



Spacecraft Fire Experiment

Advanced Exploration Systems Program

Spacecraft Fire Safety Demonstration

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Increments 47 and 48 Science
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International Topical Team



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- ◆ **NASA GRC Science Team**
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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**

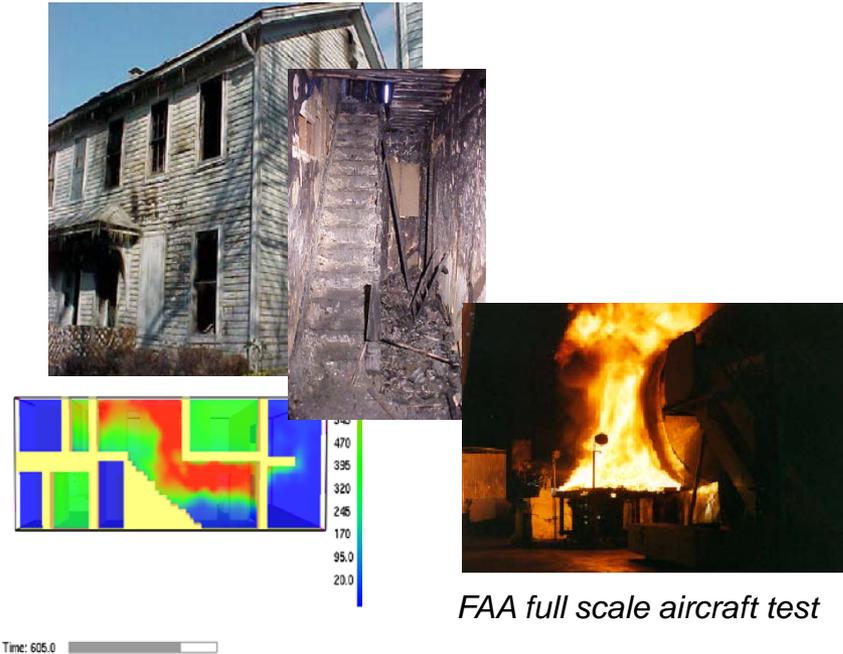
- Conduct a spacecraft fire safety experiment on three flights of Orbital Science's Cygnus vehicle that investigates large-scale flame spread and material flammability limits in long duration low-gravity.
 - OA-6: March 2016 (launch date, operations occur ~2 months later)
 - OA-5: May 2016
 - OA-7: October 2016

◆ **Needs:**

- ◆ Quantify the development and growth of a realistic fire for exploration vehicles
- ◆ Determine low-g flammability limits for spacecraft materials

- ◆ **This question lies at the heart of the development of a fire safety strategy**
 - Terrestrial or spacecraft applications
- ◆ **Rate of fire growth impacts:**
 - Time to detect
 - Early detection reduces impact of fire, response strategy
 - Size of fire
 - Amount of fire suppression agent required
 - Heat release rate, fire spread to surrounding materials
 - Collateral damage
 - Emission of combustion products
 - Post-fire cleanup strategy and consumables

NIST Full Scale Fire test



FAA full scale aircraft test

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



Saffire Overview

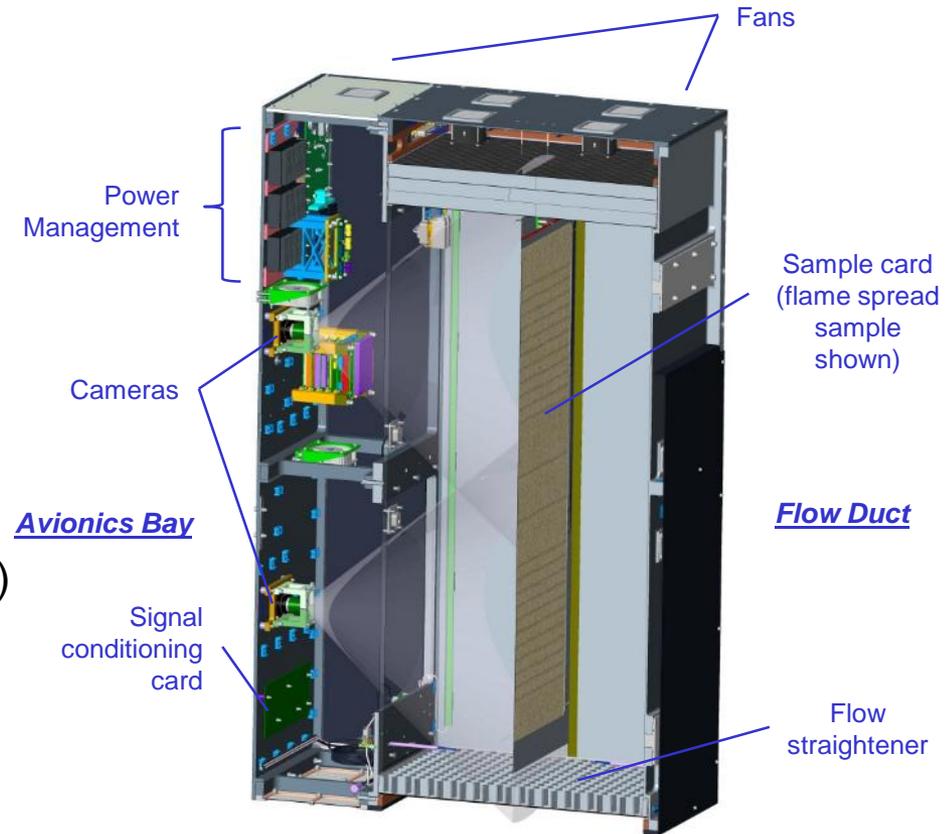


Objectives:

- ◆ *Saffire-I*: Assess flame spread of large-scale microgravity fire
- ◆ *Saffire-II*: Verify oxygen flammability limits in low gravity
- ◆ *Saffire-III*: Assess flame spread of a large-scale microgravity fire (similar to *Saffire-I*)

Data:

- ◆ Flame size, position, and spread rate (video)
 - ◆ Flame intensity (radiometer)
 - ◆ Flame stand-off distance (t/c)
 - ◆ Flame/plume temperature (t/c)
 - ◆ O₂, CO₂ 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.*



Saffire module consists of a flow duct containing the sample card and an avionics bay. All power, computer, and data acquisition modules are contained in the bay. Dimensions are approximately 53- by 90- by 133-cm



Spacecraft Fire Safety Demonstration Research Objectives



◆ Two major stakeholders in sample selection

- Scientific community
 - Large-scale low-gravity flame spread
 - 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 flame spread (large) samples (0.5 m x 1.0 m)
 - 9 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 (20 Gbits total)**
 - Thermocouples (6 total, shared by all 9 samples on Saffire-II)
 - Radiometer (four total, two on front and back)
 - Camera (front view)
 - Maximum run time of 6 minutes
- ◆ **Flow**
 - Flow rate range is 10-30 cm/s
 - Concurrent (upstream ignition) or opposed (downstream ignition)
- ◆ **Ignition power and system**
- ◆ **Long-term sample storage**



Saffire I & III Samples



- ◆ Material was developed for microgravity flight experiments and has been studied extensively
 - Ground-based experiments
 - Modeling
 - Small-scale low-g experiments
- ◆ Cotton component simulates crew clothing
- ◆ Fiberglass substrate prevents cracking of charred fabric
 - Flame burns preferentially along the cracks
 - Alters the flow characteristics
 - Makes modeling considerably more difficult

◆ **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
 - Modeling of fire response
- Details of low-g flame spread

◆ **Conclusive low-g flammability limit (Maximum Oxygen Concentration) data**

- Flammability limit sample materials must to cross the flammability limit in 21% O₂
 - Requires approaches to alter flammability including: material thickness, heat loss (metal backing/matrix), radiative feedback (surface variation (grooves), inert (non-flammable) coatings

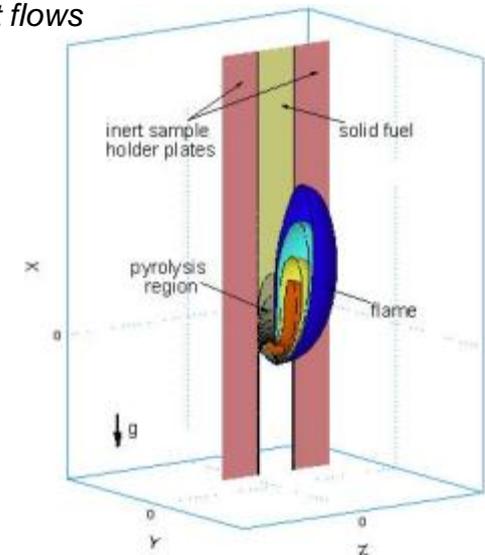


Burning and Suppression of Solids (BASS)

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

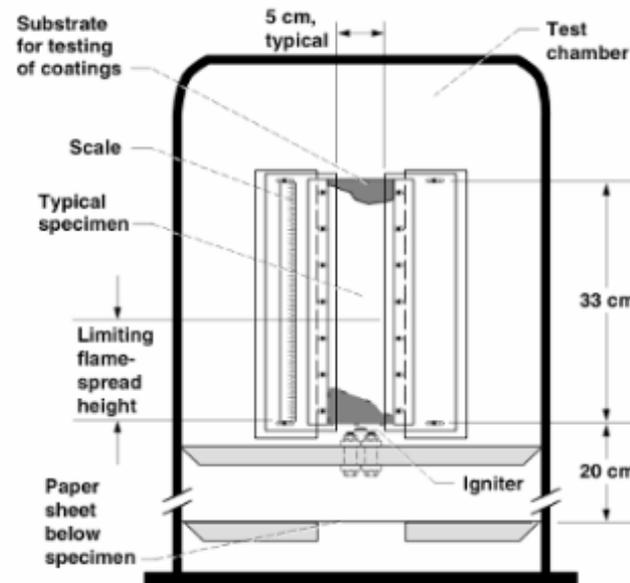




Material Flammability Screening Test



- 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

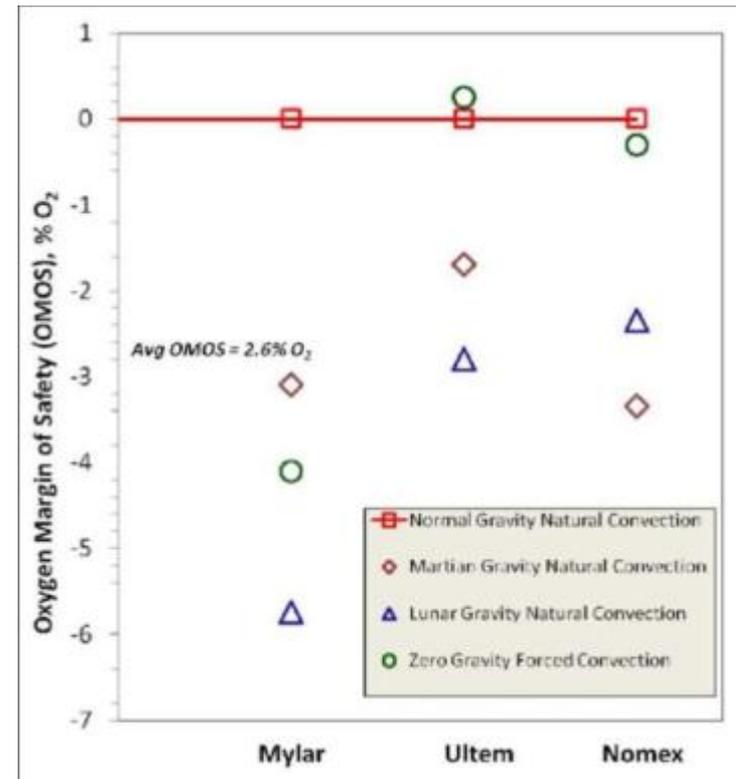
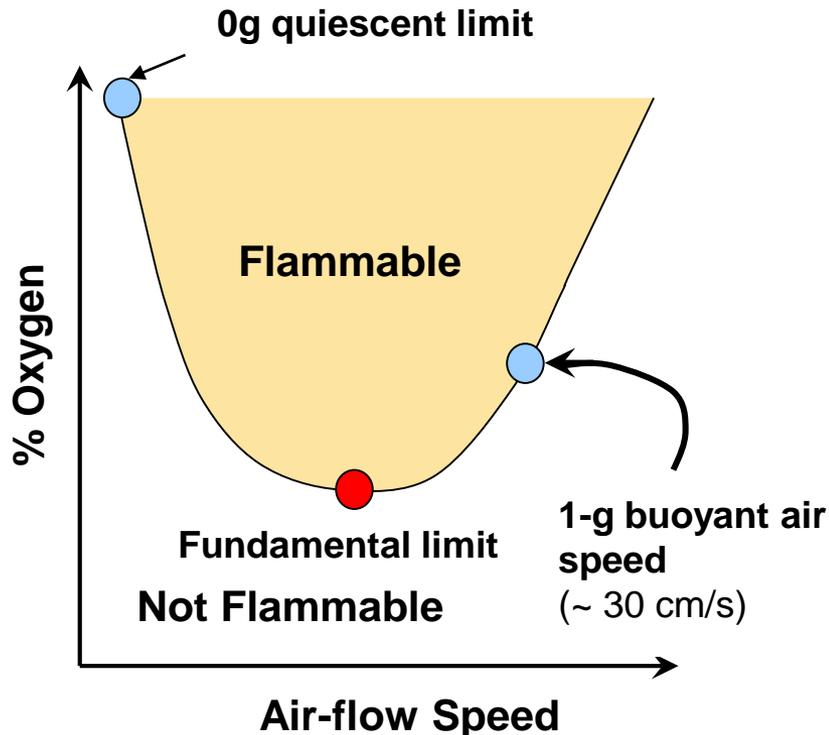
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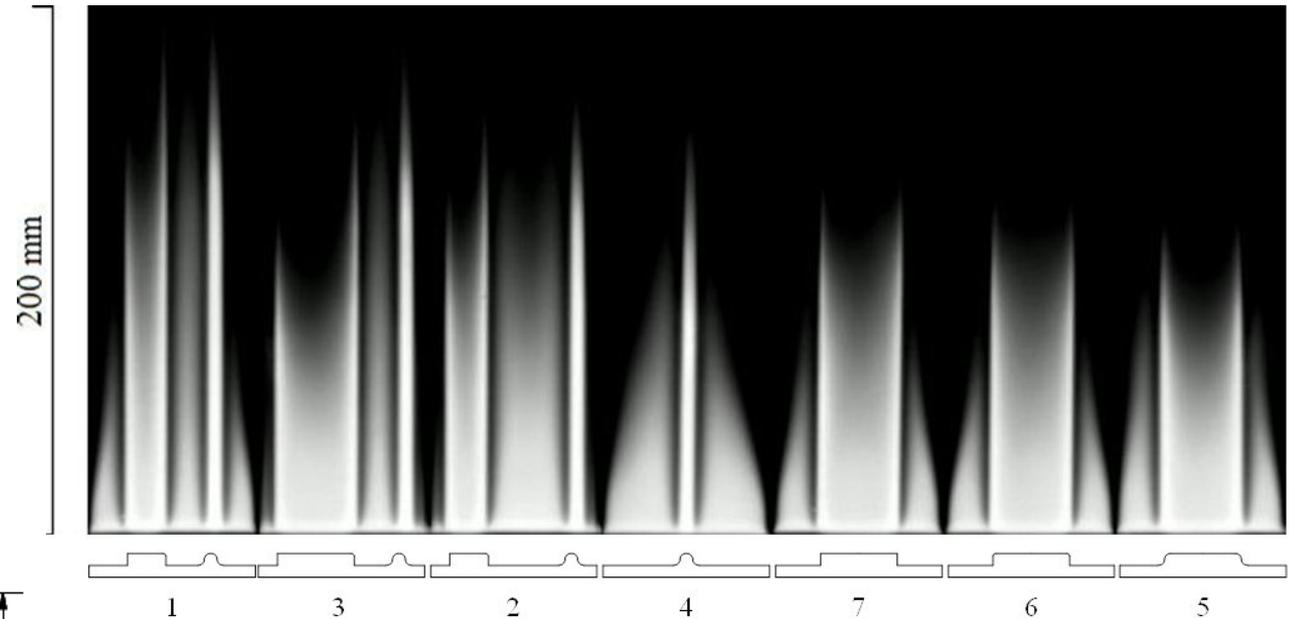
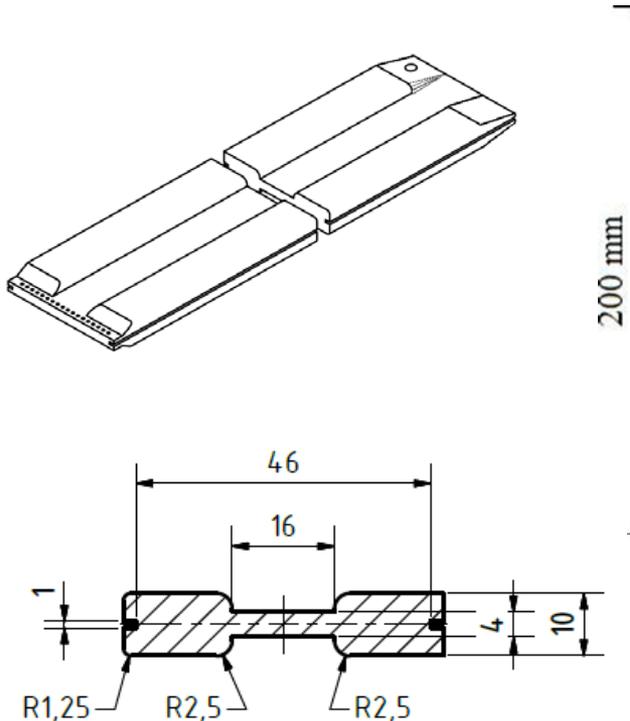
Low-g Maximum Oxygen Concentration



- 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

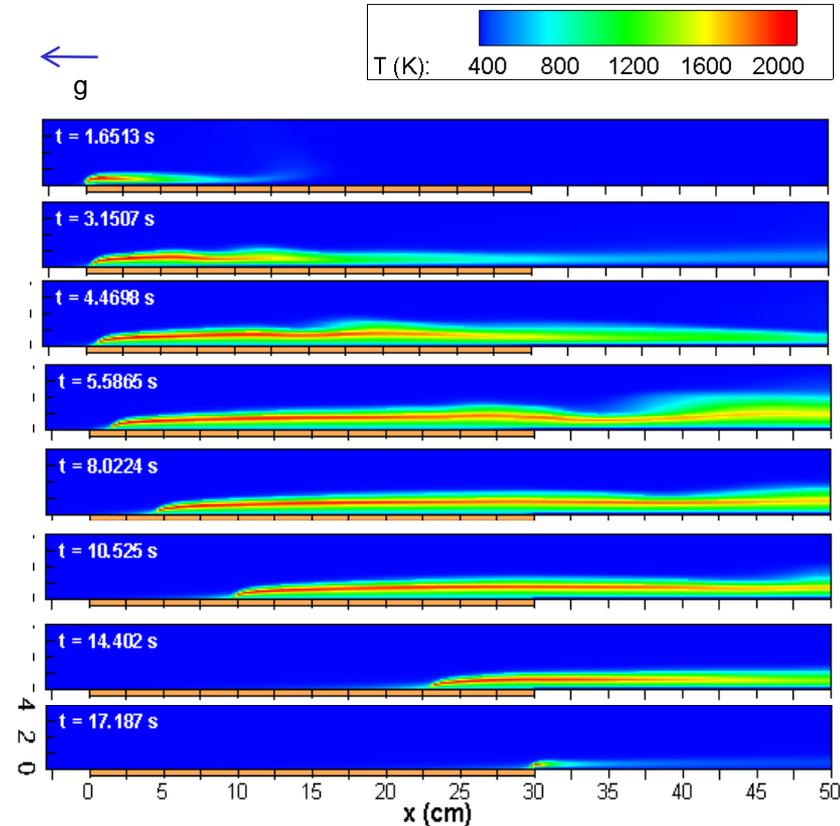


- International Topical Team members from Bremen, Germany are conducting ground tests of one of the samples to be flown on Saffire-II.
- This is a polymethyl methacrylate (PMMA) sheet with a machined ridges and grooves on the surface
- This will investigate the influence of surface structure on the spread rate of a low-g flame



Images obtained using an infrared (IR) camera of a flame on structured PMMA sample. The design of structures machined into the sample are shown below each image. The effect of edge curvature and type of structure on the flame is evident. These results were obtained in 1-g after 60 seconds for all images.

- Xiaoyang Zhao and Prof. James T'ien (Case Western Reserve University) are expanding the capability of an existing flame spread model to simulate Saffire test conditions.
- Data from Saffire-I, -II, and -III experiments will be compared to extended versions of these models.



Buoyant flow sample is 5 cm wide by 30 cm long, sandwiched by metal plates



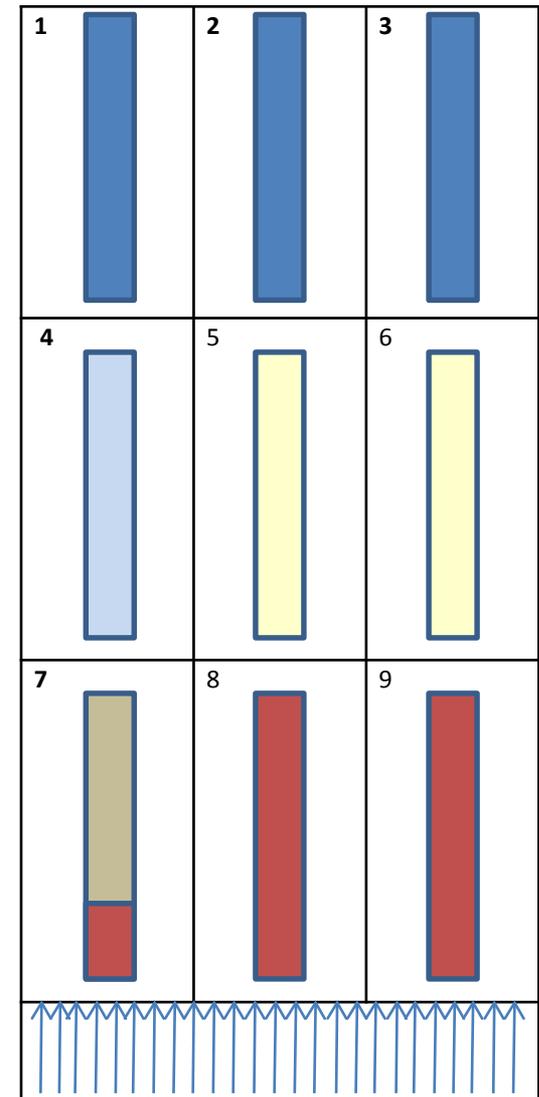
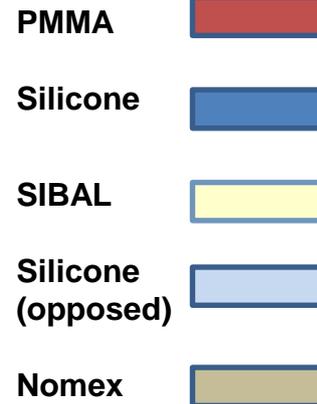
Temperature along center plan (colors) vs. time (top to bottom) for a buoyant flow condition. (In low-g, Saffire conditions will be in forced flow.)



Result: Saffire-II --- Array of 9 samples



- ◆ Samples are 5 cm x 29 cm
- ◆ Four different sample materials
 - Concurrent and opposed for Silicone
- ◆ Motivation
 - Previous low-g data (small scale)
 - Material flammability limits
 - NASA-STD-6001 Test 1
 - Spacecraft fire safety strategy

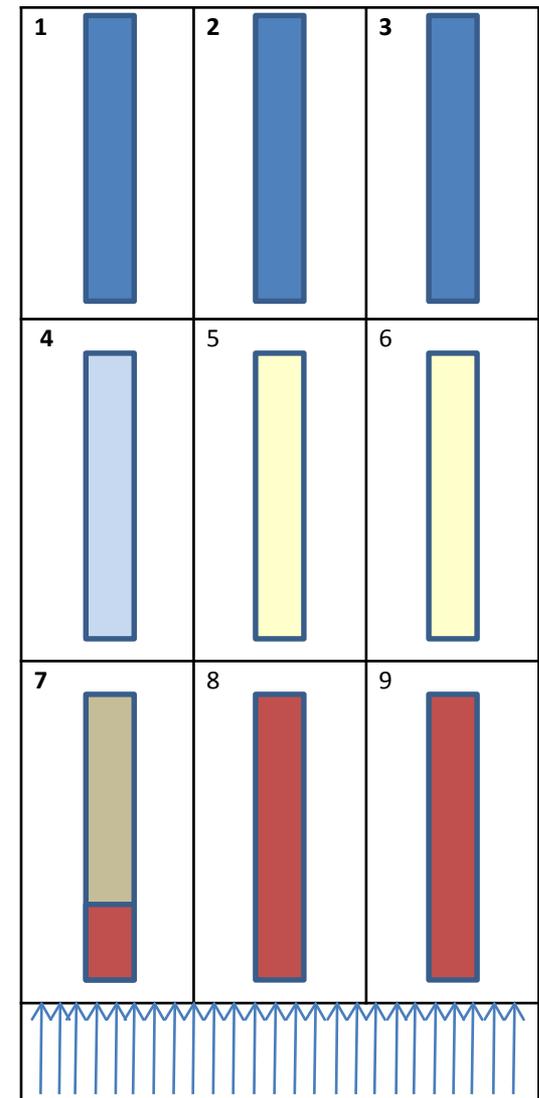




Saffire-II: Array of 9 samples



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

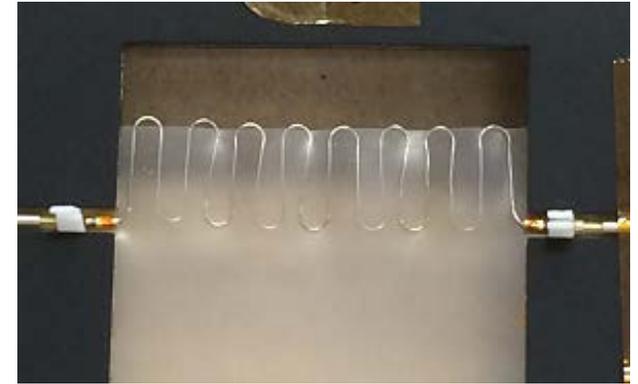


- Populated and wired sample card for Saffire-II



- Igniter wire “loops” on a silicone sample
 - Space upstream of sample allows edge ignition

Flow





Conclusions



- ◆ **Through novel utilization of an existing carrier, Saffire has broken the path for a new research platform.**
- ◆ **Saffire tests exceed (in size) all prior low-gravity combustion testing by more than an order of magnitude, bringing the flames to a realistic scale.**
- ◆ **Saffire results will provide an important benchmark data set for future space craft fire safety design and analysis.**

