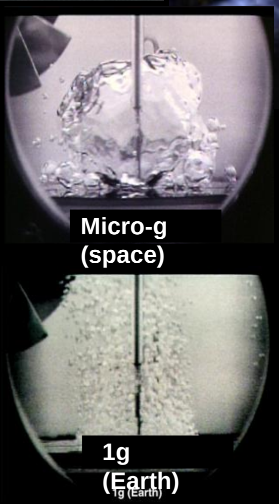
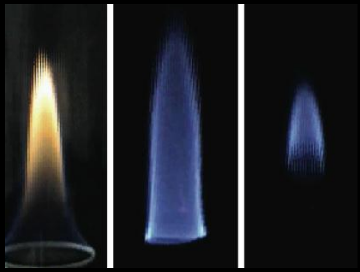
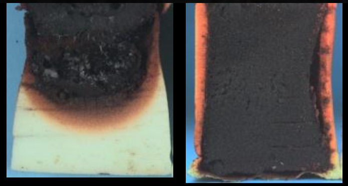
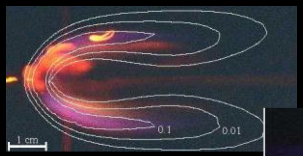
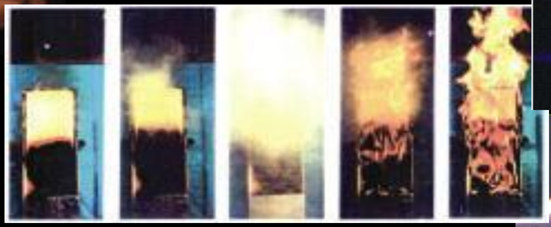
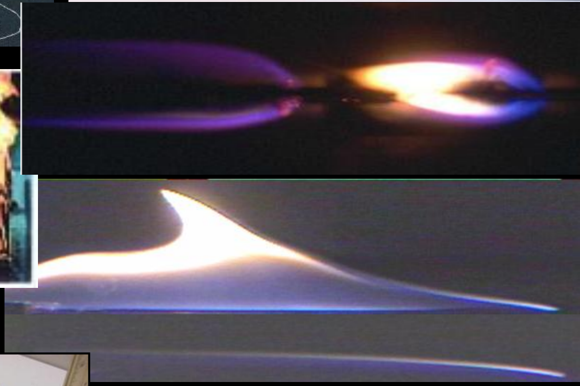
Potential for Research in Fluid Physics and Combustion Science on Suborbital Platforms



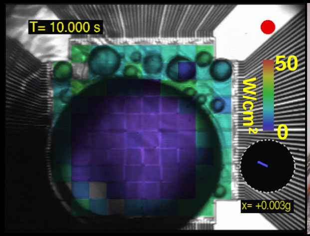


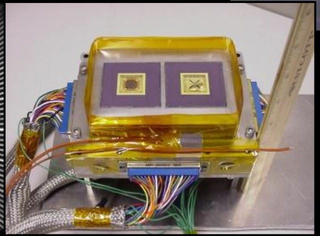
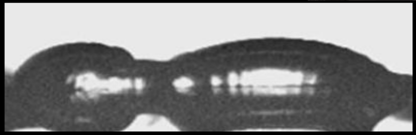





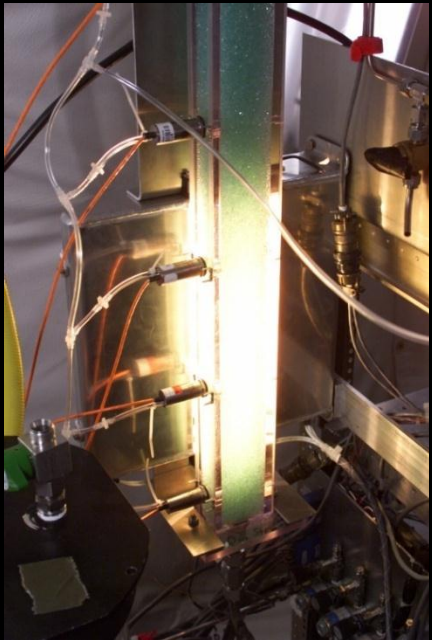




March 1, 2011





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Combustion

Combustion is:

- our primary delivered energy source (85%)
- the primary cause of air pollution and global warming,
- an inherent part of many industrial processes –
  steel/iron, glass, carbon black (tires)
- a major source of new materials -
  nano-tubes, diamonds, ceramics etc.,
- a major source of the loss of property and life,
- the dominant power source for portable applications,
- a potential catastrophic hazard for manned space flight,
- arguably man's first technology but also remarkably
  complex.
- **Improvements in the quality of life in space and on earth can be realized with our ability to predict and control combustion.**

Fluid Physics

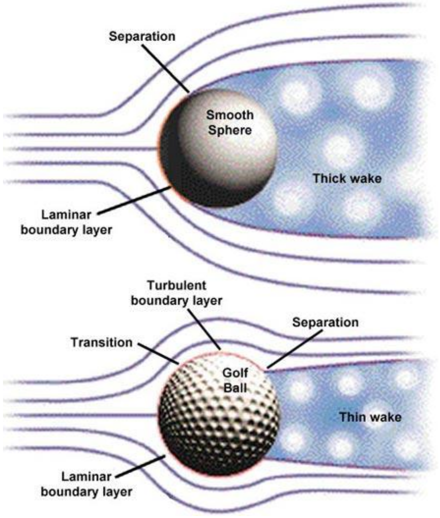
Fluid physics - the study of the motions of liquids and gases and the associated transport of mass, momentum and energy.

- Dates back to ancient Greece, when Archimedes wrote, “Any floating object displaces its own weight of fluid.” in his treatise, *On Floating Bodies*

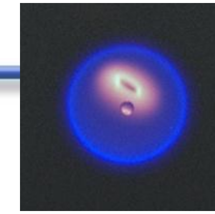
- Studies arise from nature...
  - meteorology
  - oceanography
  - living plants & animals

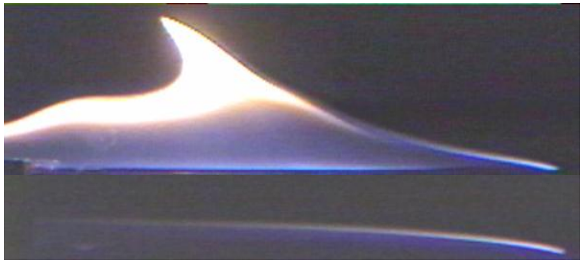
and technology.
  - biological
  - chemical/petroleum
  - materials processing
  - mechanical/fluid systems

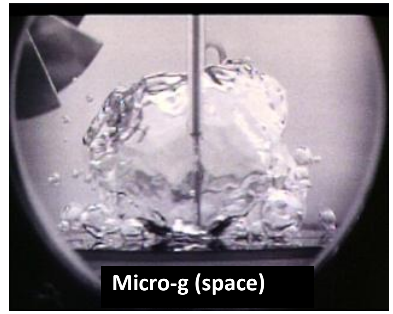
- Continues today driven by a vigorous, multidisciplinary research community
  - global atmospheric change, groundwater pollution, oil production, and advanced materials manufacturing often rely on advances in fluid physics for their progress.
- **Ensuring sufficient supplies of fresh water for current and future generations is among humanity’s most critical challenges.**

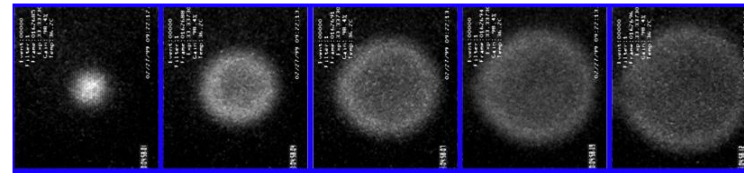


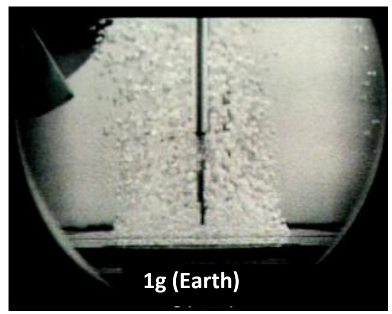
Gravity











"When the influence of gravity on fluid behavior is diminished or removed, other forces, otherwise of small significance, can assume paramount roles."

- NRC Report to NASA, 2003

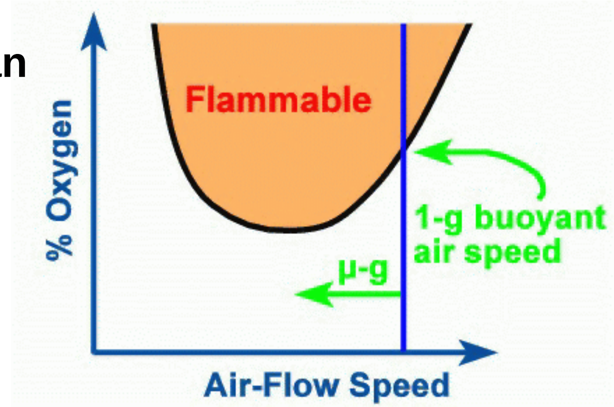
- The near elimination of buoyancy and sedimentation within inhomogeneous fluids in low-gravity allows scientists to study the behavior of a whole range of fluids.
- Permits expanded spatial scales, yielding better diagnostic resolution.
- Allows scientists to produce and study 1-d spherical flame geometries.
- Eliminates buoyancy driven flows in combustion process, allowing much lower flow velocities than in 1-g.
- Combined effects of other forces must be better understood to enable space exploration as well as processes in Earth-bound industries.

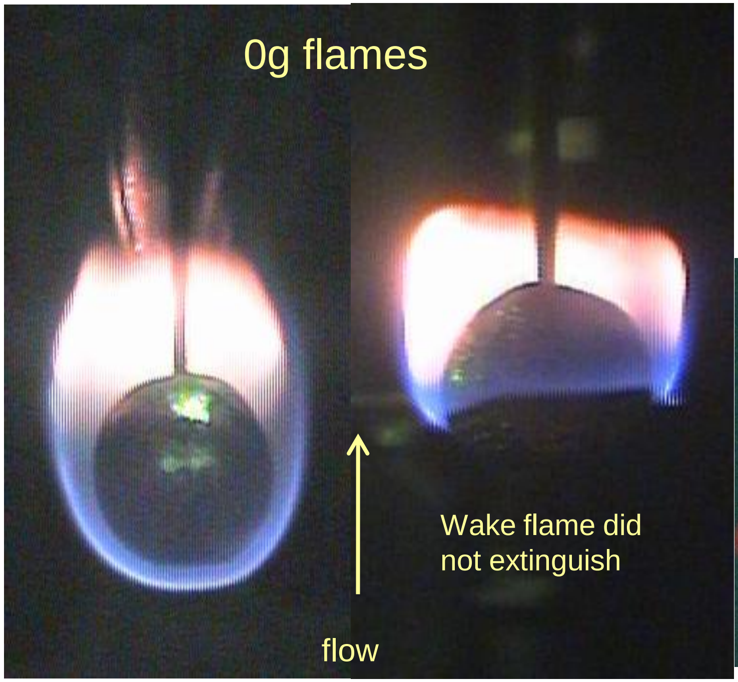
Solid Fuel Combustion and Material Flammability

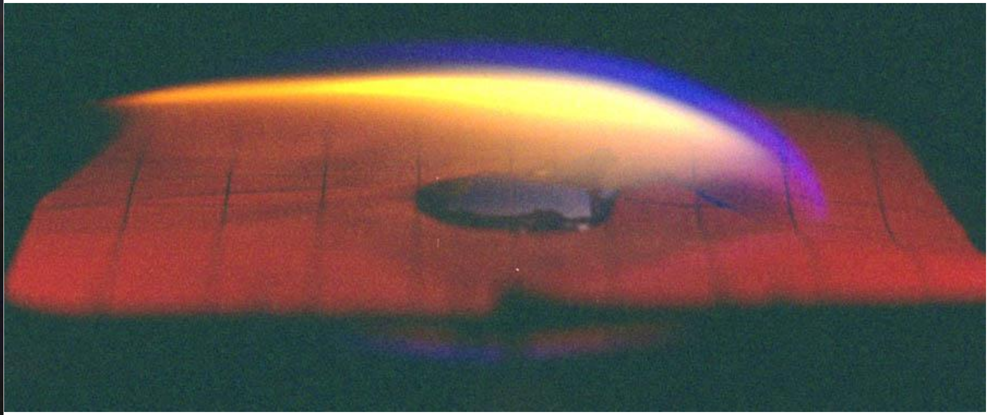
Low speed air flows achieved only in reduced gravity have a strong impact on material flammability.

Flame spread, ignitability, flame growth, and extinguishment behavior in low-gravity are substantially different from 1-g.

The prevalent assumption that 1-g is always a worse case than low-g may be incorrect.

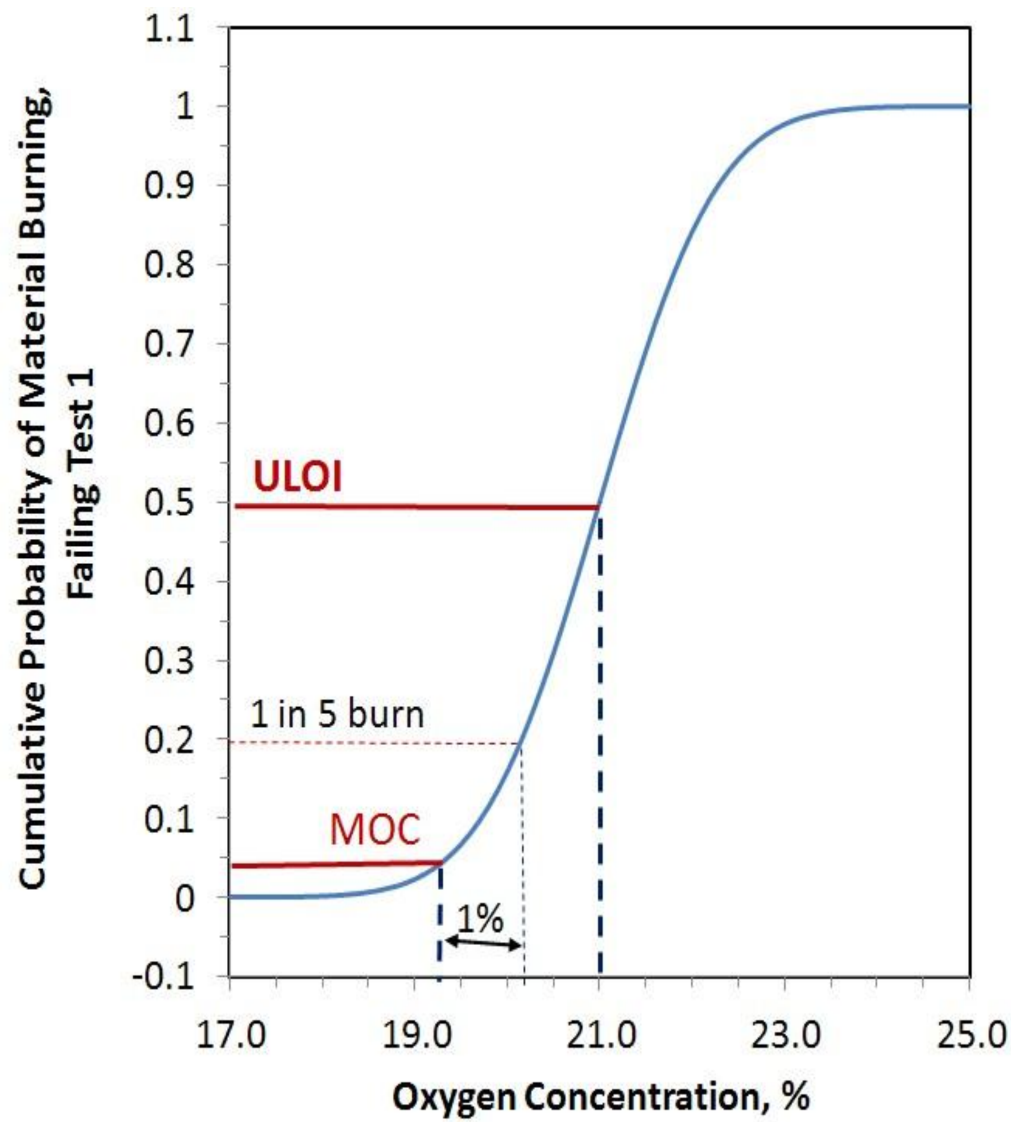




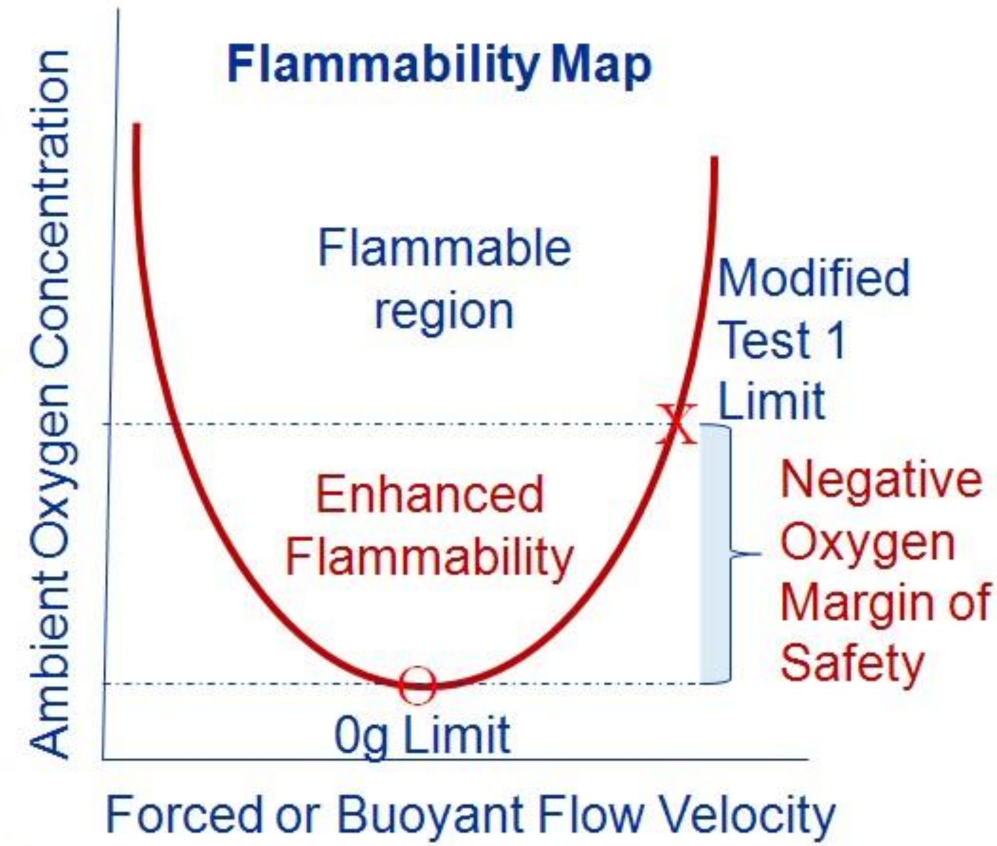


Solid Fuel Combustion and Material Flammability

- The oxygen concentration in Test 1 is successively reduced to find the limits.
- The 1g **ULOI** is defined as the oxygen concentration at which a material passes 50% of the time.
- The 1g **MOC** is defined as the oxygen concentration where at least five samples passed the burning criterion and where at least one sample (20%) failed in the environment that contained 1 percent more oxygen by volume.



Solid Fuel Combustion and Material Flammability



- 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

Solid Fuel Combustion and Material Flammability

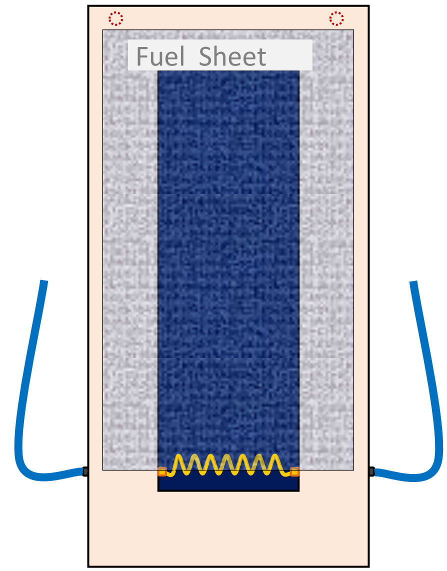
Recent work using a centrifuge in the drop tower holds real promise for exploring partial gravity conditions.

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

Dome

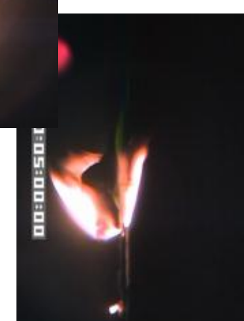
Experiment support plate

Control hardware and electronics

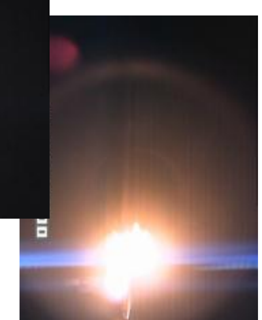


Ultem 1000

Nomex

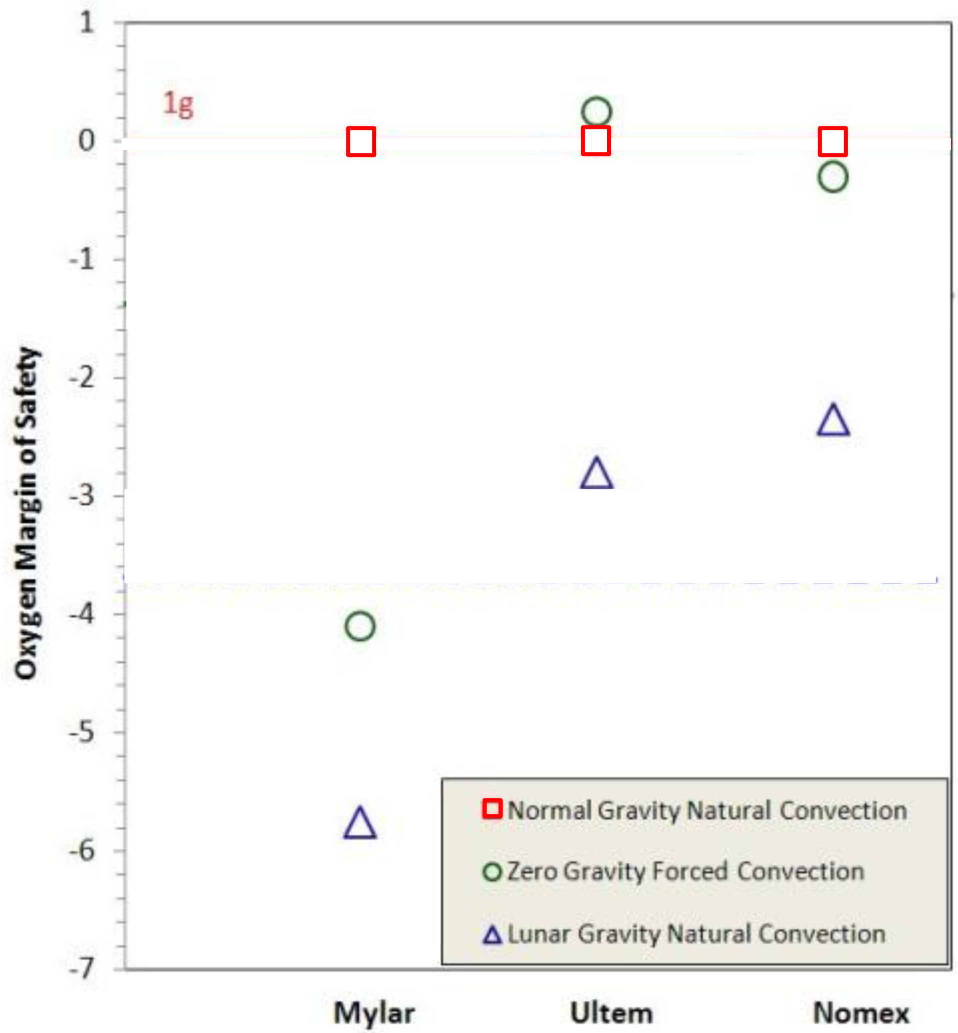


Mylar



Solid Fuel Combustion and Material Flammability

- 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.



Solid Fuel Combustion and Material Flammability

Testing to date has been limited to thin fuels (drop towers) or a few thick samples.

In-flight sample change out and cleanup have hampered experiments.

Orbital testing of real materials is impractical due to chamber opening issues (toxic products and crew time)

Suborbital platform is ideal for these studies.
Test times for many conditions are easily accomplished in a suborbital flight.

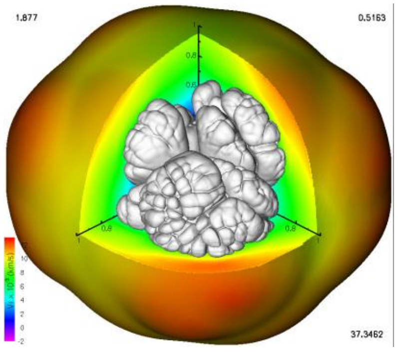
Premixed Flames

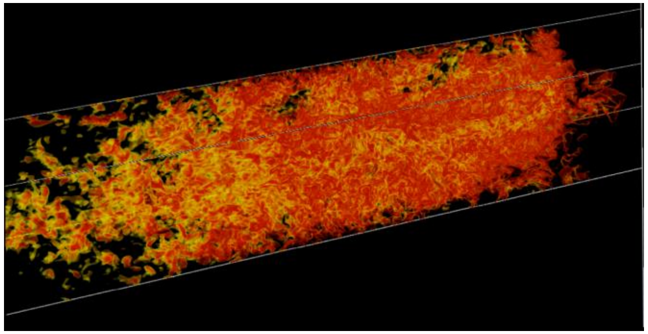
- Typical premixed-gas flames occur in automotive and turbine engines. The goal is to premix fuel and oxidant intimately.
- Premixed flames propagate in background gas *flame velocity*
- Combustion in engines is intensely turbulent, a chaotic mixture of small flamelets.

- Accidental explosions (e.g., in mine shafts, chemical refineries) occur when premixed flames transition to detonations.
- Explosions can originate from barely flammable tiny kernels.
- Understanding premixed flames, *the basic unit of combustion*, is key to understanding turbulent combustion in general.

Premixed Flames

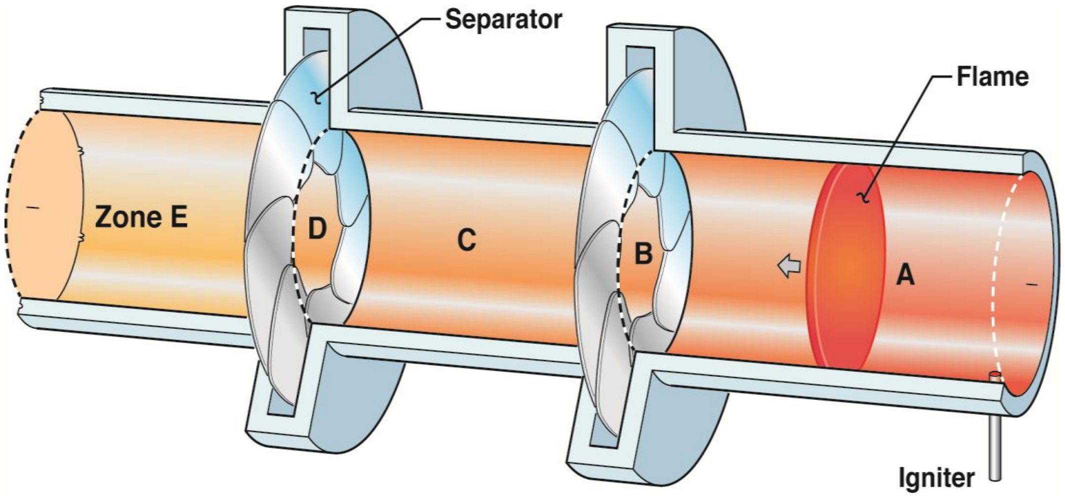
- Fuel-lean combustion (closer to *flammability limit*) promise higher thermal efficiencies and reduced pollutant emissions.
- Near-limit flames are weak (i.e., small flame velocities) and are susceptible to blowout, flashback, instabilities, ….
- Fidelity of CFD codes for design and analysis relies on accuracy of *flame velocities* supplied as input.
- Improving our understanding into what might spark colossal explosions of Type Ia supernovae.
- Thus, implications for energy conversion, fire safety, and even astronomy.





Premixed Flames

- Because of aspect ratio issues, Sounding rockets offer real opportunities for premixed flame propagation studies



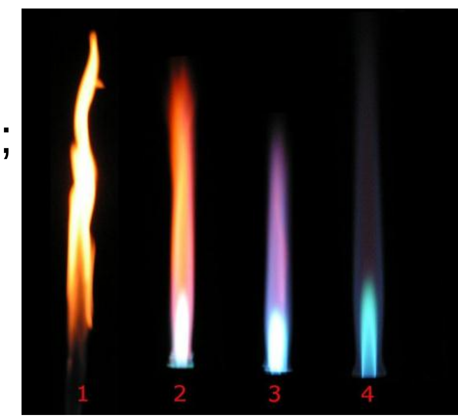
Successive zones can be different
- fuel/oxidant concentration ratio
- diluent concentration or identity
- pressure
- tube diameter
- turbulence level
- Alternatively obstructions can be placed along the tube to observe acoustic interactions

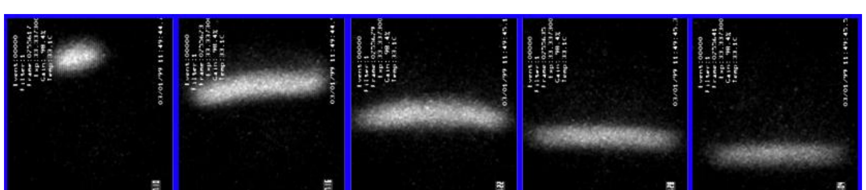
Measurements:
- Flame speed (photodiodes/video)
- Flame behavior recording (video)
- Concentrations (chromatography)
- Pressure

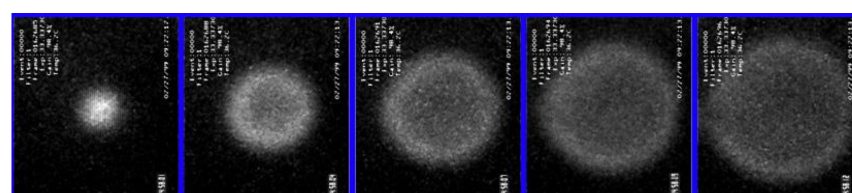
Low-energy Premixed Systems

0-g presents a unique opportunity for low-energy flames:

- Stationary, spherical flame structure (flame balls), proposed by Zel'dovich over half a century ago is achievable in low-gravity.
- Experimental measurements of premixed gas flammability limits in microgravity, clarify issues regarding the role of buoyancy in limit phenomena.
- Opportunities to establish unusual initial conditions (stratification etc.)
- Areas of interest: flame propagation through gradients of reactivity; cool flames; diffusion properties in flame conditions; limit behavior.

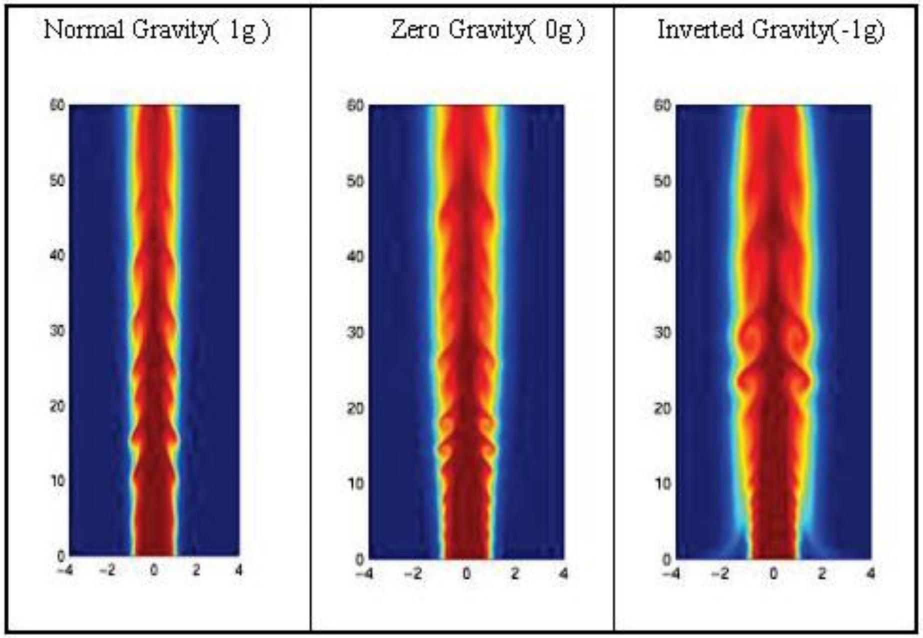


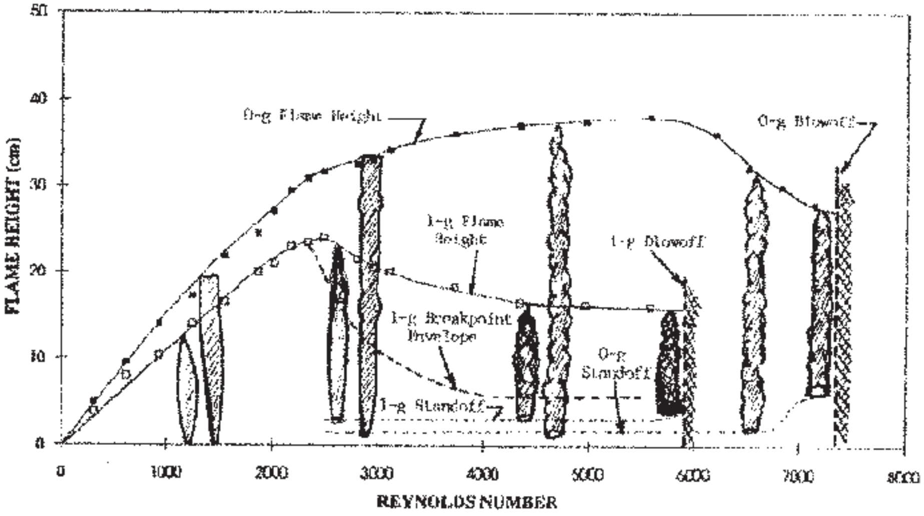




Turbulent Combustion

- Most practical combustors are turbulent
- Buoyancy intrudes on flame structure even at high Froude numbers.
- Fully turbulent flames have never been studied in low-gravity because of the length scale and venting requirements.
- These issues make these flames an ideal candidate for sounding rocket carriers.



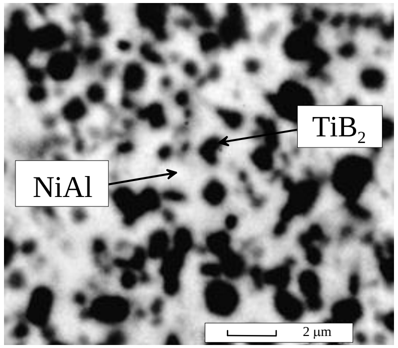


Combustion Synthesis

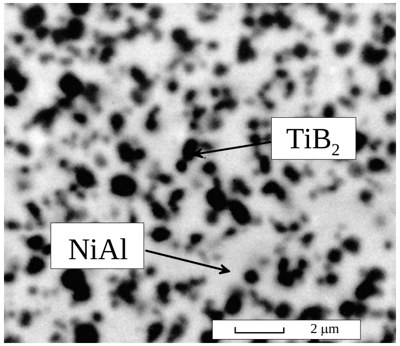
SHS (Self Propagating High-Temperature Synthesis) have shown significant gravity dependence

Increased and more controlled porosity are present in foamed ceramics synthesized in low g.

Readily accomplished in suborbital vehicles due to sample return and sample change out issues



Normal Gravity



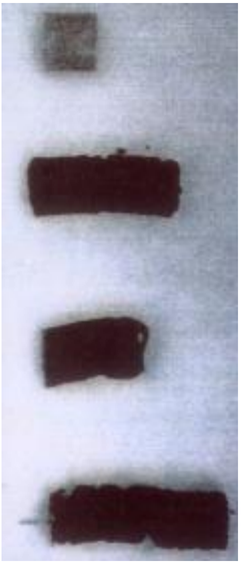
Microgravity

Green Pellet

1-g

2-g

0-g



Capillary Flows and Interfacial Phenomena

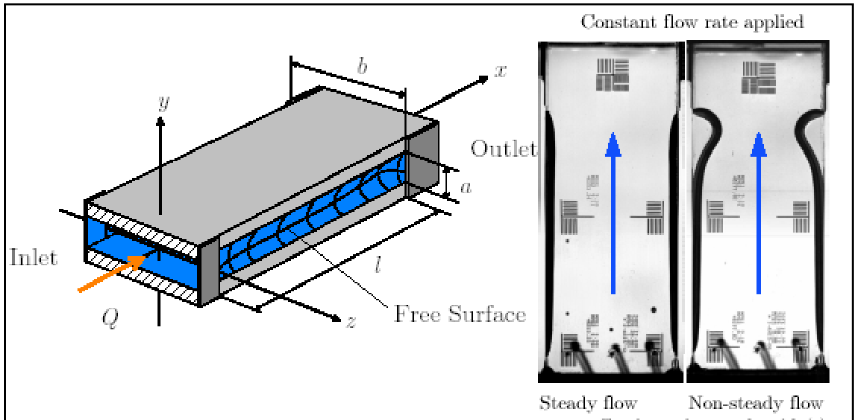
- The dynamics of moving contact lines is an important but poorly understood aspect of wetting and is not only important to NASA for management of liquids in 0-g, but it is also critical to thin films, coating flows, and drying processes.
- There are a number of important basic geometries yet to be studied in microgravity to provide a more fundamental understanding of capillary forces as well as to establish engineering guidelines:
- This research is well suited for the Suborbital platform and compliments NASA funded ISS research.

Fundamental areas:

- Wicks and idealized porous media
- Variable corners
- Materials and their wetting properties

Applied/Engineering areas:

- Liquid Acquisition Devices (tanks)
- Textured surfaces tolerant to partially wetting fluids
- Cryogenic bubble point pressures for screens

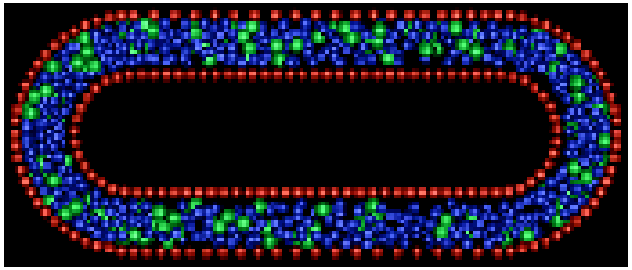


Example of a capillary channel
Liquid withdrawn at the outlet, liquid provided at the inlet


45° vane angle in microgravity.

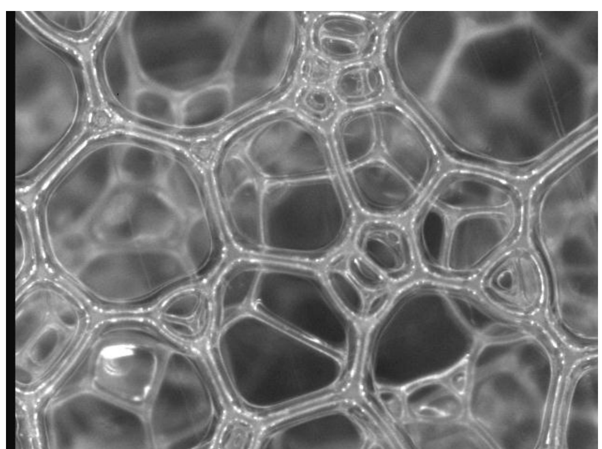

45° vane angle in earth gravity.

Complex Fluids



Study of granular particles size segregation driven by mechanisms other than gravity in a binary mixture (green/blue) of spheres

- MR Fluids
- Foams
- Coalescence and Aggregation
- Granular Flows
- Electrostatics of Granular Materials
- Colloids
- Non-Newtonian Fluids

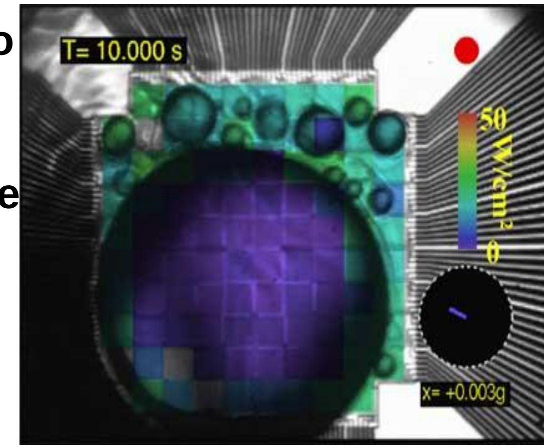


- **Many complex fluids require time scales from 10 minutes to days.**
- **Can use suborbital platform to see valuable initial rate changes for both science and engineering data.**

BCAT-5 colloid experiment presently on the International Space Station (ISS).

Two-Phase Flow and Boiling/Condensation

- A comprehensive study of gas-liquid two-phase flow research in 0-g should be conducted.
- The study should make detailed experimental measurements to develop and confirm two-phase models. These models would be used to enable reliable extension of the application of the fundamental fluid mechanics in two-phase flow behavior for the design of both future space-based and terrestrial systems.



- <u>Research Areas:</u>
- Component characterization such as fittings, tees, flow restrictions.
- Active and passive separat
- Spray cooling.
- System stability tests.
- Condensers.
- Boilers.
- Porous Media.

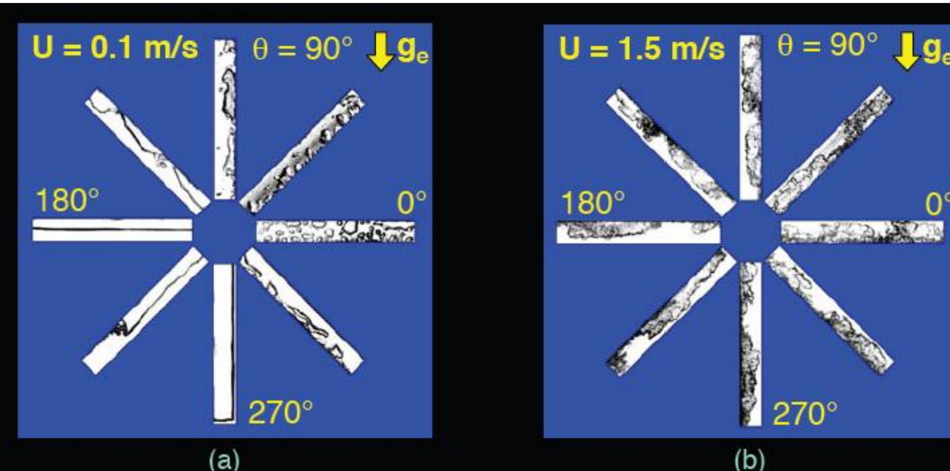


FIG. 6 Vapor behavior just prior to CHF for different orientation at (a) U = 0.1 m/s and (b) U = 1.5 m/s (Zhang, Mudawar and Hasan, 2002).

Boiling and Two-Phase Flow Laboratory *Purdue University*

Conclusion

- Physical Science Research in Fluids Physics and Combustion Science on ISS continues at an aggressive pace.
- However there are significant uncovered areas. Some have been limited for cost reasons and others are not suited for ISS research.
- Areas such as materials synthesis, colloidal systems, capillary flows, turbulent flames, and premixed flames all have direct application to terrestrial systems and should have multiple interested parties (outside of NASA).
- Materials flammability, multiphase systems have direct application to NASA exploration systems.
- Low cost Suborbital flights provide a critical platform to advancing microgravity physical sciences.