SoFIE Design/Status

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Spacecraft Materials Flammability Workshop
May 20-22, 2019 at NASA Glenn Research Center (GRC)

SoFIE — Solid Fuel Ignition and Extinction

Overall Objective:

- Ignition and flammability of solid spacecraft materials in practical geometries and realistic atmospheric conditions

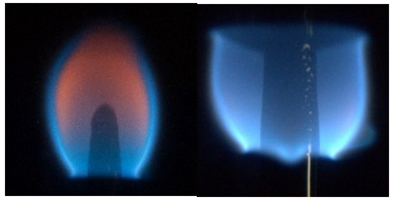
Relevance/Impact:

- Improve EVA suit design
- Safer selection of cabin materials
- Validate NASA materials flammability selection 1-g test protocols for low-gravity fires
- Improve understanding of early fire growth behavior
- Validate material flammability numerical models
- Determine optimal suppression techniques for burning materials by diluents, flow reduction, and venting

Development Approach:

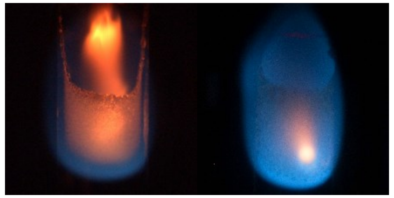
- Develop SoFIE facility (CIR insert and avionics) to support multiple solid-material combustion and fire suppression studies
- Utilize Combustion Integrated Rack (CIR); common infrastructure

SoFIE — Solid Fuel Ignition and Extinction

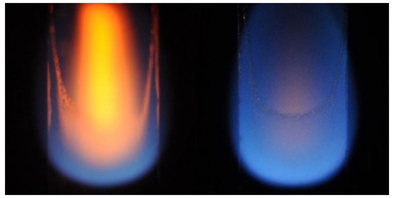


Material Ignition and Suppression Test (MIST)
Fernandez-Pello: UC Berkeley
Externally applied heat flux; Fuel: acrylic cylinders (PMMA)

Spacecraft Materials Microgravity Research on Flammability (SMμRF)
Olson: NASA GRC
Concurrent-flow flammability curve for acrylic cylinders (PMMA); and opposed and concurrent burning behavior of actual engineering materials (sheets)



Narrow Channel Apparatus (NCA)
Miller: San Diego State University
Opposed-flow flame spread data for a thick acrylic (PMMA) slab



Residence Time Driven Flame Spread (RTDFS)
Bhattacharjee: San Diego State University
Opposed-flow flame spread over thin acrylic sheets (PMMA) to examine thickness effects

Growth and Extinction Limit (GEL)
T'ien: Case Western Reserve University
Acrylic spheres (PMMA) in concurrent flow; effect of gravity, flow, O_2, pressure, and preheating

Material Ignition and Suppression Test (MIST)

PI: Carlos Fernandez-Pello, University of California at Berkeley
International Co-I: Nickolay Smirnov, M.V. Lomonosov State University, Moscow, Russia

Opposed-flow flame spread over PMMA rods in μg

Objectives:

- Determine the boundaries for ignition and extinction of a solid fuel (PMMA cylinder) as a function of flow speed, oxygen concentration, and external radiant flux.
- Understand the effects of the space exploration atmospheres under consideration by NASA (lower pressure and increased oxygen concentrations compared to air) on the flammability and suppression of materials.
- Provide guidance to interpret current NASA testing procedures to environments expected in space-based facilities.
- Develop ground-based apparatus that better reflects the environments that are expected in space-based facilities.
- Establish theoretical modeling and an extensive normal gravity data base, together with a few of the validation space experiments, to support the testing methodology.

Spacecraft Materials μg Research on Flammability (SMμRF)

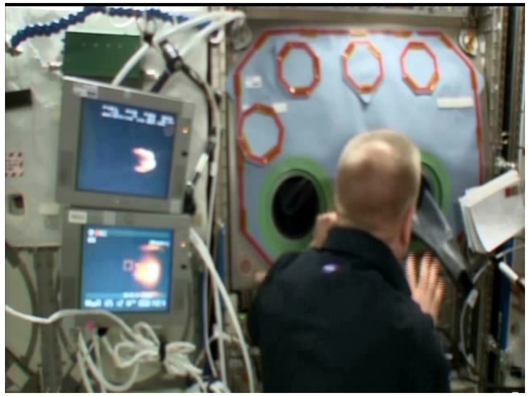
PI: Sandra Olson, NASA Glenn Research Center

Objectives:

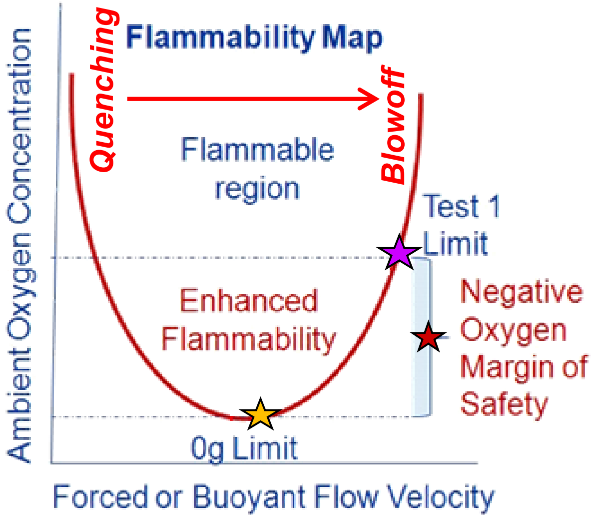
- Refine materials fire screening: Tests are done in 1g, but materials are more flammable in 0g.
- ★ In the normal gravity screening tests, flames extinguish by blowoff, where the buoyant flow is too fast for the chemical reactions to occur in the hot flame zone.
- ★ In reduced gravity (0g, Lunar g, Martian g), the flow is slower (reduced-g buoyancy or spacecraft ventilation flows of 5-20 cm/s) and a flame can be sustained at lower O_2 where the slower reactions have enough residence time in the hot zone.
- ★ We need to measure the Negative Oxygen Margin of Safety to de-rate materials. PMMA rods: Negative Oxygen Margin of Safety = 1.4% O_2
- Thin fuel sheets: Very few materials have been rated even in 1g at 34% O_2, 8.2 psia (exploration atmosphere).

Blowoff in **0g**: flame strengthens but then blows off when flow is increased

~15% O_2 ⟵ FLOW



Astronauts Tim Kopra and Scott Kelly are amazed at a BASS-II blowoff test.



Narrow Channel Apparatus (NCA)

PI: Professor Fletcher Miller, San Diego State University
Co-I: Sandra Olson, NASA GRC and Indrek Wichman, Michigan State University

Objectives:

- Use a "narrow channel" to create flow conditions in normal gravity – defined by pressure, oxygen concentration, and velocity - that closely reproduce the conditions aboard an actual spacecraft by controlling the effect of buoyancy. The creation of these conditions will allow microgravity opposed-flow flame spread rate and (possibly) extinction limits (due to any of the above three factors) for both thermally thick and thin fuels to be determined on earth in the apparatus.
- Measure flame spread rate across a thermally thick solid fuel (PMMA slabs) as a function of forced opposed flow velocity, oxygen concentration, and pressure. The conditions chosen will correspond in particular to NASA's proposed Exploration atmospheres (i.e. along the normoxic curve).
- Determine opposed-flow extinction limits for thick solid fuel by lowering the velocity until the flame extinguishes at a given oxygen concentration and pressure.
- Obtain additional data that can be used to compare to a numerical model of the flame spread process. These include surface temperature and side view images of the flame.

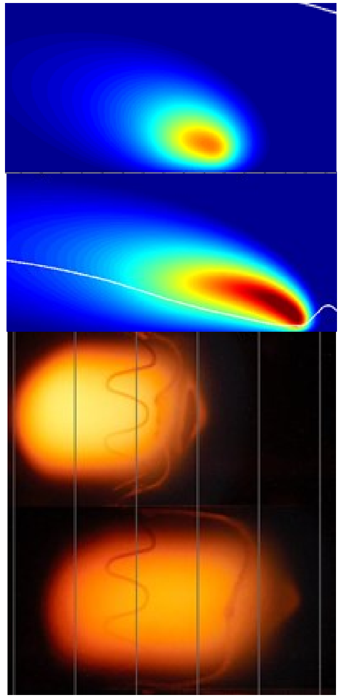
Flame burning PMMA slab in μg from BASS experiments.

Residence Time Driven Flame Spread (RTDFS)

PI: Subrata (Sooby) Bhattacharjee, San Diego State University, San Diego, CA
International Co-I: S. Takahashi and K. Wakai (岐阜大学 Gifu University, Japan)

Objectives:

- Establish the boundaries of radiative quenching in terms of the critical velocity of the oxidizer and critical thickness of fuel (PMMA sheets) in a microgravity environment using experiments, theory, and computational model.
- Establish the mechanism of flame extinguishment by delineating the thermal field from the concentration field through microgravity experiment and numerical results.
- Conduct ground based experiments at normal gravity with similar setups and develop a comprehensive set of data on flame spread over thin fuels in the radiative, thermal, and kinetic regimes.



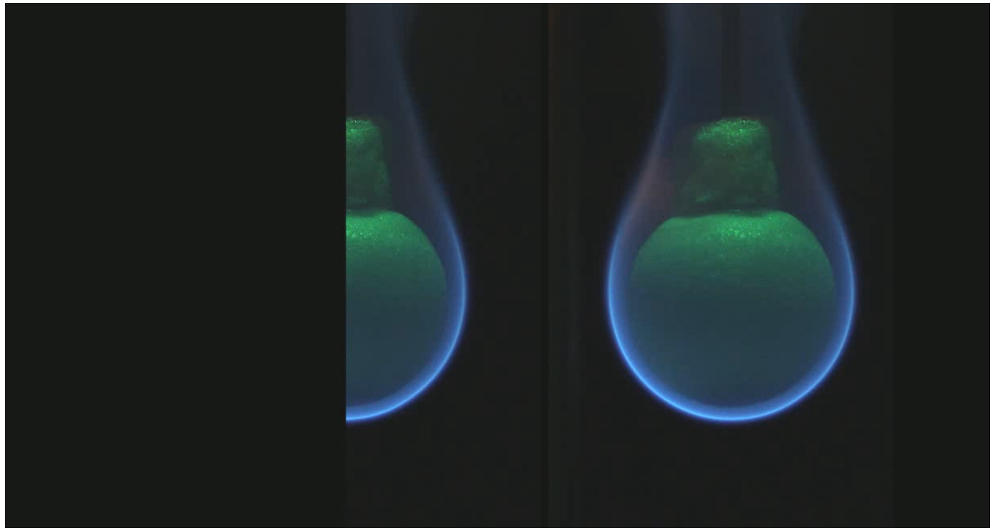
Flame spread over a thin PMMA sheet in μg with air as the oxidizer as a function of time. The top two images are side view of the computational flames and the bottom two images are from recent BASS-II experiments.

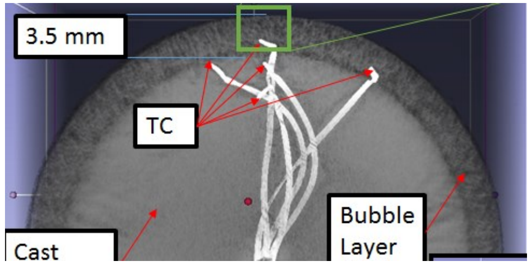
Growth and Extinction Limit of Solid Fuels (GEL)

PI: James S. T'ien, Case Western Reserve University, Cleveland, Ohio
Co-Is: Paul Ferkul, USRA/NASA GRC; Sandra Olson, NASA GRC
International Co-I: Oleg Korobeinichev, Siberian Branch Russian Academy of Sciences, Novosibirsk, Russia

Objectives:

- Experimentally determine the flame growth characteristics (growth rate, flame shape and dimensions) over a thick solid fuel (PMMA spheres) as a function of flow velocity, oxygen percentage, pressure and the degree of internal heating.
- Experimentally determine the flame extinction characteristics (quenching and blowoff limits) over a thick solid fuel as a function of flow velocity, oxygen percentage, pressure and the degree of internal heating.
- Establish a high-fidelity numerical model that can be compared with the microgravity results and serve as a tool connecting normal gravity and microgravity performance.



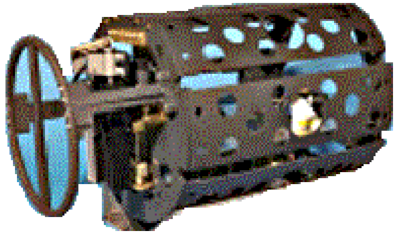


CIR Sub-rack Payload Relationship

The Combustion Integrated Rack (CIR) includes support subsystems and combustion diagnostics

Payload specific and multi-user hardware customizes the CIR in a unique laboratory configuration to perform research effectively.

Solid Fuel Ignition and Extinction Insert Assembly



Payload Specific Hardware

- Unique hardware components
- Specific Diagnostics
- Unique PI source gases

Chamber Insert

- Infrastructure that uniquely meets the needs of PI experiments
- Unique science requirements

FCF Combustion Integrated Rack

- Power Supply
- Avionics/Control
- Structural Support & Power
- Common Diagnostics and Illumination
- Environmental Control
- Data Processing/Distribution
- Fluids Control/Distribution
- Combustion Containment

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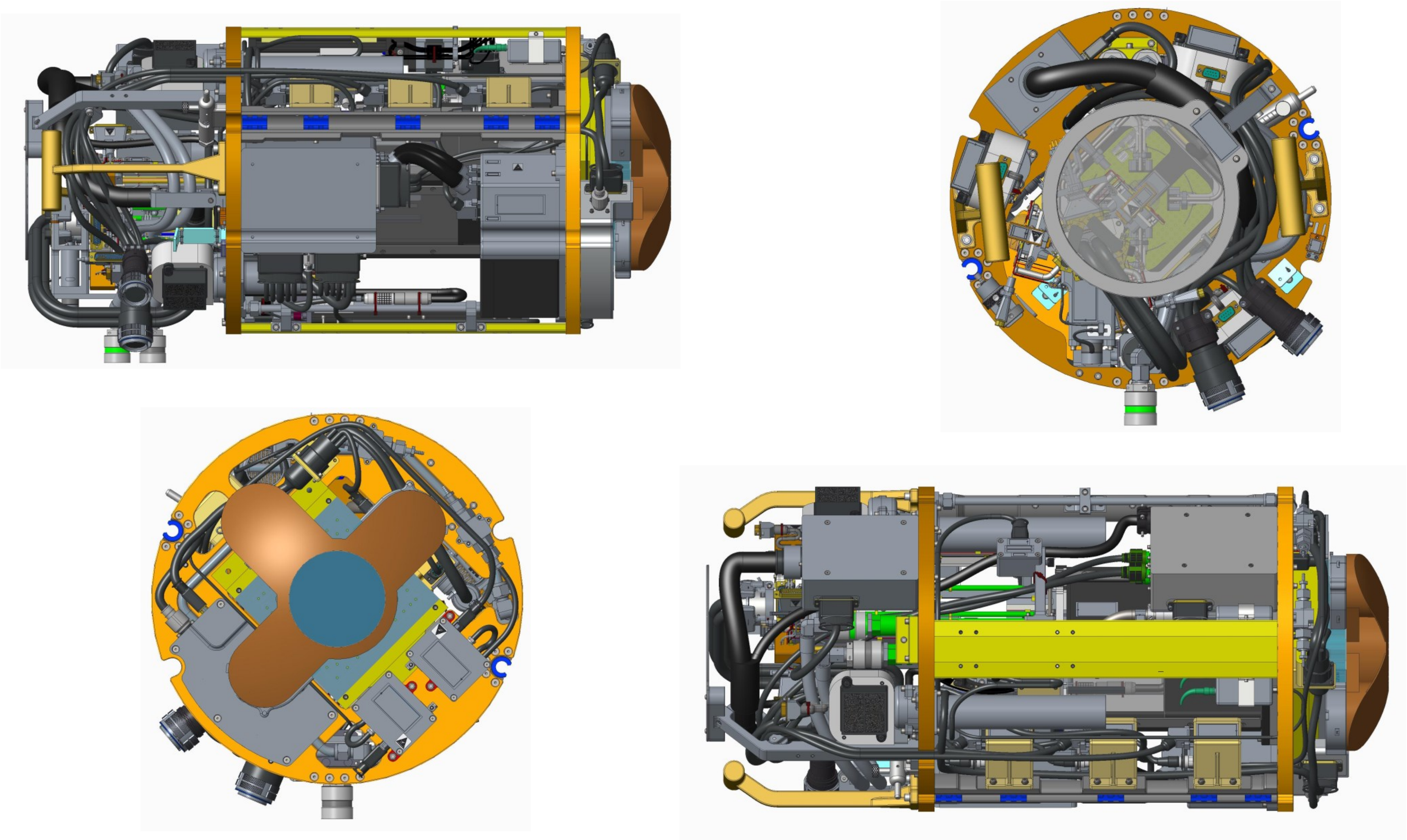
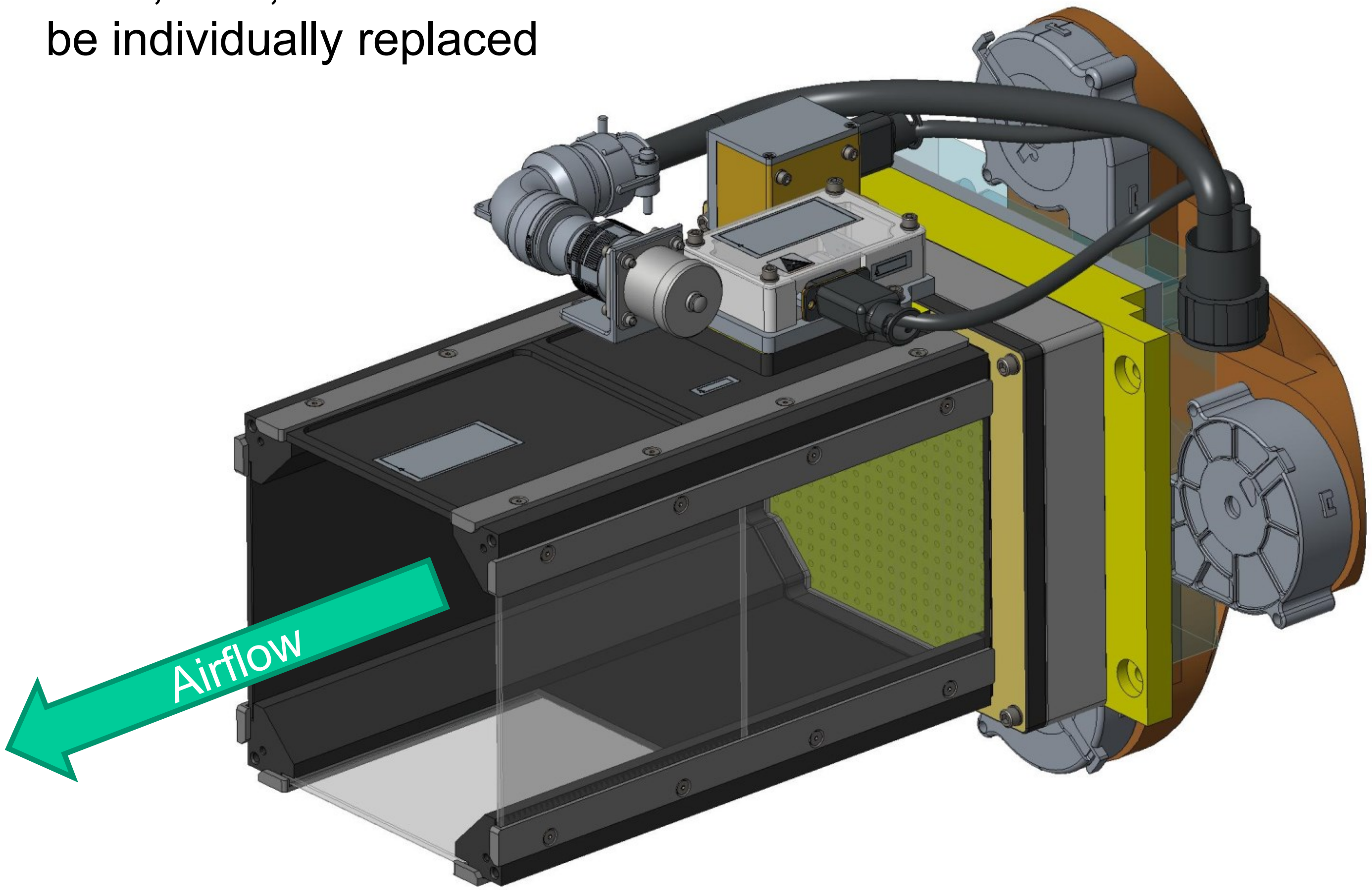
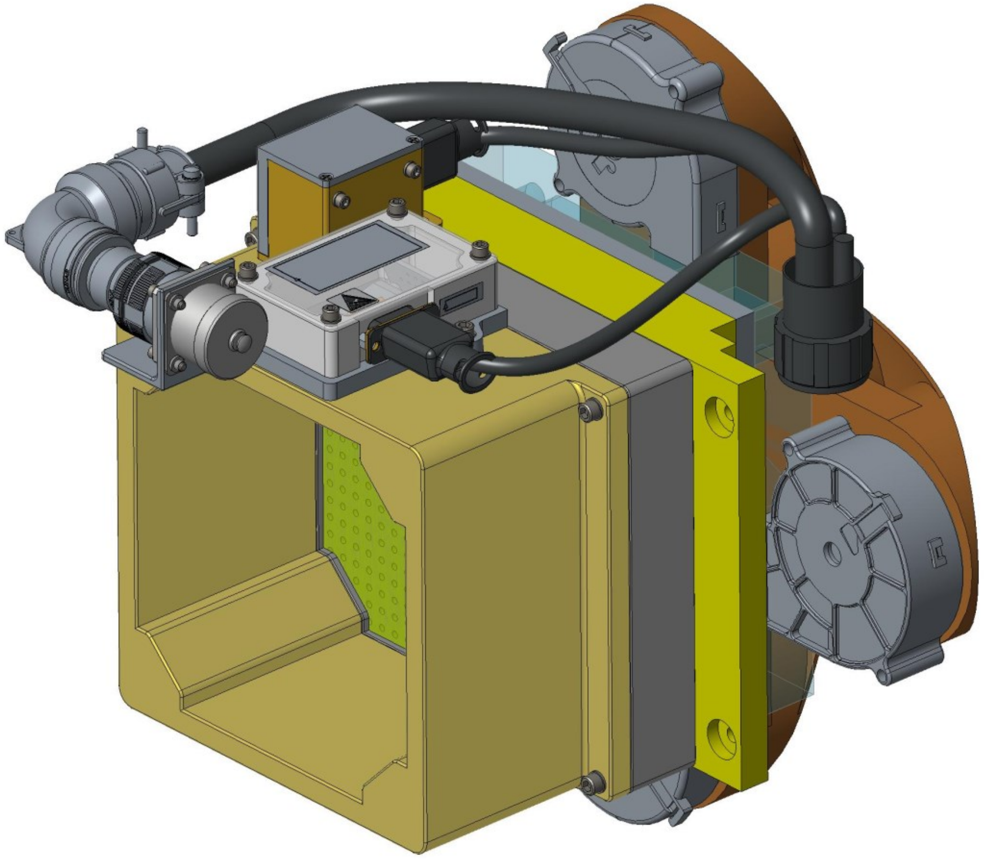
SoFIE Chamber Insert Assembly



Flow Duct (Full-size and Short)

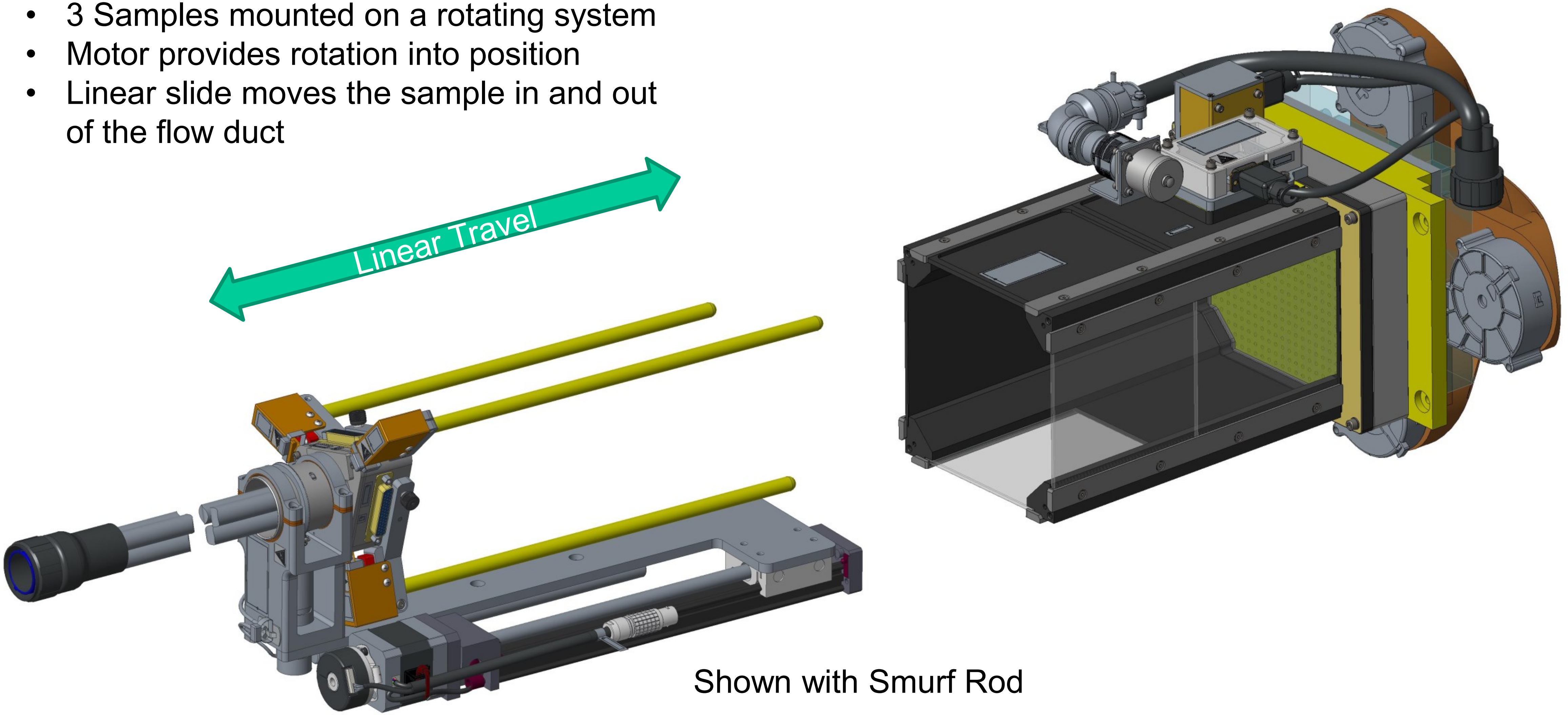
- Replaceable filter
- Integral air speed and radiometer
- 2 transparent sides with Sapphire windows for imaging
- Fans, duct, radiometer and filter can be individually replaced





Sample Rotation and Translation

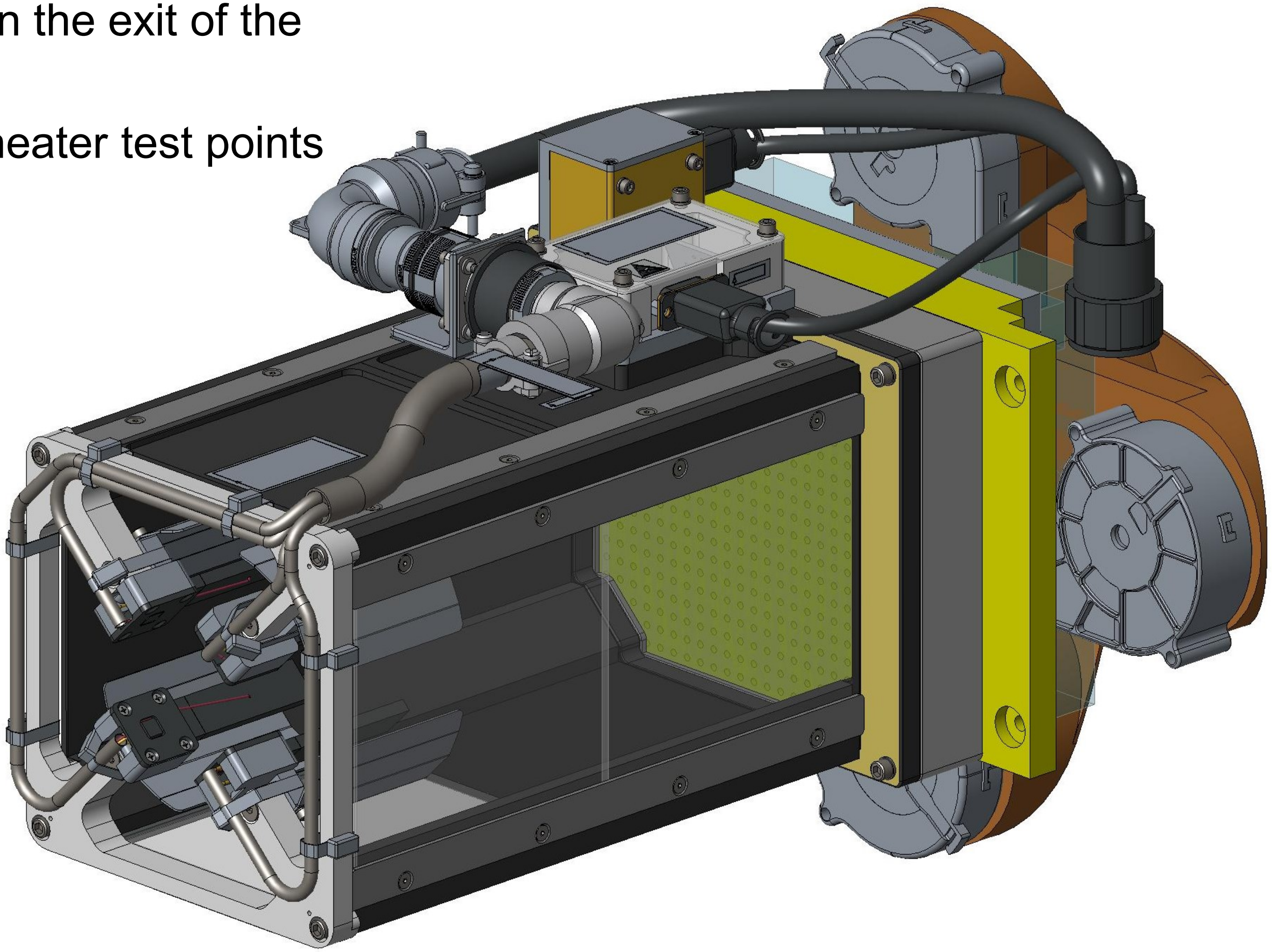
- 3 Samples mounted on a rotating system
- Motor provides rotation into position
- Linear slide moves the sample in and out of the flow duct



Shown with Smurf Rod

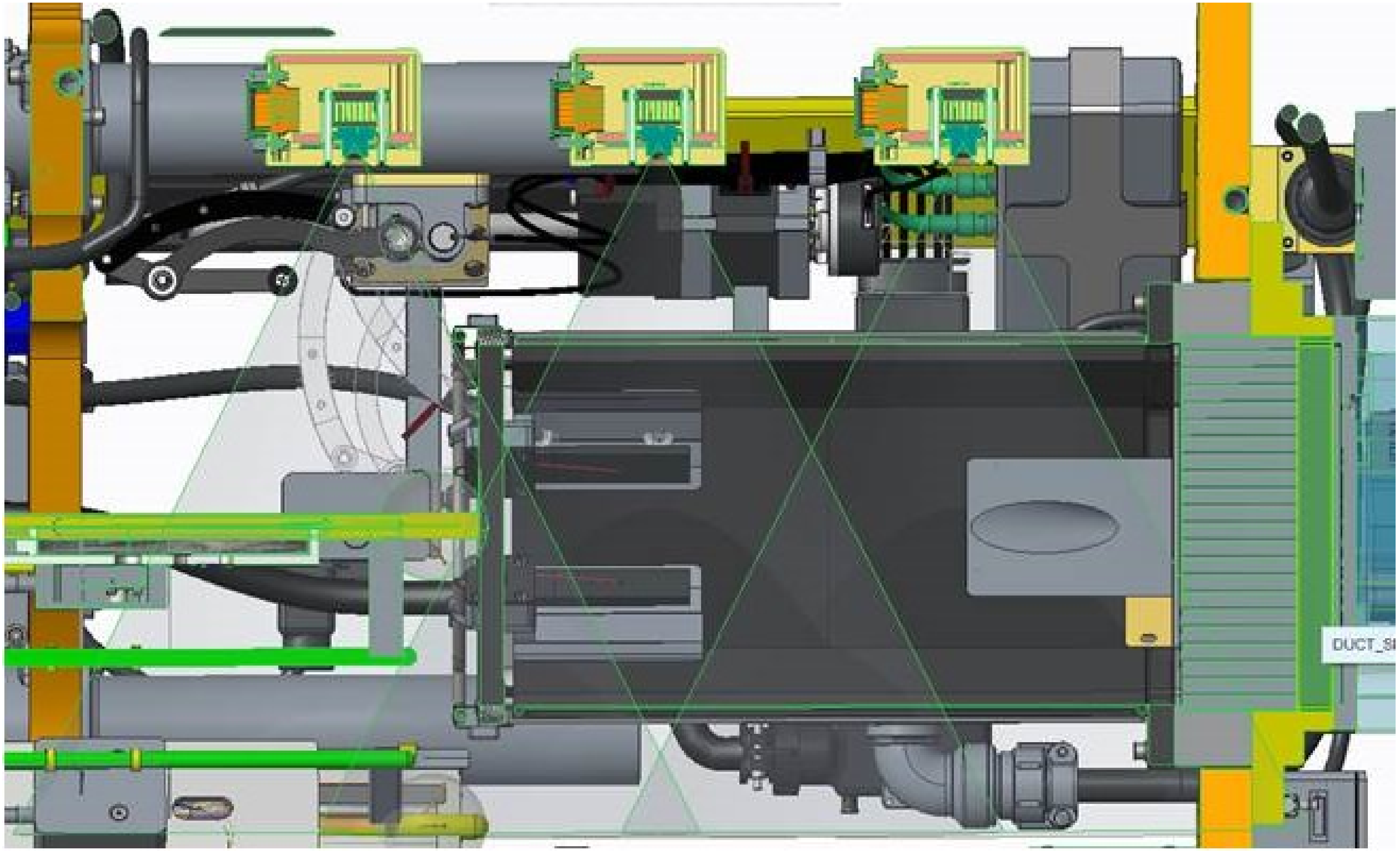
MIST Sample Heater Installed

- The Heater Assembly installs on the exit of the flow duct
- Removed and stowed for non-heater test points



Internal Cameras

- Internal cameras act in conjunction to image the entire combustion area
- External camera images orthogonal view



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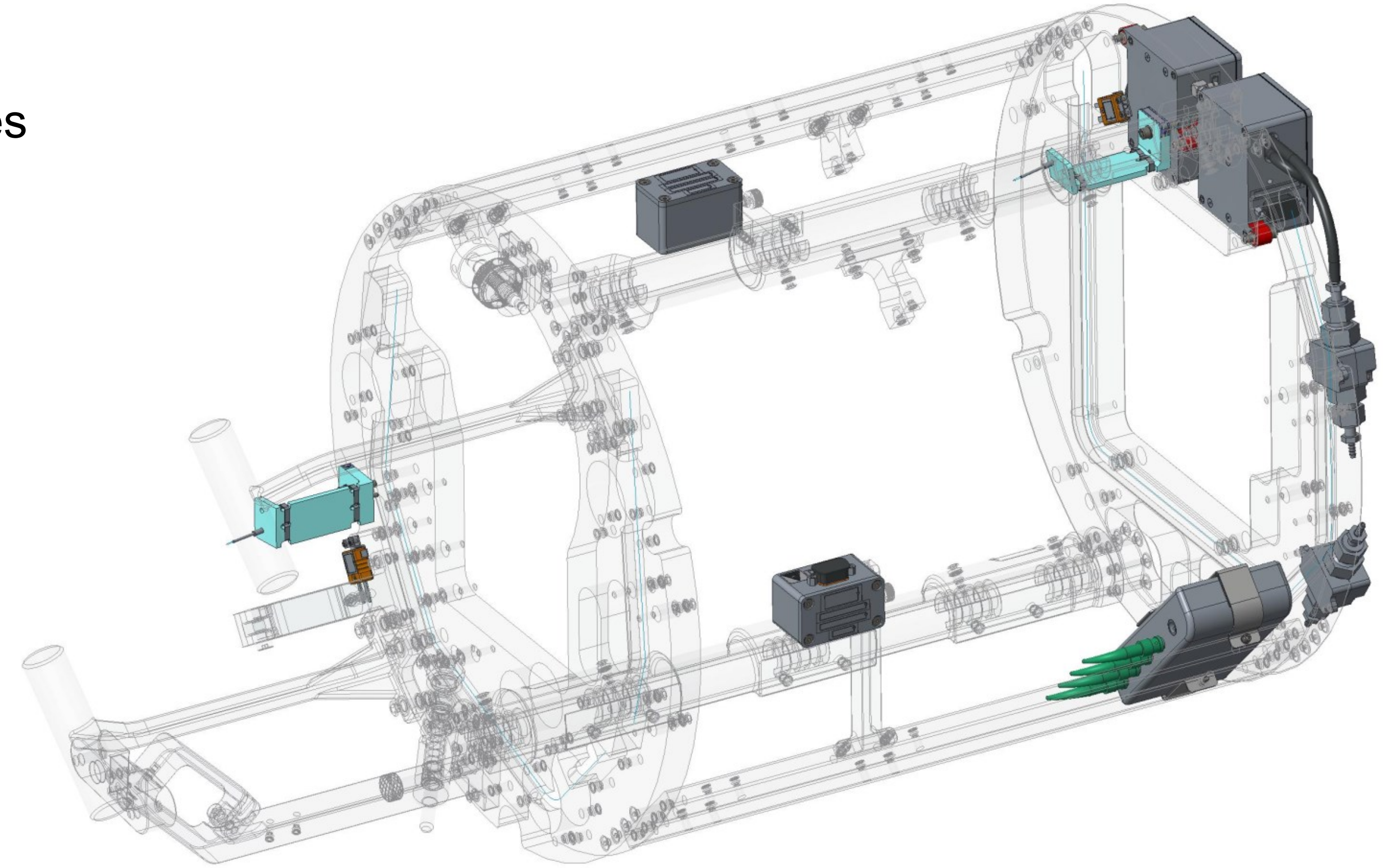
Sensors and Diagnostics

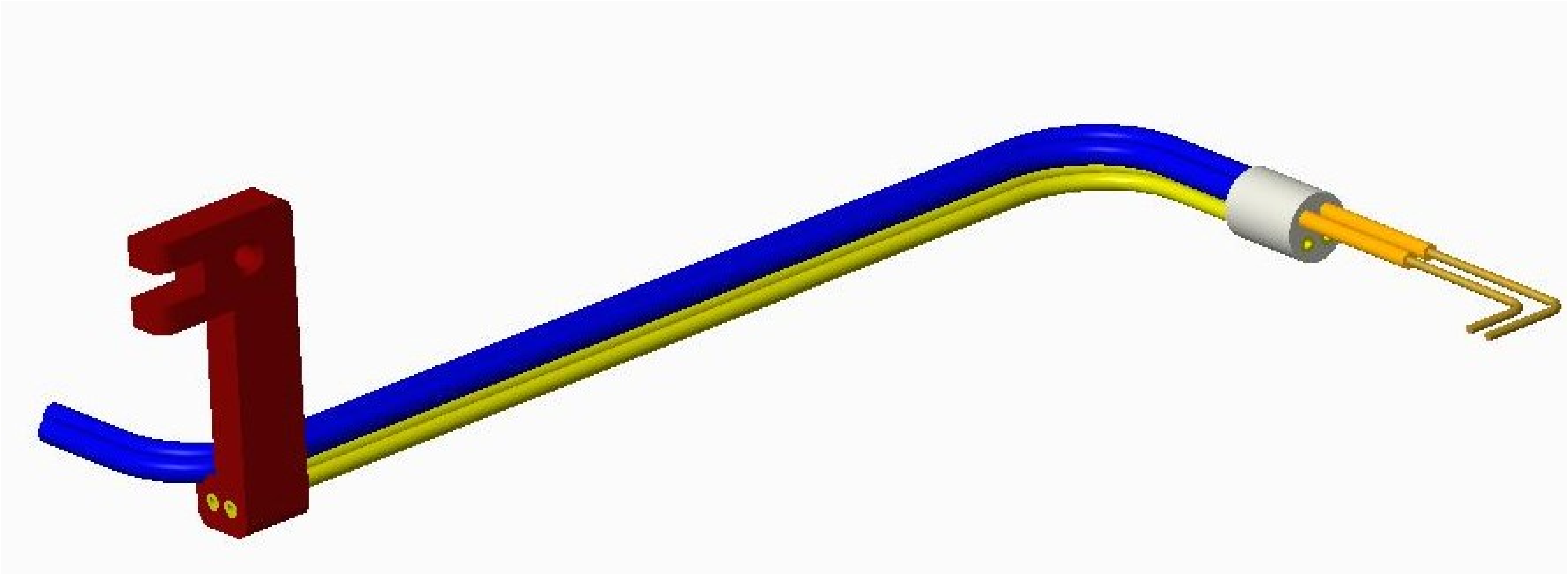
In addition to the radiometer in the duct and sample based measurements, the following sensors and diagnostics are in the system

- 2 CO_2, CO, and relative humidity modules with filtering
- 2 Additional radiometers for orthogonal views to the duct
- PyroScience FireStingO2 Fiber Optic Oxygen Sensor Module with 4 inputs
- 2 Far Field Thermocouples



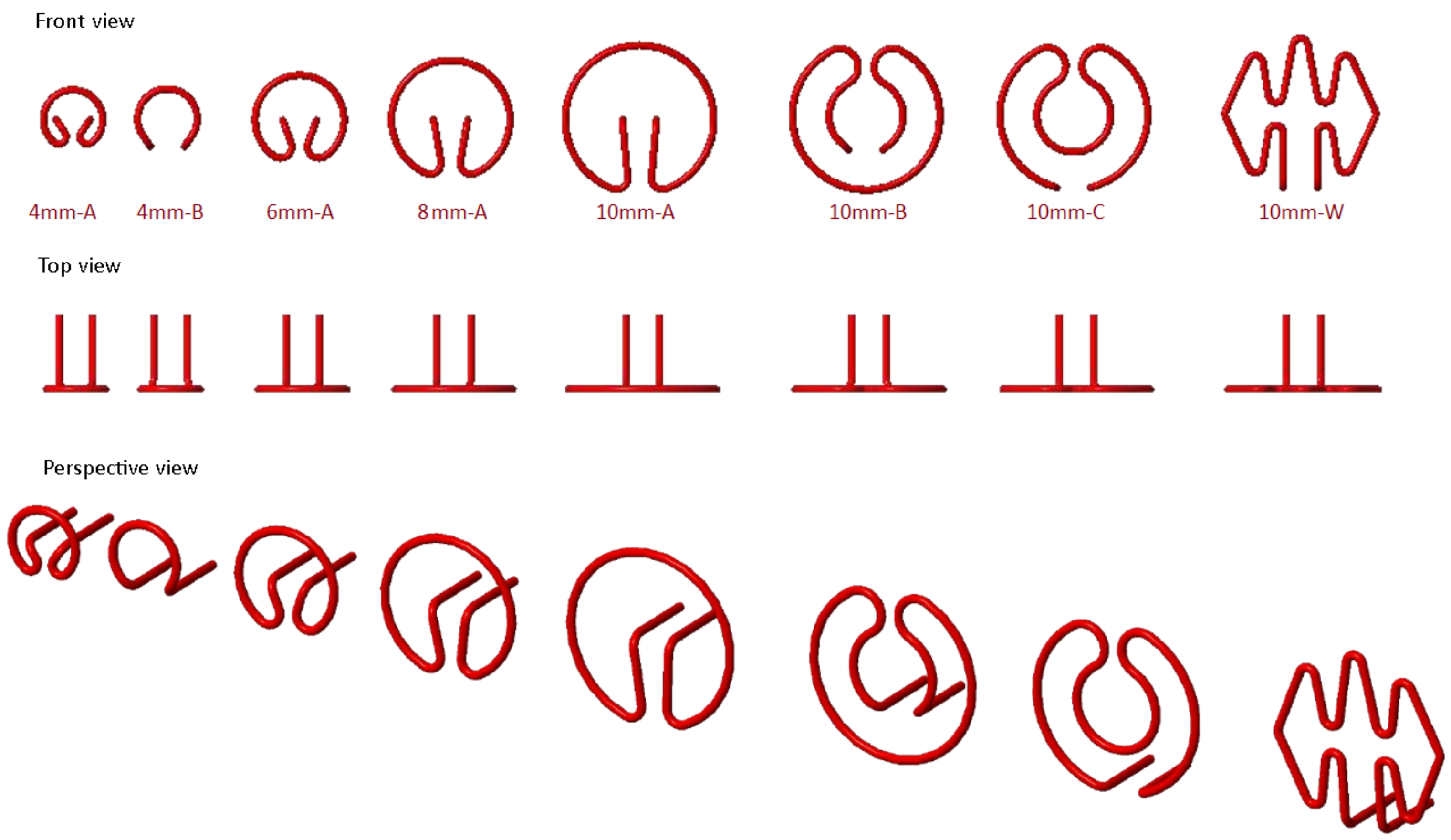
Igniter Mounting Arm

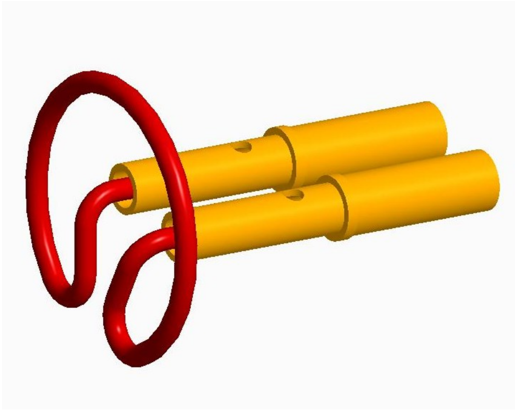
- The Igniter Mounting Arm attaches to the end of the positioning arm
- Provides support and power connections to the igniter tip
- Can be replaced based on sample requirements

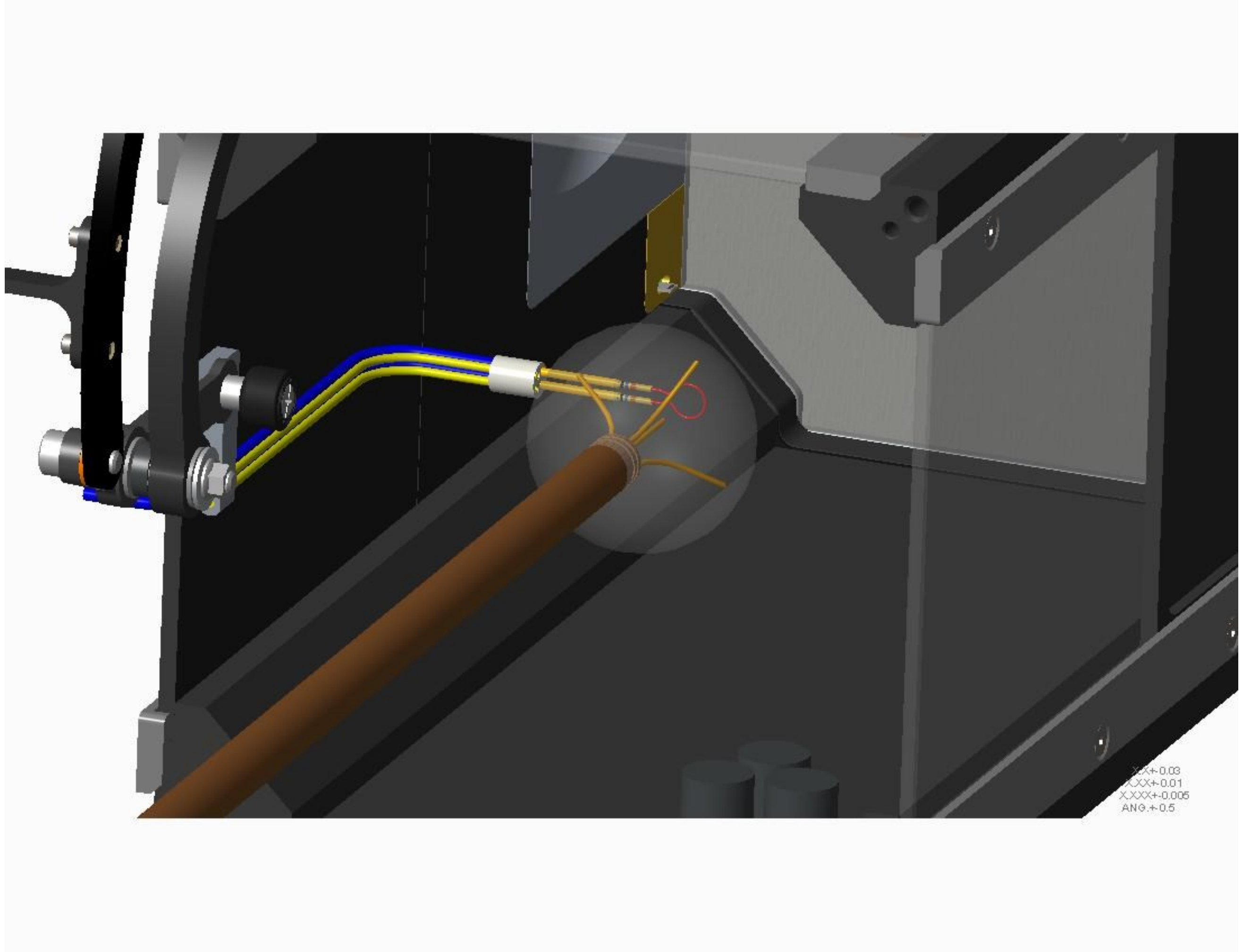


Igniter Tips

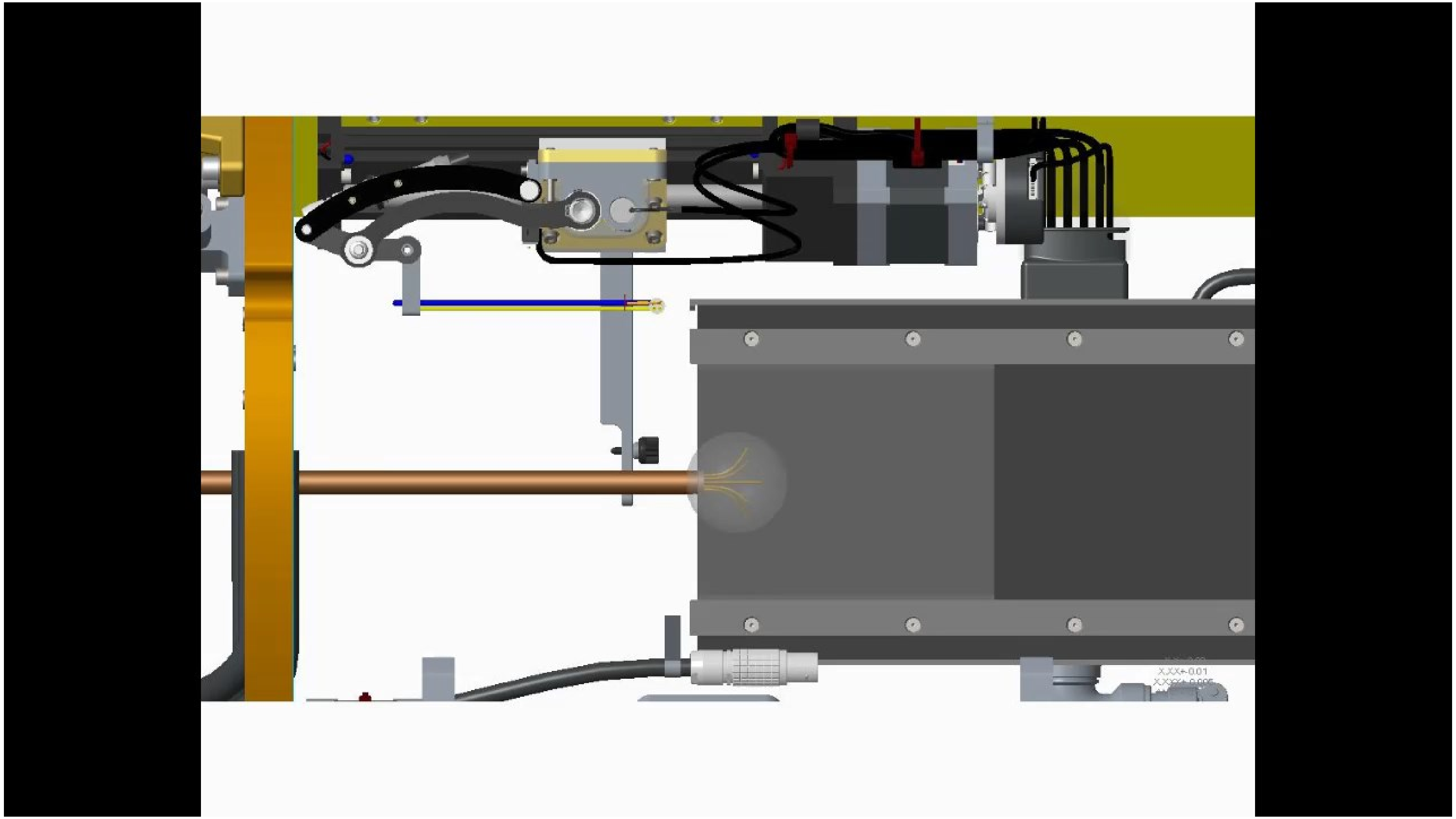
- Igniter tips are 24 Gauge Kanthal-A wire
- Different shapes will be provided based on PI requirements
- Tips are individually replaceable



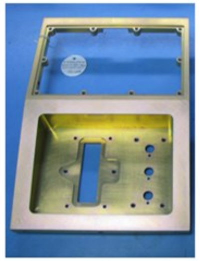


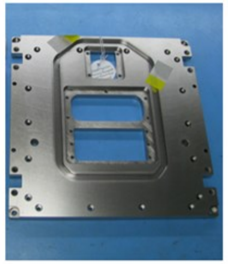

X.XX+-0.03
X.XXX+-0.01
X.XXXX+-0.005
ANG.+-0.5

Igniter Insertion Animation



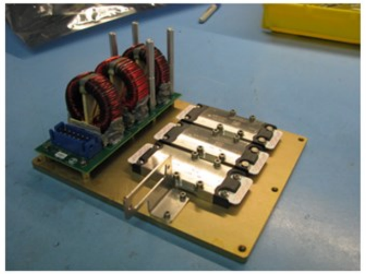
Hardware fabrication is underway

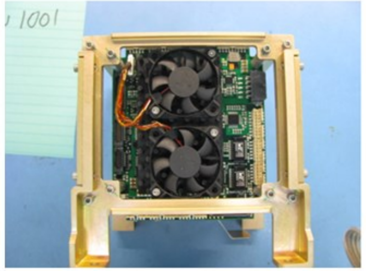

AVP Front Frame and Insert Assembly


AVP Base Insert


AVP Left Housing Frame


AVP Right Housing Frame


AVP Power Distribution Assembly


AVP Card Cage Assembly


Cooling Hose Holder Attachment


Component for Igniter Arm

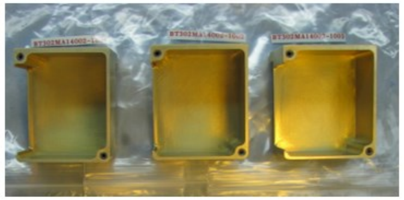

Igniter Tip Interface


AVP Circuit Breaker Cover


Camera Test Harness


AVP Test Harness


Soot Catch Screen


Components for the Internal Camera Insert

SoFIE Schedule Overview

Flight Hardware Availability: July 2020

Experiment Operations Begin: July 2021

Experiment Operations End: December 2023

End