Microgravity Science on the ISS

A primer for new researchers

Introduction

The Earth’s Surface

- Weight felt because ground pushes against us
- Physics, chemistry, and biology dominated by the effects of *gravity*

Low Earth Orbit

- Force of gravity is actually 89% of sea level normal
- We don’t feel it in orbit because we’re in a state of perpetual freefall

Freefall

In orbit, we fly fast and high enough to fall and not hit the Earth

The centripetal force from circular motion is equal and opposite to the force of gravity

The International Space Station

A Unique Platform for Science

- Crew tended
- Suitable for long-term studies

Critical Capabilities

- Microgravity
- Exposure to the thermosphere
- Observations at high altitude and velocity

Microgravity is Different

Critical phenomena affected by or dominant in microgravity:

- Surface wetting & interfacial tension
- Multiphase flow & heat transfer
- Multiphase system dynamics
- Solidification
- Fire phenomena & combustion

Gravity-Density Gradients

On the ground, fluid systems stratify by density

- Example: In a boiler, gases rise and separate from the liquids

On orbit, there is no restoring force when the interface between phases is disturbed

- Separation between gases and liquids is indeterminate
- Good for particulate or droplet dispersal, bad for a boiler (or a cryogenic tank)

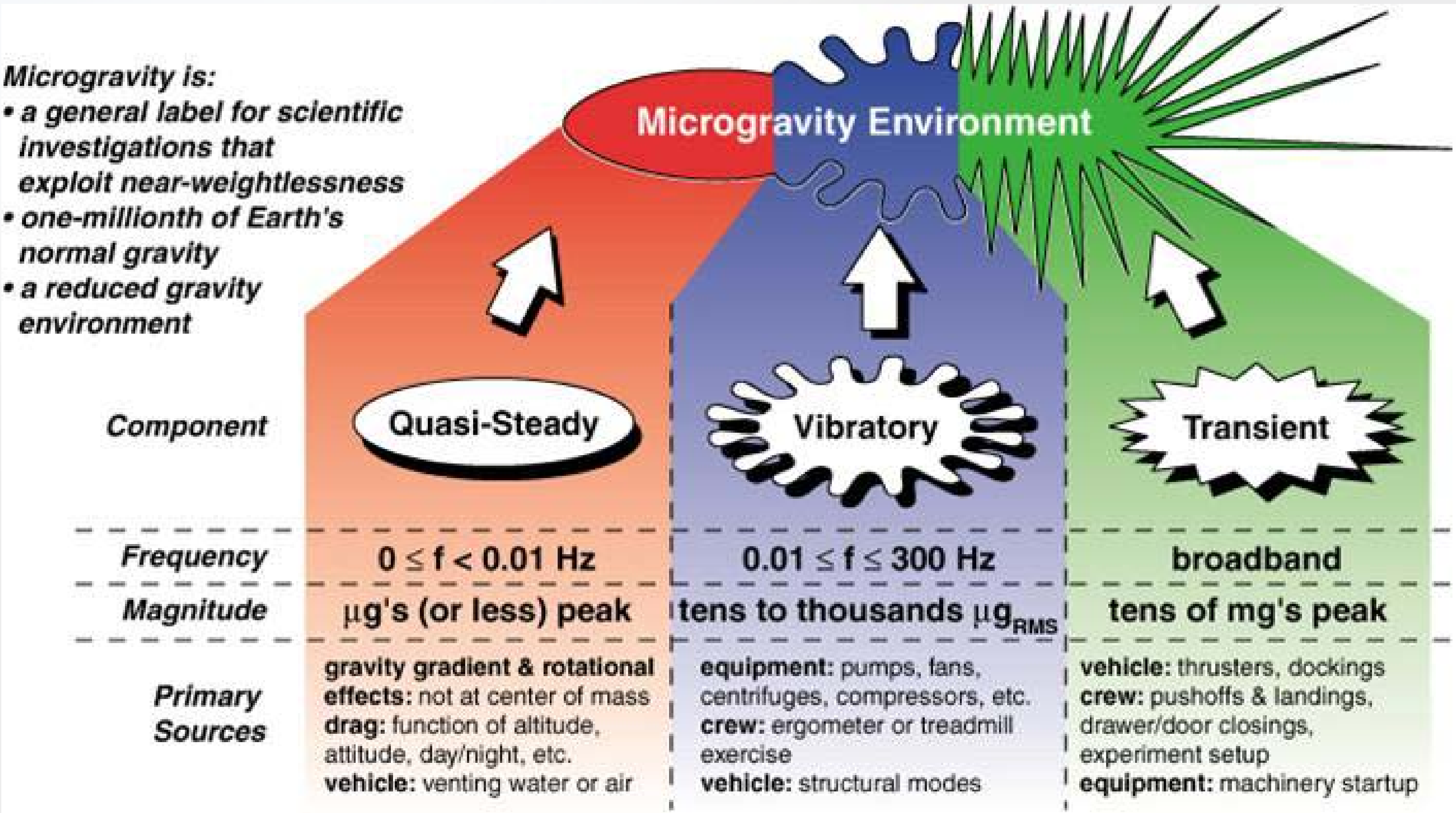
Gravity-Density Effects

Buoyancy becomes insignificant

Underlying processes on Earth emerge

- Pressure-driven flows
- Capillary flows
- Diffusion
- Viscosity
- Electromagnetic forces
- Vibration

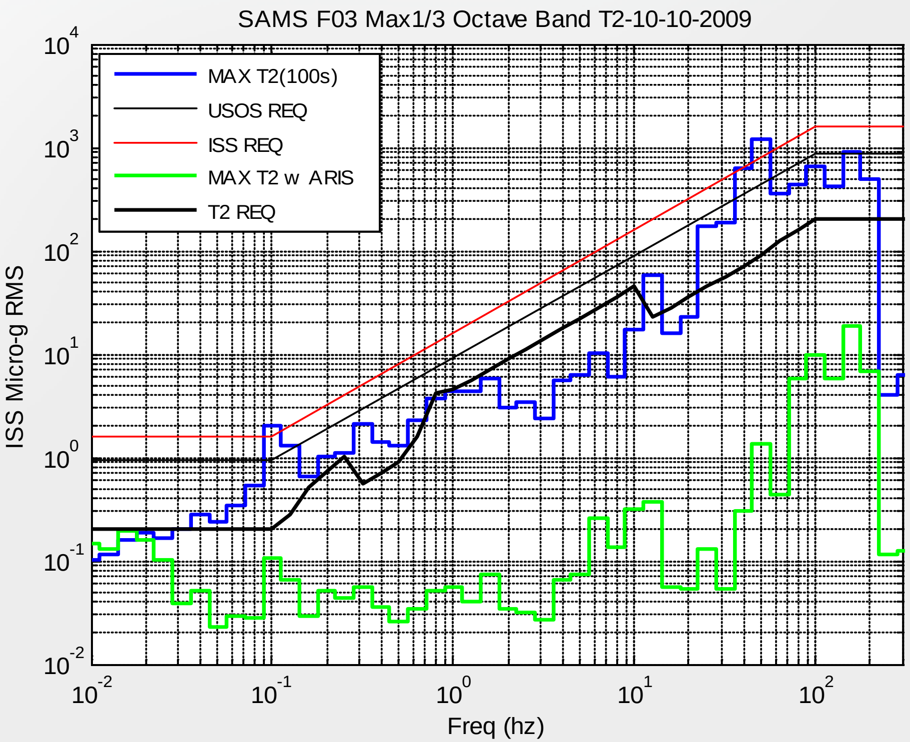
The Microgravity Environment

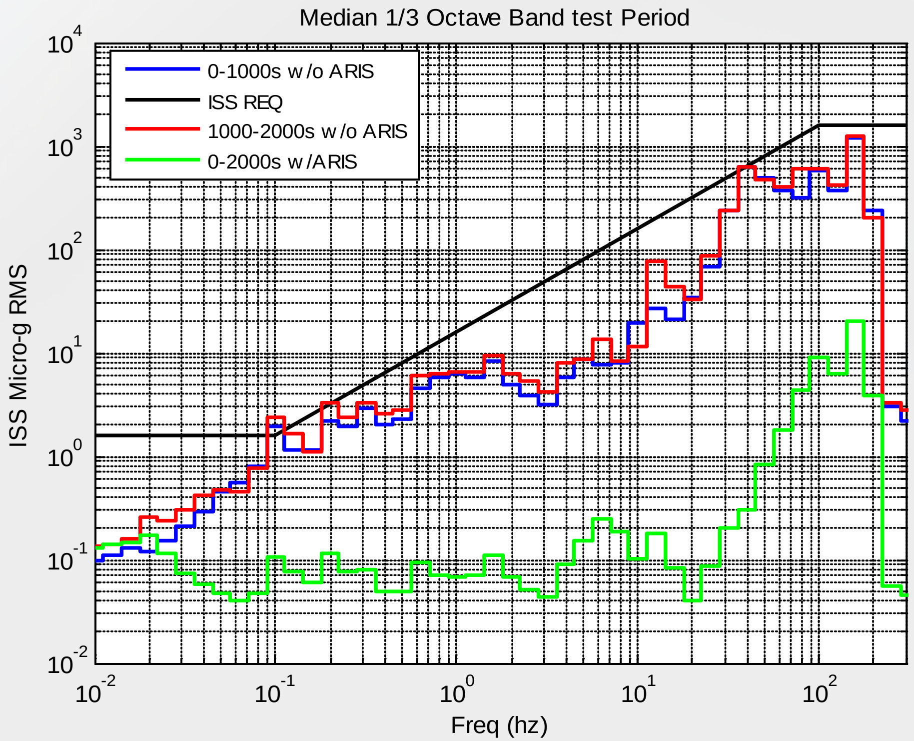


The Microgravity Environment

On-board sensors monitor perturbations to the microgravity state on the ISS.

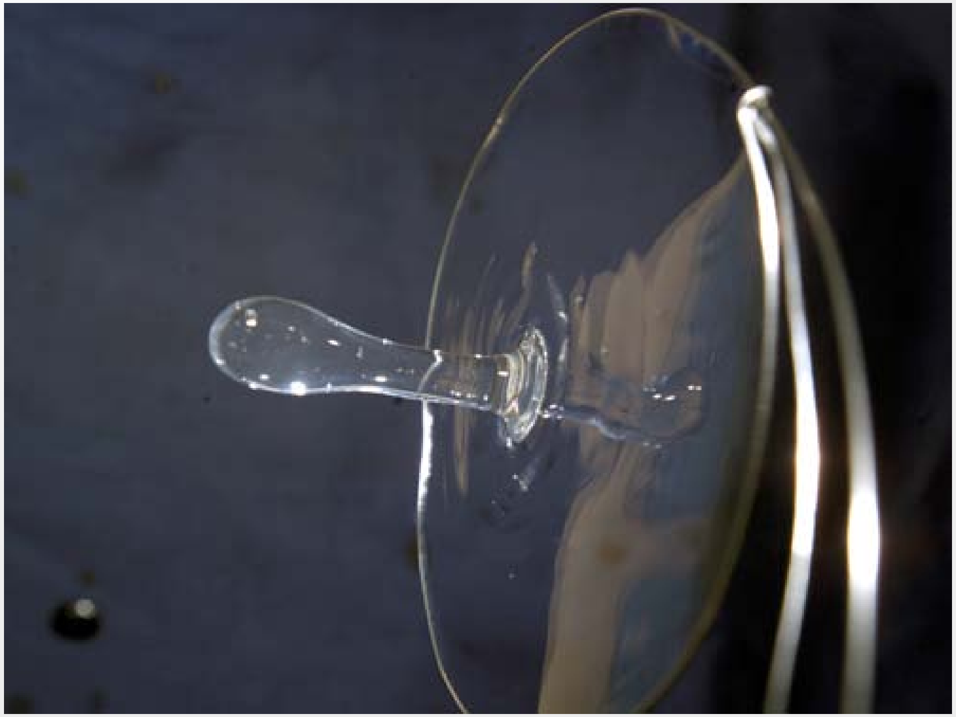
Even without the Active Rack Isolation System, vibrations are typically within ISS requirements.





While the Station is at its most "quiet" during the eight hours of crew sleep, the Active Rack Isolation System can be effective even during crew exercise.

Interfacial Phenomena



Capillary Effects

Surface tension-induced rise/fall of a liquid in a tube

- Static equilibrium shapes in microgravity well-examined
- Uncontrolled excursions due to dynamic effects less quantified

Can dominate flow in microgravity

Wetting

One condensed phase spreads over the surface of a second condensed phase

Not significantly affected by presence of gravity

Can become dominant in microgravity

Marangoni Effect

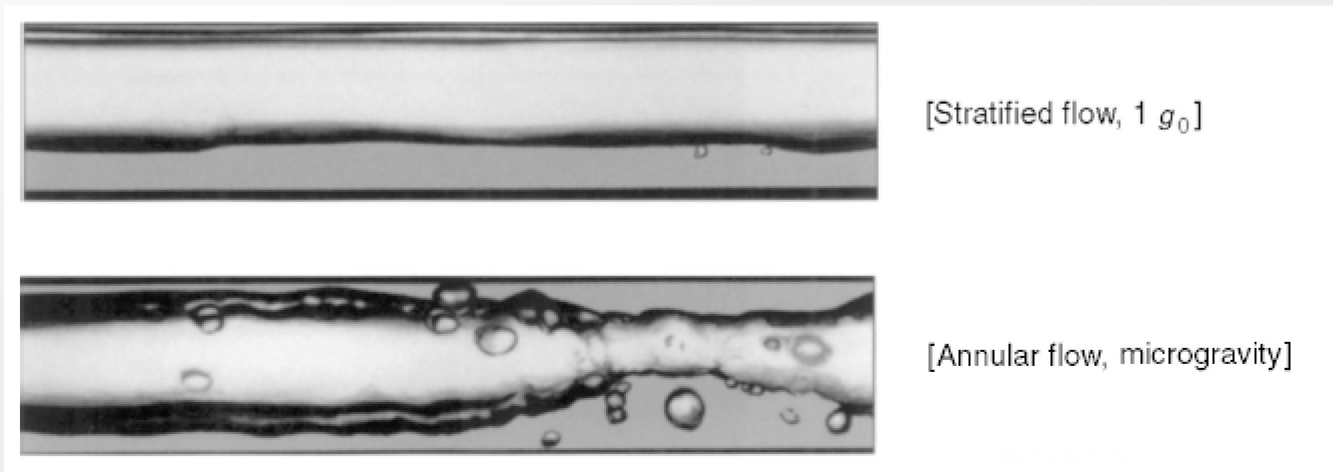
Liquid convection caused by surface tension gradients

- At the free surface of a liquid or interface between two liquids
- Arises in the presence of temperature or composition gradients along the surface

The counterbalancing viscous force to the resultant force from the surface tension gradient

Dominant cause of diffusion in microgravity

Multiphase Flow



Phase Separation & Distribution

The phases in a flowing multiphase mixture may separate non-uniformly under acceleration

- Result of large differences in inertia for each phase

Flow regime transition can occur from lateral phase distributions

Mixing

Chaotic mixing may occur due to turbulence

May be possible to create metallic alloys with fibrous or multilayer film microstructures

- Gravity-induced phase separation prevents this on Earth

Flow of mixtures of immiscible liquids in microgravity little understood

Multiphase Flow Instabilities

Excursive Instabilities

- A boiling system may undergo Ledinegg-type flow excursions if the irreversible pressure loss in the system is much less than the external pressure change

Pressure-Drop Instabilities

- Flow excursions can be converted into periodic oscillations

Density-Wave Oscillations

- Stability increases as gravity is reduced

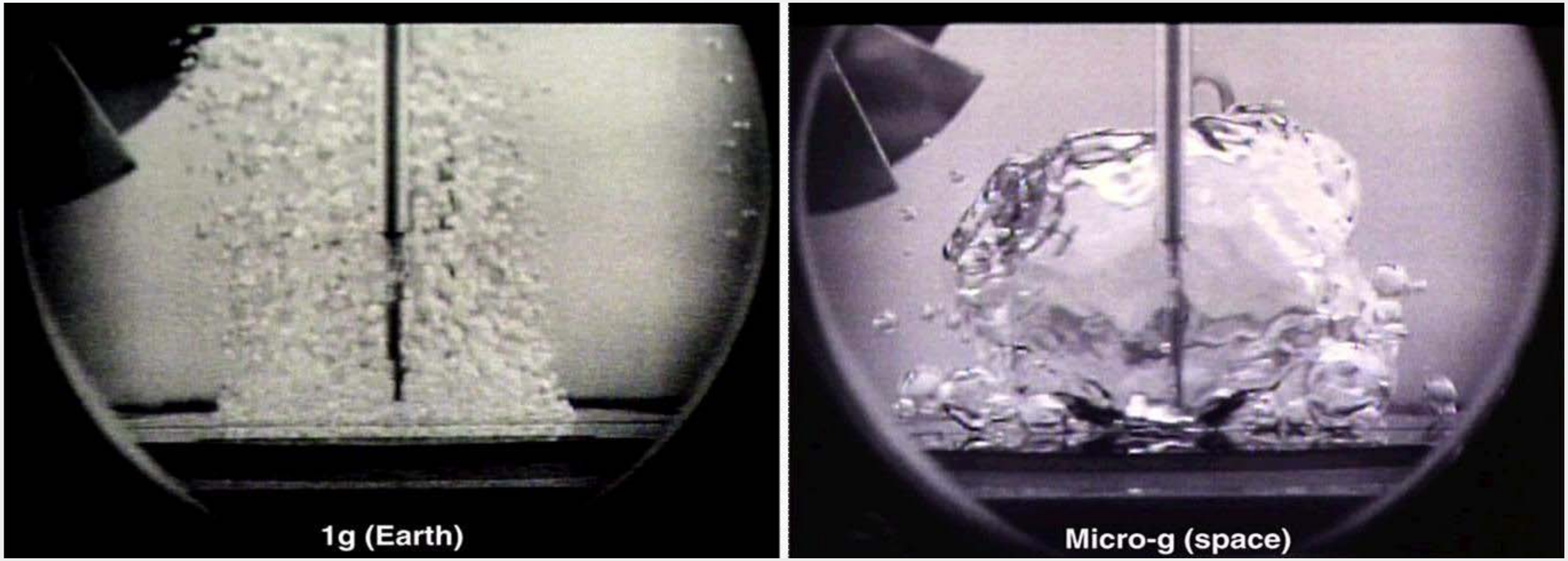
Flow in Porous Media

Capillary and viscous forces control the phase distribution in microgravity

No fundamental studies have been performed in reduced gravity or microgravity

Theory suggests low-frequency gravitational oscillations could significantly affect flow stability

Heat Transfer



Conduction & Radiation

Heat conduction in solids and liquids not affected by gravity

Heat conduction in gases indirectly reduced in low gravity because gas density reduces

Thermal radiation heat transfer is not affected by gravity

Convection

Gravity can greatly affect fluid motion in convection

- Evaporation
- Boiling
- Condensation
- Two-phase forced convection
- Phase-change heat transfer

Convection

Evaporation

- Not well-understood, but likely to be driven by surface tension and viscous forces

Boiling

- Available results are contradictory and do not allow for accurate prediction
- In one experiment, bubbles grew as a result of direct heating from the rod

Convection

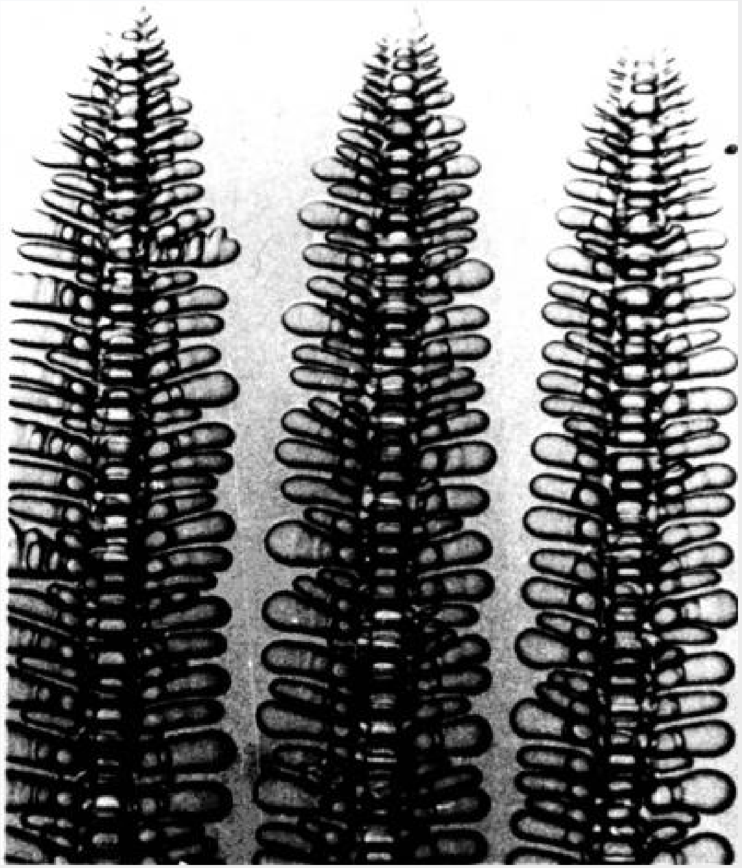
Two-Phase Forced Convection

- Measured heat transfer coefficients are sometimes lower than predicted by normal-gravity correlations
- No experimental data for bubbly flow, little data for slug or annular flow

Phase-change heat transfer

- Melting likely to be affected by thermocapillary forces, instead of buoyancy
- Solidification heat transfer has not been studied in theory or experimentally

Solidification



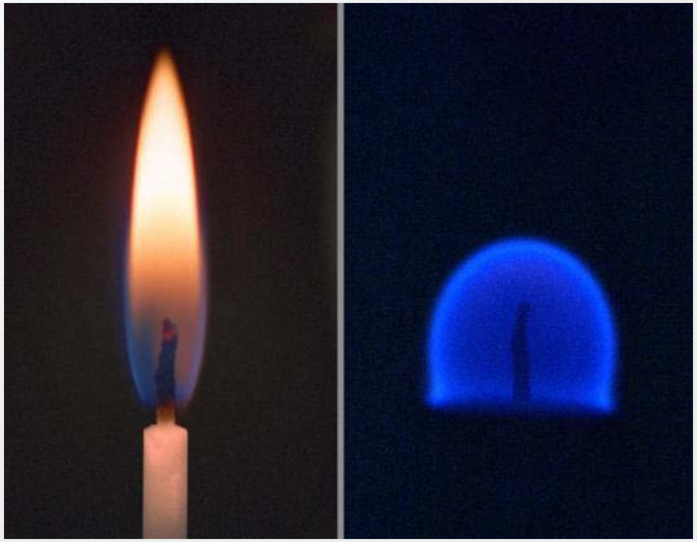
Solidification

Nucleation in a liquid as a result of latent heat loss

The lack of buoyancy-induced convection is dominant factor in microgravity

- Affects distribution of temperature and composition at liquid/solid interface
- Affects distribution of foreign particles and gas bubbles

Chemical Transformation



Ground On-orbit

Combustion

The ratio of buoyancy to viscous forces, the Grashof number, is high on the ground

- High temperature changes lead to large density changes

“Quiescent” combustion studies are virtually impossible to conduct without some element of freefall

Slow-flow combustion also difficult to study on the ground

- High forced-flow velocity required to overcome buoyancy effects

Combustion

Mixture Flammability

- Flammability limits driven by radiative losses and/or effects of chemical kinetics

Flame Instabilities

- Driven by heat and mass diffusion and hydrodynamic effects

Gas Diffusion Flames

- Fuel flow and flame speed mismatching
- Laminar flames longer and wider, more sooty
- Radiative losses increase

Combustion

Droplet Combustion

- Unsteady effects initially slowly increase burning rates & flame diameters
- Soot shells may form

Cloud Combustion

- Uniform dispersion may allow combustion of clouds that would not burn on the ground due to settling

Smoldering

- Oxygen transport to and product removal from smoldering surfaces absent in microgravity

Combustion

Flame Spread

- Opposed with respect to oxidizer flow
- Reduced propagation speed from radiative losses can lead to flame extinction

Thin Fuels

- Flammability may be greater because low-speed opposing flow can overcome higher oxygen limiting concentration

Combustion

Thick Fuels

- No steady state spread
- Increased conduction needed to raise the temperature of the heated layer
- Enhanced radiative losses and decreased oxygen transport lead to flame extinction

Liquid Fuels

- Surface tension gradients draw the fuel out
- Shallow pools behave similarly as on the ground

Pyrolysis

Very dependent on the reactants and products involved

Involves elements of many of the aforementioned processes

For example, oxygen production from lunar regolith would be affected by gas diffusion and heat transport issues

Solution Chemistry

Density-driven convection cannot be used for mixing

- Mechanical stirring and/or careful reaction chamber design can allow complete mixing

Immiscible multiphase mixtures can remain suspended for longer

- Enhanced phase interaction rates possible