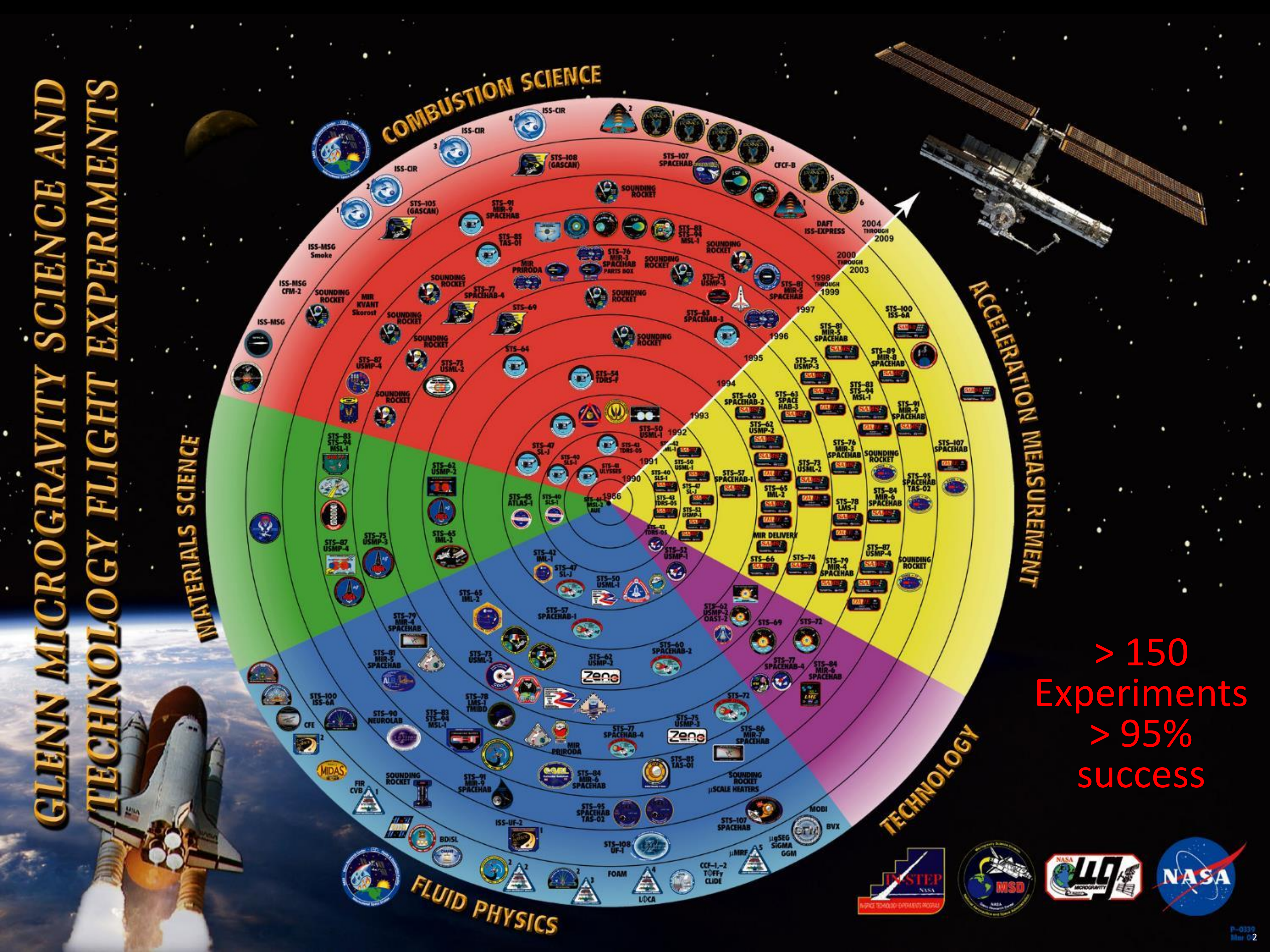
National Aeronautics and
Space Administration

Spacecraft Fire Safety Systems Maturation Team Status

Gary A. Ruff |SFS Demo Project Manager, Space Flight Systems Division| NASA GRC



> 150 Experiments
> 95% success

Spacecraft Fire Safety Systems Maturation Team

Roster

- Gary A. Ruff, Lead, NASA GRC
- David L. Urban, NASA GRC
- Daniel Dietrich, NASA GRC
- John Graf, NASA JSC
- Ariel Macatangay, NASA JSC
- Michael Pedley, NASA JSC
- David Shindo, NASA JSC
- Harold Beeson, NASA WSTF
- Susana Harper, NASA WSTF

Note:

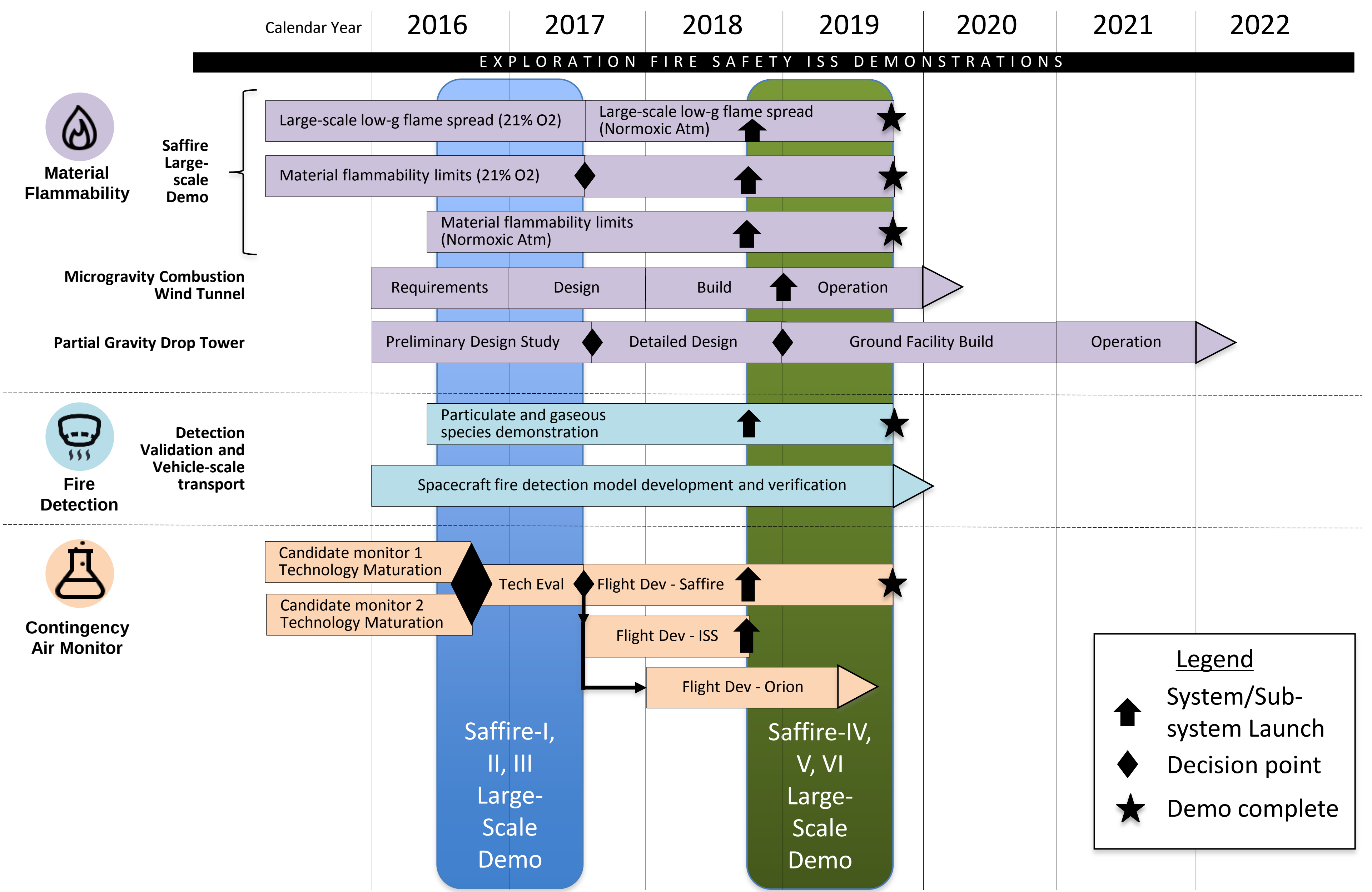
Additional fire safety personnel will be included for specific expertise and to review materials as needed.

Fire Safety Capability Gaps

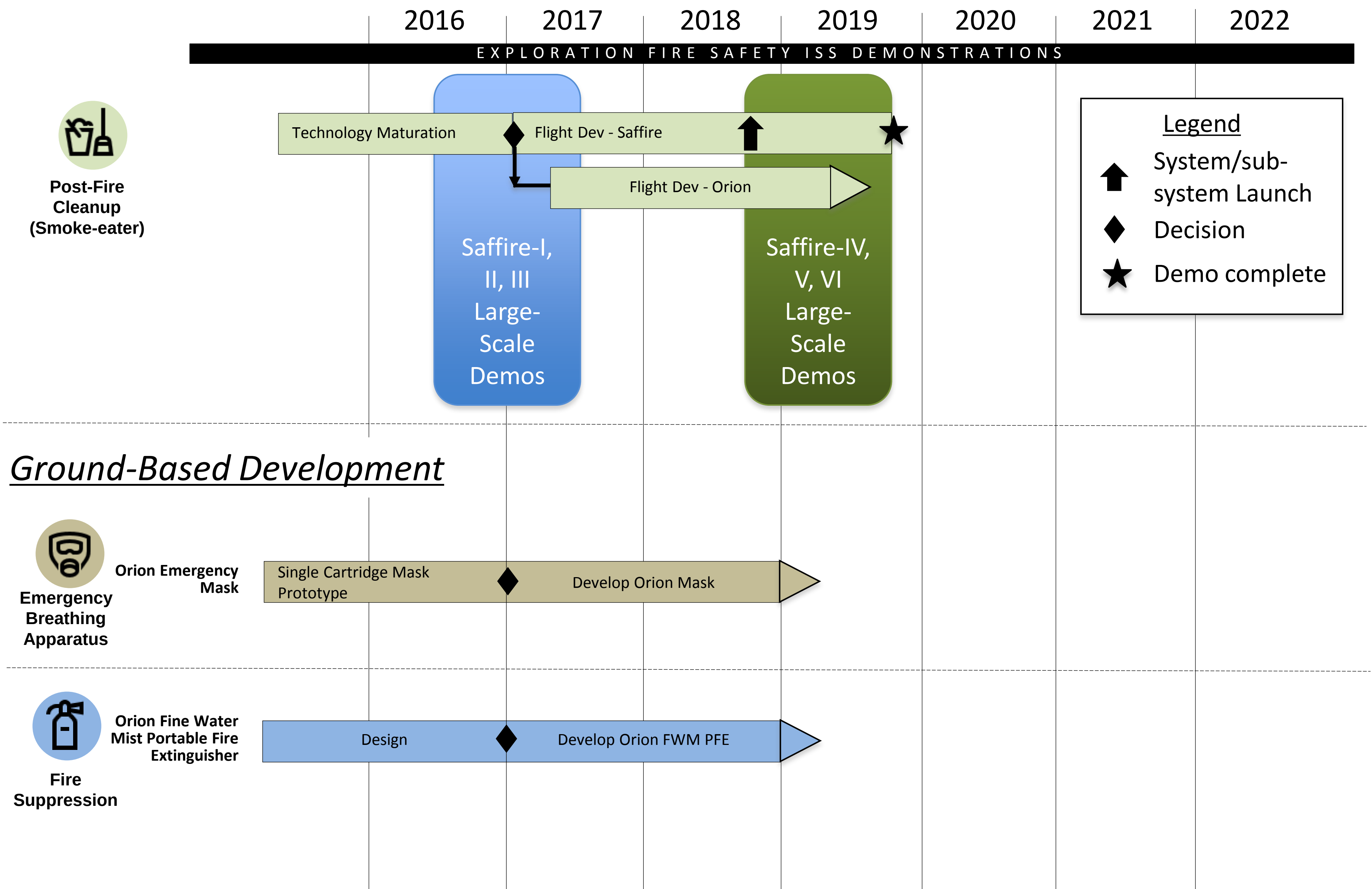
Function	Capability Gaps	Gap criticality as applicable to mg transit Hab	Orion Need
Fire Suppression	ECLSS-compatible and rechargeable fire suppression; compatible with small cabin volumes.	5	X
Emergency Crew Mask	Single filtering cartridge mask (fire, ammonia, toxic spill), compatible with small cabin volumes (no O2 enrichment)	5	X
Combustion Product Monitoring	Contingency air monitor for relevant chemical markers of post-fire cleanup; CO, CO_2, HF, HCl, HCN; battery-operated; hand-held calibration duration 1-5 years; survives vacuum exposure.	5	X
Low- and partial-gravity material flammability	Identify material flammability limits in low-g environment	4	X
Post-fire cleanup/smoke eater	Contingency air purifier for post-fire and leak cleanup; Reduce incident response time by 75% compared to getting in suits and purging atm	4	X
Fire Scenario Modeling and Analysis	Definition of a realistic spacecraft fire to size	3	X
Fire Detection	Early fire detection; particle size discrimination (false alarms)	2	X

Gap Criticality:
5 = high
1 = low

Exploration Fire Safety Roadmap



Exploration Fire Safety Roadmap



Progress – Fire Response and Post-Fire Cleanup

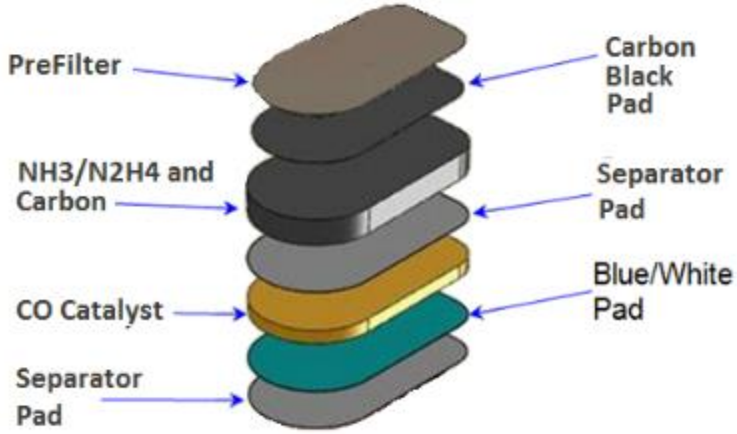
Emergency Crew Mask

- Joint NESC/Commercialization Readiness Program (CRP)-funding to develop a single, rigidly mounted cartridge for emergency response
  - Protect against either a small-scale fire or 30,000 ppmv (3%) ammonia for >15 min
  - TDA, Inc. funded on Phase III SBIR to develop sorbents

Cartridge is 8 cm wide; sorbent bed is 3 cm deep.

Post-fire/leak clean-up (Smoke-eater)

- Smoke-eater system is being developed concurrently with the emergency crew mask
  - Contains the same adsorber stack but is larger than the crew mask
- Self-contained unit includes a fan
- Demo in Saffire-IV-VI will only include CO catalyst and sized for the Cygnus vehicle and anticipated fire in Saffire



Progress – Fire Suppression

- Fine water mist technology originally developed through SBIRs
- Determined amount of water to extinguish test fires (battery, SFOG)
- Developing light-weight extinguisher tanks based on ISS fine water mist (FWM) portable fire extinguisher (PFE) technology
  - Welded titanium with in internal rubber bladder
  - Carbon-over-wrapped pressure vessel
- Evaluated performance of prototype systems

Engineering Development Unit of an Orion FWM PFE

Engineering Development Unit of an ISS FWM PFE

Discharge against the stored energy battery fire (left) and prior to discharge against an open cabin fire (right).

Progress – Combustion Product Monitoring

- Technology development for candidate combustion product monitors has been on-going for several years
  - Two similar technologies have reached maturity to be considered for downselect
- Both technologies measure O_2, CO_2, CO, HCN, HF, HCl
- Recent effort has been to decrease mass, volume, and power to meet ISS and Orion operational requirements
- Prototype units have been evaluated with calibration gases (JSC) and are under-going testing in pyrolysis products (GRC)
  - Component hardening, vibration testing, thermal testing by ZIN Technologies, Inc.
- Down-select to be performed in Nov 2016

➢ ISS/Orion flight hardware development

➢ Demonstration in Saffire-IV-VI

Candidate "next-generation" Combustion product monitors.

Above: Instrument from JPL/Port City Instruments

Right: Instrument from Vista Photonics, Inc.

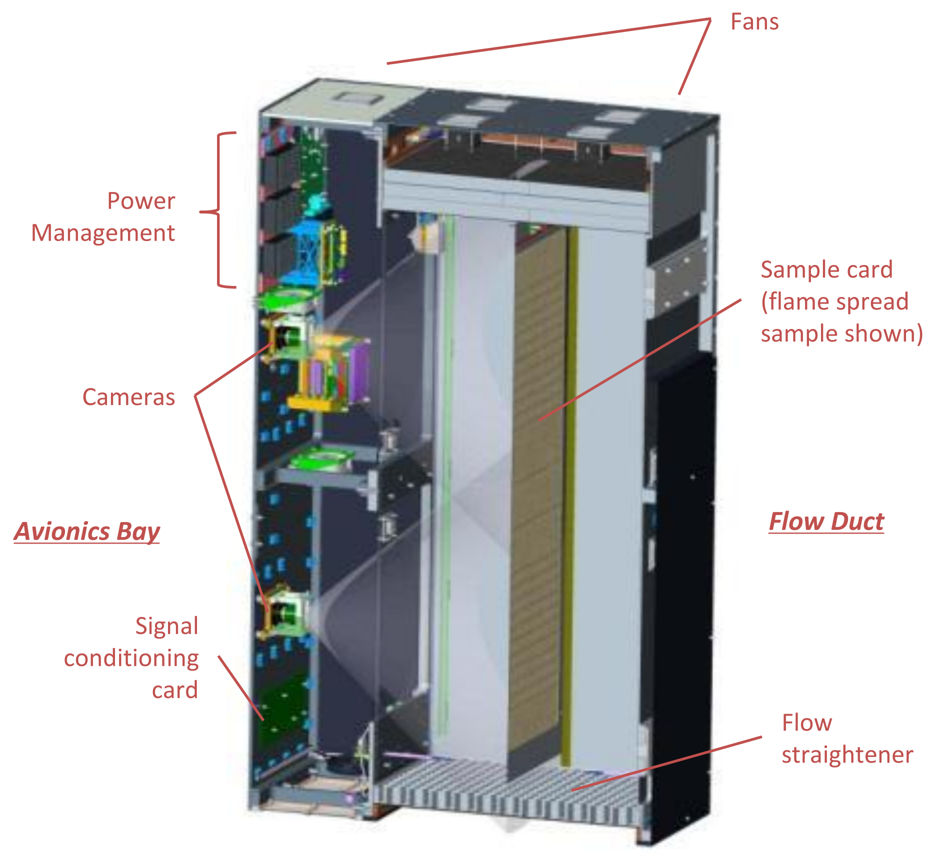
Saffire-I, II, & III Overview

Needs:

- *Low-g flammability limits for spacecraft materials*
- *Definition of realistic fires for exploration vehicles*
  - *Fate of a large-scale spacecraft fire*

Objectives:

- *Saffire-I*: Assess flame spread of large-scale microgravity fire (spread rate, mass consumption, heat release)
- *Saffire-II*: Verify oxygen flammability limits in low gravity
- *Saffire-III*: Same as Saffire-I but at different flow conditions.



- *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*

Saffire Mission Operations

Spacecraft Fire Experiment

Saffire-I Launch: *March 22, 2016*

- **Successful launch of Saffire-I onboard Cygnus OA-6 (SS Rick Husband) on March 22, 2016**

Launch of OA-6 on March 22 carrying Saffire-I

Saffire-I photograph taken by the ISS crew following initial ingress to the PCM

- **OA-6 Pressurized Cargo Module (PCM) berthed to the ISS on Saturday, March 26 with crew ingress into the PCM on March 27**

Saffire-I Operations: *June 14-20, 2016*

NASA and Orbital ATK teams at MCC-Dulles (above) and Flight Operations-GRC (right) conducted and monitored Saffire-I operations

- **Operations received considerable coverage on social media**
  - NASA GRC and Advanced Exploration Systems Division (AES)

- **OA-6 unberthed from the ISS at 9:30 a.m. EDT on June 22**
- **Saffire-I was powered on at 2:23 p.m.**
- **RUN command was sent at 4:41 p.m.**
  - Ignition at 4:44 p.m.
- **Cygnus smoke detector readings received at 4:52 p.m.**

SAFFIRE in the Media

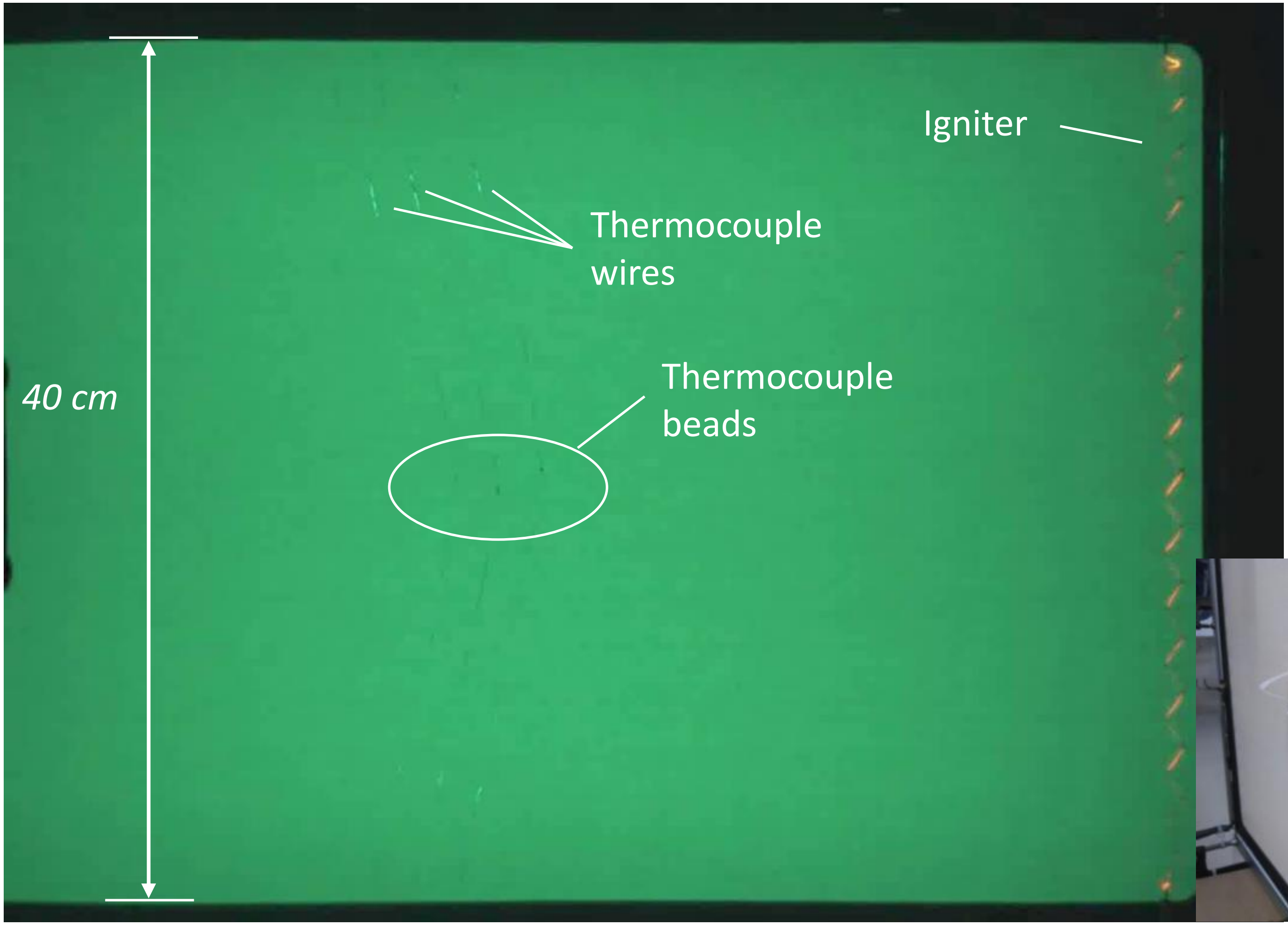
- **Traditional Media:**
  - Covered by **315** media outlets worldwide
  - Includes: PBS News Hour, CBS News, USA Today Online, Aviation Week and Popular Mechanics Online

- **Social Media:**
  - **20** total posts from NASA accounts (Facebook, Twitter, Instagram, LinkedIn)
  - **392,102** total engagements (likes, comments and shares)
  - **61.5M** people reached

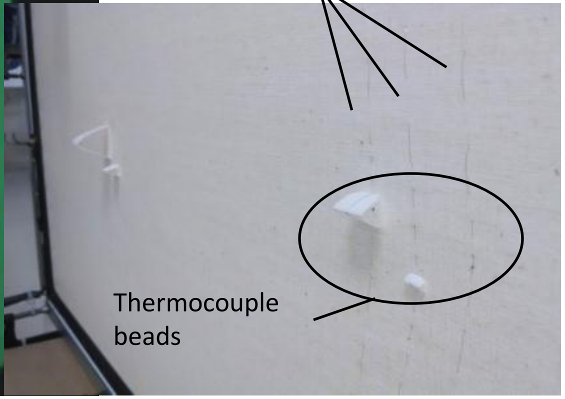
Data compiled June 14-30, 2016

JOURNEY TO MARS

Saffire-I Results - *Concurrent Flow Igniter*

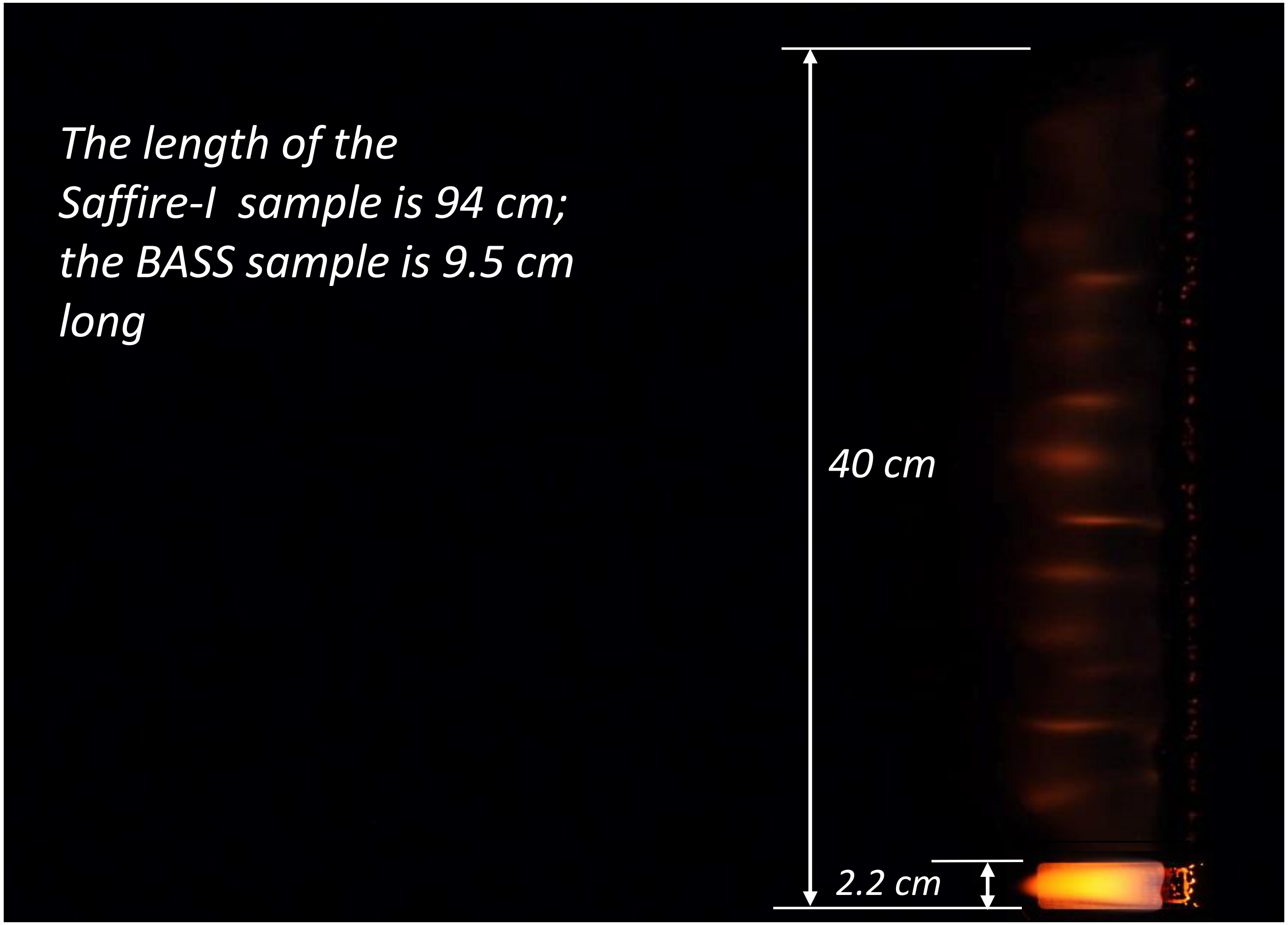


Thermocouple wire woven into the fabric to assess flame structure



Saffire-I sample material at the beginning of the concurrent (upstream) burn.
Thermocouple wires are sewn into the sample material with thermocouple beads at various heights in the center of the sample.

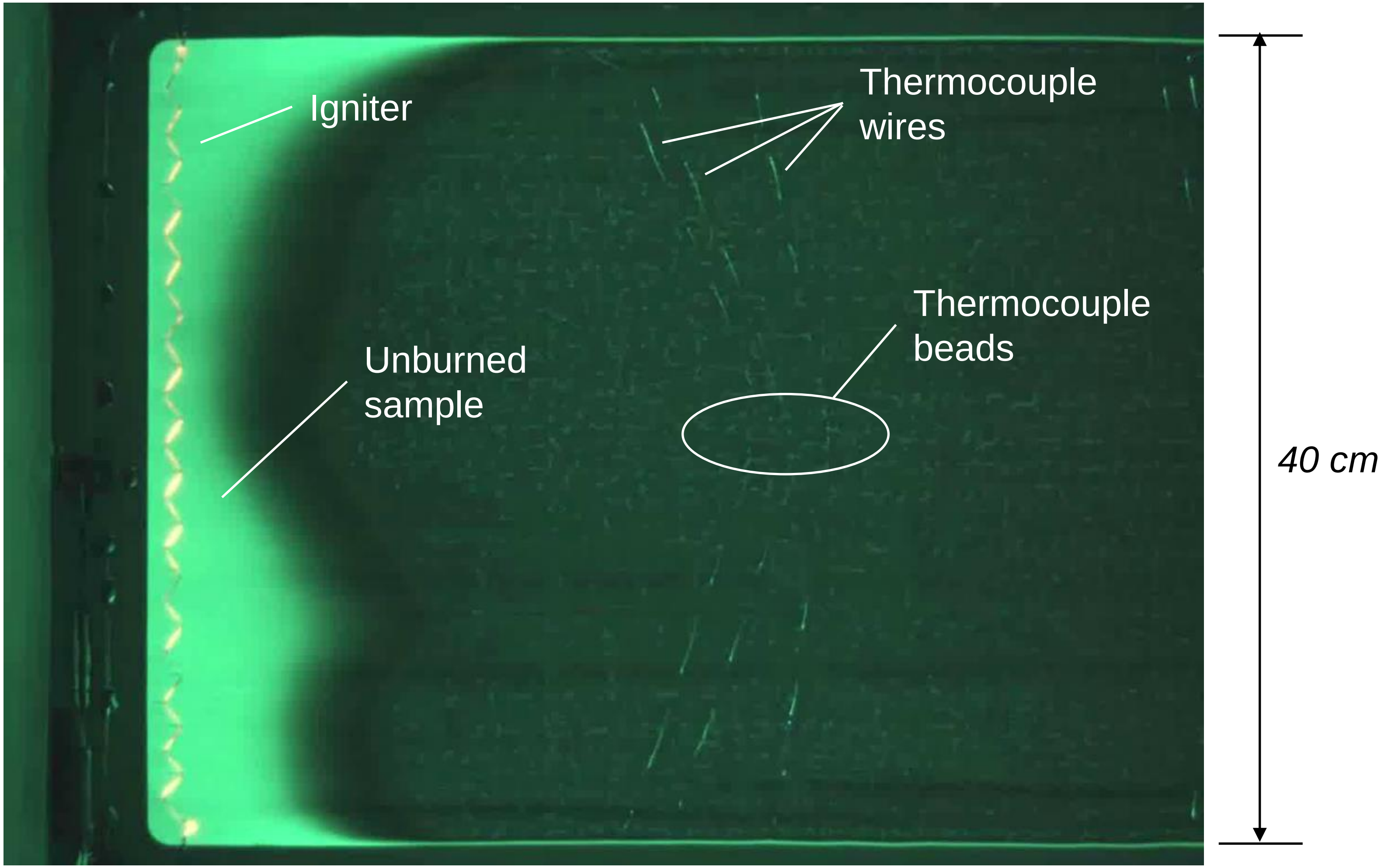
Saffire-I Operations - *How big is the flame?*



Flow

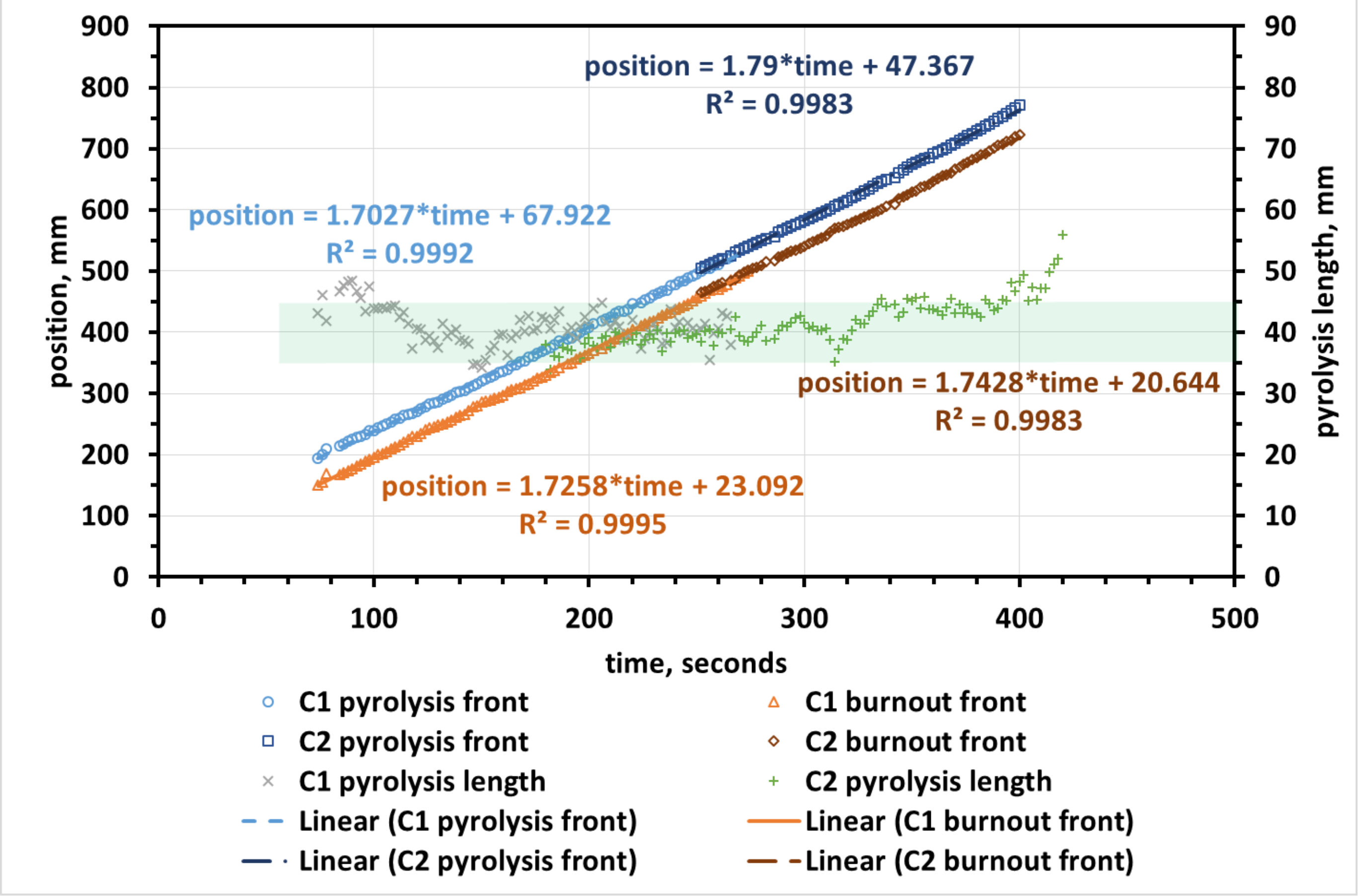
Saffire-I flame compared to a flame from the Burning and Suppression of Solids (BASS) experiment conducted in the Microgravity Science Glovebox . *Camera exposures and gains are different between the two experiments.*

Saffire-I Operations
Opposed Flow Igniter



Saffire-I sample material at the beginning of the opposed flow (downstream) burn. *The light portion of the image is sample material unburned from the concurrent burn. A second set of thermocouple wires are sewn into the sample material with thermocouple beads at various heights in the center of the sample.*

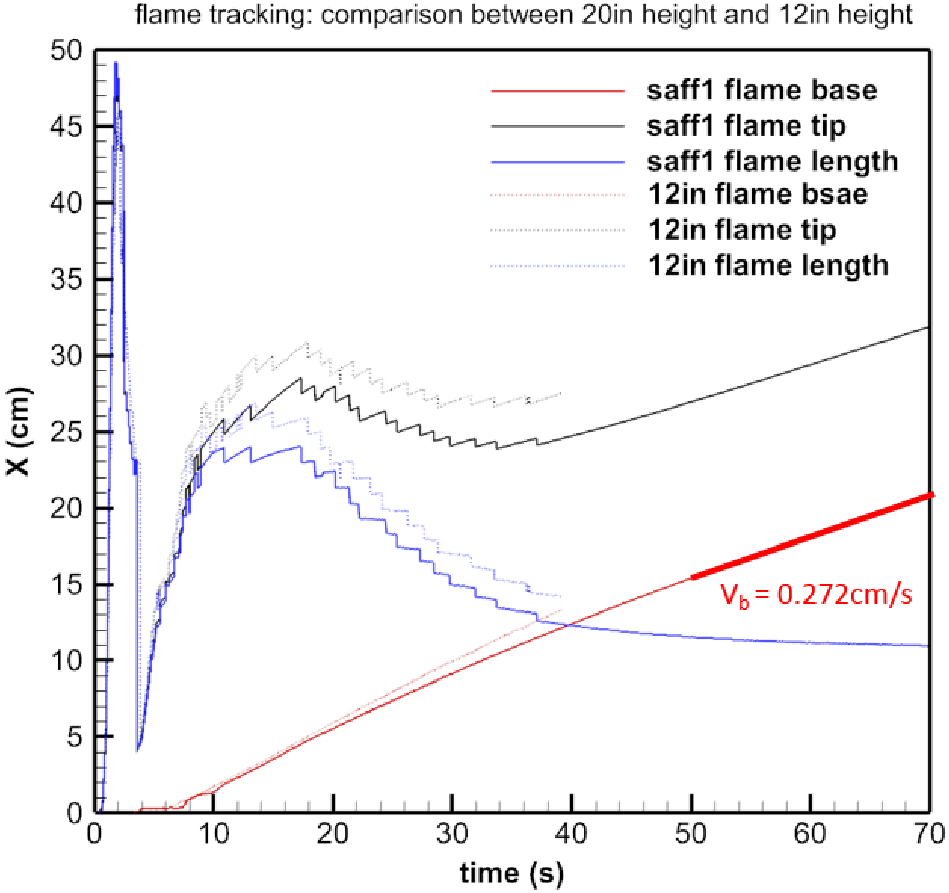
Saffire-I Flame Spread Rates

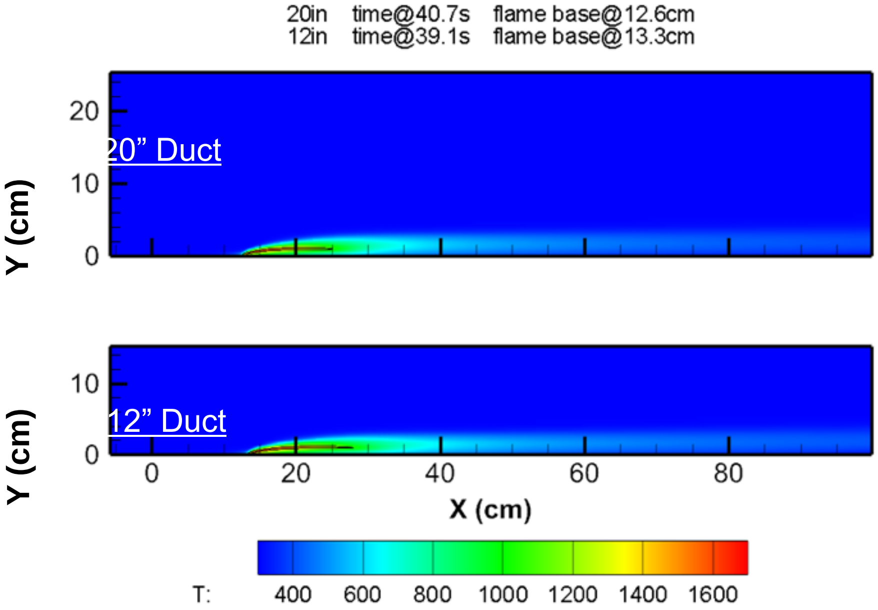


- Average spread rate was ~ 1.75 mm/s +- 0.05 mm/s

- Average pyrolysis length was ~ 40 mm +-5 mm (shown by green bar) except early and late in the otherwise 'steady' data.

Modeling of Saffire-I





Flame Spread Rate Data

- BASS: 0.51 cm/s
- Model: 0.272 cm/s
- Saffire-I: 0.175 cm/s

Summary of Saffire-I Results… *So Far!*

- **Flame reaches a limiting length in forced convective concurrent flow even for very wide sample**
  – Implies a steady spread rate and a limiting heat release rate
  – *A fire on a spacecraft vehicle may reach a steady size (?)*
- **Concurrent flame spread rate was much slower than expected from previous space experiments**
  – 65% less than observed in Burning and Suppression of Solids experiment on ISS
  – *What is different between these two experiments?*
  – *What is the impact of slower growth on release of combustion products? On fire detection? How does this depend on flow velocity?*
- **Proximity to and interaction with side walls appears to impact the flame more than expected**
  – *Computational models and results of previous microgravity experiments need to be re-evaluated*
- **Opposed flames spread at about the same rate as concurrent flames**
  – *How does this depend on flow velocity? Are concurrent flames always the worst case for microgravity fires?*
- **We need to make a bigger fire to impact the vehicle**

Saffire-II and III

- Sample card and samples are the only differences between the three flight units

Saffire-I, -III Sample Card

Composite fabric (SIBAL cloth)
(75% cotton – 25% fiberglass by mass)
(0.4 m x 0.95 m)

Saffire-II Sample Card

<u>Saffire-II Samples (5 cm x 29 cm)</u>

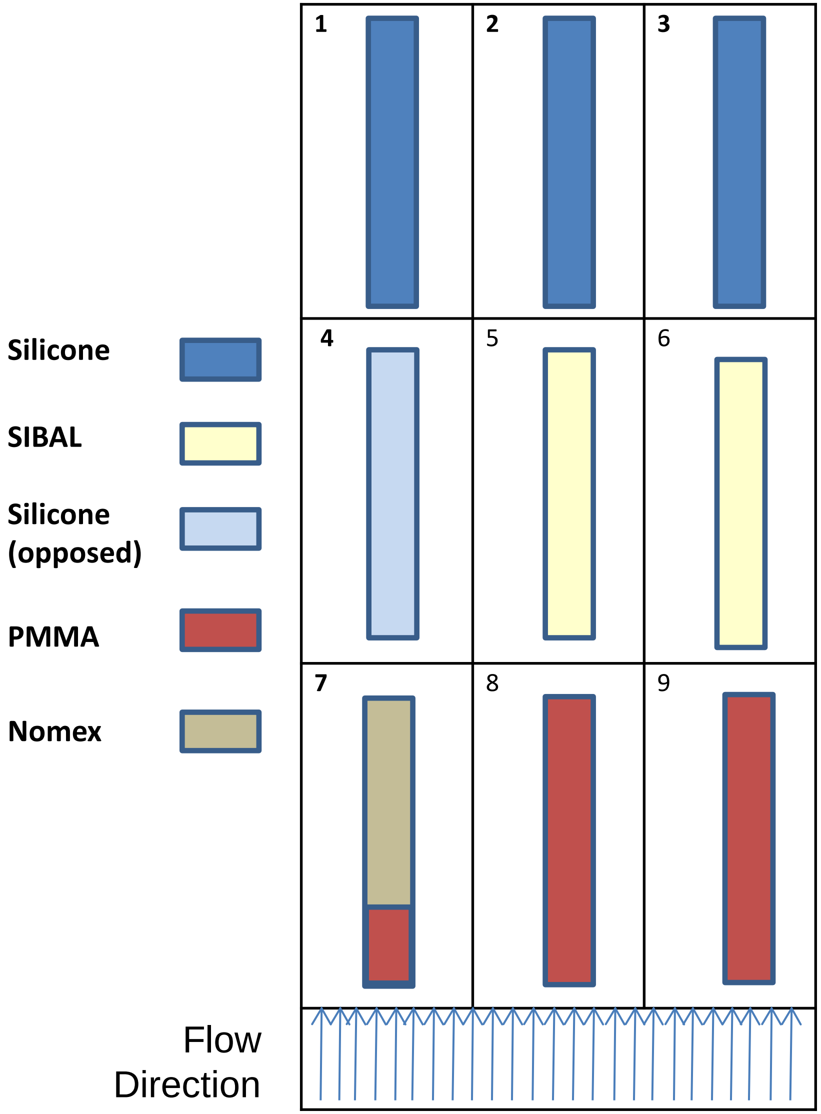
- PMMA (flat and structured)
- Silicone (3 thicknesses, different ignition direction)
- SIBAL
- Nomex (with PMMA ignition)

- *As of October 11*, the launch of OA-5 (Saffire-II) from Wallops Flight Facility is scheduled for 8:03 p.m. on October 16
  - Departure of OA-5 from ISS (operation of Saffire-II) is scheduled for November 18
- Launch of OA-7 (Saffire-III) scheduled for February 10, 2017 with berthing on February 13, 2017 and departure (Saffire-III operations) approx. May 23

Saffire-II *Samples*

Motivation

- Samples 1-3: Samples have different thicknesses and different flammability limits (in the vicinity of 21% O_2 by volume)
  - Assess flammability limits in low-g against NASA-STD-6001 Test 1
- Sample 4: Downstream ignition to assess flammability against normal-g ignition
- Samples 5 & 6: Same material and conditions as Saffire-I and III.
  - Comparison to Saffire-I and III results at a "medium" scale
- Sample 7: Assess low-g flammability of Nomex
- Samples 8 & 9: Structured and flat PMMA 10 mm thick



Saffire-IV, V, and VI

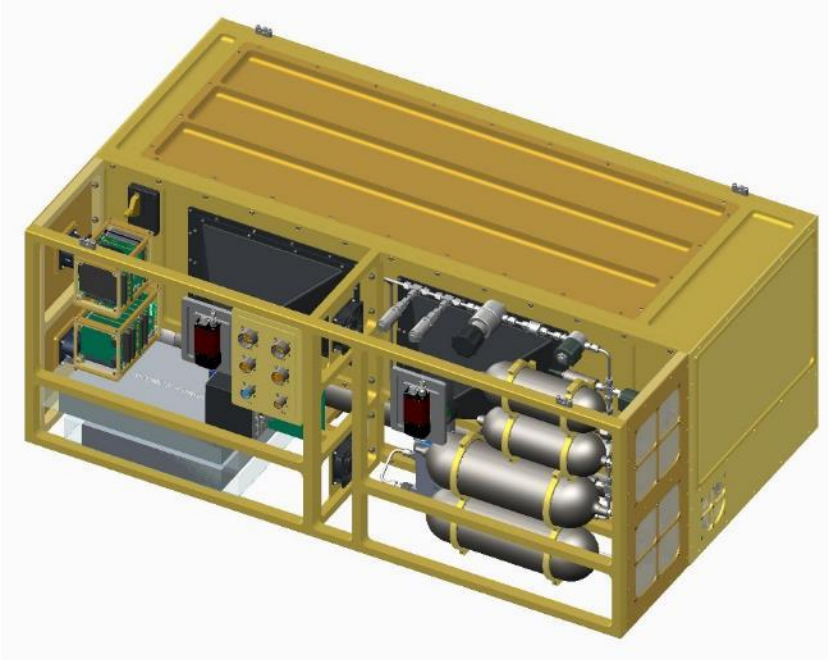
Needs:

- *Demonstrate spacecraft fire detection, monitoring, and cleanup technologies in a realistic fire scenario*
- *Characterize fire growth high O_2/low pressure atmospheres*
- *Provide data to validate models of realistic spacecraft fire scenarios*

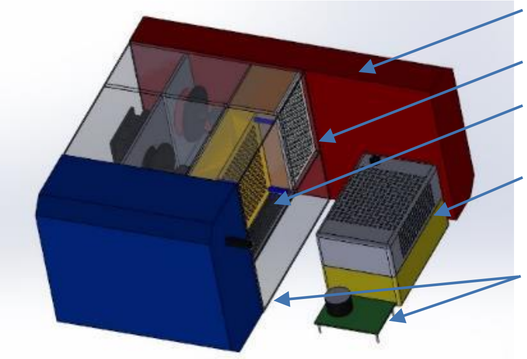
Objectives:

- *Saffire-IV*: Assess flame spread of large-scale microgravity fire (spread rate, mass consumption, heat release) in exploration atm
- *Saffire-V*: Evaluate fire behavior on realistic geometries
- *Saffire-VI*: Assess existing material configuration control guidelines

- All flights will demonstrate fire detection, monitoring, and cleanup technology

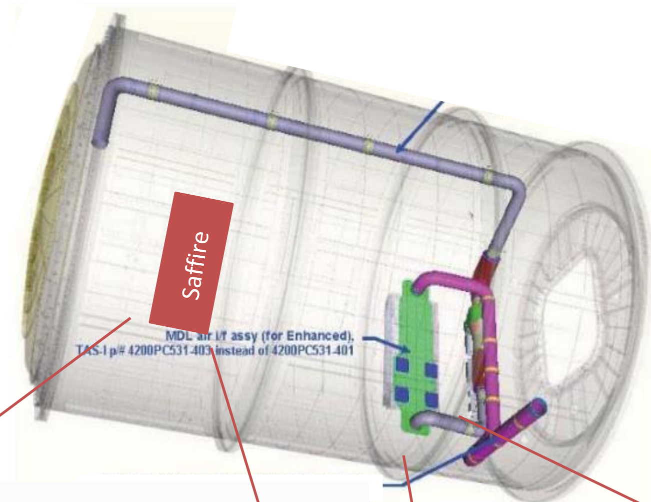


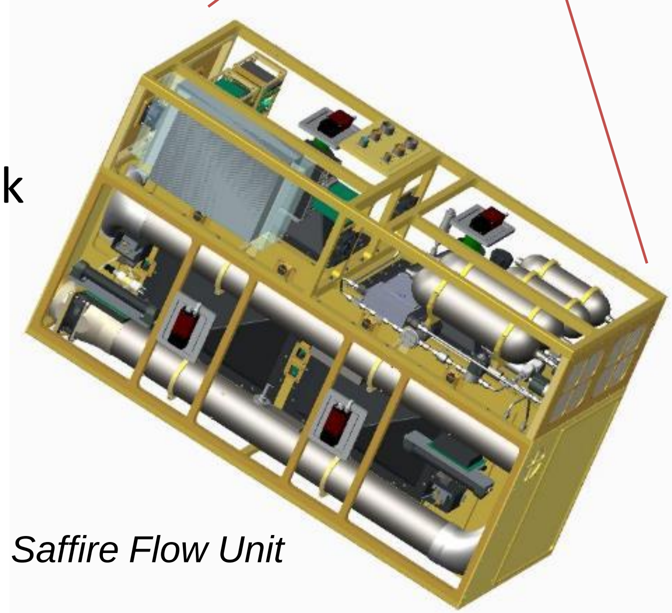
Conceptual design of Saffire-IV-VI experiment module.
Dimensions are approximately 53- by 90- by 133-cm. additions from previous Saffire include side view of sample card and oxygen addition.



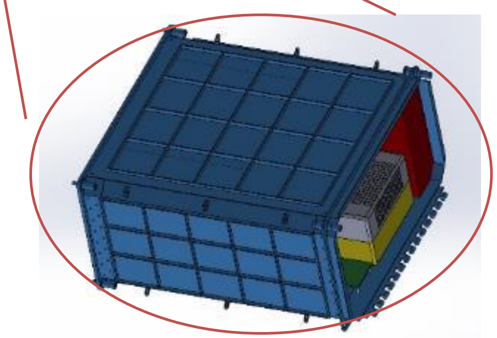
Saffire-IV, V, and VI Experiment Concept

- Concept consists of three distinct hardware locations
  - Saffire flow unit
  - Far-field diagnostic
  - Distributed sensors
- Far-field diagnostic module
  - Combustion product monitor
  - CO and CO_2 sensors
  - Post-fire cleanup module
- Distributed sensor network
  - Temperature
  - CO_2





Saffire Flow Unit

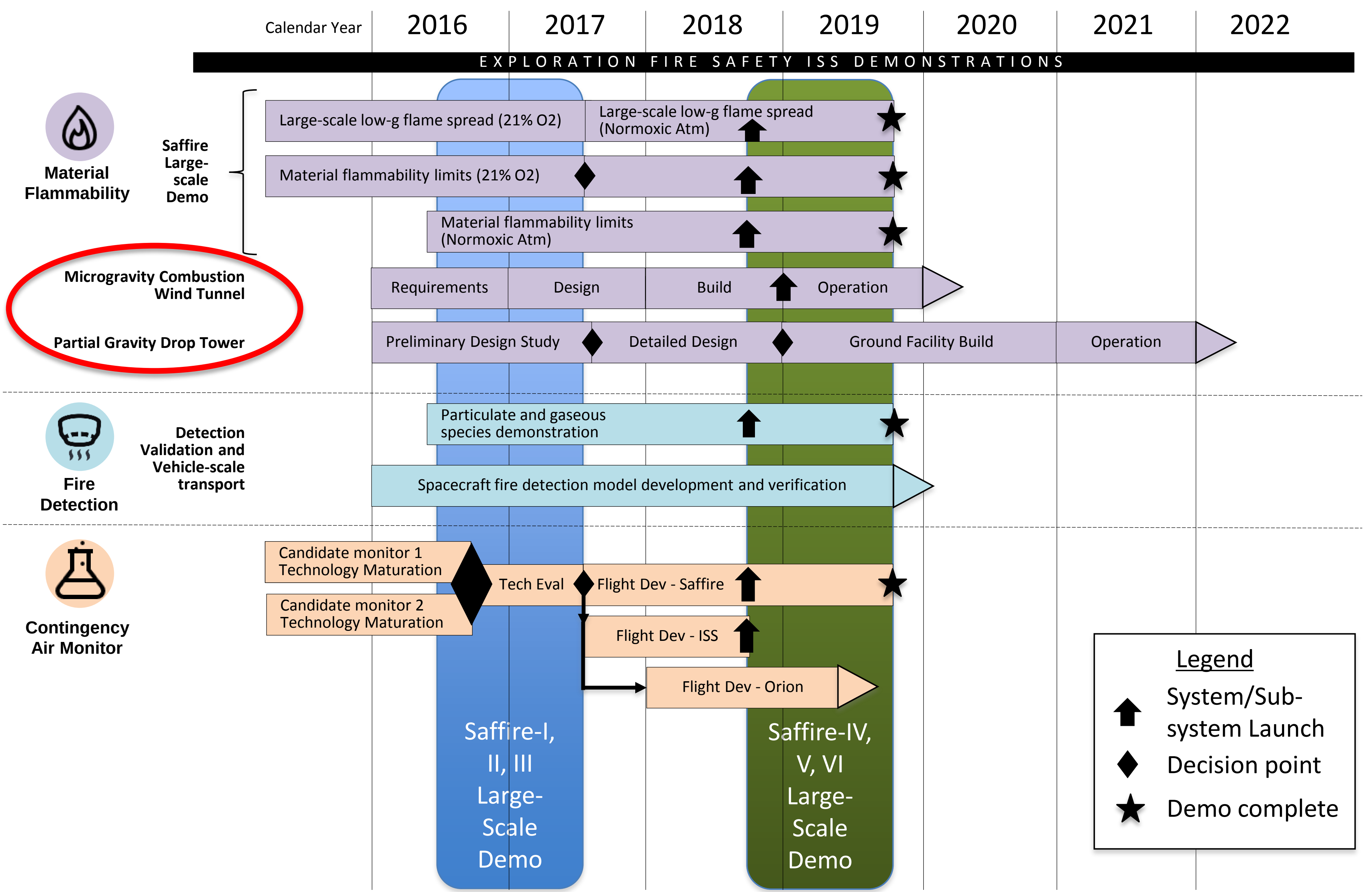


Far Field Diagnostic containing Smoke-eater, combustion product monitor, and particulate diagnostics

Expected Results of the Saffire-IV, V, and VI Experiments

- **Flammability in normal and exploration atmospheres**
  - Traceability to Saffire-I, II, and III
- **Oxygen calorimetry for a large-scale microgravity fire**
  - Rate of heat release for fire scenario modeling
- **Rate of change of cabin pressure and temperature during a large-scale fire**
- **Transport and mixing of an inert gas (CO_2)**
  - Fire detection
  - Fire scenario modeling
- **Demonstration of advanced combustion product monitor to quantify CO, CO_2, and acid gases (HF, HCl)**
- **Transport/decay of acid gases (HF, HCl) in a post-fire environment**
- **Demonstration of advanced sorbents for cleanup of CO and CO_2**
  - Sizing of smoke-eater for exploration applications

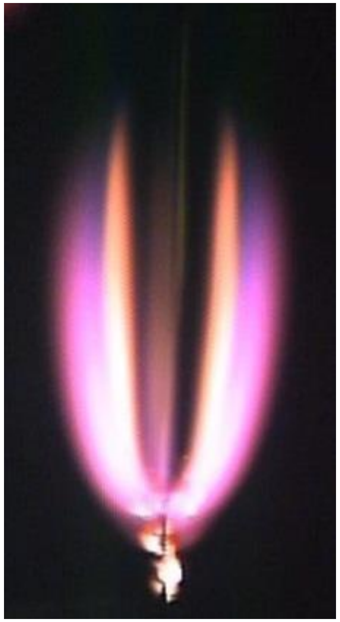
Exploration Fire Safety Roadmap



Microgravity Wind Tunnel – Fire Safety (MWT-FS)

GRC Project Manager: MSI/Robert Hawersaat
SDT Lead: Dr. Sandra Olson, NASA GRC
GRC Project Scientist: Paul Ferkul, USRA
Engineering Team: ZIN Technologies, Inc.
NASA Customer: HEOMD/Space Life and Physical Sciences

***Above**: PMMA rod quench sequence in microgravity; **Below**: Side view of concurrent flame spread*



Need:

•Saffire series of experiments anchor flammability at large scale with limited number of data points

Description:

- Build a new larger air flow duct assembly.
- Evaluate select materials' flammability limits in microgravity for comparison to 1 g limits for various types of materials (charring, non-charring, smoldering, and composites).
- Study large sample flame ignition, stabilization, and fuel geometry effects on flame spread.
- Crew required to set up and operate the experiment. Image data and digital data down-linked to the ground for evaluation.

Benefits include:

- Extend Saffire results with greater data set, validate flammability standard NASA-STD-6001 Test #1, larger sample size, ease of operations, and increased PI opportunities.

Assumptions/BOE's:

- Used the BASS combustion experiment to develop the cost and schedule estimate. Reduce the SDT per member cost from Prime SDT$100k, and SDT #2 to $75k, and SDT #3 to $75k.

Zero Gravity Facility Upgrade Study

GRC Point of Contact: LTX/David Urban

Facilities Lead: TBD

NASA Customer: HEOMD/Space Life and Physical Sciences, AES, Aeronautics

Objective:

To investigate the proposed upgrade to the Zero-G Facility and provide an accurate cost estimate.

- The upgrade will expand ground-based capabilities
  - optimize flight research
  - maximize science and technology development
  - Reduced cost = higher utilization rates
  - Address critical path issues in exploration

Relevance/Impact:

Future ground-based test capability needs

- Combustion science (high pressure engine research)
- Spacecraft fire safety (exploration atmospheres)
- In-situ Resource utilization (reactor design, regolith behavior)
- Complex Fluids
- Interfacial phenomena (fluid control on spacecraft and E.T.)
- Fluid Physics (fluid systems)
- Materials
- Fundamental Physics
- Plant Biology
- Aeronautics (Supercooled Large Droplet Icing)

Development Approach:

- Utilize funding from several sources
- Perform a cost and feasibility study
- Solicit for funding

Summary

- **Fire Safety gaps are being addressed through ground and flight-based demonstrations**
  - Saffire-I, II, and III are addressing material flammability gaps
  - Saffire-IV, V, and VI will address detection, monitoring and clean-up demonstrations
    - Technologies are being simultaneously developed for ISS and Orion
- **Plans are being developed for specialized facilities that can continue the evaluation of material flammability screening and partial gravity**
- **Fire Safety SMT participates in definition of the demonstrations and evaluation of results**

Questions?