

# Preliminary Results from the Saffire VI Experiment

2024 53rd International Conference on Environmental Systems

July 21-25, 2024, Louisville, KY



# Authors



- **David L. Urban, Gary A. Ruff, Paul Ferkul, John Easton, Michael Johnston, Jay Owens, Sandra Olson, Claire Fortenberry** *NASA Glenn Research Center, Cleveland, OH, USA*
- **John Graf, Oageng George,** *NASA Johnson Space Center, Houston, TX, USA*
- **Balazs Toth,** *ESTEC, Noordwijk, Netherlands*
- **Florian Meyer, Christian Eigenbrod,** *University of Bremen (ZARM), Bremen, Germany*
- **James S. T'ien, Ya-Ting T. Liao,** *Case Western Reserve University, Cleveland, OH, USA*
- **A. Carlos Fernandez-Pello,** *UC Berkeley, Berkeley, CA, USA*
- **Guillaume Legros,** *CNRS-ICARE, Univ. Orléans, Orléans, France*
- **Augustin Guibaud,** *University College, London, UK*
- **Nickolay Smirnov,** *Moscow State University, Russian Federation*
- **Osamu Fujita,** *Hokkaido University, Sapporo, Japan*
- **Ulises Rojas Alva, Grunde Jomaas,** *Slovenian National Building and Civil Engineering Institute, Ljubljana*

*Acknowledgements: NASA Mars Campaign Office*

*Space and Research agencies that have supported this work including but not limited to JAXA, ESA, RSA, CNES, DLR, the Russian Academy of Sciences and NASA. ]The excellent support by the engineering team (NASA and Zin Technologies), Northrup Grumman and the on-orbit crew are gratefully acknowledged.*

# How rapidly can a fire spread in low-g?

- **This question lies at the heart of the development of a spacecraft fire safety strategy**
  - Similar to any terrestrial fire safety application
- **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*

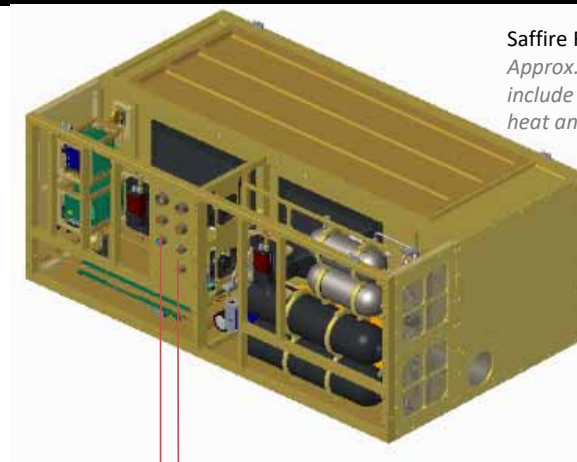
**ALL terrestrial occupied structure types have been the subject of full scale fire tests (planes, ships, cars, trains, buildings, mines etc.)**

# Background



## Background

- First conceived in 2003 for a different spacecraft
- First funded in 2011
- 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 and Saffire VI flew in December 2023



**Saffire Flow Unit**  
Approx. 53x90x133cm. New features include 2 side view cameras, acid gas, O<sub>2</sub>, heat and byproduct release to cabin



**Far Field Diagnostics (in Mid Deck Locker)**  
Avionics, CO<sub>2</sub> scrubber, Smoke Eater, Combustion Products Monitor, particulate monitors (DustTrack & Ion Chamber)



**Remote Sensors (6)**  
Measure temp & CO<sub>2</sub> in standoffs, hatch and end cone

# Cygnus Spacecraft



**Pressurized  
volume 19 m<sup>3</sup>**

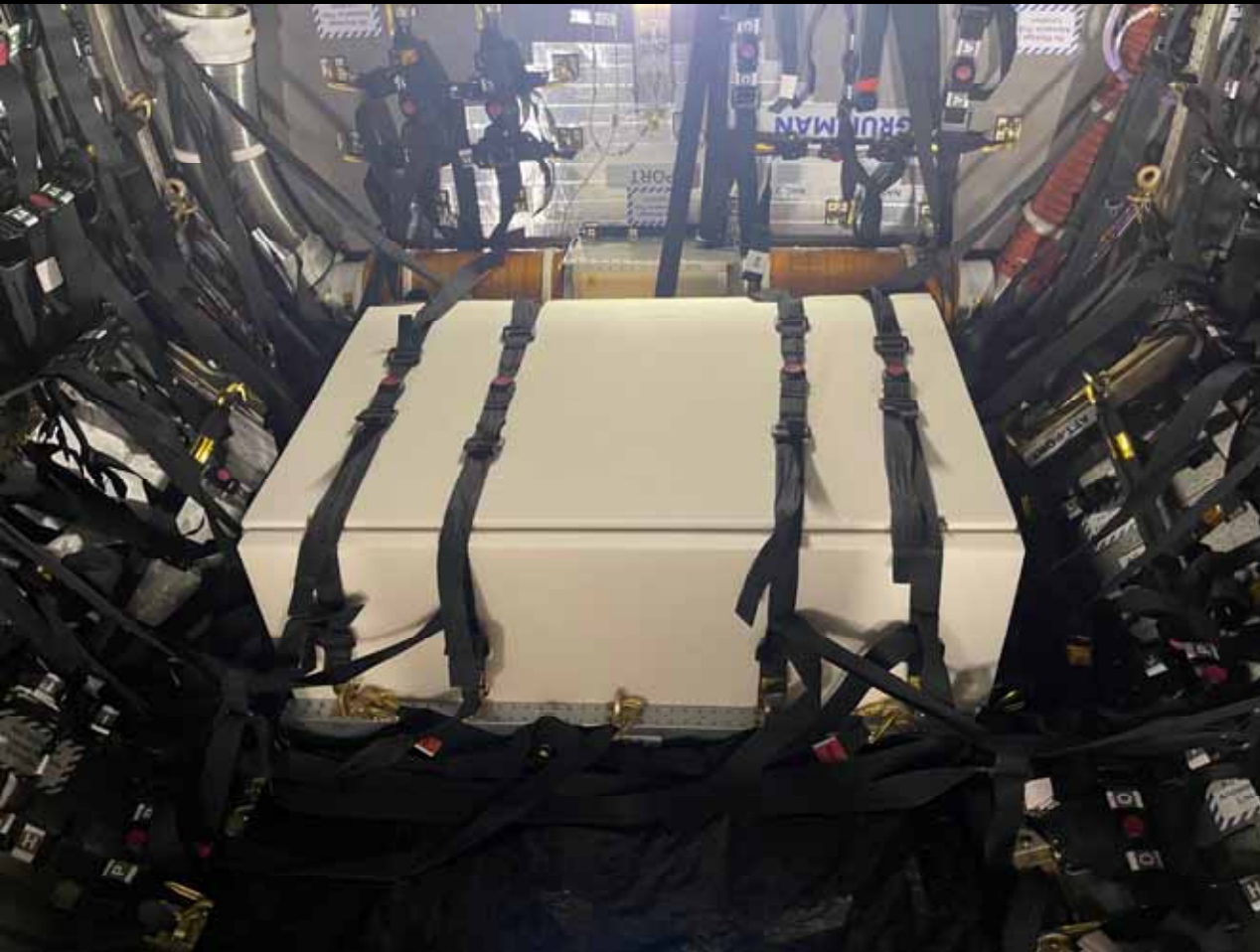
**Typically, on-orbit  
for several  
months**

**19 successful  
flights since 2013**

# Saffire InstallaTION



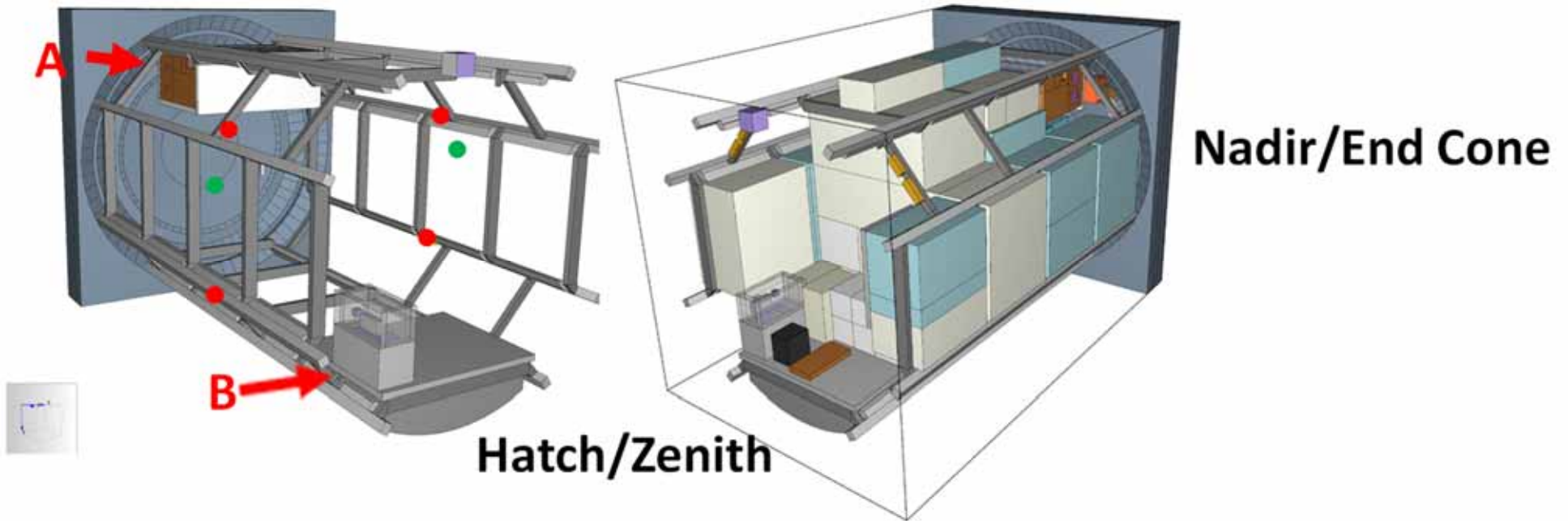
As installed



# Spacecraft Interior before return



## Configuration in spacecraft

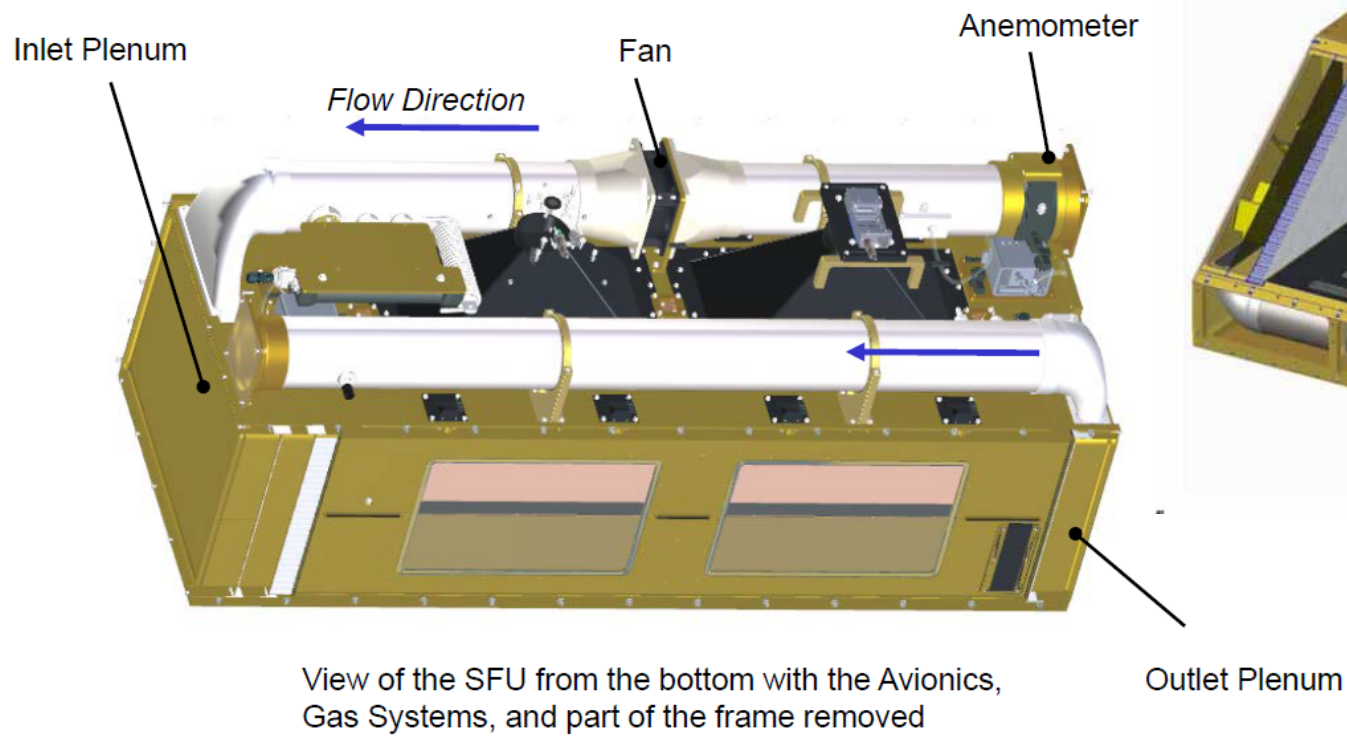


Dots are remote sensors, **RED** in standoffs, **GREEN** in end cone or hatch.

**A: Saffire Flow Unit**

**B: Far Field Diagnostics**

# Overview of Flow System



## Test Matrix (as executed)

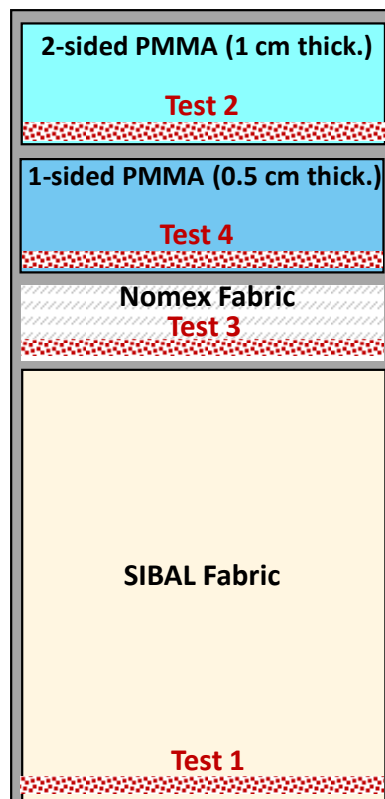


<b>Flight/Sample</b>	<b>IV-1</b>	<b>V-2</b>	<b>VI-2</b>	<b>VI-3</b>	<b>VI-4</b>
<b>Material/configuration</b>	<b>SIBAL Cloth</b>	<b>Cotton Jersey</b>	<b>SIBAL Cloth</b>	<b>Two-Sided PMMA</b>	<b>One-Sided PMMA</b>
<b>Length (cm)</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>18</b>	<b>18</b>
<b>Air Flow Rate (cm/s)</b>	<b>20</b>	<b>20</b>	<b>20</b>	<b>20</b>	<b>20</b>
<b>Flow Direction</b>	<b>Concurrent</b>	<b>Concurrent</b>	<b>Concurrent</b>	<b>Concurrent</b>	<b>Concurrent</b>
<b>Ambient Pressure (kPa)</b>	<b>100.0</b>	<b>70.7</b>	<b>54.1</b>	<b>54.6</b>	<b>55.2</b>
<b>Oxygen Concentration (mol %)</b>	<b>22.0</b>	<b>26.2</b>	<b>31.0</b>	<b>30.3</b>	<b>28.8</b>
<b>Free volume (m<sup>3</sup>)</b>	<b>17.9</b>	<b>19.0</b>	<b>16.7</b>	<b>16.7</b>	<b>16.7</b>

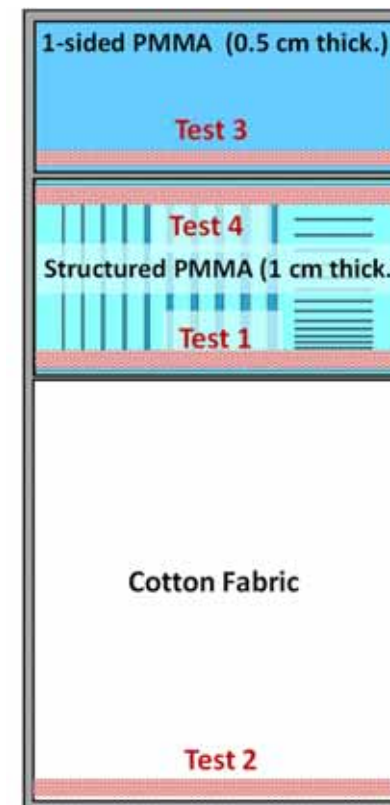
# Sample configuration



Saffire IV & VI



Saffire V

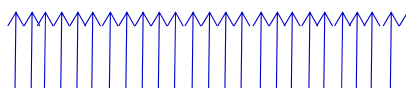


Duct width 45 cm

Duct Length 109 cm

Duct Half Height 15 cm

Samples 41 cm wide

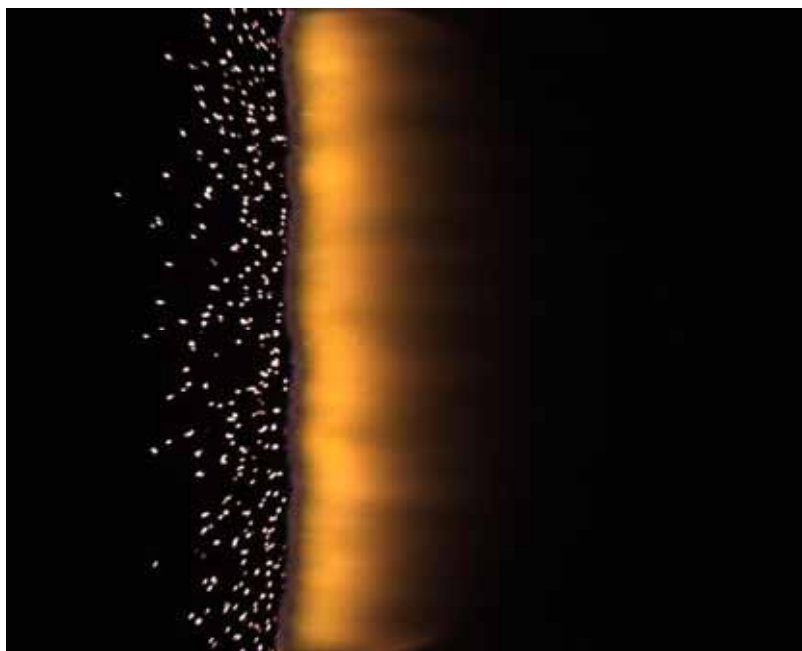


Air and Normoxic O<sub>2</sub>  
with forced flow



Normoxic O<sub>2</sub> with  
forced flow

## Saffire VI samples



**SIBAL fabric (test 2)**



**2-sided  
PMMA  
(test 3)**



**1-sided  
PMMA  
(test 4)**

**Oxidizer flow is from the left at 20 cm/s in all cases.**

# SIBAL Sample



## SAFFIRE VI

Ignition Time: -4.728 s

Global Time: 125.000 s

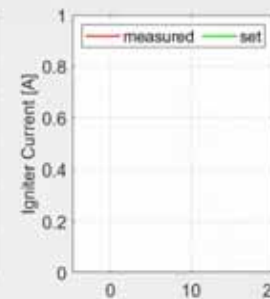
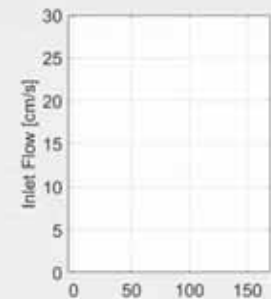
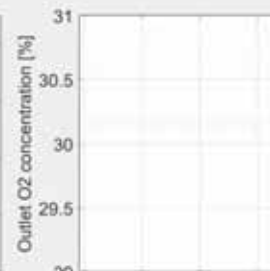
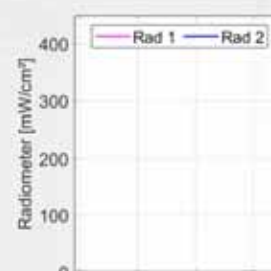
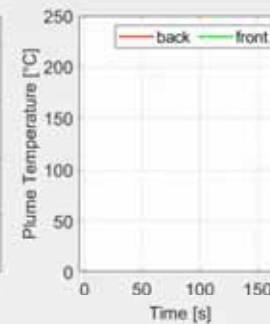
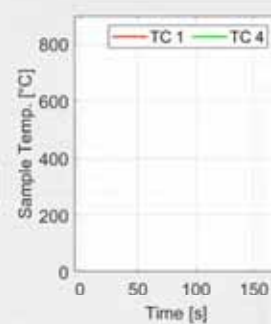
### Test 5

Sibal - concurrent

Start Conditions:  
54.3 kPa  
30.9% O2

No image data available

No image data available



# 2-Sided PMMA Sample

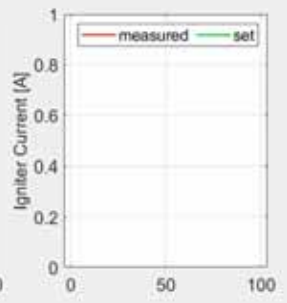
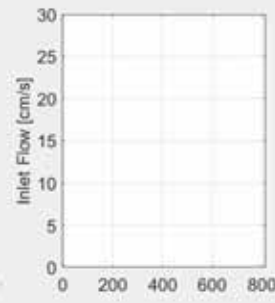
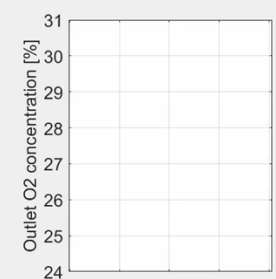
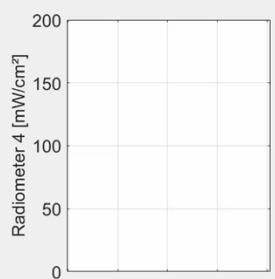
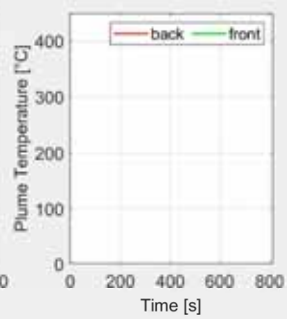
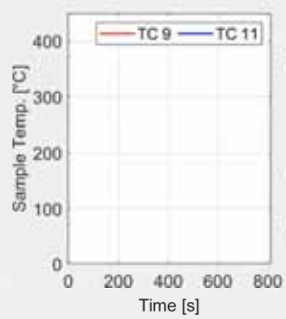


**SAFFIRE VI**  
**Ignition Time: -3.610 s**  
**Global Time: 633.000 s**  
**Test 6**  
PMMA (two-sided) - concurrent

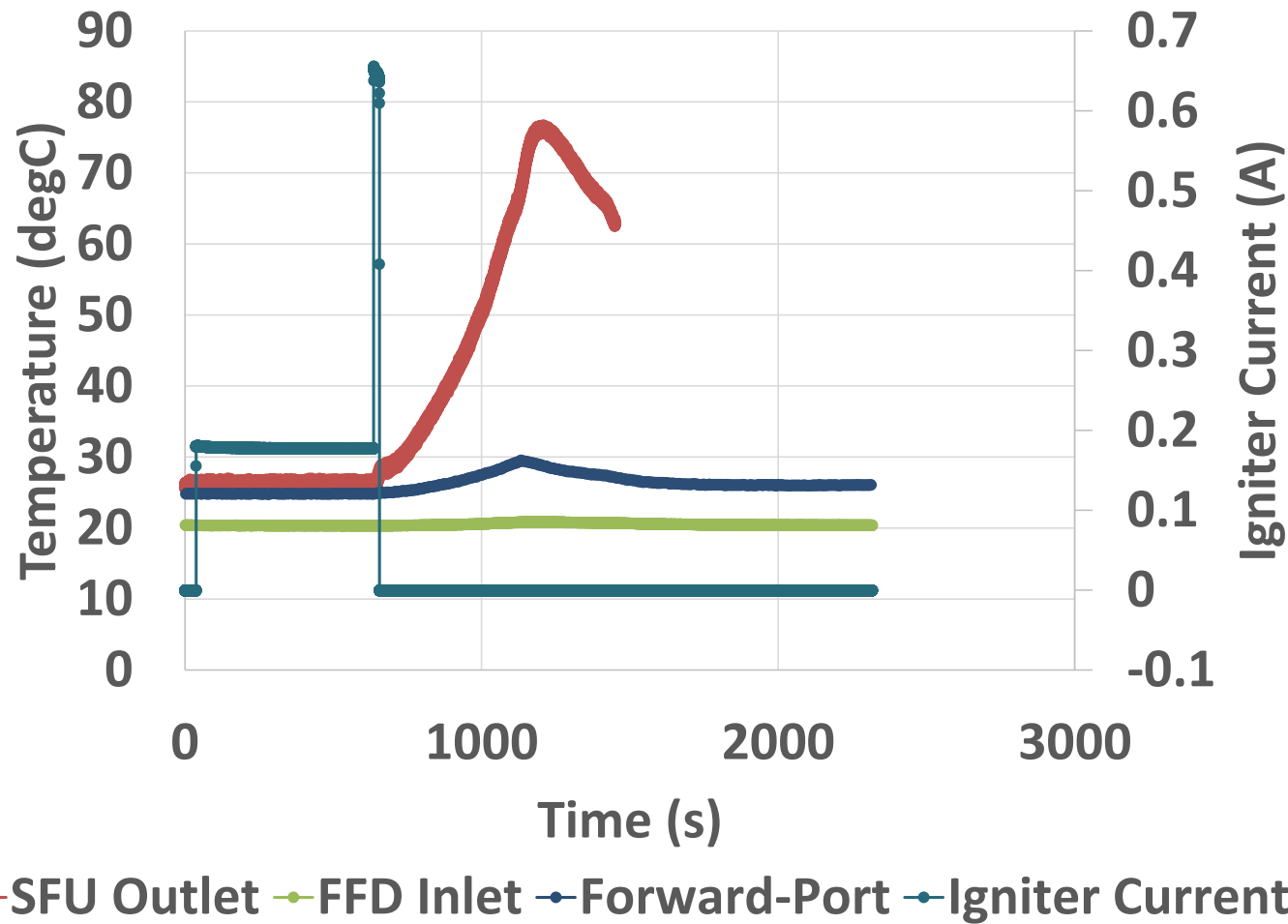
Start Conditions:  
54.7 kPa  
30.4% O2

No image data available

No image data available



# Temperature results for Saffire VI-3 (two-sided PMMA).



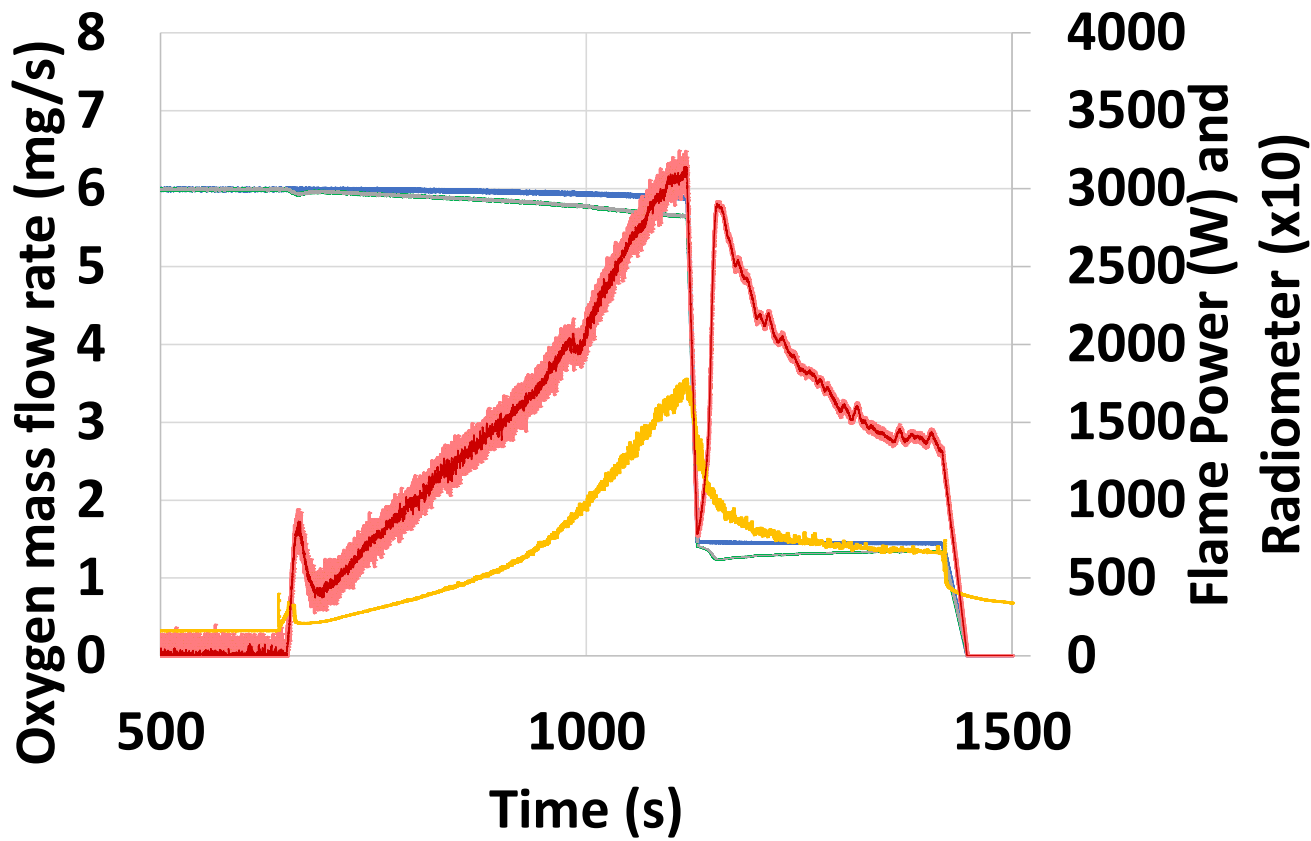
**Ignition at 637 s**

**Flow reduced at 1120 s**

**Duct flow terminated at 1420 seconds**

**The forward port sensor is the nearest to the Saffire flow duct outlet.**

# Heat Release for Saffire VI-3 (two-sided PMMA)



**Ignition at 637 s**

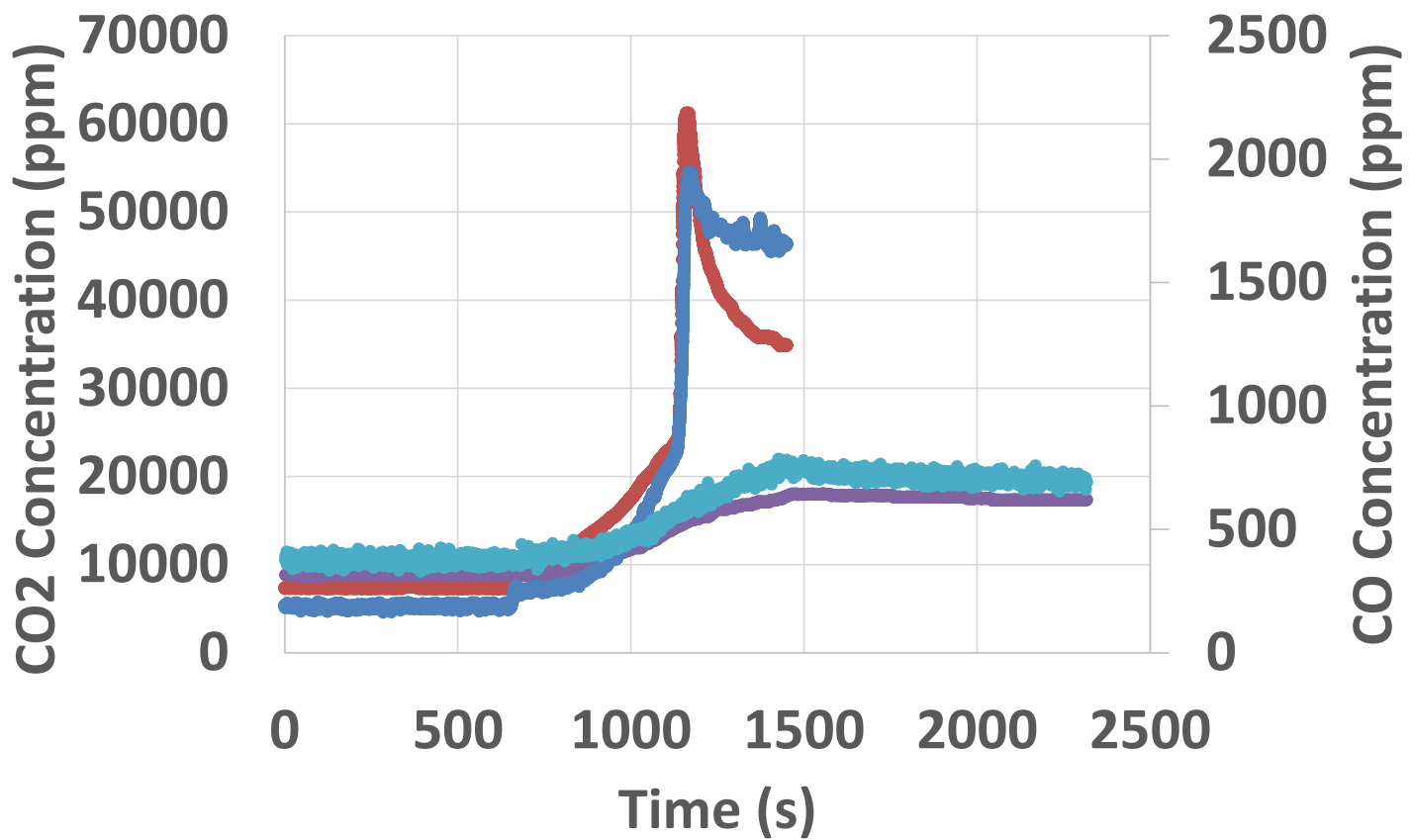
**Flow was changed from 20 cm/s to 5 cm/s at 1120 seconds**

**Flow terminated at 1420 s.**

- Inlet O2
- Outlet O2
- Radiometer #4 (x10)
- Flame power
- 10 per mov. avg.



# CO and CO2 concentrations for Saffire VI-3 (two-sided PMMA)



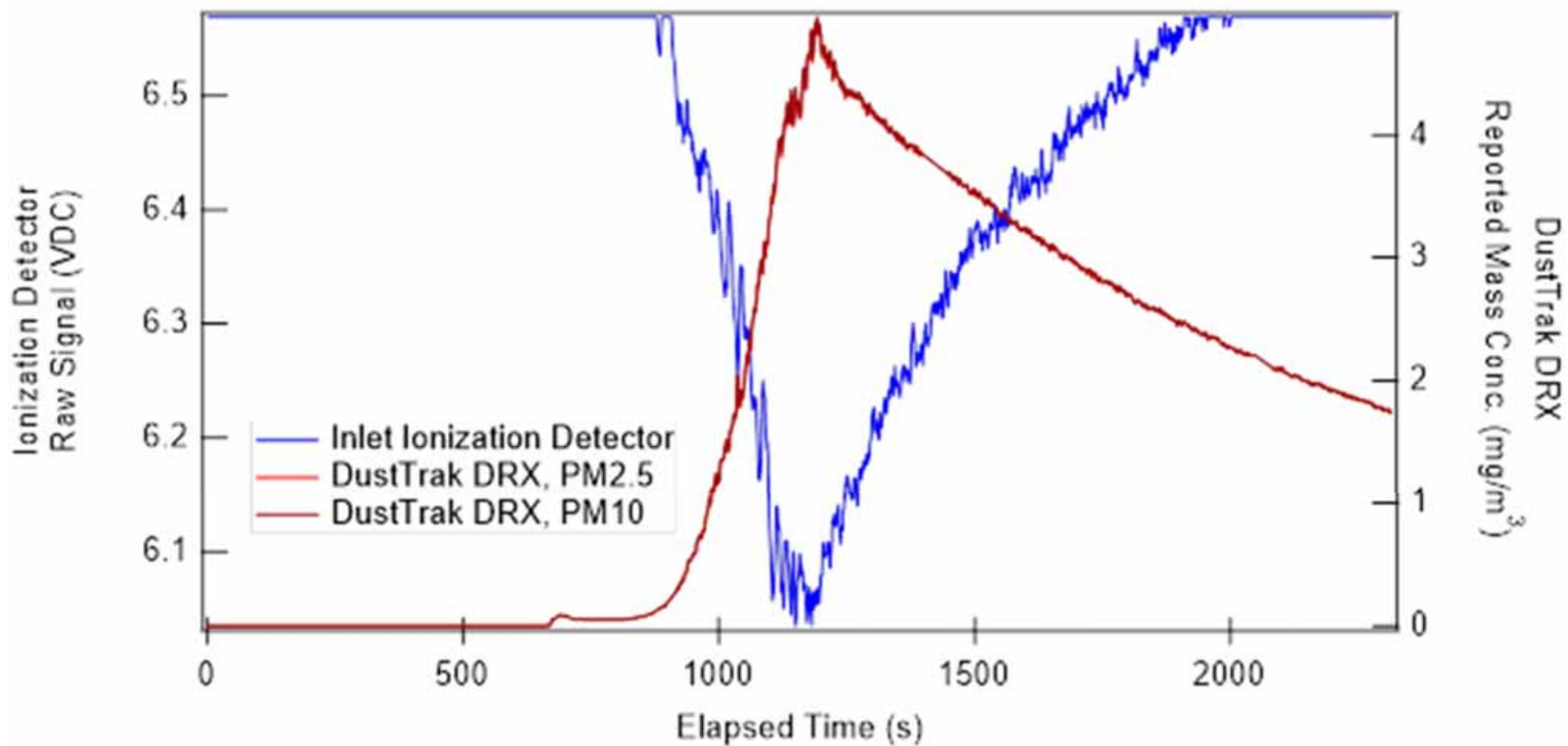
**Ignition at 637 s**

**Flow reduced from 20 cm/s to 5 cm/s at 1120 seconds.**

**Flow terminated at 1420 seconds**

— SFU Outlet CO2 — FFD CO2 — SFU Outlet CO — FFD CO

# Far field ionization smoke detector and particulate matter measurements for Saffire VI-3 (two-sided PMMA).



# Heat Release Results



Saffire Flight/ Sample	Material	Burn duration (s)	Oxygen Consumption Calorimetry		Fuel Consumption Calorimetry						
			Peak Heat Release (W)	Total Heat Release (kJ)	Average Heat Release (W)	Total Heat Release (kJ)	Max Temp at SFU outlet	Max Temp at FFD or nearest location	FFD inlet CO <sub>2</sub> increase (ppm)	CO <sub>2</sub> partial pressure increase (mmHg)	FFD inlet CO increase (ppm)
IV-1	SIBAL	130			3,150	409	45	25	1390	1.03	80
V-2	Cotton Jersey	200			2,800	560	46	23	2360	1.26	83
VI-2	SIBAL	112	3217	580	3,650	409	48	20	2800	1.15	120
VI-3	2-sided PMMA	780	3080	1280			77	21	8539	3.51	308
VI-4	1-sided PMMA	1200	1507	830			57	21	8117	3.37	320

1-hour limit for CO<sub>2</sub> is 3 mmHg, 1 hour limit for CO is 425 ppm, 24 hours is 100 ppm

## Conclusions



- Practical scale fires ranging from 1.5 to 3.2 kW were tested in unmanned spacecraft with free air volumes of 17 to 19 cubic meters.
- The temperature only increased significantly very near to the fire itself.
- Ambient concentrations of carbon monoxide exceeded the the 24-hour carbon monoxide limit. (for PMMA tests)
- Ambient concentrations of carbon dioxide exceeded the 1-hour carbon dioxide limit (for PMMA tests)
- The smoke was readily detected at 981 seconds (after most of the hazardous gas release had occurred)
- The human hazard from a fire in a spacecraft is very similar to terrestrial fires where the heat from the fire is not the principal hazard and rathe the smoke and gaseous products are a much greater concern.

