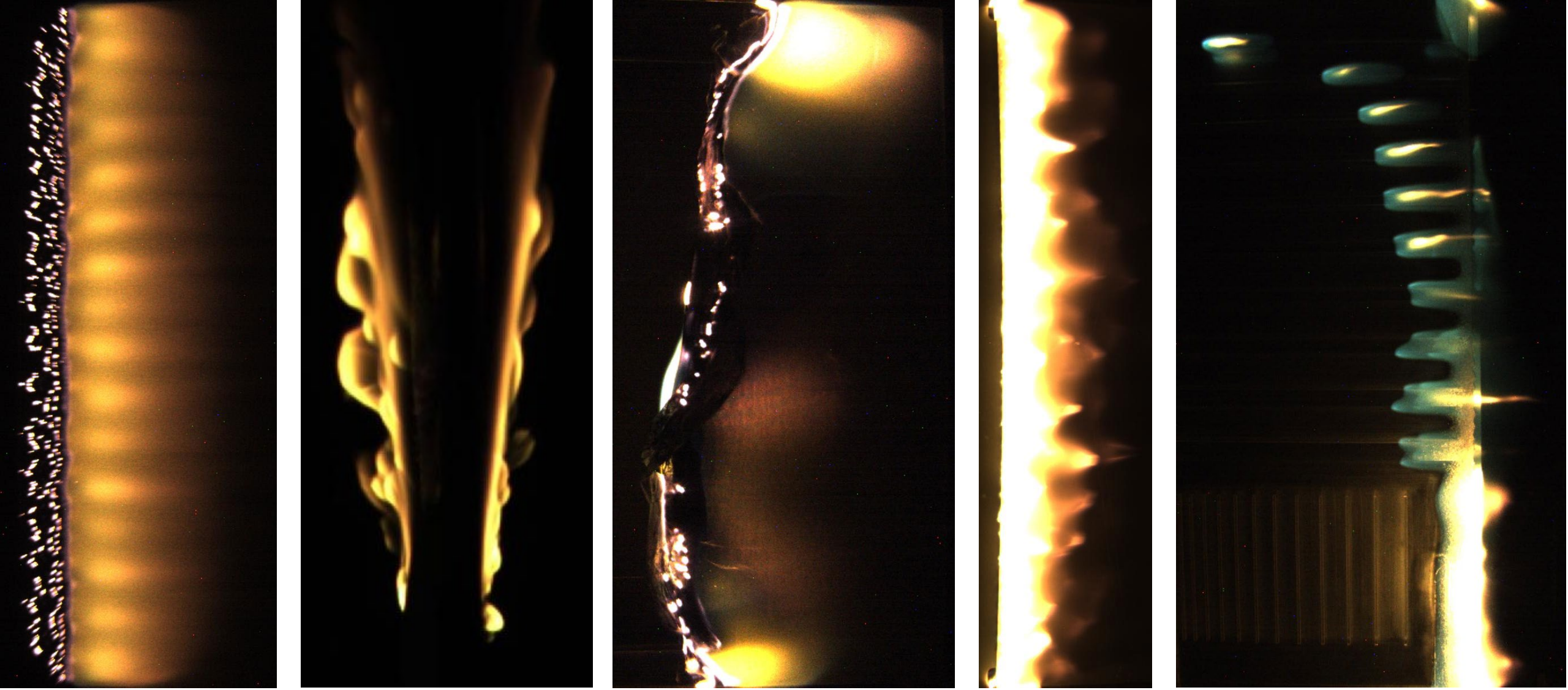

Fire Safety Implications of Preliminary Results from Saffire IV and V Experiments on Large Scale Spacecraft Fires

July 14, 2021

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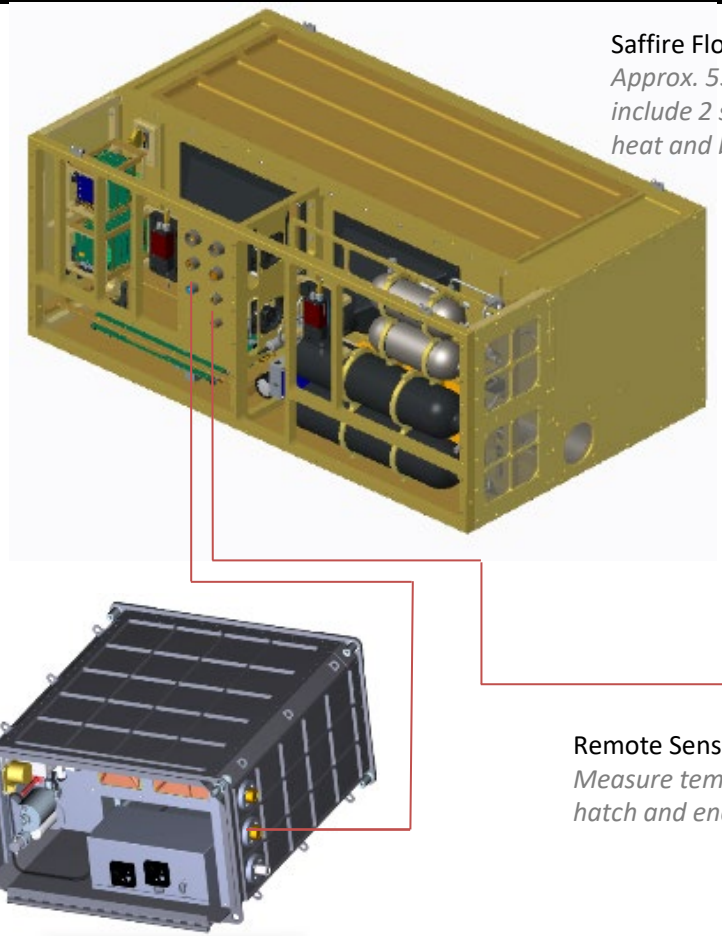
Motivation and Background

- **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



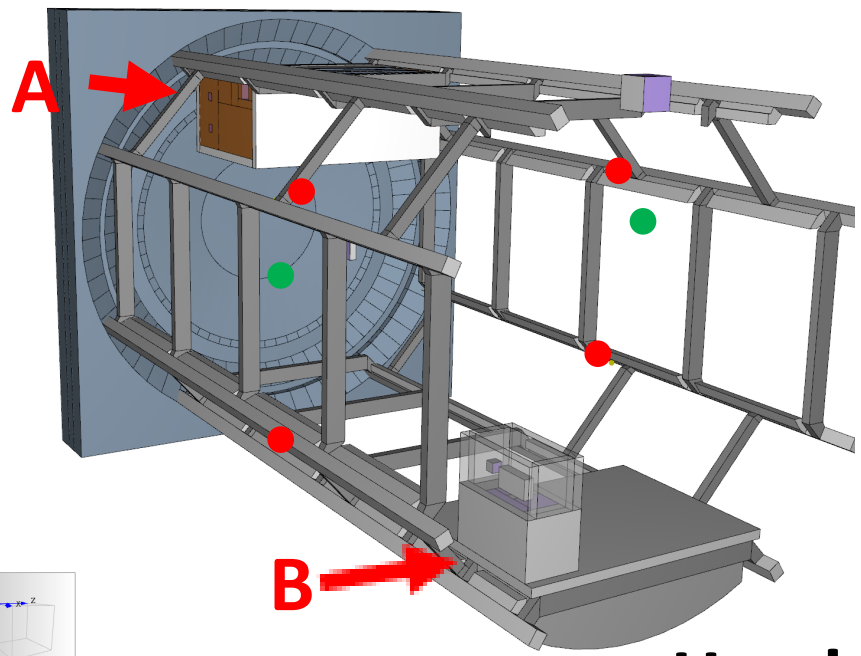
Saffire Flow Unit
Approx. 53x90x133cm. New features include 2 side view cameras, acid gas, O_2, heat and byproduct release to cabin

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

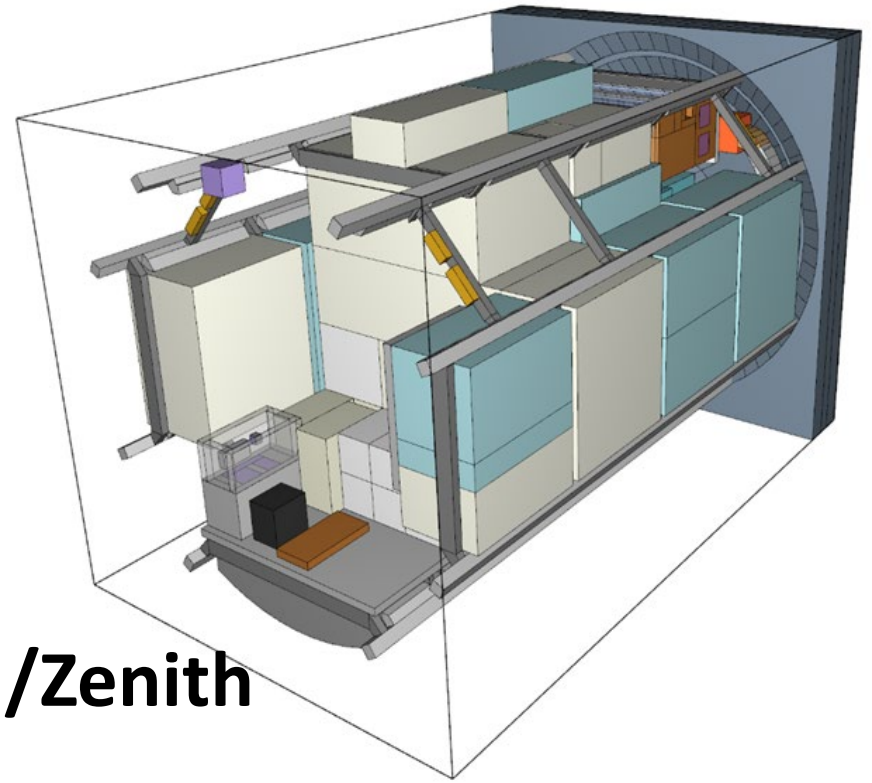
Far Field Diagnostics (in Mid Deck Locker)
Avionics, CO_2 scrubber, Smoke Eater, Combustion Products Monitor, particulate monitors (DustTrack & Ion Chamber)

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

Configuration in spacecraft



Hatch/Zenith



Nadir/End Cone

Dots are remote sensors, **RED** in standoffs, **GREEN** in end cone or hatch.

A: Saffire Flow Unit

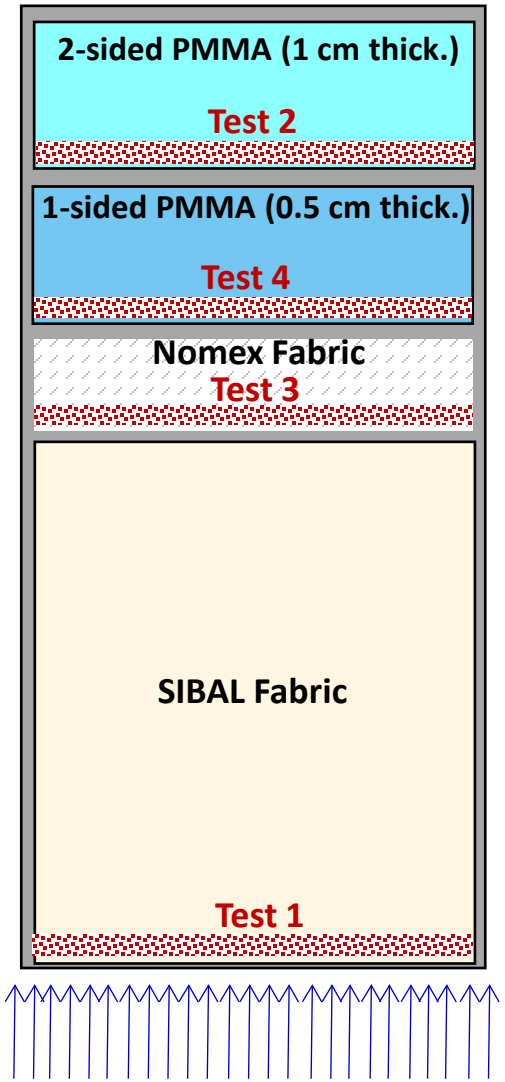
B: Far Field Diagnostics

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		

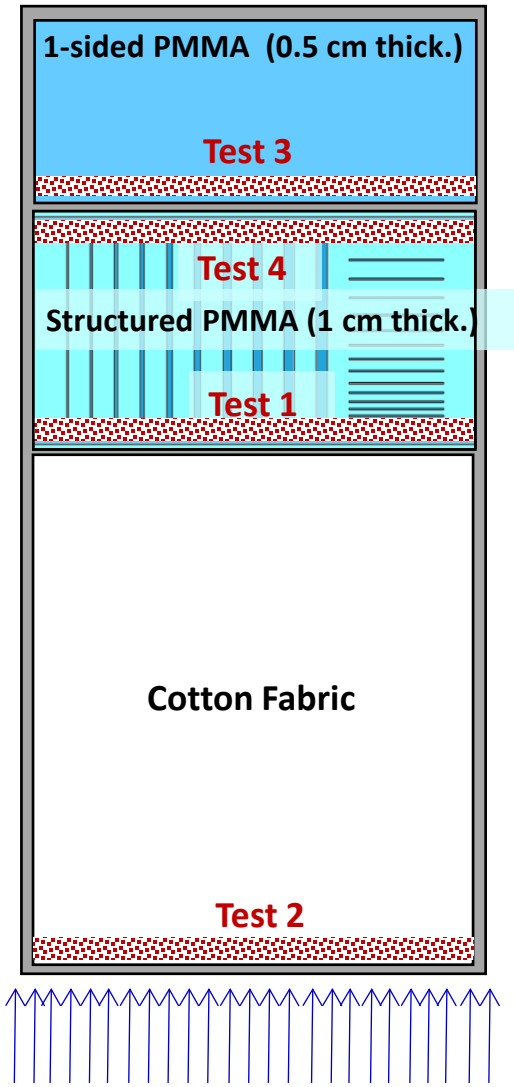
Sample configuration

Saffire IV



Air and Normoxic O_2 with forced flow

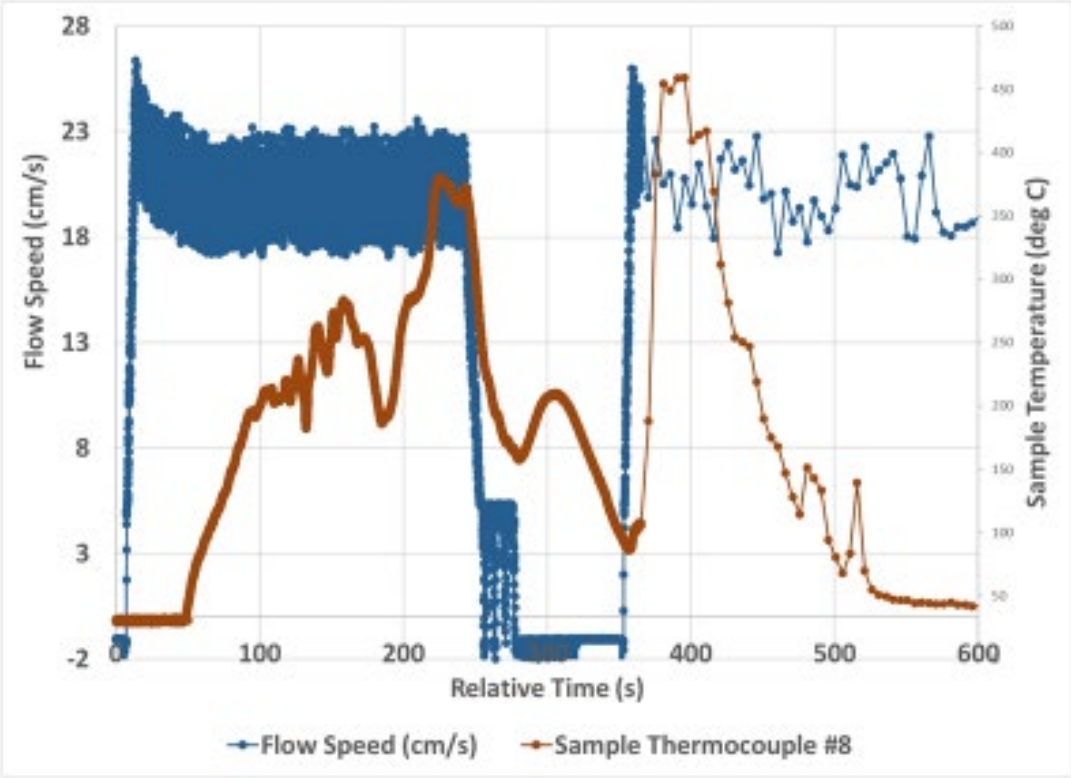
Saffire V



Normoxic O_2 with forced flow

Findings-Extinguishment

Extinguishment of thin charring fuels at increased oxygen cannot be assumed to occur rapidly in quiescent conditions.



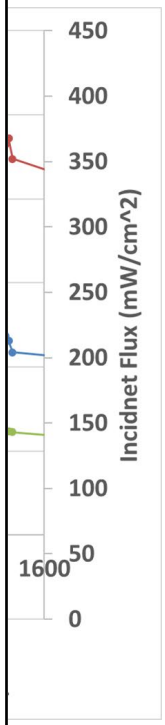
Saffire V-2 (cotton jersey)

Low flow for 35 s

Flow was off for 70 seconds

10 X speed video- top view

Findings-Extinguishment

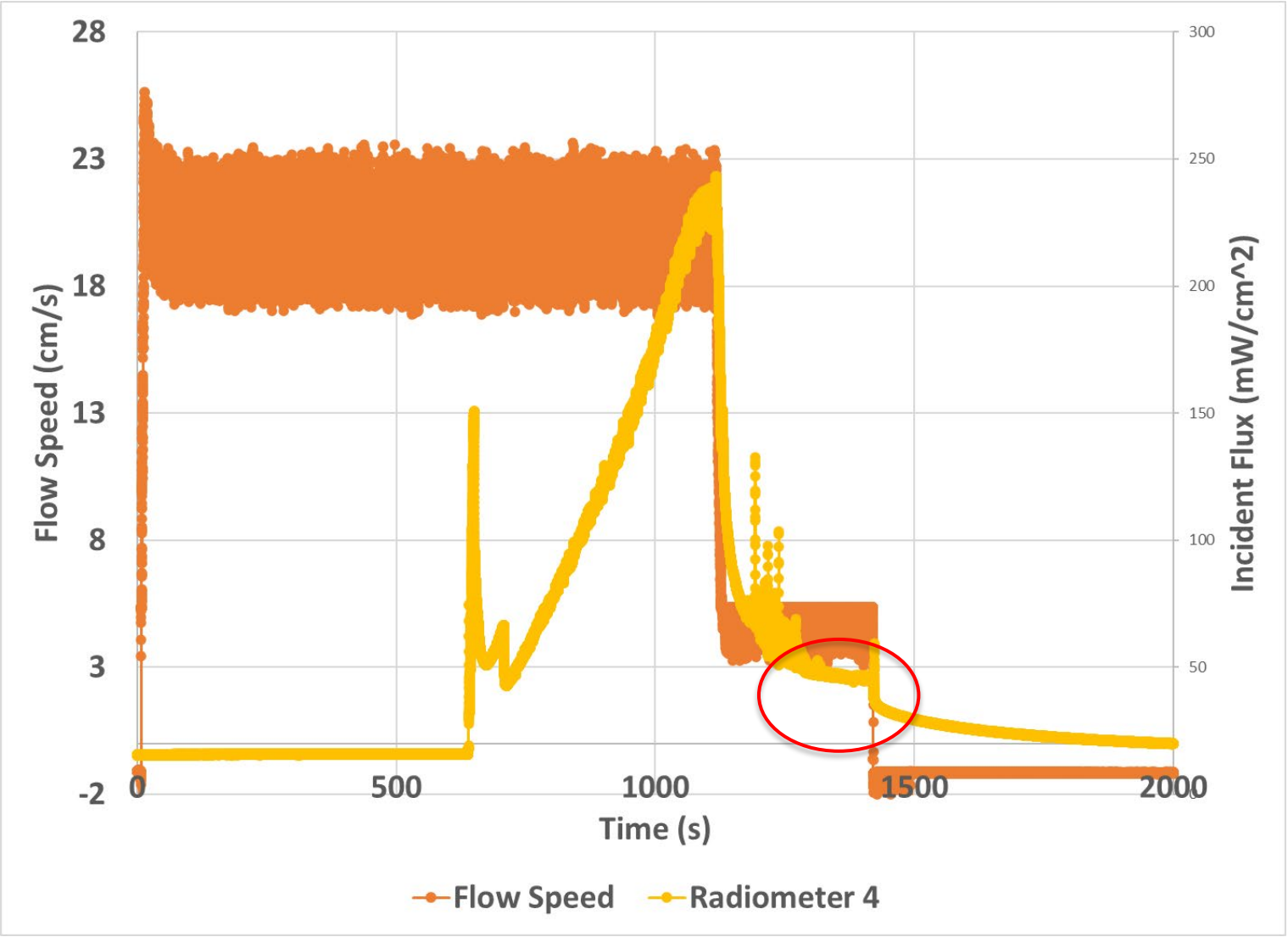


Extinguishment of bubbling polymers cannot be assumed to occur rapidly in quiescent conditions

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-Extinguishment

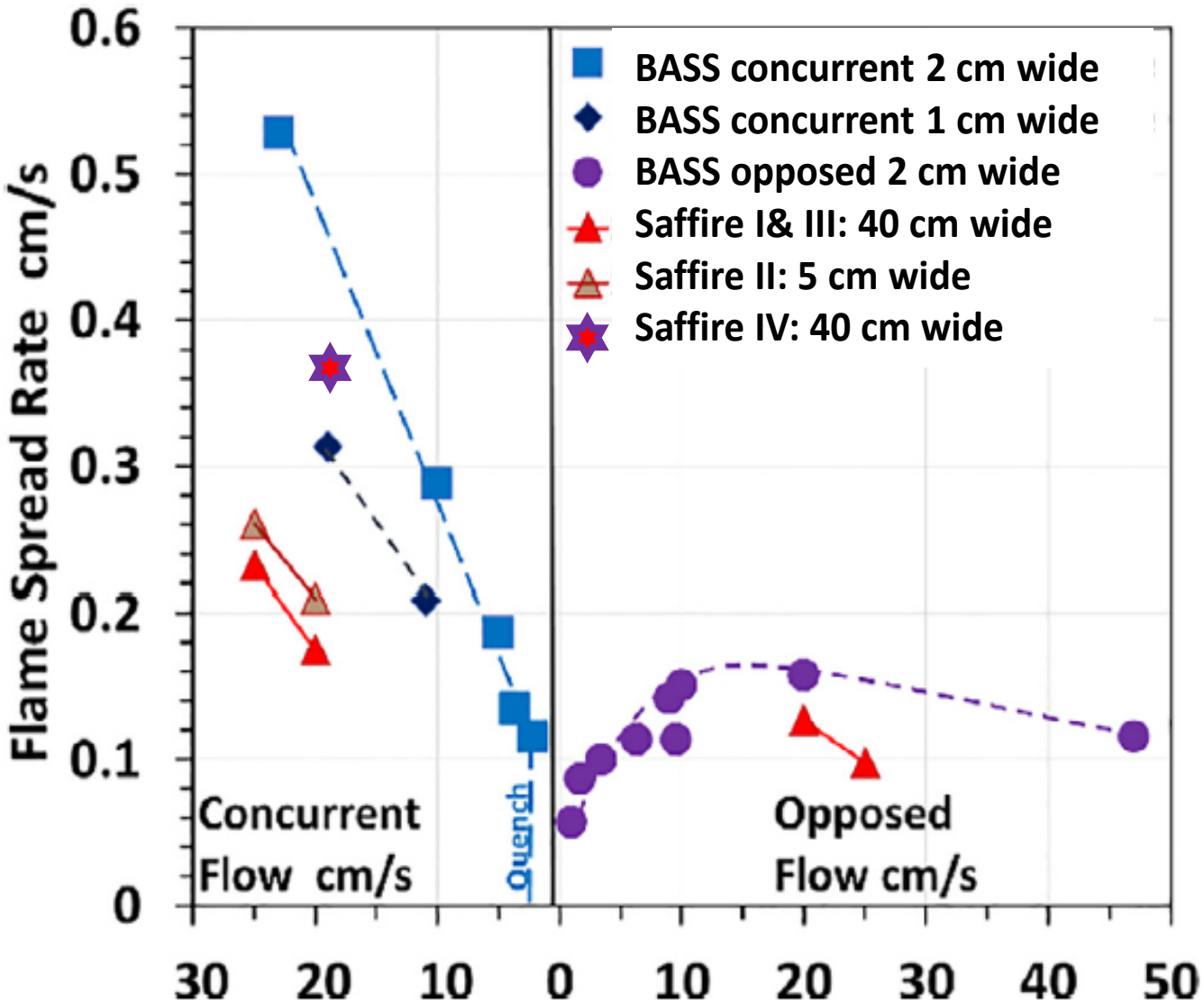


One sided PMMA.

300 seconds of low air flow (5 cm/s)

In some circumstances, reducing air flow to a small value rather than quiescent conditions may be useful to disperse fuel vapor and help cool the material to enable extinction

Findings - Spread rate

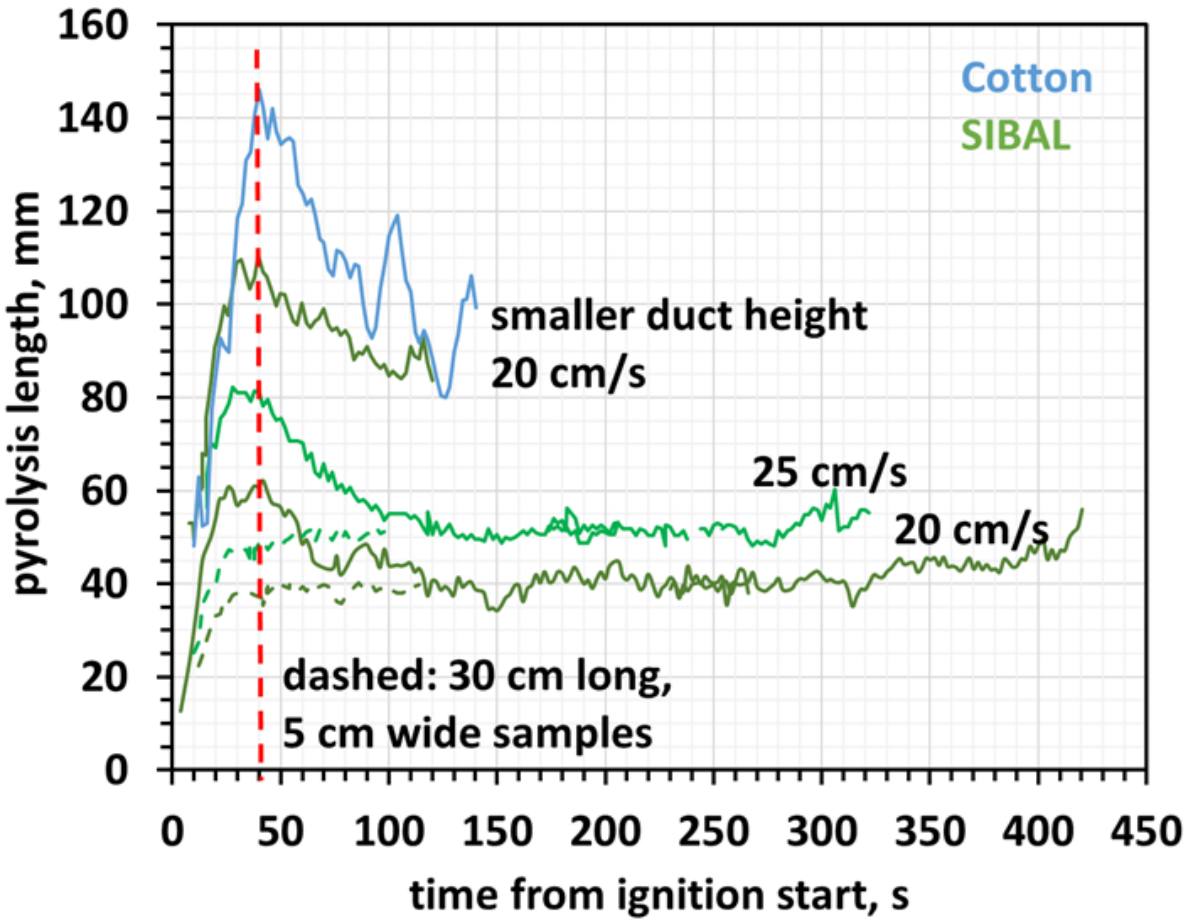


Duct size and flow development can affect the spread rate and the pyrolysis length

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.

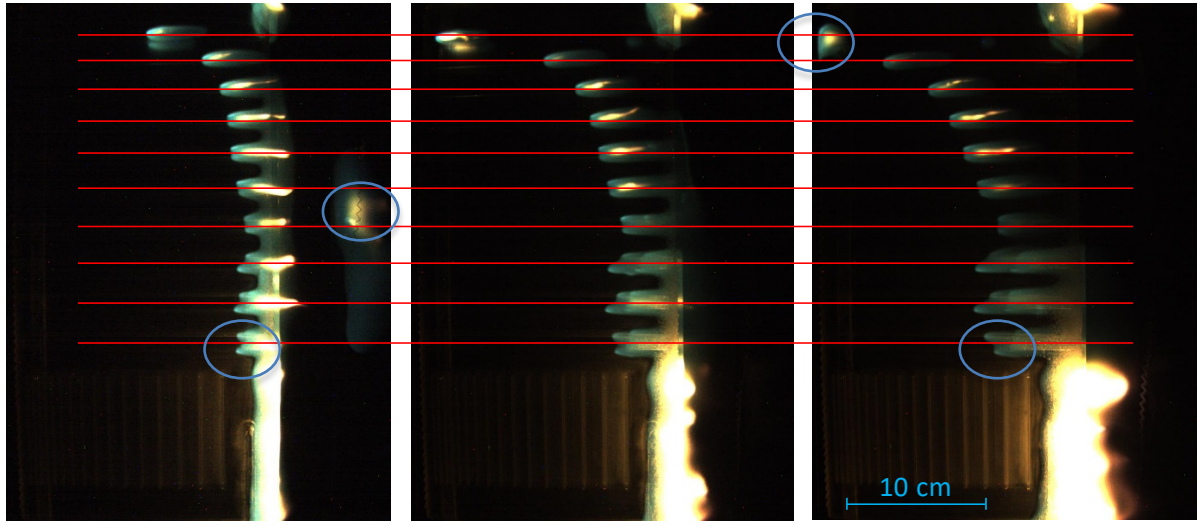
Findings-Flow/configuration

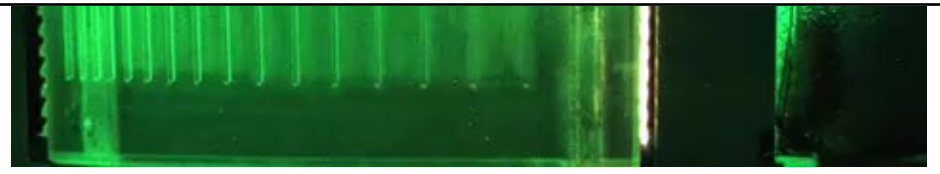


- Cotton and SIBAL samples from Saffire I-V

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

Findings - Surface structure





In opposed spread over thick materials, the size of ridges or other surf 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

Overview

- **Spread and Growth**
  - Flames were seen to develop to nearly steady lengths in all configurations.
    - This includes concurrent and opposed spread on thin fuels and on thick fuels.
  - Flames on thick fuels in concurrent flow did not spread and were instead pinned to the leading edge of the sample
    - In opposed flow on thin structures, the flames spread toward the leading edge where they became pinned, flames behind obstacles did not spread.
  - Once a flame achieved its limiting size, downstream flames were inhibited or extinguished by the oxygen “shadow” of the upstream flame.
  - Thick fuel flame growth was found to be dissimilar from that seen in NASA STD 6001 Test 1: concurrent flames established a finite size and did not grow further. This does not invalidate the test but does affect the interpretation of the test results
  - In one case, a flame was seen to jump a 4.5 cm gap to ignite a previously warmed PMMA surface.

- **The Saffire experiments have identified important features of flame spread and growth on solid fuels.**
- **The experiments had a measurable impact on the spacecraft itself**
  - These results will be used to validate our models of fire impact
  - Post fire cleanup results are discussed in another paper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