National Aeronautics and Space Administration

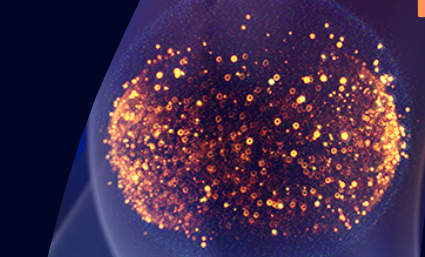


# Update on NASA Materials Flammability Research

7th FLARE International Workshop
September 8-10, 2021

David Urban
NASA John H. Glenn Research Center

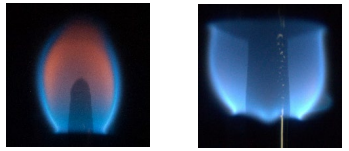
# Active programs



- **SoFIE- ISS**
- **FLARE – ISS (not discussed in this presentation)**
- **MWT – ISS : currently on hold pending Decadal Review**
- **Saffire**
- **Lunar Flammability Test Program**
  - Drop Tower
  - Modeling
  - Parabolic Aircraft (collaboration with ESA)
  - Sub-orbital
  - Lunar Lander
- **Electro motive Drop Tower**

# ISS-SoFIE

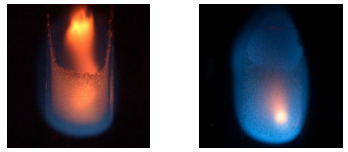
## Solid Fuel Ignition and Extinction (SoFIE)



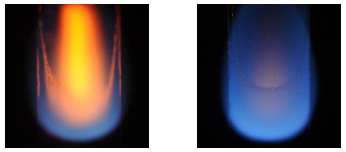
**Material Ignition and Suppression Test (MIST)**
**A. Carlos Fernandez-Pello: UC Berkeley**
Fundamental experiments of solid material ignition from an external heat source



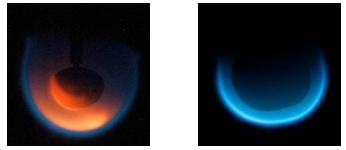
**Spacecraft Materials Microgravity Research on Flammability (SMµRF)**
**Sandra Olson: NASA GRC**
Flame spread experiments studying the flammability limits of solid fuels



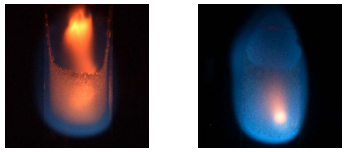
**Narrow Channel Apparatus (NCA)**
**Fletcher Miller: San Diego State University**
Flame spread experiments focused on thick polymeric materials



**Residence Time Driven Flame Spread (RTDFS)**
**Subrata Bhattacharjee: San Diego State University**
Opposed-flow flame spread over thin acrylic sheets to examine fuel thickness effects

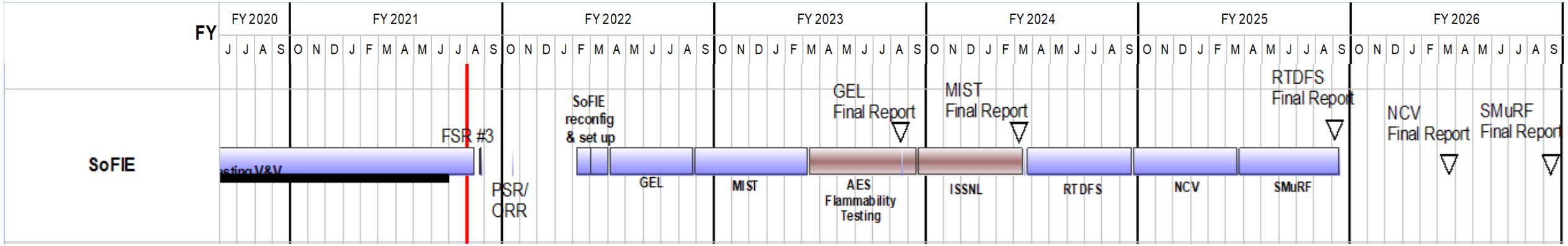


**Growth and Extinction Limit (GEL)**
**James S. T'ien: Case Western Reserve University**
Investigating effect of gravity, flow, $O_2$, pressure, and fuel preheating on the combustion of polymeric spheres



**Material Flammability test for Spacecraft Materials**
**Advanced Exploration Systems, Gary A. Ruff Project Manger**
Testing spacecraft materials for comparison with NASA 6001 Test 1

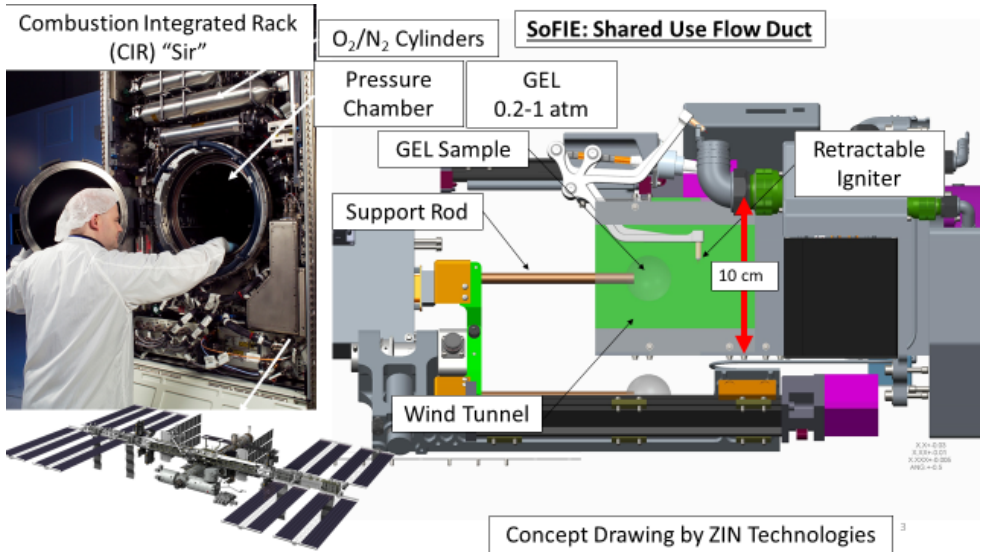
# SoFIE Schedule




Additional Investigations:

AES: Material Flammability test for Spacecraft Materials

ISSNL: National Science Foundation investigation into flame spread under fluctuating air flow



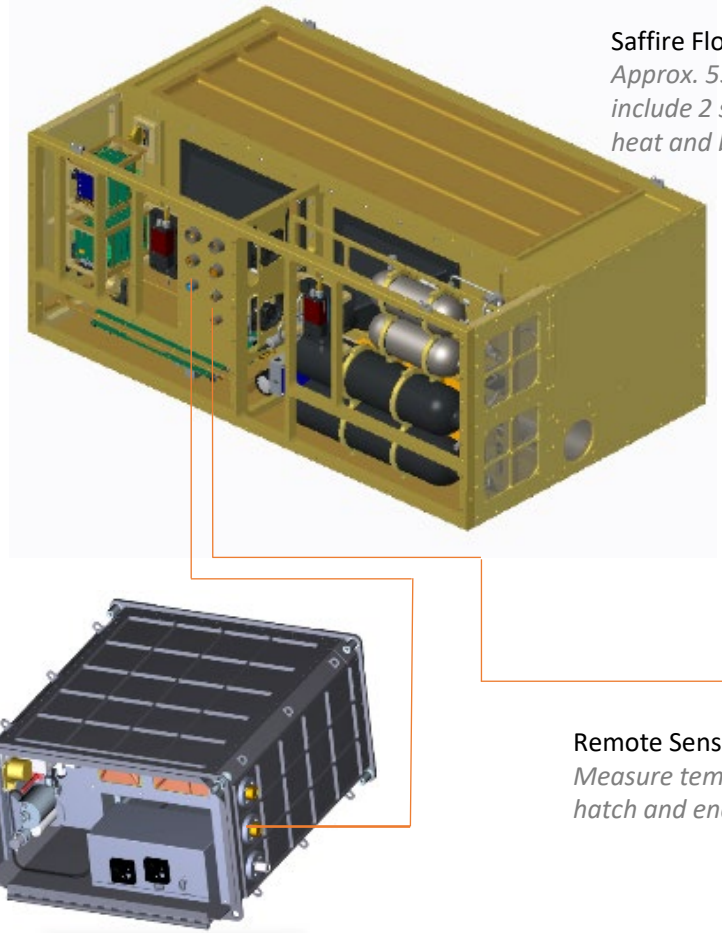
# Saffire Motivation and Background

- **How rapidly can a fire spread in low-g?**
- **How long will it take to detect it?**
- **How will it affect vehicle habitability?**

**Background**

- Saffire I-III flew in 2016 & 2017
- Examined fire growth on thin fuels and flammability limits

- **Saffire IV-VI objectives**
  - Consider thick fuels, longer burn times & exploration atmospheres,
  - Examine impact on the vehicle and post fire recovery
  - Saffire IV and V flew in 2020 and 2021
  - Saffire VI postponed, targeting late 2022-early 2023



Saffire Flow Unit
*Approx. 53x90x133cm. New features include 2 side view cameras, acid gas, $O_2$, heat and byproduct release to cabin*

Remote Sensors (6)
*Measure temp & $CO_2$ in standoffs, hatch and end cone*

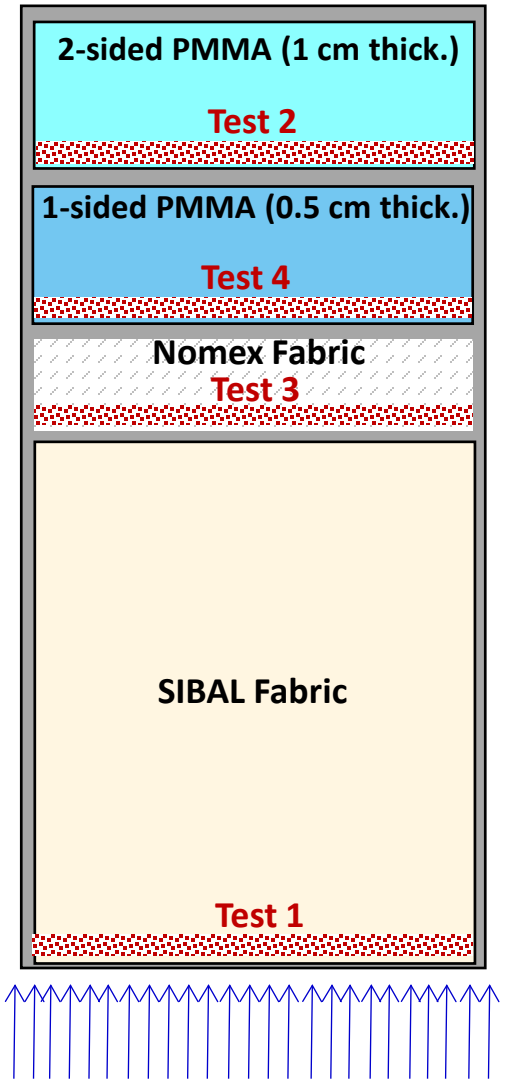
Far Field Diagnostics (in Mid Deck Locker)
*Avionics, $CO_2$ scrubber, Smoke Eater, Combustion Products Monitor, particulate monitors (DustTrack & Ion Chamber)*

**ALL terrestrial occupied structure types have been the subject of full scale fire tests (planes, ships, cars, trains, buildings, mines etc.)**

# Saffire sample configuration

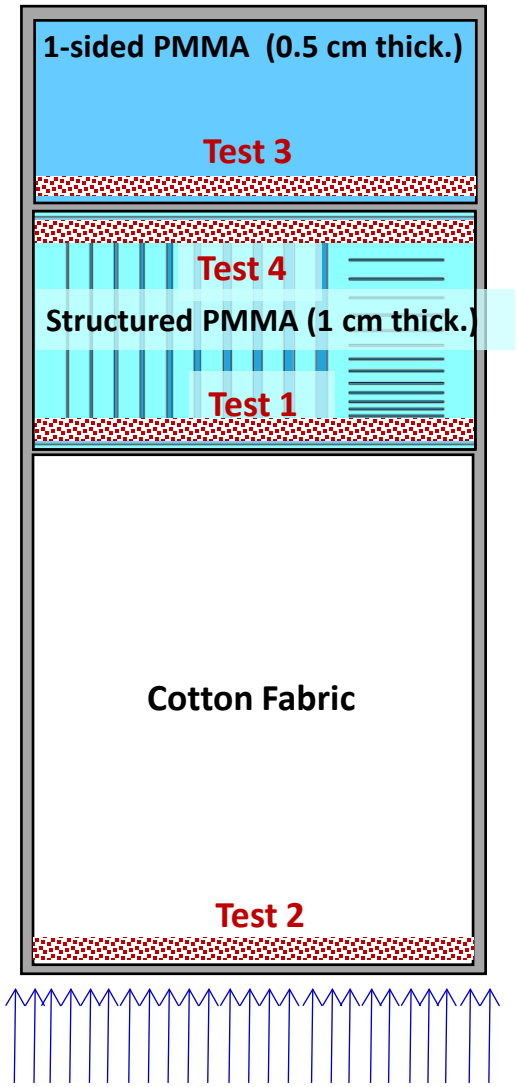
**Saffire IV**

**(Saffire VI card is identical but the test order will change**




Air and Normoxic $O_2$ with forced flow

**Saffire V**




Normoxic $O_2$ with forced flow

# Saffire IV-V Test Matrix (as executed)

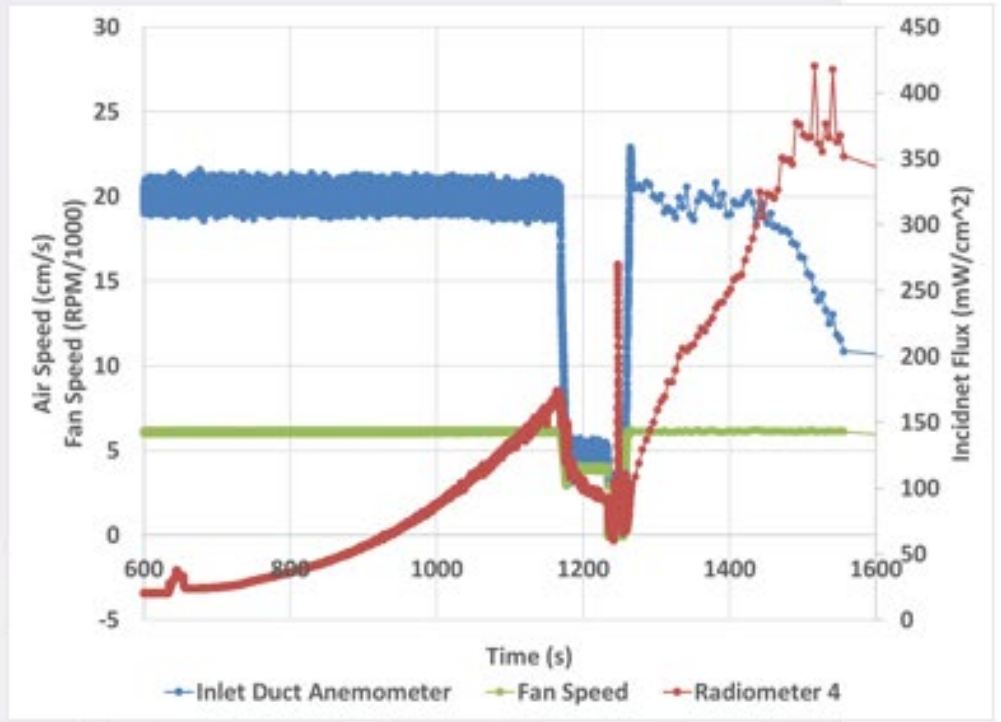
| Flight/Sample | IV-1 | IV-2 | V-2 | V-3 | V-4 |
|---|---|---|---|---|---|
| Material/configuration | SIBAL Cloth | 2-sided PMMA | Cotton Jersey | 1 sided PMMA | Structured PMMA |
| Length (cm) | 50 | 18 | 50 | 18 | 20 |
| Air Flow Rate (cm/s) | 20 | 20 | 20 | 20 | 20 |
| Flow Direction | Concurrent | Concurrent | Concurrent | Concurrent | Opposed |
| Ambient Pressure (kPa) | 100.0 | 100.0 | 70.7 | 71.3 | 72.6 |
| Oxygen Concentration (mol %) | 22.0 | 22.0 | 26.2 | 25.4 | 25.7 |
| Pressurized Volume ($m^3$) | 18.7 | | 19.2 | | |
| Free volume ($m^3$) | 17.9 | | 19.0 | | |

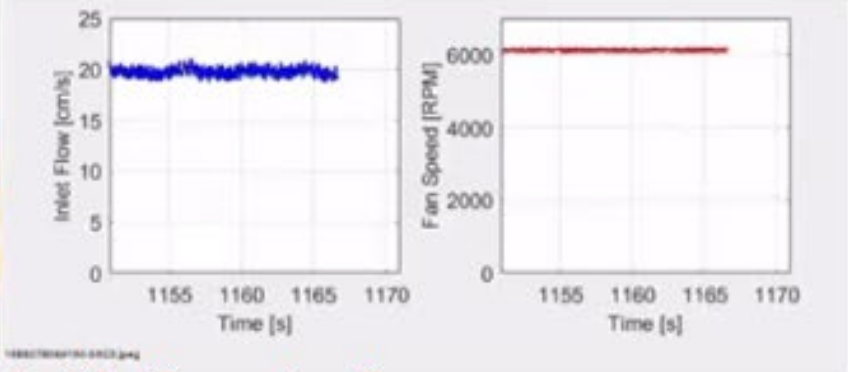
# Findings-Extinguishment







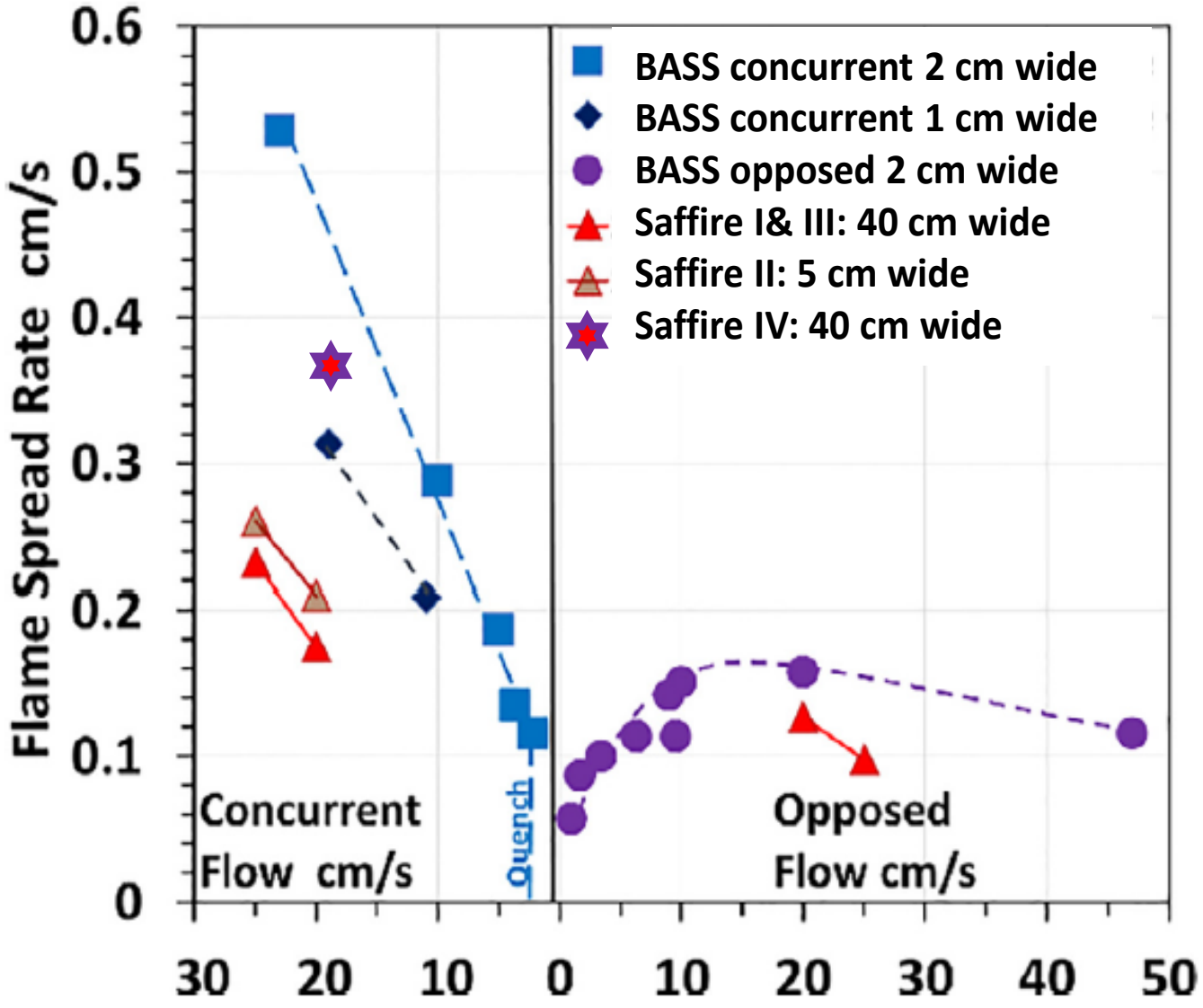




**Extinguishment of bubbling polymers cannot be assumed to occur rapidly in quiescent conditions**

*Flame shrank during the reduced flow interval of 65 seconds but survived the 15 second no-flow interval.*

*Flame extinguished below the sample for 6.4 seconds but reignited*

# Findings - Spread rate

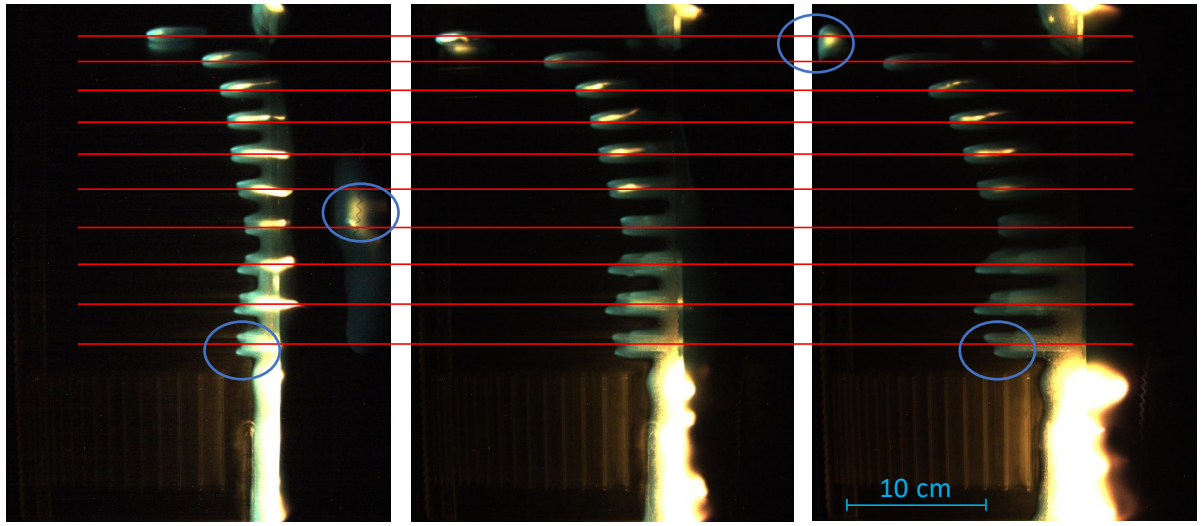



**Duct size and flow development can affect the spread rate and the pyrolysis length**

Effect of sample size and duct dimensions

*Saffire I-III were in a 46 cm duct and Saffire IV was in a 30 cm duct.*

# Findings - Surface structure



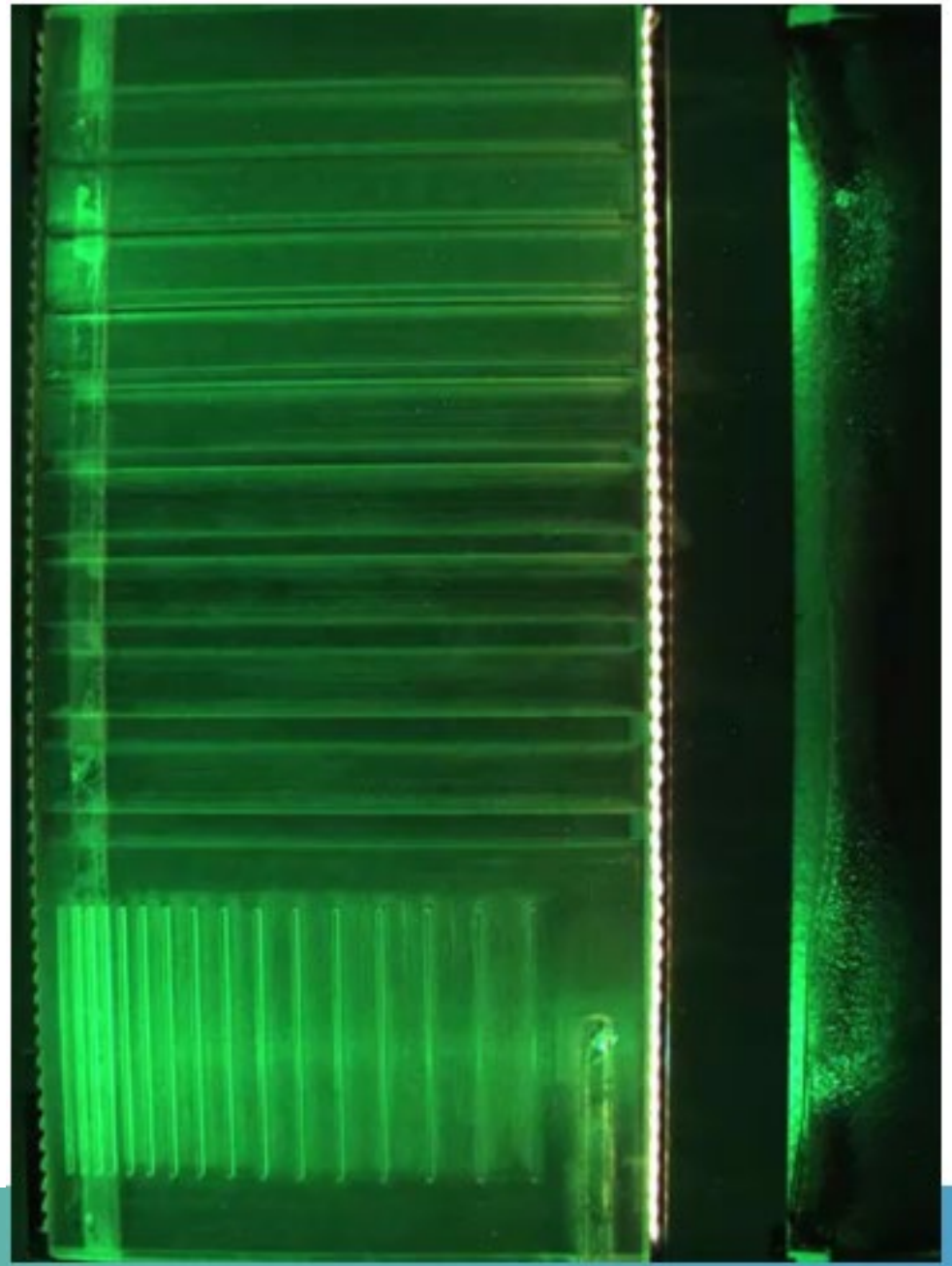

**In opposed spread over thick materials, the size of ridges or other surface shape structures can have a significant effect on flame spread.**

**Opposed flame spread on ribbed PMMA.**

***Flow is from left to right at 20 cm/s.***

***Sample rib centerlines (red lines) are indicated. Ribs are 3 mm high with widths increasing from 1 mm to 10 mm by 1 mm increments***

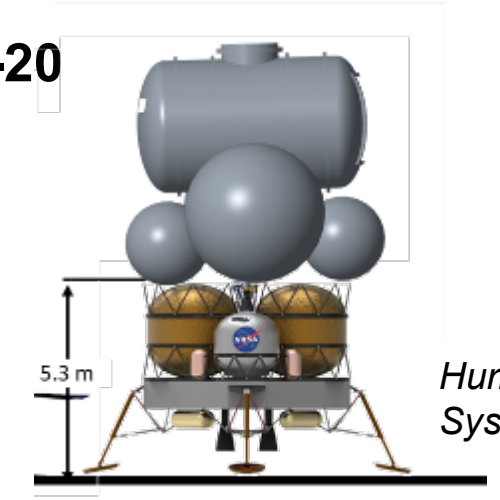
***2 cm between adjoining rib faces***



# NASA's Lunar Lander/Habitat

- **Reduced total cabin pressure and increased oxygen concentration: 8.2 psi/56.5 kPa and 34%+ vol.% $O_2$**
  - Decompression sickness prevention
  - Less preparation time for extravehicular activities
- **Partial gravity $g_{lunar}$=0.16 $g_{earth}$**
- **Low velocity flows (HVAC) ~ 10-20**




*Human Landing System concept*

# Experimental Results:
# Effects of pressure, oxygen concentration and gravity

1 g

Ambient Pressure

100 kPa | 80 kPa | 60 kPa | 50 kPa | 40 kPa | 30 kPa | 25 kPa | 15 kPa

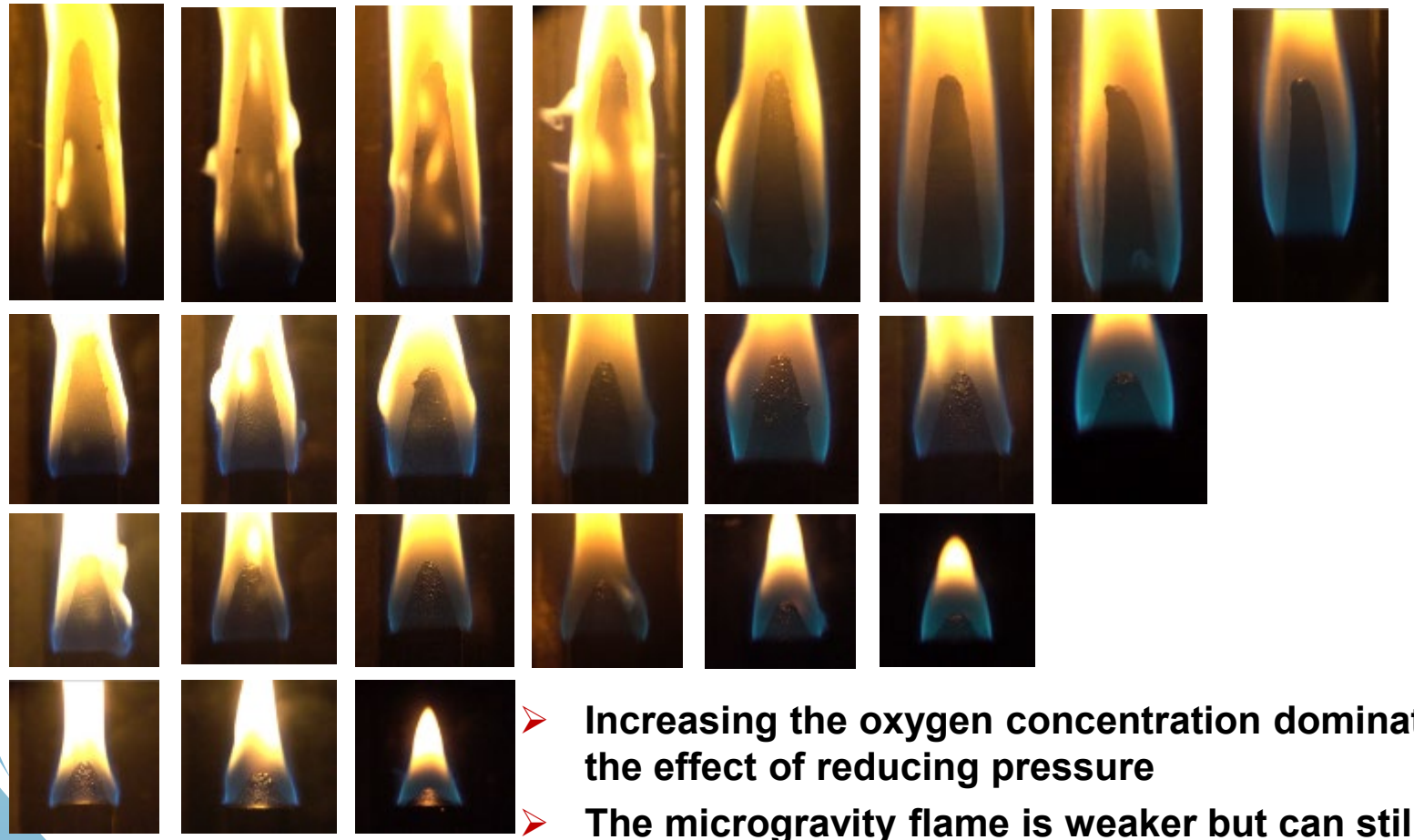
Oxygen Concentration

23%

21%

20%

19%



- **Increasing the oxygen concentration dominates the effect of reducing pressure**
- **The microgravity flame is weaker but can still propagate and at lower %$O_2$ than in 1-g**

μg

100 kPa

21%

19%

17%

Oxygen Concentration



Micro-g images obtained from the Microgravity Science Glovebox on ISS

# Test Performed to Date -Reduced Gravity Flammability Threshold Tests

***Objective***

- **Quantify the low-g oxygen upward flammability thresholds for typical spacecraft materials and compare results with thresholds determined in normal gravity**

gravity

*Ultem 1000*



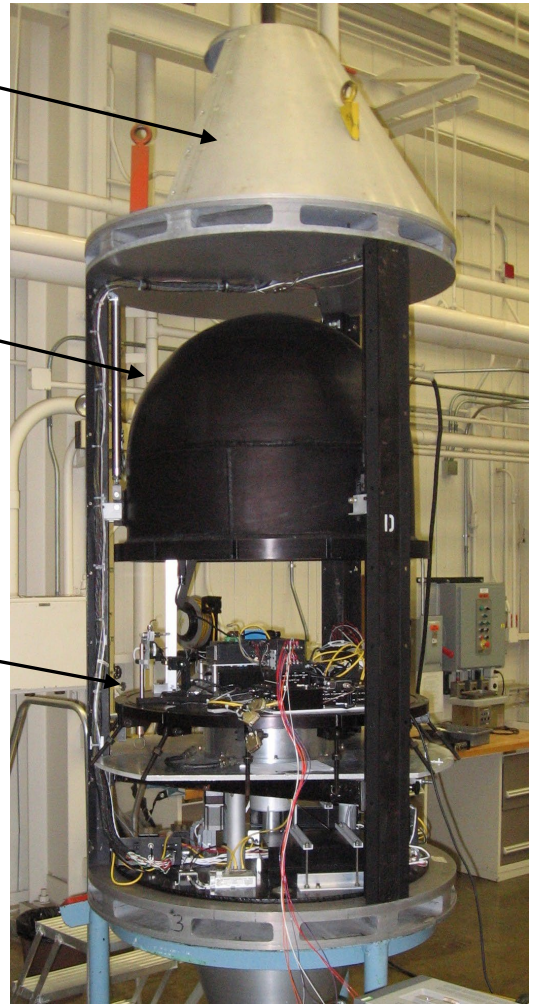
*Nomex*



*Mylar*



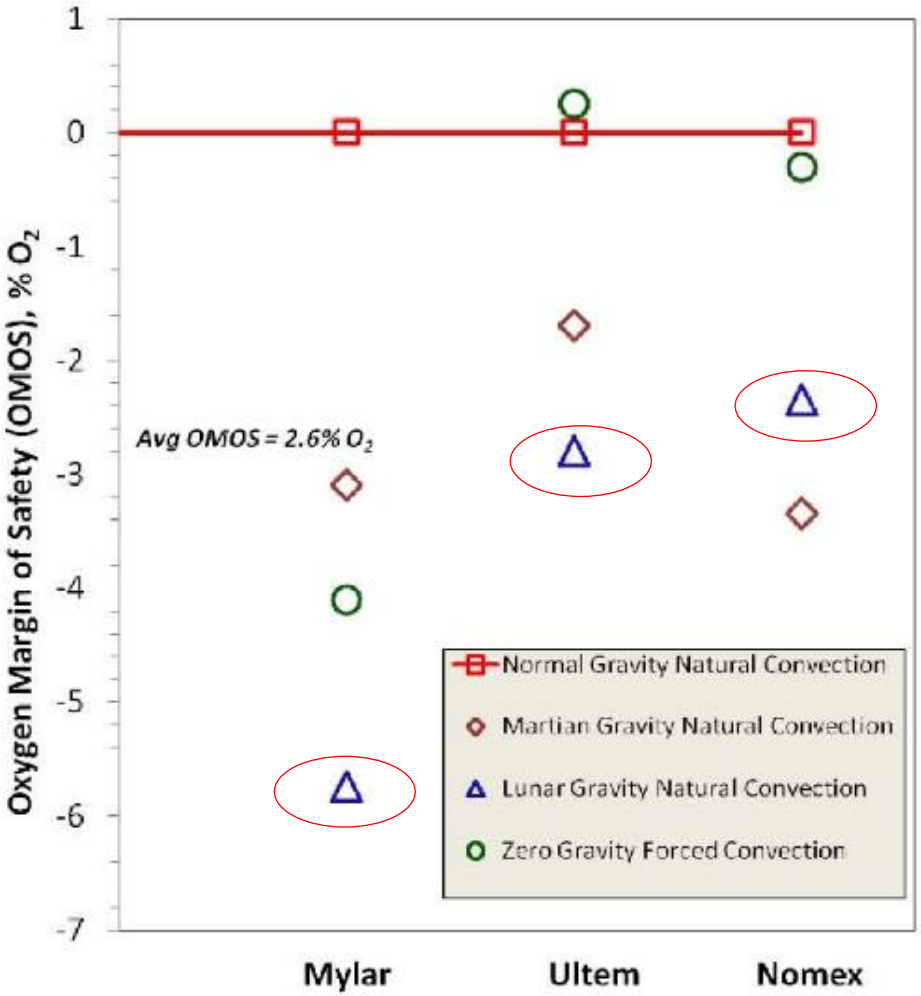
*Right: Centrifuge test rig for the Zero Gravity Facility*




- **Tests were conducted in Zero Gravity Facility at NASA-GRC for Ultem 1000, Nomex, and Mylar**
  - 5.2-sec limits samples to thin materials
- **Maximum Oxygen Concentration defined as the maximum oxygen concentration at which a material will pass NASA-STD-6001, Test 1 (extinguishment limit)**

# Maximum Oxygen Concentration (MOC) at 0-g, Martian-g, and Lunar-g

- **Tests were conducted at WSTF (normal-g) and GRC (partial-g) to quantify changes in the MOC for Nomex, Mylar, and Ultem**
- **Data for normal-, Martian-, Lunar- and zero-g has been obtained**
  - Partial-g flames propagated at the normal-g MOC for all materials (charring and non-charring)
  - Lunar-g MOC can be lower than either zero- or Martian-g levels
  - Variation of MOC with gravity level is dependent on the material
    - Requires additional testing
- **Cessation of ventilation flow is not an effective extinguishment strategy in Lunar- or Martian-g (natural convection)**
- **Fires can exist in small spaces in partial gravity driven by buoyant flow (chimney effect) where they cannot exist in low-gravity.**



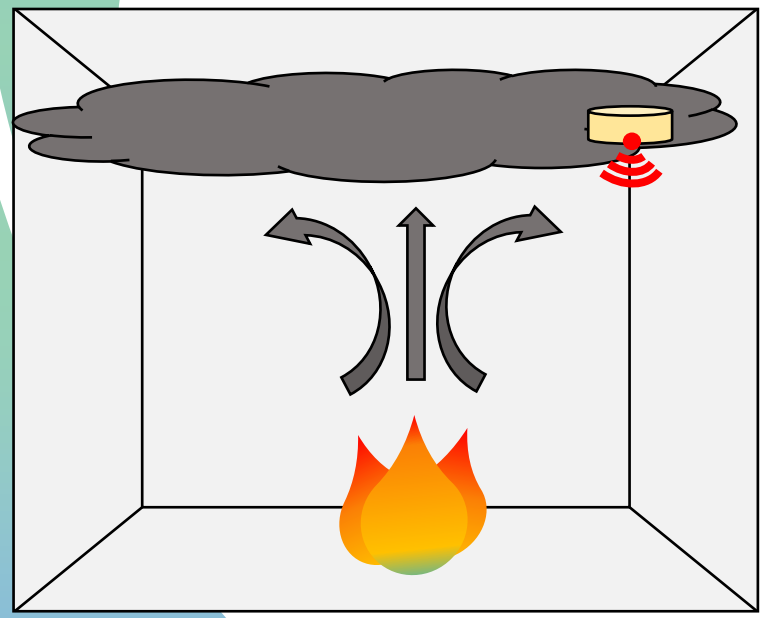
# Partial-Gravity Assessment Tools

| Platform/Activity | Duration | Time Frame (to start) | Comments |
|---|---|---|---|
| LOI Test Technique | Full burn | 2021 | LOI is a standard test technique that could be related to partial-g more easily than Test 1 |
| *ZGF Centrifuge Rig* | 5 sec | 2021 | Direct partial-g burn or blow-off tests? |
| $P^2$-g Scaling | Full burn | 2021 | Evaluated for flame propagation rather than flammability limits |
| *Modeling* | Full burn | 2021 | Status of model; Data for comparison of model is limited |
| Parabolic Aircraft (with ESA) | 20 sec | 2022 | Direct partial-g burn or blow-off tests? |
| *Blue Origin Rotating Capsule* | 120 sec | 2022 (initial flight)<br>2023 (full campaign) | Need to assess capability prior to full commitment to test campaign starting in mid-2023 |
| *Commercial Lunar Payload Services (CLPS) Experiment* | Full burn | 2024 | Provides a “Lunar truth” but tests are very limited in size and number |

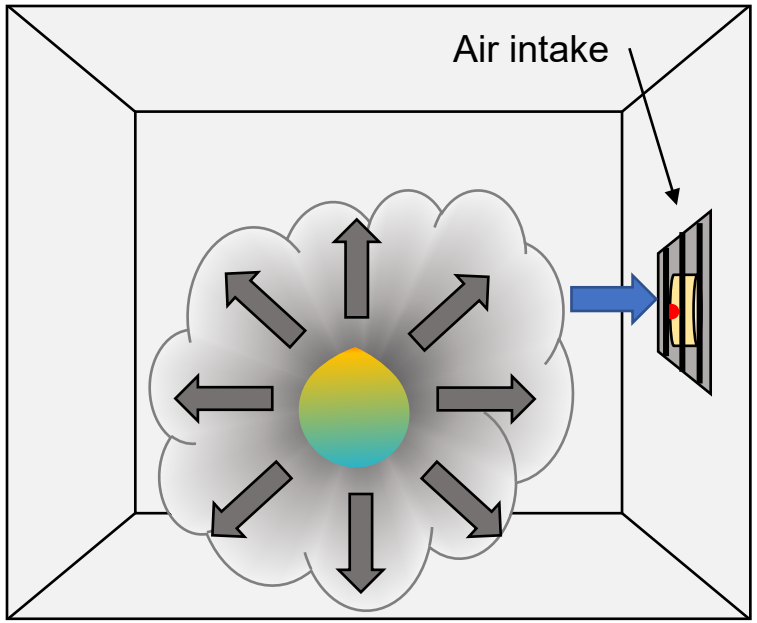
- A plan to assess lunar-g flammability most likely contains a combination of these activities

# Fire Detection in Lunar - G

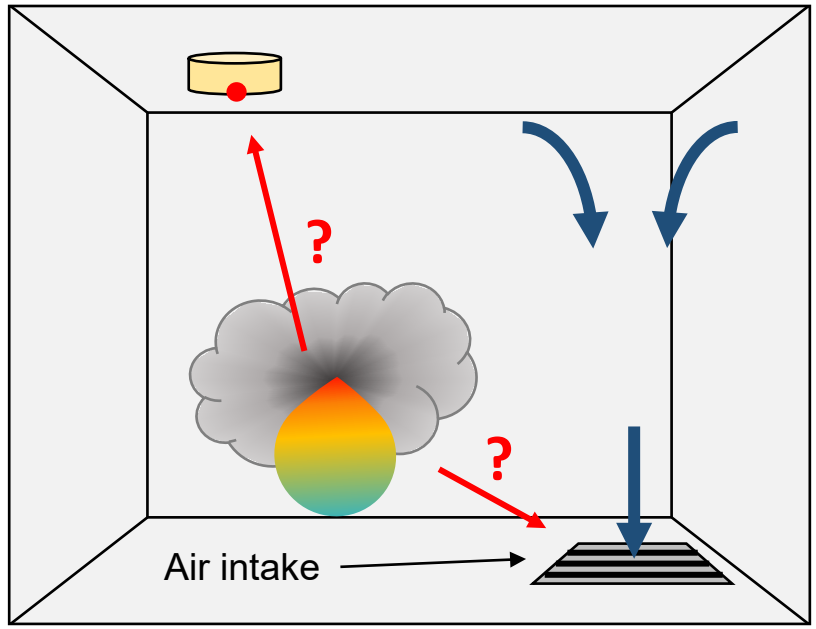
- In terrestrial fires, buoyancy drives smoke upward, allowing convenient placement of smoke detectors on ceilings. In microgravity, this buoyant flow does not occur.
- In lunar gravity (1/6 g), some buoyant flow is expected, but it's currently unclear how the limited buoyancy will affect smoke transport.
- It is expected that air intakes would be near the floor to capture lunar dust. Modeling is required to determine whether smoke detectors should be at the ceiling or near the air intakes at the floor.
- This will require good predictions of the potential fire sources



**1-g**




**0-g**




**0.167-g**

# ElectroMotive Drop Tower (EMDT) upgrade proposal

**Motivation:** Provide inexpensive, reliable and flexible access to 10 s of zero-g or partial-g to facilitate fundamental research, technology development, and flight hardware risk mitigation testing.

**Concept:** Convert the existing 5.2-second GRC Zero Gravity Research Facility to a state-of-the-art ~10-second, 0 to 0.5g test facility using a vertical rail and linear synchronous motor system to provide a revolutionary capability in testing at low and partial gravity at a significantly lower operating cost.

## Target Metrics:

- 10 s duration
- $10^{-5}$ g below 20 Hz
- Launch/landing 4 g avg 6 g max
- Payload size 1 m x 1 m x 1.8 m
- Payload mass 455 kg
- 20 tests / day (1 OOM increase)
- $300 / test (1 OOM reduction)

## Status:

- Engineering Model Design Complete

- Seeking funding for build and test (2 years) of engineering model before final approval to proceed.

## Applications:

- Physical Sciences
  - Fundamental Physics
  - Combustion
  - Fluid Physics
- Life Support
  - Fire Safety
  - Thermal Control
  - Fluid Acquisition/Control
  - Dust Behavior
- Life Science
  - Gravitropism
  - Plant Thermal Model
- ISRU
  - Reactor Design
  - Regolith Acquisition/ Handling
- Science
  - Asteroid Sampling
  - Soil Physics

