Advanced Exploration Systems Program

Large-Scale Spacecraft Fire Safety Experiments in ISS Resupply Vehicles.

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Outline

- Overview of the Spacecraft Fire Safety Demonstration Project
- Science and Technology Demonstration Objectives
  - Details of Sample Selection
- Supporting Ground-based Research

Spacecraft Fire Safety Demonstration
Requirements and Goals

- **Level 1 Requirements**
  - The project shall conduct an experiment on an International Space Station resupply vehicle after it leaves the ISS and before it re-enters the Earth's atmosphere.
  - The experiment performed on this vehicle shall meet a critical need for developing rational spacecraft fire safety strategy on future exploration vehicles.
- **Project Goals**
  - Conduct a spacecraft fire safety experiment on three flights of Orbital Science's Cygnus vehicle that investigates large-scale flame spread and material flammability limits in long duration low-gravity.
    - Orb-5: February 2015 probable slip to December 2015
    - Orb-6: September 2015 probable slip to June 2016
    - Orb-7: February 2016 probable slip to October 2016
  - Complete the major experiment development work no later than September 30, 2014.
- **Needs:**
  - Quantify the development and growth of a realistic fire for exploration vehicles
  - Determine low-g flammability limits for spacecraft materials

Saffire Overview

Objectives:

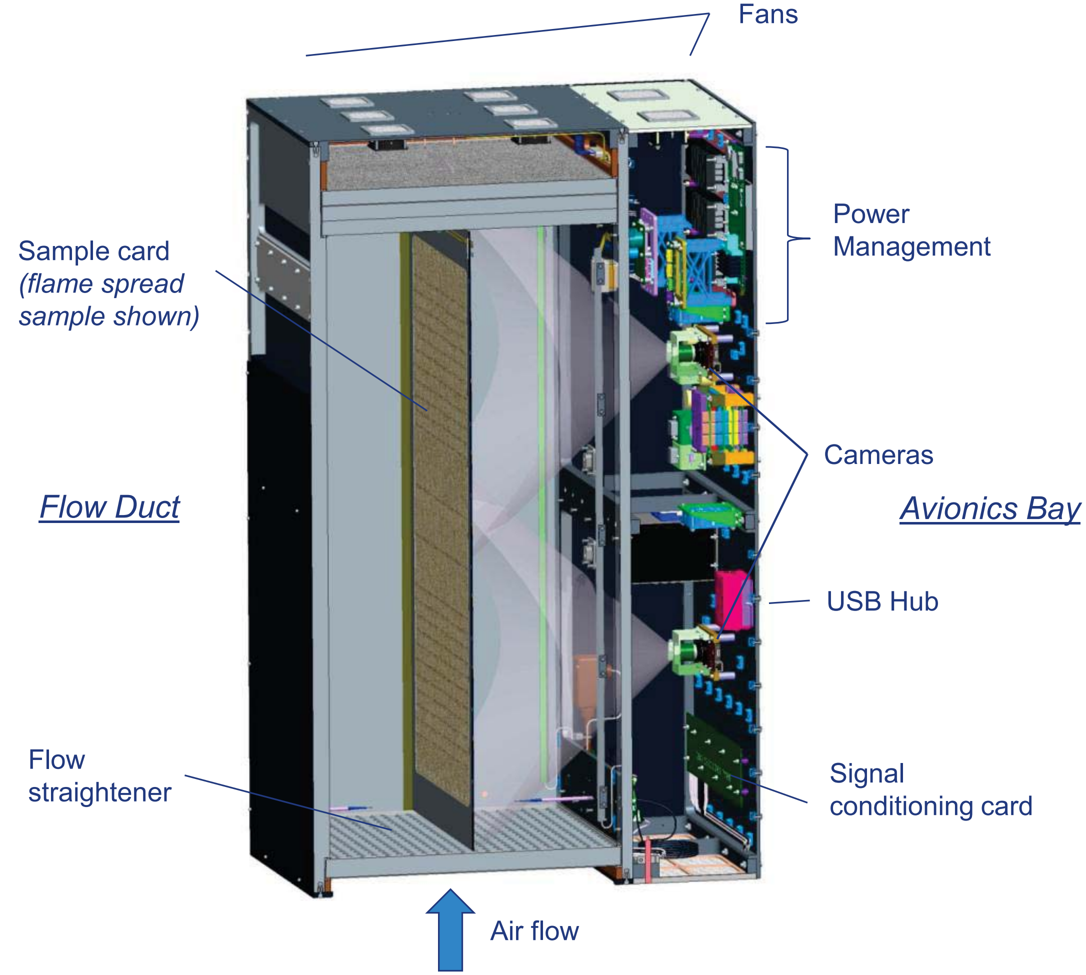
- *Saffire-I*: Assess flame spread of large-scale microgravity fire
- *Saffire-II*: Verify oxygen flammability limits in low gravity
- *Saffire-III*: Similar to Saffire–I at different air flow

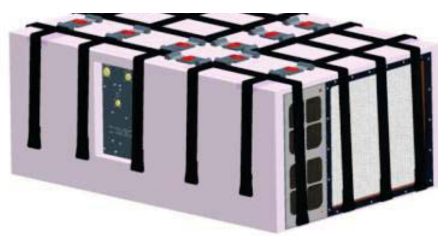
Data:

- Flame size, position, and spread rate (video)
- Flame intensity (radiometer)
- Flame stand-off distance (t/c)
- Flame/plume temperature (t/c)
- O_2, CO_2 concentrations

- *Data obtained from the experiment will be used to validate modeling of spacecraft fire response scenarios*
- *Evaluate NASA's normal-gravity material flammability screening test for low-gravity conditions.*

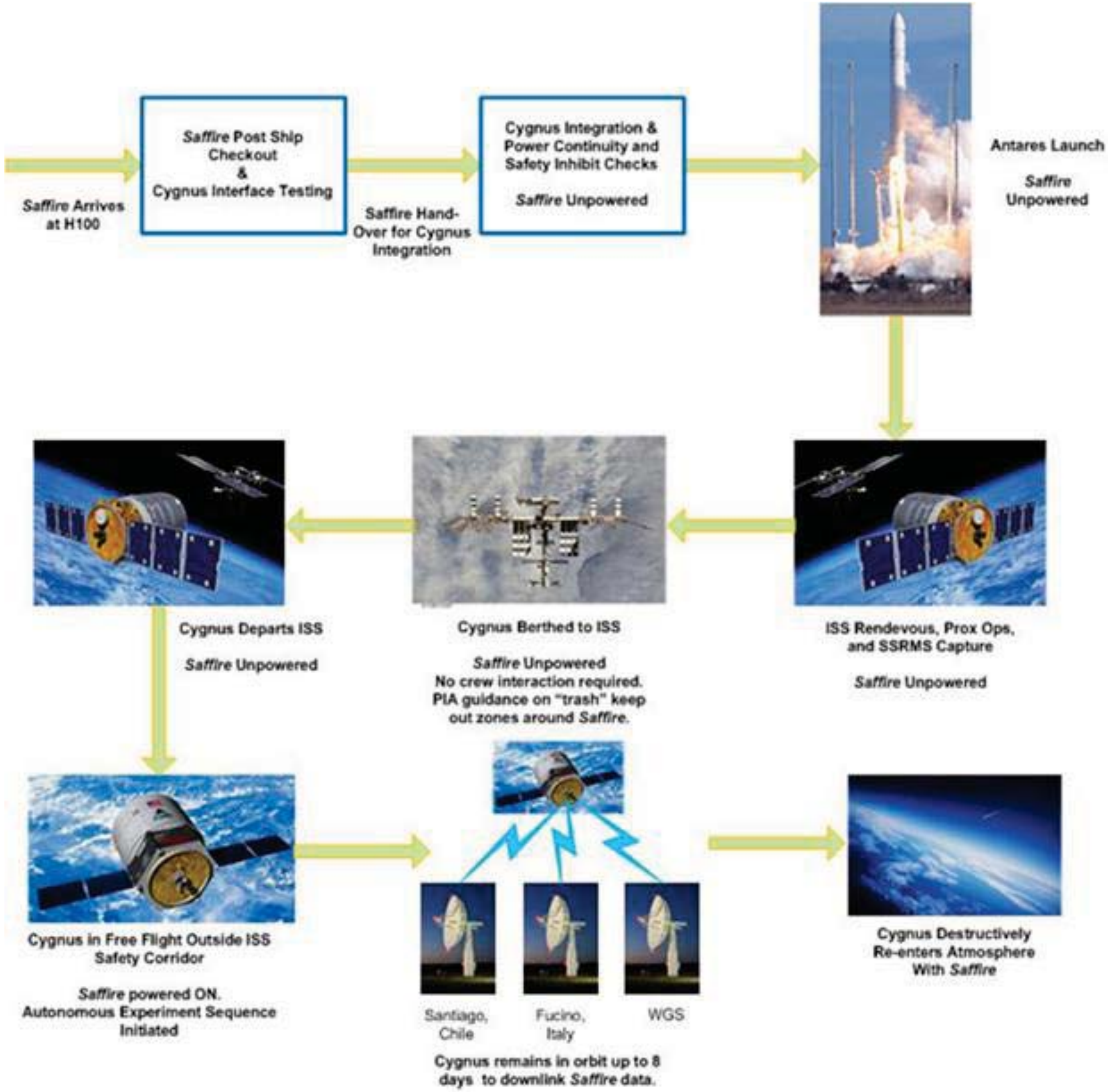
Experiment Layout



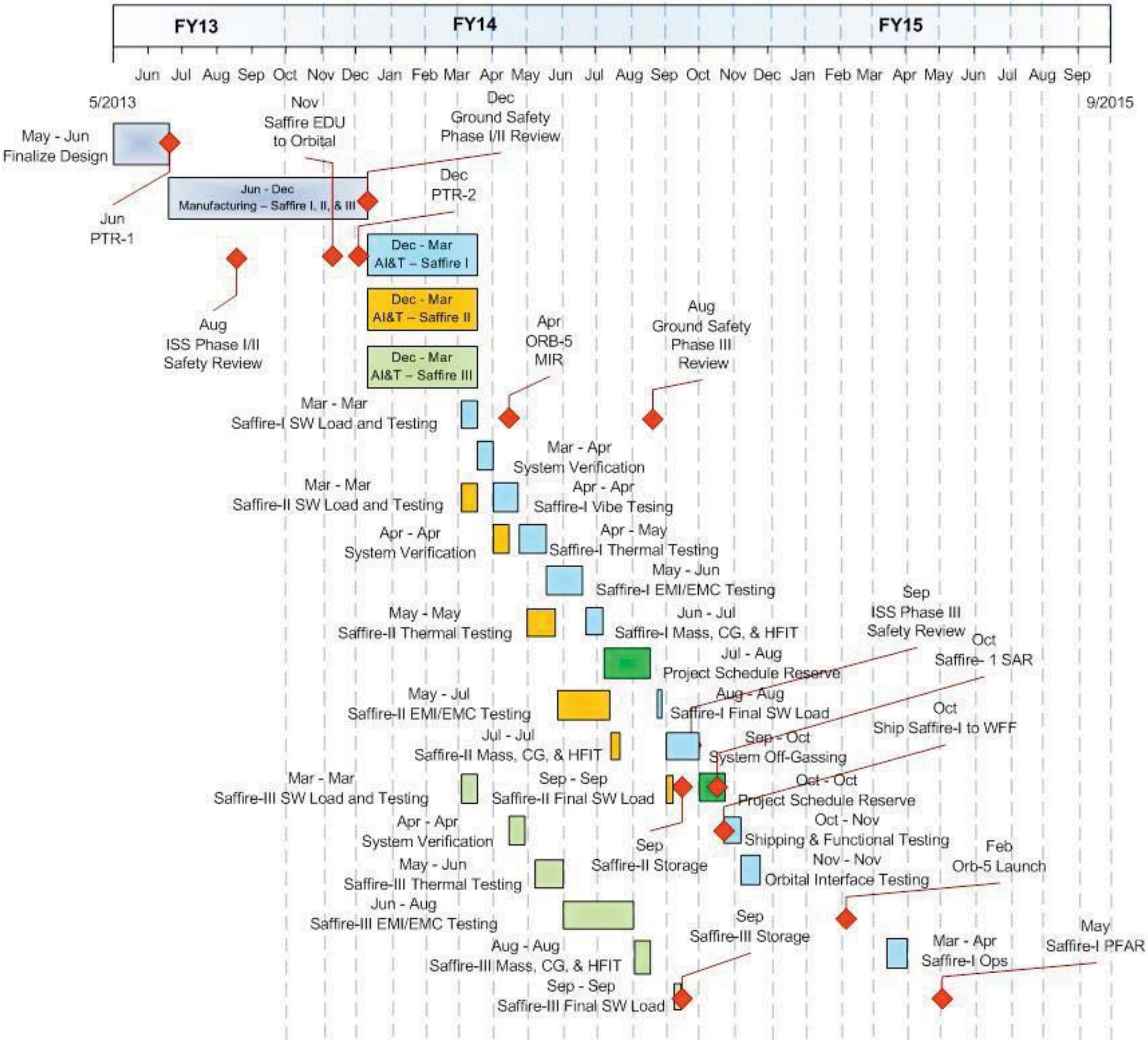


. *Dimensions are approximately 53- by 90- by 133-cm*

Operations Concept



Saffire-I, II, & III Schedule & Milestones



Milestone	Date
PTR-1	6/19/13
FSDP Submit	7/3/13
ISS Flight Safety Phase I/II Review	8/20/13
Saffire Simulator to Orbital	11/2013
PTR-2	12/4/13
System AI&T Start	**12/12/13**
Ground Safety Phase I/II Review	12/12/13
Verification and Environmental Test Start	**3/19/14**
Ground Safety Phase III Review	8/21/14
ISS Phase III Review	9/24/14
SAR	10/17/14
***Saffire-I* Ship to WFF**	**10/24/14**

Spacecraft Fire Safety Demonstration Research Objectives

- **Two major stakeholders in sample selection**
  - Scientific community
    - Address both the "no ignition" and "no flame spread" criteria involved in passing standard material flammability testing
    - Materials can pass NASA-STD-6001 Test 1 because ignition energy is not sufficient to start the flame spread process
  - NASA Materials and Processes
    - If a material passes NASA Test 1 on the ground, will it pass the test in microgravity? (i.e. is the ground test the worst case scenario)
- **The long-term relevance to spacecraft fire safety applications depends on the careful and well-informed selection of the sample materials**
  - Relevance requires:
    - Scalability
    - Amenable to modeling

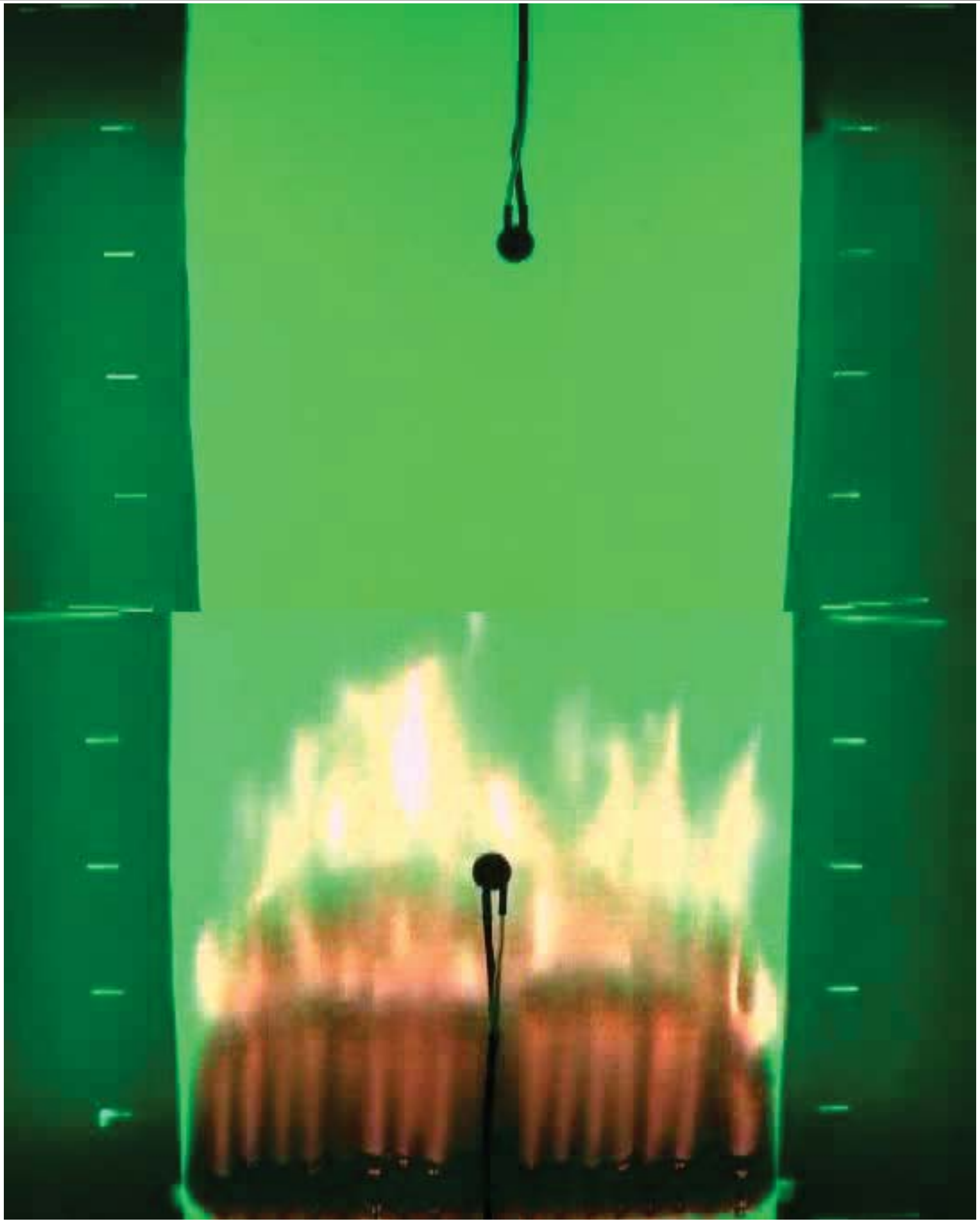
Sample Selection Constraints

- Dimensions and energy release
  - 1 or 2 flame spread (large) samples (0.5 m x 1.0 m)
  - 9 or 18 material flammability samples (5 cm x 30 cm)
  - Thickness can be a maximum of 10mm
  - Total energy released can be a maximum of 54 grams of fuel (cellulose equivalent)
- Data Acquisition
  - Thermocouples (6 total shared by all 9 samples)
  - Radiometer (two sides)
  - Camera (front view)
  - Maximum run time of 6 minutes
- Flow
  - Flow rate range is 10-30 cm/s
  - Concurrent or opposed
- Ignition power and system
- Long-term sample storage

Saffire-I & 3

Large-Scale Flame Spread Test

- Upward flame spread test on a fabric sample
  - Solid Inflammability Boundary at Low Speed (SIBAL)
    - *Cotton on a fiberglass substrate*
    - *75% cotton by weight (18.05 mg/cm^2)*
  - 0.4 m x 0.94 m
  - Saffire-I: 20 cm/s air flow
  - Saffire-III: 30 cm/s air flow

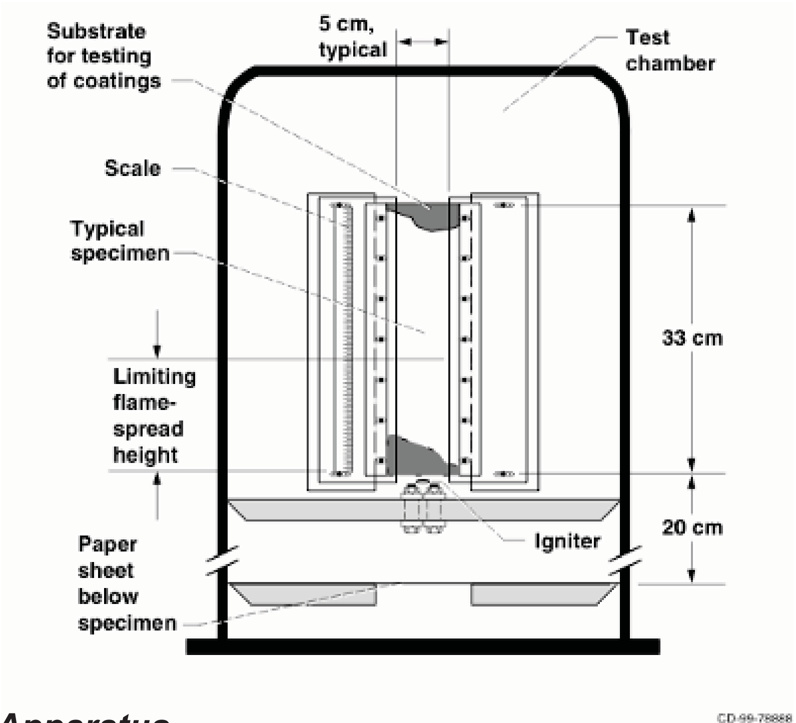


Normal gravity test conducted in the VF-13 facility at NASA GRC.

Material Flammability Samples

- NASA-STD-6001 describes the test methods used to qualify materials for use in space vehicles.
- The primary test to assess material flammability is Test 1: Upward Flame Propagation
- Materials "pass" this test if the flame self-extinguishes before it propagates 15 cm

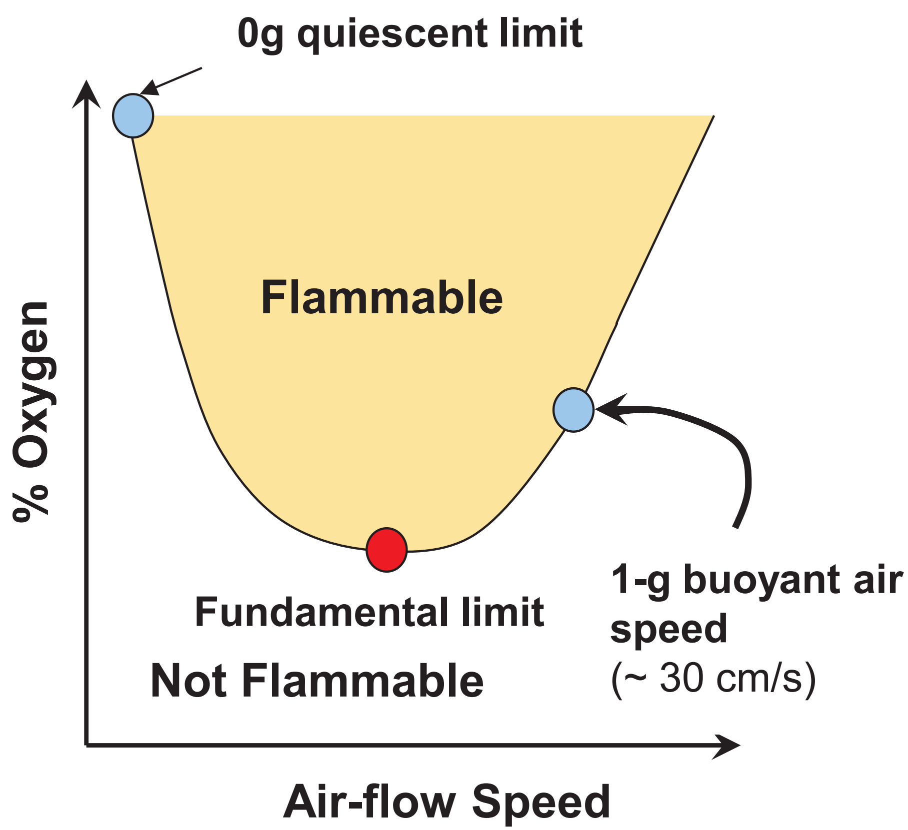
➢ *Maximum oxygen concentration (MOC) is defined as the highest O_2 at which material passes Test 1*

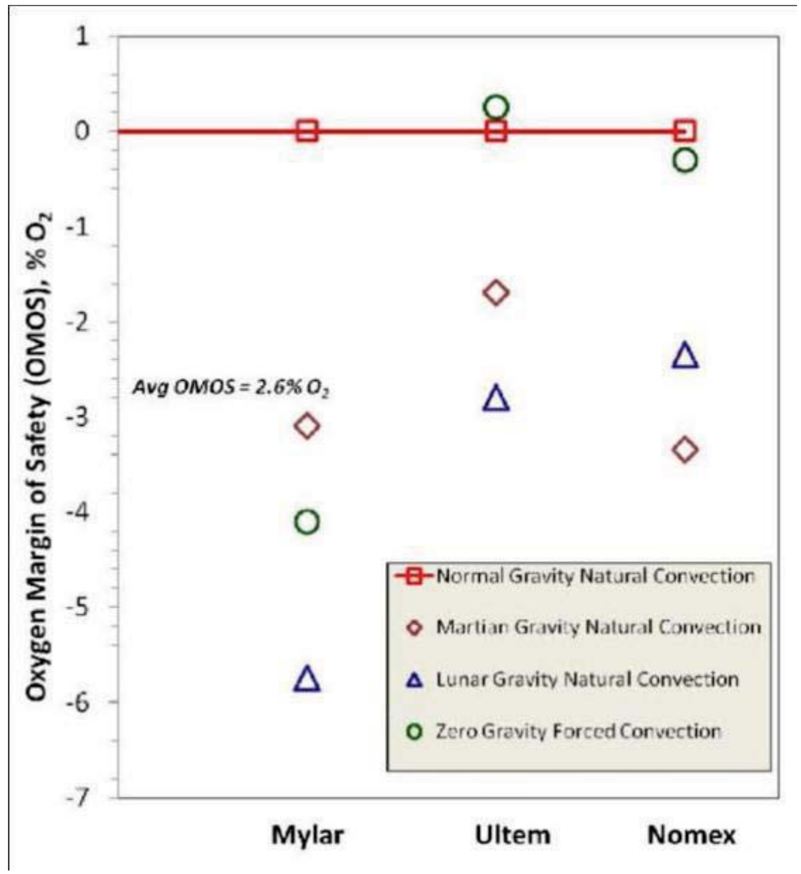


Test 1 Apparatus

Low-g Maximum Oxygen Concentration

- Flammability limits determined by this test are strongly influenced by natural convection
  - Normal gravity flames induce a natural convective flow that transports oxygen to the flame *but also removes heat*
  - Forced convection in low-g transports oxygen to the flame but rate of heat removal is reduced





Ferkul, P.V. and Olson, S.L., "Zero-gravity Centrifuge Used for the Evaluation of material Flammability in Lunar-Gravity," AIAA 2010-6260, 40th International Conference on Environmental Systems, Barcelona, Spain, July 11-15, 2010.

Sample Selection Goals

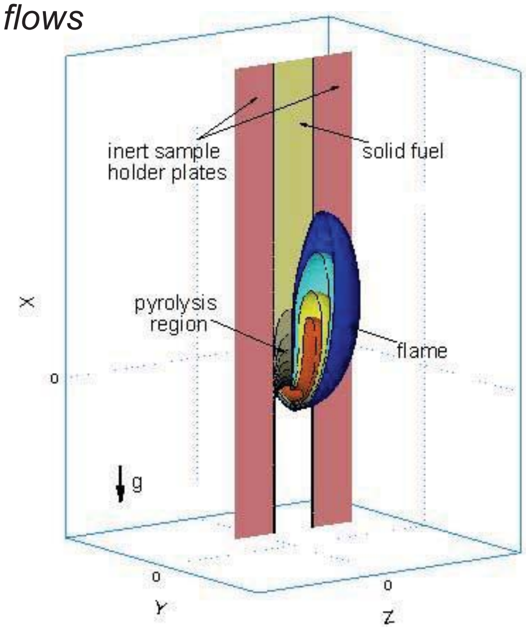
- **Build data sets on scalability of low-g fires**
  - Materials that have been tested in low-g at different length scales
- **Amenable to modeling**
  - Large, vehicle scale fire modeling
    - Impact on vehicle
    - Real-time modeling of fire response
  - Details of low-g flame spread
- **Conclusive low-g flammability limit (Maximum Oxygen Concentration) data**
  - Flammability limit sample materials must cross the flammability limit in 21% O_2
    - Requires approaches to alter flammability including: material thickness, heat loss (metal backing/matrix), radiative feedback (surface variation (grooves), inert (non-flammable) coatings

Burning and Suppression of Solids (BASS)

2cm and 1cm Flat Samples

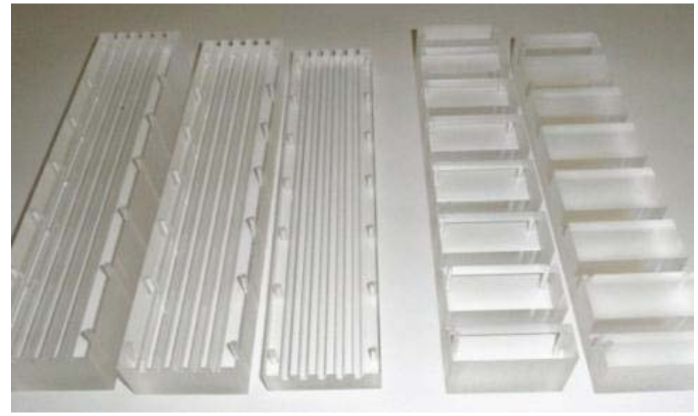
- SIBAL- cotton-fiberglass fabric
- Nomex- flame resistant material related to nylon
- Ultem - thermoplastic resins used in medical and chemical instrumentation

Three-dimensional, time dependent upward flame spread in buoyant flows



Candidate Samples

- **Nomex (HT90-40, Combo)**
- **Mylar**
- **Ultem**
- **SIBAL cloth**
  - Solid Inflammability Boundary at Low Speed (SIBAL)
    - *Cotton on a fiberglass substrate*
    - *75% cotton by weight (18.05 mg/cm^2)*
- **Silicone (2-3 thicknesses, concurrent/ opposed spread)**
- **PMMA**
  - Straight, tapered, or structured
- **Cellulose (with backing/metal matrix)**
- **Fire-resistant coating**
- **Wires**



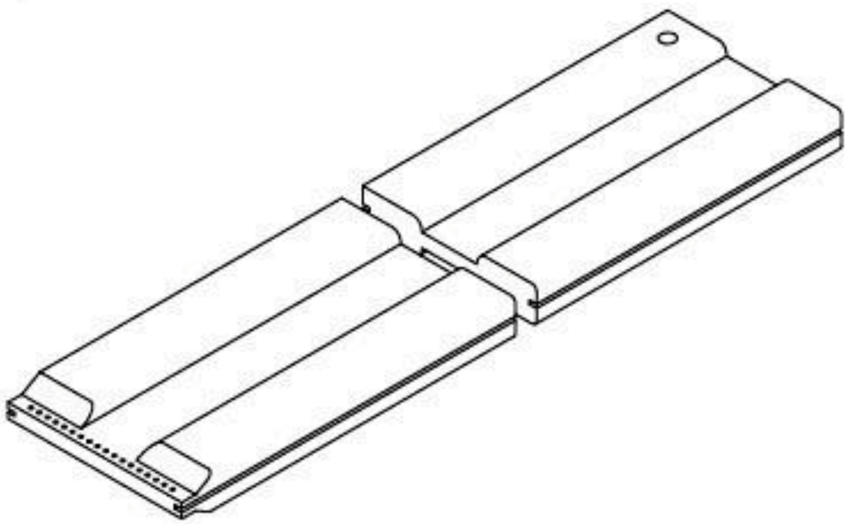
PMMA-samples shaped at University of Bremen with grooves parallel or perpendicular to the flame propagation direction

MOC and ULOI of Potential *Saffire* Samples

	MOC	ULOI
Composites and Laminates		
Epoxy/Glass laminate NEMA G-11, H-23842	23	23.6
Rigid Plastics		
P1700 polysulfone	25	27.5
Zytel 42 from 93-27463	24.1	24.5
Fabrics		
Nomex HT 90-40, L/N 7254	24	24.8
Nylon Tricot ST11N791-01	23	24.3
TCU Bottom, P/N SKD38114488-01	21	22.8
Nomex Webbing P/N 9981	22	23.4
Foams		
L-200 Minicel Foam	20	21.7
TA-301 Polyimide foam	25	27.3
Films		
Ultem 1000 Film, P/N DLI1648	21	22.1
PEEK Victrex Film, 10-mil	21.1	22
Kapton HN Film	26	27.2
SSP-M823 Silicone membrane, 0.004"	17	17.5
SSP-M823 Silicone membrane, 0.010"	18	19.7
SSP-M823 Silicone membrane, 0.014"	19	21
SSP-M823 Silicone membrane, 0.024"	20	22.8
SSP-M823 Silicone membrane, 0.040"	22	23.4

Selected Samples

- **Nomex (HT90-40) with PMMA promoter (1 sample)**
- **SIBAL cloth (2 samples at the same flow rates as Saffire 1 & 3)**
- **Silicone (3 thicknesses for concurrent spread and 1 thickness for opposed spread)**
- **PMMA** 10 mm thick
  - Flat sample
  - Structured sample



Top view of PMMA sample -edges have different radii

PMMA / Nomex

- Example with 4 inch SIBAL cloth promoter
- 8 inch Nomex

After Test

After Igniter is off

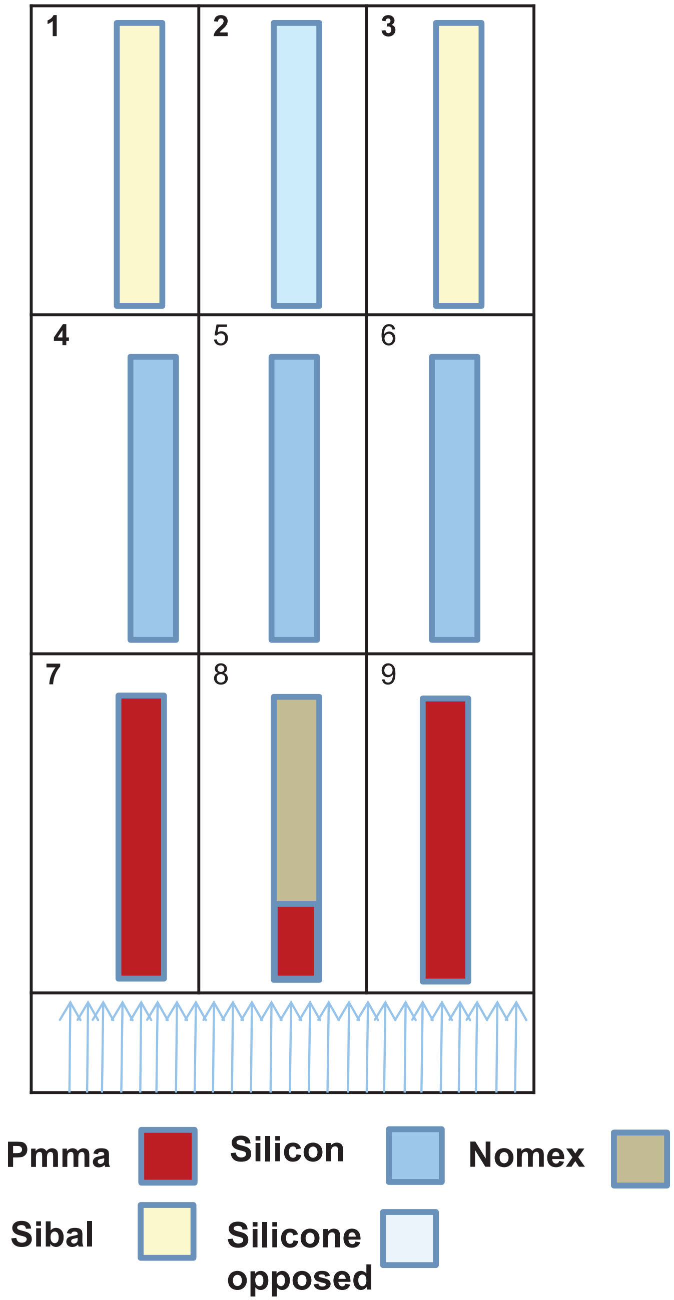
Flame Out

Downward Silicone

- Average ~ 5 minutes to burn 30 cm
- 0.014” thick Silicone will burn downward but not upward

.01” down burn

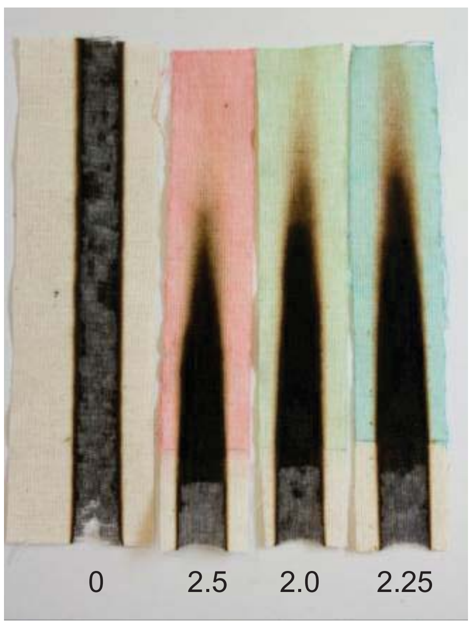
Flight 2 Sample Selection



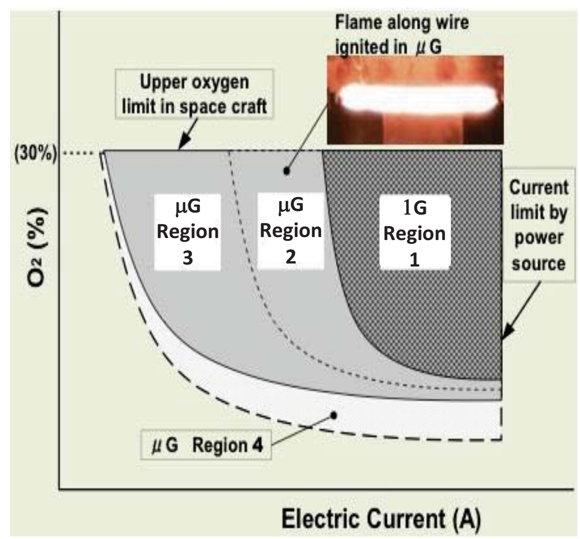
Sample #	Material	Sample Thickness	Flow (cm/s)	Igniter Position
Saffire-2-S1	SIBAL	N/A	20	Bottom
Saffire-2-S2	Silicone down	0.36 mm (0.014") Silicone	20	Top
Saffire-2-S3	SIBAL	N/A	30	Bottom
Saffire-2-S4	Flam limit 1 Silicone	0.25 mm (0.010") Silicone	20	Bottom
Saffire-2-S5	Flam limit 2 Silicone	0.36 mm (0.014") Silicone	20	Bottom
Saffire-2-S6	Flam limit 3 Silicone	0.61 mm (0.024") Silicone	20	Bottom
Saffire-2-S7	PMMA 2 sided burning	10 mm with tapered edge for ignition	20	Bottom
Saffire-2-S8	Transition 1: PMMA to NOMEX	N/A	20	Bottom
Saffire-2-S9	PMMA 2 sided burning	10 mm with tapered edge for ignition	30	Bottom

Ground-based Supporting Research

- **The outcomes of this experiment are multiplied by tasks performed by contributing team members (and the funding from other organizations)**
  - Sample Selection
    - Structured materials:
      - Nickolay Smirnov, *Moscow Lomonosov State University, Moscow, Russia*
      - Christian Eigenbrod, *University of Bremen (ZARM), Bremen, Germany*
    - Wires: Osamu Fujita, *Hokkaido University, Sapporo, Japan*
    - Coated materials: James S. T'ien , *Case Western Reserve University, Cleveland, OH, USA*
    - Nomex: Carlos Fernandez-Pello, *UC Berkeley, Berkeley, CA, USA*



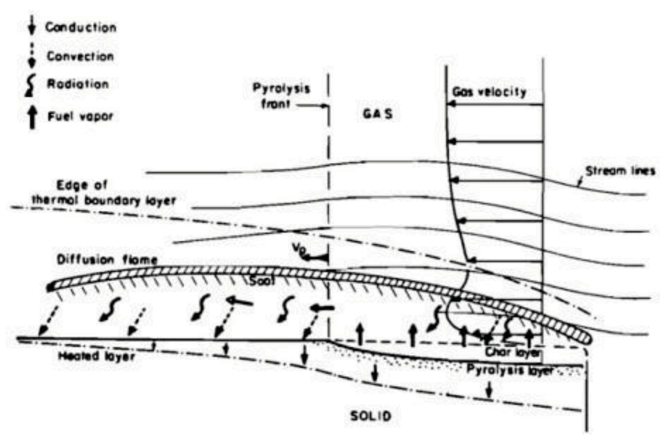
Guanylurea Phosphate (GUP) (g) in 25 mL water (samples are 2 cm x 18 cm)



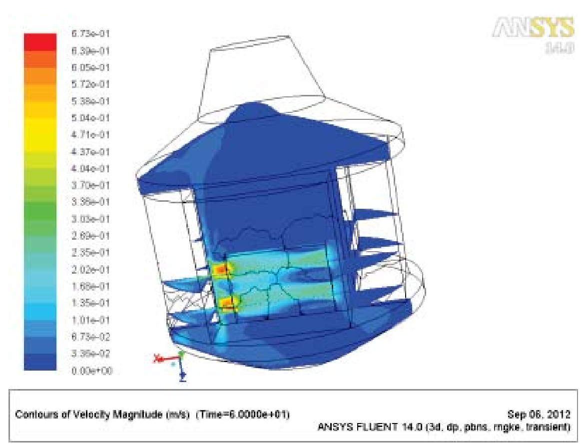
Ignition map of overloaded wire. Region 1: Ignition limit in 1-g. Region 2: Ignition limit in short-term μg tests. Region 3: Ignition limit in long-term μg tests. Region 4: Ignition but no sustained flame.

Ground-based Supporting Research
(continued)

- **The outcomes of this experiment are multiplied by tasks performed by contributing team members (and the funding from other organizations)**
  - *Modeling*
    - Low-g Fire Dynamics
      - James S. T'ien , *Case Western Reserve University, Cleveland, OH, USA*
    - Real-time fire response:
      - Jose L. Torero, *University of Queensland, Brisbane, Australia*
      - Adam J. Cowlard, *University of Edinburgh, Edinburgh, UK*
    - Vehicle-scale fire scenario modeling
      - Sebastien Rouvreau, *Belisama R&D, Toulouse, France*
      - *Dan Dietrich, NASA GRC, Cleveland, OH*
      - *Suleyman Gokoglu, NASA GRC, Cleveland, OH*

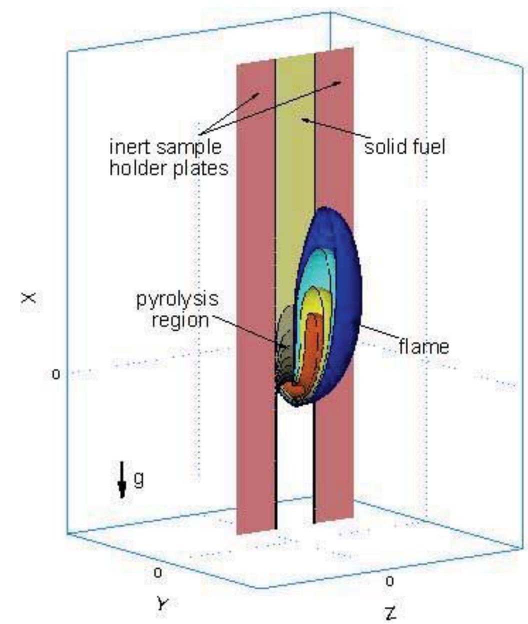


Schematic for a concurrent spread over the flat surface of a solid combustible



: Fluent model calculation of velocity magnitude in ATV configuration after 1 minute of heat release.

Three-dimensional, time dependent upward flame spread in buoyant flows



Ground-based Supporting Research *(continued)*

- **The outcomes of this experiment are multiplied by tasks performed by contributing team members (and the funding from other organizations)**
  - *Diagnostics*
    - Fuel Characteristics: Adam J. Cowlard, *University of Edinburgh, Edinburgh, UK*
      - *Flame Propagation Apparatus: Heat release rate of materials to support detailed modeling of fire response*
    - Soot Volume Fraction in Low-g: Guillaume Legros, *Université Pierre et Marie Curie, Paris, France*
      - *Laser extinction technique to measure soot volume fraction in large-scale normal- and low-g flames*

Summary

- **The *Saffire* experiment (Spacecraft Fire Safety Demonstration Project) is in development to address knowledge gaps in low-g material flammability**
- **Sample were selected to meet stakeholder requirements and to ensure the long-term impact of the project on the spacecraft fire safety protocol.**
- **Samples will address both flame spread and material flammability understanding.**
- **Recent studies and analyses have confirmed the fire safety needs for long-term exploration missions. Spacecraft fire safety technologies have been identified as enabling for some exploration missions, enhancing for others**
  - The *Saffire* experiments address several of these but lack fire detection, suppression, and post-fire cleanup
- **An end-to-end demonstration of a fire detection, suppression, and clean-up scenario would verify hardware and the ability to properly size fire response hardware**

NASA