Hazard Monitoring and Control in Lunar and Planetary Life-Support Systems

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Hazard Monitoring and Control in Lunar and Planetary Life-Support Systems

- Overview
  - This is not a new topic, but adaptation of existing experience to the exploration mission is *not* simply extrapolation
    - Extended-duration missions introduce reliability and maintenance issues
    - The local environment is very different
  - It is unlikely that effective solutions can be engineered without new knowledge of the detailed relationship between the physical/chemical/biological mechanisms and the environment
  - Issues raised in the context of life support systems are applicable elsewhere. Effective use of precious research opportunities has to be comprehensively planned.

Essential Capabilities in Exploration Life Support Hazard Monitoring and Control

- Protect the integrity of life-support systems, the supply of life-support consumables, and the handling of waste against threats from system failures and environmental factors.
  - Detectors and detector systems linked to the signature of the hazard in the operational environment
    - Performance deterioration
    - Event detection (leaks, fire, contamination, …)
  - Surveillance systems that are sustainable and automated
  - Preventive maintenance that minimizes spares and disposables
  - Emergency response strategies that call for and use relevant sensor and system model data
  - System software as well as hardware

Essential Capabilities in Exploration Life Support
Hazard Monitoring and Control

- Some Hazard Classes in Habitable Environments
  - Fire: material selection, detection, control, recovery
  - Air contamination: equipment failure, material off-gassing, biological, temperature, humidity
  - Air contamination: environmental sources (dust! – again!)
  - Water contamination
  - Food contamination
  - Loss of supplies from leaks: seals, punctures
  - Radiation
- The sources, detection and control of these hazards are affected by gravity
    - Signatures: dominant physical/chemical mechanism is different
    - Transport (detector activation, remediation functionality)

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Challenges to Establishing Essential Capabilities in Lunar and Planetary Hazard Monitoring and Control

- The primary challenges to anticipating, preventing, detecting and controlling hazards in the lunar and planetary environments are derived from *limited knowledge of the effects of those environments on critical systems*.
  - Extreme temperatures (~40K-400K), temperature variations and the environmental consequences of those variations
  - Bombardment by high-velocity particles, solar and cosmic wind molecules and radiation
  - Hard vacuum (<10^{-10} torr)
  - Regolith / regolith dust and it's in-situ transport mechanisms
  - Partial gravity (~1/6th Earth gravity)

Gravitational Environmental

- Gravity induces flow when spatial density variations are present in fluid systems:
  - Multi-phase systems
  - Non-isothermal systems: heat exchangers, reactors, flames
  - The magnitude of the motion depends on the magnitude of density variations, size of the system, & transport properties
- Scale modeling and numerical simulations provide reasonable predictions of behavior, *but only if the correct physical and chemical mechanisms are included.*

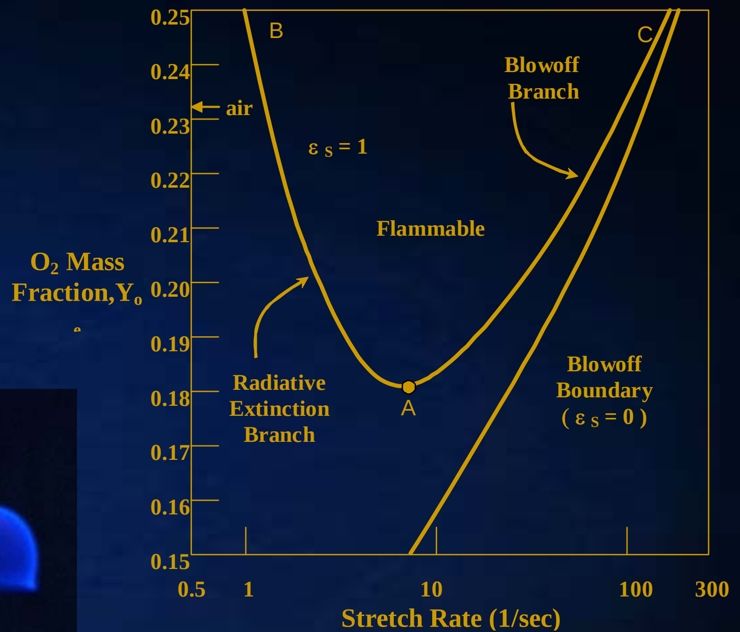
Gravitational Environmental

- Mechanisms important in low gravity are often not apparent in normal gravity observations.
- Microgravity research has provided dozens of examples of new physical insight :
  - Flames in reduced gravity
    - radiation influences or dominates many flames.
    - chemical pathways (soot and other flame emissions) are altered
    - limiting behaviors (e.g. flammability limits) change
  - Two-phase (liquid-gas) systems, motion and heat transfer may be dominated by free-surface effects
  - Microstructure of materials formed in low-g are affected by mechanisms present but small in normal g.

Fire in Reduced Gravity

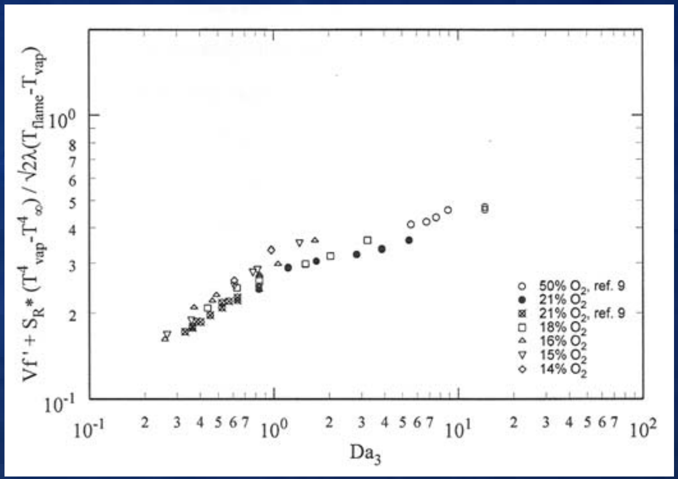
Flames spreading in low-speed flows:

- Early ground-based testing and numerical simulations suggested participation of radiation in spread and flammability limit behavior.



J. S. T'ien, Combust. Flame, (1986)

Candle Flame in Air



Downward Flame Spread over Thin Fuel in Buoyant Flow

Extensive KC-135 testing provided the basis for understanding how flame spread is likely to be enhanced by the lunar gravity level

Without low-gravity testing, the dominant mechanism of flame spread in lunar gravity would be unknown

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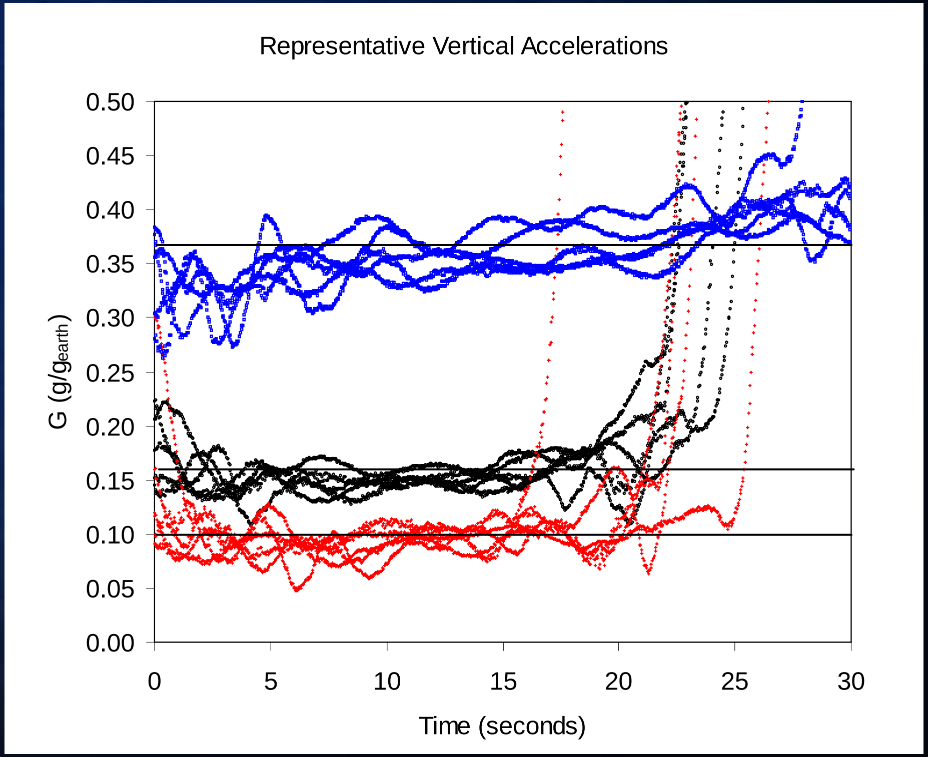
Partial Gravity Testing in Aircraft

- Parabolic aircraft provide partial gravity as well as "micro-gravity"
- Test time and "signal to noise" ratio increase with gravity level
- Short duration tests in reduced gravity provide:
  - Observations of initial transient behavior – some confirmation of system time constants
  - Opportunities to have your science surprises before launch, not during a flight mission
- "Steady" signatures of reacting systems require longer test times than are available on Earth

KC-135 (N930) over Galveston Bay



Research for Design of Exploration Life Support Hazard Monitoring and Control Systems

- For any environmental or system-failure hazard, effective detection and remediation techniques will follow from (or the closest practical approximation of):
  - Knowing the essential physical, chemical and biological properties of the hazard source
    - The properties may change *in the operational environment* and therefore require *In-Situ* measurements.
    - Cost saving extrapolations (i.e. guesses) from terrestrial experience may be wrong and ultimately expensive.
  - Developing and validating analytical, scaling and/or numerical models of hazard sources and remediation techniques which can *link a terrestrial testing protocol with the environment on the lunar or planetary surface*
  - Pre-operational validation of technologies in the operational environment including functionality, system degradation pathways and long-term reliability
  - Adaptation that is responsive to ongoing surveillance of operational performance

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Research Enabled by the Lunar Environment

- Signatures of incipient fires using engineering materials in steady partial gravity environment
- Signatures of atmospheric contamination where the source phenomena is affected by changes in gravity
- The behavior and transport of regolith and regolith dust
  - Partial gravity environment
  - Vacuum
  - Specific interactions with engineering systems (seals, fabrics, mechanical systems, etc.)
  - Regolith properties unaltered by transportation to Earth

Research Enabled by the Lunar Environment

- Ground-based partial gravity testing is a prerequisite useful for discovery, but is insufficient for phenomena with time constants longer than seconds.
- Much of the testing needed to arrive at effective hazard detection and control capabilities could and should be accomplished using robotic missions *before human systems are built*.
- The physical and chemical insight that is possible from lunar-based testing can be useful to multiple engineering capabilities if the planning is done well

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