SoFIE Design/Status

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Spacecraft Materials Flammability Workshop
May 20-22, 2019 at NASA Glenn Research Center (GRC)
Overall Objective:

• Ignition and flammability of solid spacecraft materials in practical geometries and realistic atmospheric conditions

Relevance/Impact:

• Improve EVA suit design
• Safer selection of cabin materials
• Validate NASA materials flammability selection 1-g test protocols for low-gravity fires
• Improve understanding of early fire growth behavior
• Validate material flammability numerical models
• Determine optimal suppression techniques for burning materials by diluents, flow reduction, and venting

Development Approach:

• Develop SoFIE facility (CIR insert and avionics) to support multiple solid-material combustion and fire suppression studies
• Utilize Combustion Integrated Rack (CIR); common infrastructure
SoFIE — Solid Fuel Ignition and Extinction

Material Ignition and Suppression Test (MIST)
Fernandez-Pello: UC Berkeley
Externally applied heat flux; Fuel: acrylic cylinders (PMMA)

Spacecraft Materials Microgravity Research on Flammability (SMuRF)
Olson: NASA GRC
Concurrent-flow flammability curve for acrylic cylinders (PMMA); and opposed and concurrent burning behavior of actual engineering materials (sheets)

Narrow Channel Apparatus (NCA)
Miller: San Diego State University
Opposed-flow flame spread data for a thick acrylic (PMMA) slab

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

Growth and Extinction Limit (GEL)
T’ien: Case Western Reserve University
Acrylic spheres (PMMA) in concurrent flow; effect of gravity, flow, O₂, pressure, and preheating
Material Ignition and Suppression Test (MIST)

PI: Carlos Fernandez-Pello, University of California at Berkeley
International Co-I: Nickolay Smirnov, M.V. Lomonosov State University, Moscow, Russia

Objectives:

- Determine the boundaries for ignition and extinction of a solid fuel (PMMA cylinder) as a function of flow speed, oxygen concentration, and external radiant flux.

- Understand the effects of the space exploration atmospheres under consideration by NASA (lower pressure and increased oxygen concentrations compared to air) on the flammability and suppression of materials.

- Provide guidance to interpret current NASA testing procedures to environments expected in space-based facilities.

- Develop ground-based apparatus that better reflects the environments that are expected in space-based facilities.

- Establish theoretical modeling and an extensive normal gravity data base, together with a few of the validation space experiments, to support the testing methodology.

Opposed-flow flame spread over PMMA rods in μg
Objectives:

• Refine materials fire screening: Tests are done in 1g, but materials are more flammable in 0g.

⭐ In the normal gravity screening tests, flames extinguish by blowoff, where the buoyant flow is too fast for the chemical reactions to occur in the hot flame zone.

⭐ In reduced gravity (0g, Lunar g, Martian g), the flow is slower (reduced-g buoyancy or spacecraft ventilation flows of 5-20 cm/s) and a flame can be sustained at lower O₂ where the slower reactions have enough residence time in the hot zone.

⭐ We need to measure the Negative Oxygen Margin of Safety to de-rate materials. PMMA rods: Negative Oxygen Margin of Safety = 1.4% O₂

• Thin fuel sheets: Very few materials have been rated even in 1g at 34% O₂, 8.2 psia (exploration atmosphere).
**Narrow Channel Apparatus (NCA)**

**PI:** Professor Fletcher Miller, San Diego State University  
**Co-I:** Sandra Olson, NASA GRC and Indrek Wichman, Michigan State University

**Objectives:**

- Use a “narrow channel” to create flow conditions in normal gravity – defined by pressure, oxygen concentration, and velocity - that closely reproduce the conditions aboard an actual spacecraft by controlling the effect of buoyancy. The creation of these conditions will allow microgravity opposed-flow flame spread rate and (possibly) extinction limits (due to any of the above three factors) for both thermally thick and thin fuels to be determined on earth in the apparatus.

- Measure flame spread rate across a thermally thick solid fuel (PMMA slabs) as a function of forced opposed flow velocity, oxygen concentration, and pressure. The conditions chosen will correspond in particular to NASA’s proposed Exploration atmospheres (i.e. along the normoxic curve).

- Determine opposed-flow extinction limits for thick solid fuel by lowering the velocity until the flame extinguishes at a given oxygen concentration and pressure.

- Obtain additional data that can be used to compare to a numerical model of the flame spread process. These include surface temperature and side view images of the flame.
Residence Time Driven Flame Spread (RTDFS)

*PI:* Subrata (Sooby) Bhattacharjee, San Diego State University, San Diego, CA

*International Co-I:* S. Takahashi and K. Wakai (Gifu University, Japan)

**Objectives:**

- Establish the boundaries of radiative quenching in terms of the critical velocity of the oxidizer and critical thickness of fuel (PMMA sheets) in a microgravity environment using experiments, theory, and computational model.

- Establish the mechanism of flame extinguishment by delineating the thermal field from the concentration field through microgravity experiment and numerical results.

- Conduct ground based experiments at normal gravity with similar setups and develop a comprehensive set of data on flame spread over thin fuels in the radiative, thermal, and kinetic regimes.
Growth and Extinction Limit of Solid Fuels (GEL)

PI: James S. T’ien, Case Western Reserve University, Cleveland, Ohio
Co-Is: Paul Ferkul, USRA/NASA GRC; Sandra Olson, NASA GRC
International Co-I: Oleg Korobeinichev, Siberian Branch Russian Academy of Sciences, Novosibirsk, Russia

Objectives:

• Experimentally determine the flame growth characteristics (growth rate, flame shape and dimensions) over a thick solid fuel (PMMA spheres) as a function of flow velocity, oxygen percentage, pressure and the degree of internal heating.

• Experimentally determine the flame extinction characteristics (quenching and blowoff limits) over a thick solid fuel as a function of flow velocity, oxygen percentage, pressure and the degree of internal heating.

• Establish a high-fidelity numerical model that can be compared with the microgravity results and serve as a tool connecting normal gravity and microgravity performance.
The Combustion Integrated Rack (CIR) includes support subsystems and combustion diagnostics.

Payload specific and multi-user hardware customizes the CIR in a unique laboratory configuration to perform research effectively.

**Payload Specific Hardware**
- Unique hardware components
- Specific Diagnostics
- Unique PI source gases

**Chamber Insert**
- Infrastructure that uniquely meets the needs of PI experiments
- Unique science requirements

**FCF Combustion Integrated Rack**
- Power Supply
- Avionics/Control
- Structural Support & Power
- Common Diagnostics and Illumination
- Environmental Control
- Data Processing/Distribution
- Fluids Control/Distribution
- Combustion Containment
SoFIE Chamber Insert Assembly
Flow Duct (Full-size and Short)

- Replaceable filter
- Integral air speed and radiometer
- 2 transparent sides with Sapphire windows for imaging
- Fans, duct, radiometer and filter can be individually replaced
Sample Rotation and Translation

- 3 Samples mounted on a rotating system
- Motor provides rotation into position
- Linear slide moves the sample in and out of the flow duct

Shown with Smurf Rod
MIST Sample Heater Installed

- The Heater Assembly installs on the exit of the flow duct
- Removed and stowed for non-heater test points
Internal Cameras

- Internal cameras act in conjunction to image the entire combustion area
- External camera images orthogonal view
In addition to the radiometer in the duct and sample based measurements, the following sensors and diagnostics are in the system:

- 2 CO$_2$, CO, and relative humidity modules with filtering
- 2 Additional radiometers for orthogonal views to the duct
- PyroScience FireStingO2 Fiber Optic Oxygen Sensor Module with 4 inputs
- 2 Far Field Thermocouples
Igniter Mounting Arm

- The Igniter Mounting Arm attaches to the end of the positioning arm
- Provides support and power connections to the igniter tip
- Can be replaced based on sample requirements
Igniter Tips

- Igniter tips are 24 Gauge Kanthal-A wire
- Different shapes will be provided based on PI requirements
- Tips are individually replaceable
Igniter Insertion Animation
Hardware fabrication is underway

- AVP Front Frame and Insert Assembly
- AVP Base Insert
- AVP Left Housing Frame
- AVP Right Housing Frame
- AVP Power Distribution Assembly
- AVP Card Cage Assembly
- Cooling Hose Holder Attachment
- Component for Igniter Arm
- Igniter Tip Interface
- AVP Circuit Breaker Cover
- Camera Test Harness
- AVP Test Harness
- Soot Catch Screen
- Components for the Internal Camera Insert
SoFIE Schedule Overview

Flight Hardware Availability: July 2020

Experiment Operations Begin: July 2021

Experiment Operations End: December 2023
End