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Current Trends on the Applicability of Ground Aerospace Materials Test Data to Space System Environments

David B. Hirsch
NASA JSC White Sands Test Facility
Las Cruces, New Mexico
USA

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Agenda

- Current approach to spacecraft fire safety
- Long duration space mission fire safety challenges
- Correlation of ground flammability test data with spacecraft environments

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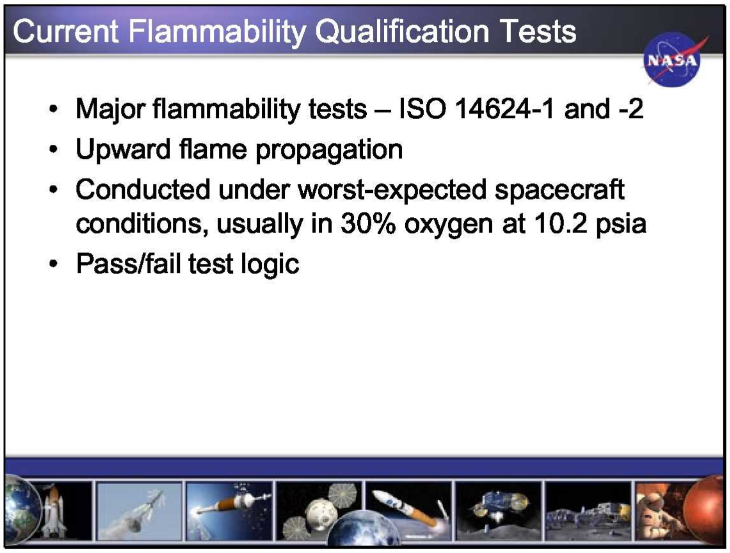

Discuss:
materials passing criteria (pass/fail approach) - qualitative
ignition source - simulates a worst case
testing in the "worst" case expected, usually 30% oxygen, 10.2 psia - explain (pre-EVA operations)
note that the pass/fail logic assumes a direct correlation between 1-g data and flammability behavior in spacecraft environments.
JSC 29353 – Flammability Configuration Analysis for Spacecraft Applications

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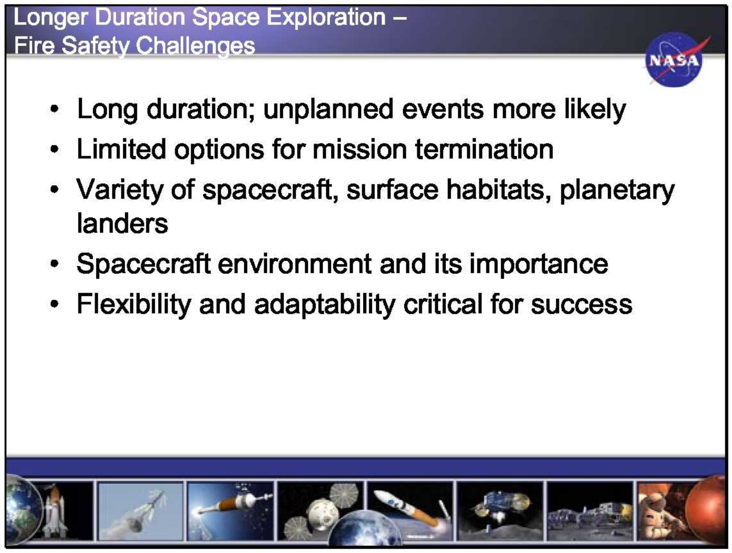

Current safety design challenges
ECLSS designed to handle a CM leak equivalent to 1/4-in. diameter for an hour
Unplanned transitory events: D N EVA C MIR

- Crew Module (CM) depressurization - real event in ISS during late 2002
- Loss of nitrogen - will drive the need to know what max oxygen concentration we can expose the CM to and still manage fire risks;
- Frequency and duration of EVAs will increase, so there may be an increase in emergency rescues of an astronaut in EVA distress; need the capability to respond quickly to EVA emergencies
- Increasing communication delays

The MIR fire of 1997

Limited options for mission termination:
a salvageable event in Earth orbit could be catastrophic during most of the transitory Earth-Mars voyages; the result could be loss of crew and mission.

Flexibility in selecting different environments for various spacecraft, surface habitats, planetary landers, or pressurized extraterrestrial rovers will allow flexibility in space system design and operation. The complexity of space system design often requires changes to mitigate various safety issues, financial impacts, and so on. Design and operational flexibility could result in increased ability to mitigate hazards or develop superior systems with less financial burdens. For example, retesting of materials will not be required if new spacecraft conditions are selected.

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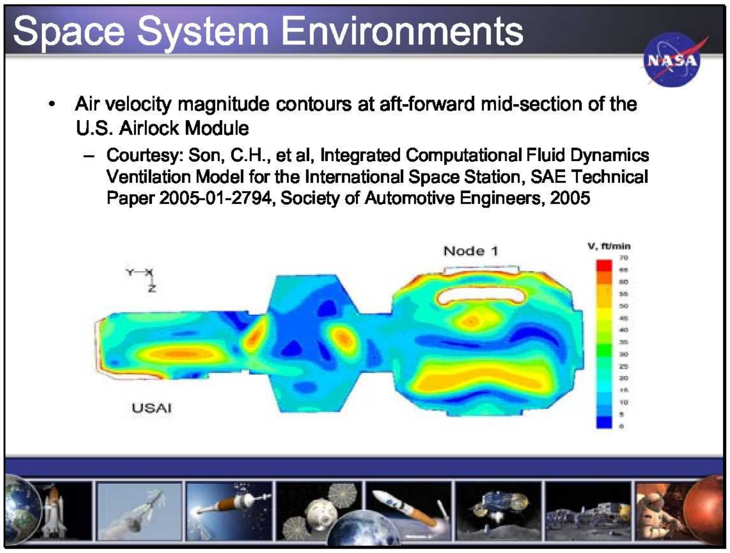

Space system environments

- Range of gravities - large at launch, microgravity during interplanetary travel, reduced gravity on the Moon and Mars
- Ventilated environment, for mixing and spacecraft skin temperature control; for example, a velocity magnitude of up to 20 cm/s is encountered in 75% of the U.S. Airlock. Velocities up to 100 cm/s are also encountered.
- Range of oxygen concentrations and total pressures for various operations (i.e., pre-EVA acclimatization to prevent decompression sickness) - with the oxygen partial pressures kept above the hypoxic levels and oxygen concentrations below what is believed to be the materials' flammability level (subject to epistemic uncertainty with the current pass/fail logic)

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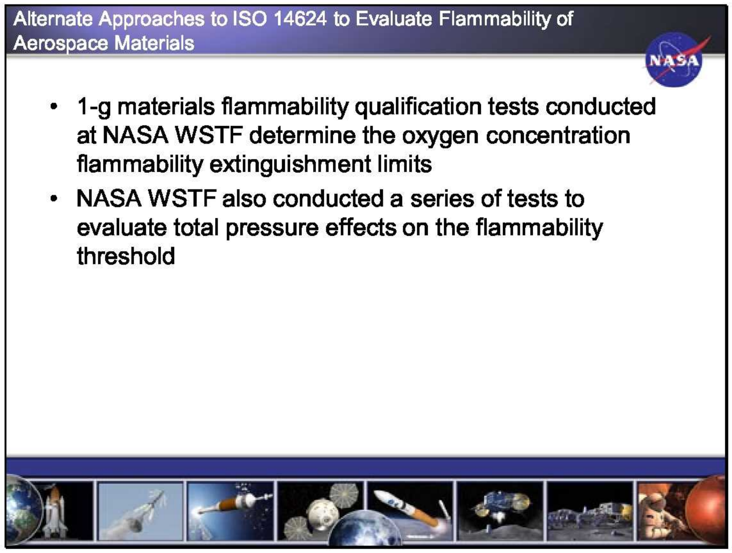

The tests conducted at WSTF will allow flexibility in spacecraft environment selection. For example, we are contemplating having environments of up to 34% in the Lunar surface habitation modules; the oxygen-enriched environments require less nitrogen and would minimize the acclimatization time required for astronauts prior to an EVA.

A practical application example of knowing the pressure effects on the flammability threshold is establishing the internal pressure limit for landing spacecraft at KSC. The WSTF data in corroboration with flammability threshold data in spacecraft environments will allow us to determine fire safety factors. American microgravity test facilities initiated flammability threshold testing following the WSTF approach. In the long term, we will be able to have accurate fire risk assessments, which will allow proper mitigation. As a consequence, we will be able to achieve increased spacecraft fire safety.

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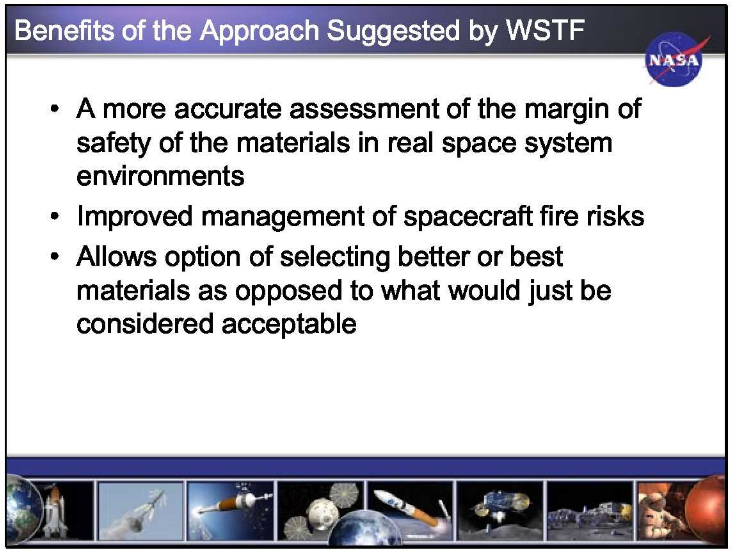

Unexpected space mission events could challenge space system fire safety design boundaries. Correlations of 1-g flammability test data relies on many assumptions, some of which may not stand up to future findings.

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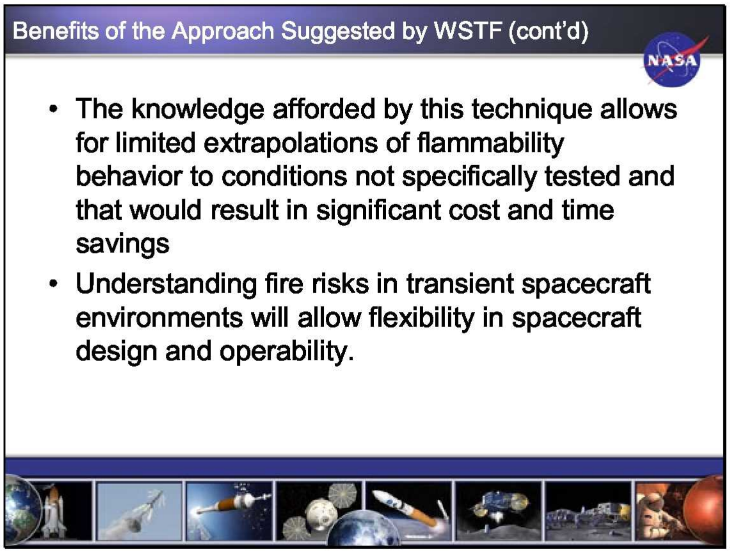

Operational flexibility is of critical importance for advanced space programs relying on integrated designs extending across multiple vehicle atmospheres and focusing strongly on crew safety and operational effectiveness.

In the future, we'll need to work on reducing the epistemic uncertainty related to space system fire safety factors and fire risks in various space vehicles, Lunar and Mars surface habitats, planetary landers, pressurized extraterrestrial vehicles, and other space systems.

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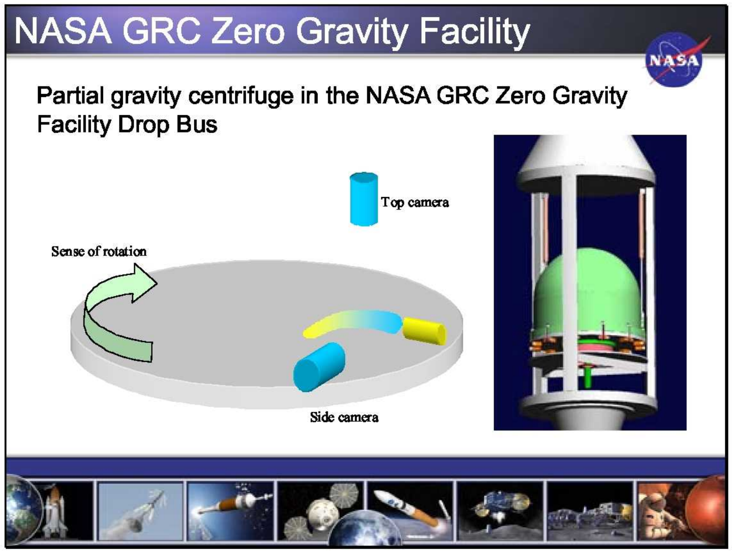

To study the partial gravity effects on ground, a centrifuge was developed for use in drop tower experiments. It consists of a turntable and a chamber dome (since the drop tower is evacuated before a drop). Note that the rotating chamber needs time to spin-up all the internal gas so that it rotates as a solid body. Only then can the analogy of centrifugal force to gravitational force be made.

The centrifugal force $F_{centrifugal}$ = m x omega^2 x R, where m is the mass of the object, omega is the angular velocity, and R is the distance of the object from the axis of rotation. Omega^2 x R is called the centrifugal acceleration.

An important limitation may be imposed by the generation of the Coriolis force, which is due to the fact that the local acceleration depends on the distance from the axis of rotation, R. $F_{coriolis}$ = -2omega x u, where u is the velocity vector of a particle moving inside the reference plane.

Another limitation arises when establishing a flame in normal gravity before a drop: the flame must swing down 90 degrees for the transition to occur, which simply takes too much time.

Unquestionably, the limitations inherent in this experiment must be validated in micro or reduced microgravity airplane flights and space experiments.

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Near Future Work

- NASA GRC and WSTF proposed a comprehensive program on correlating 1-g flammability threshold data with a variety of spacecraft-specific environments (response to a NASA Research Announcement)
  - Oxygen concentration and pressure effects (prevalent, transitions, extremes)
  - Ventilation effects (0 to 1 m/s)
  - Microgravity or partial gravity effects

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Proposed Testing – 1 g

- Materials with oxygen concentration thresholds in the 25 to 35% range will be tested
- Most oxygen concentration flammability thresholds will be evaluated at the spacecraft prevalent pressure (14.7 psia)
- Further 1-g tests will focus on the immediate post-ignition and flammability extinguishment behavior to attempt determination of a pass/fail criteria amenable to the short duration of ground microgravity tests

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Proposed Testing – Parabolic Flights

- Most reduced gravity and microgravity testing will be conducted in parabolic aircraft flights
- Approximate test time: 22 s

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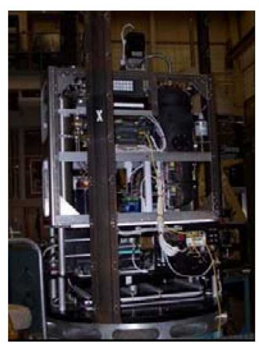
Proposed Testing – Parabolic Flights (cont'd)

- The NASA GRC microgravity wind tunnel will be modified for parabolic flights



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Microgravity Wind Tunnel Capabilities

- Flow velocities of 0 to 30 cm/s while maintaining the total test chamber pressure constant
- Total pressure range: 0-14.7 psia
- Oxygen concentration range: 0-100% oxygen

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Proposed Testing – Experimental Design

- Under set conditions (prevalent spacecraft pressure, commonly encountered surface flow velocities of
  30 cm/s), determine the oxygen concentration flammability threshold in reduced gravity and microgravity
- Current limited data indicates that somewhere between zero and 30 cm/s flow velocities the 1-g data becomes less conservative than data in microgravity and reduced lunar gravity

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Proposed Testing – Experimental Design (cont'd)

- Continue oxygen concentration flammability threshold measurements at lower velocities until a flammability velocity threshold is obtained where the oxygen concentration thresholds in 1-g and microgravity coincide
- Build a flammability threshold map and compare microgravity and 1-g threshold limits. The data will allow evaluation of the level of conservativeness (or the lack of it) of 1-g data ("safety factors")

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Proposed Testing – Experimental Design (cont'd)

- Computational Fluid Dynamics (CFD) of spacecraft flow velocities will identify zones where 1-g materials qualification data is not conservative and if ignition occurs, flame propagation would be possible. This will provide information for ventilation design to improve spacecraft fire safety.
- Knowing parametric effects on the flammability threshold will allow effective spacecraft fire risk management.

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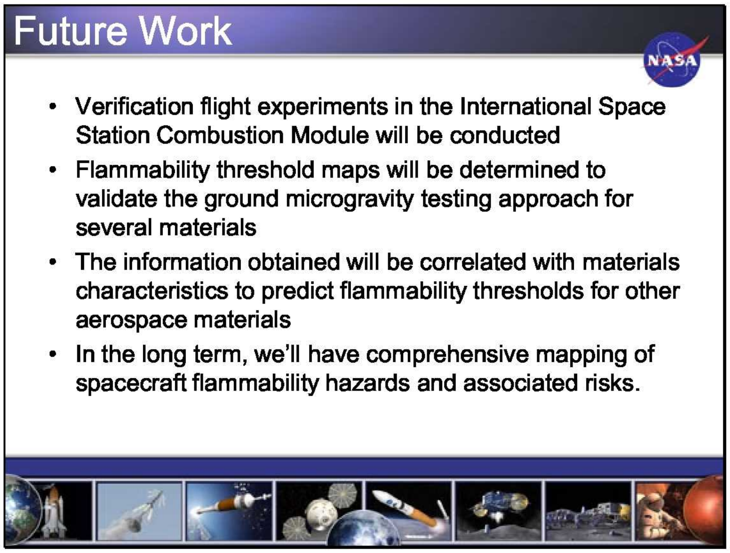

The approach to testing has been described in detail in a Technical Specification which has been proposed as a new work item