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UNMANNED VEHICLE MATERIAL FLAMMABILITY TEST

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Spacecraft Fire Safety Demonstration

- Most U.S. agencies responsible for inhabited structures and transportation systems conduct full-scale fire tests to address gaps in fire safety knowledge and prove equipment and protocols.
- NASA has been unable to conduct such tests owing to risk to the crew.
- Unmanned vehicles provide a new opportunity.
- Demonstration of this operational concept could allow future experiments to investigate additional fire safety technologies and protocols or in unrelated areas.

<u>Experiment Objective:</u>

Determine the fate of a large-scale microgravity fire

1. Spread rate, mass consumption, and heat release
   - *Is there a limiting size in microgravity?*
2. Confirm that low-g flammability limits are less than those in normal gravity
   - *Are drop tower results correct?*

FAA full scale aircraft test

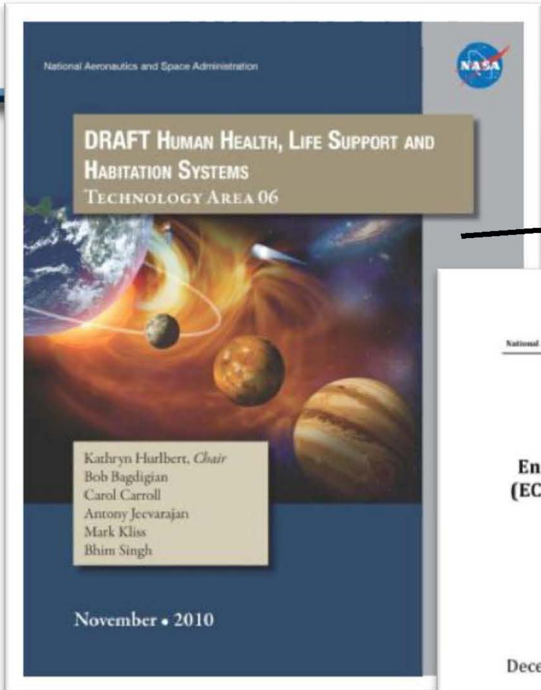
Controlled burns of structures

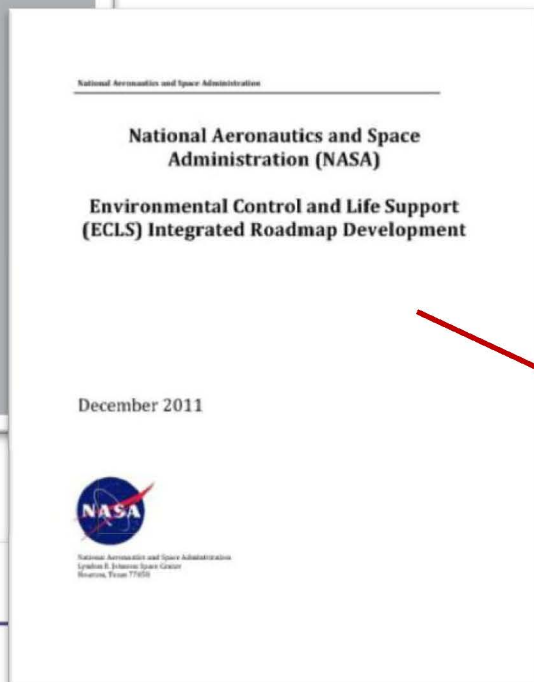
Naval Research Laboratory Ex-USS Shadwell

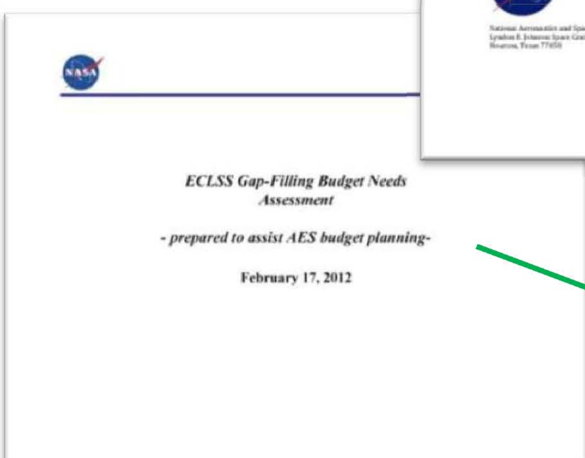
ESA's ATV approaching the ISS

Orbital Science's Cygnus approaching ISS

Knowledge Gaps







- *Low- and partial-g flammability limits for spacecraft materials*
- *Hybrid gas and particulate sensors fro fire detectors and post-fire monitoring*
- *Realistic fire challenges*

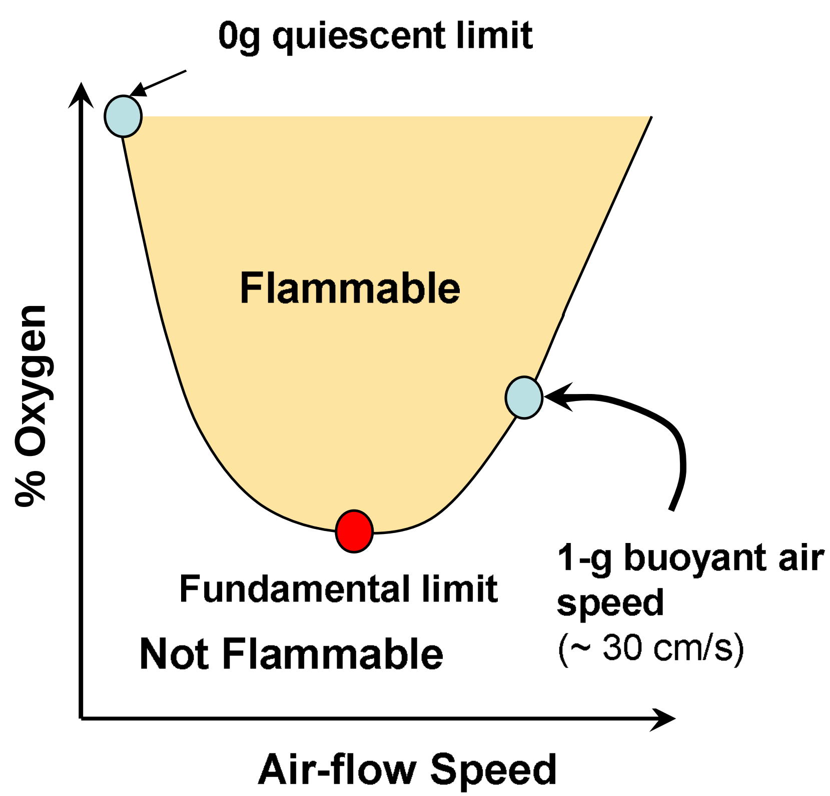
- Common smoke detectors, fire extinguisher, post-fire response and monitoring equipment
  - Smoke-eater *(Enabling)*
  - Combustion Product Monitor
- Material flammability (margin of safety) at high %O_2
  - Improved detection and suppression to reduce risk *(Enhancing)*

- Common portable fire extinguisher for exploration
- Common Smoke Eater technology
- Demonstrating technologies in SFS Demo

Scalable!

Experiment Justification

- <u>How different are low-g material flammability limits from those measured in normal gravity?</u>
  - Low-gravity oxygen flammability limits are different in low-gravity than in normal gravity
  - 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
    - The normal-gravity (and partial-gravity) oxygen concentration flammability limit is not necessarily the minimum

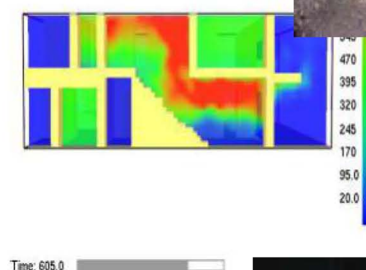


- <u>What is the fate of a large-scale fire in low-gravity?</u>
  - Extrapolation of observed low-g flame behavior to a full-scale spacecraft fire scenario is tenuous
  - Experience with “significant” fires is very limited
    - Enhance risk assessments and modeling of fire events

How rapidly can a fire spread in low-g?

- **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
    - How fast do you need to detect it?
  - Size of fire
    - How long will it remain managable?
    - 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
- **Large-scale *flame spread* sample**
  - 0.5 m wide x 1.0 m long

NIST Full Scale Fire test

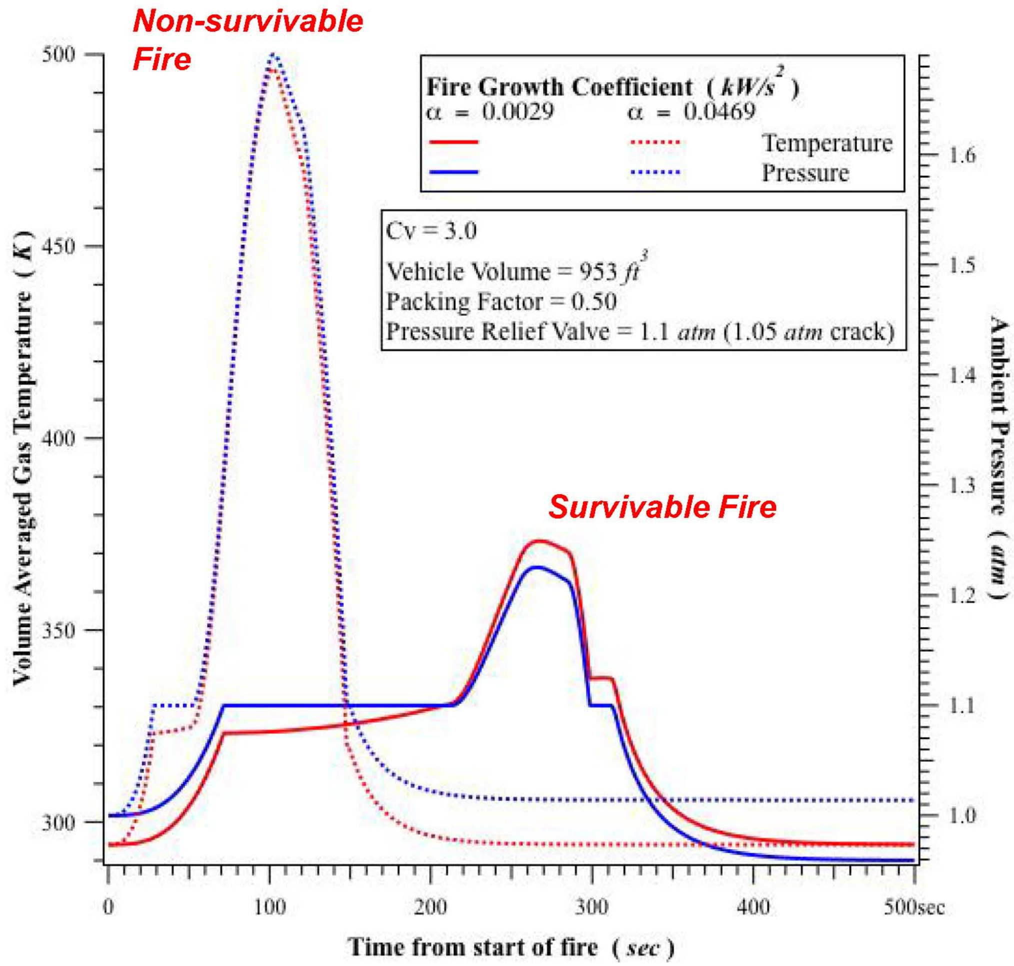


FAA full scale aircraft test

Side view of a low-g flame on a thin paper sample in a concurrent convective flow

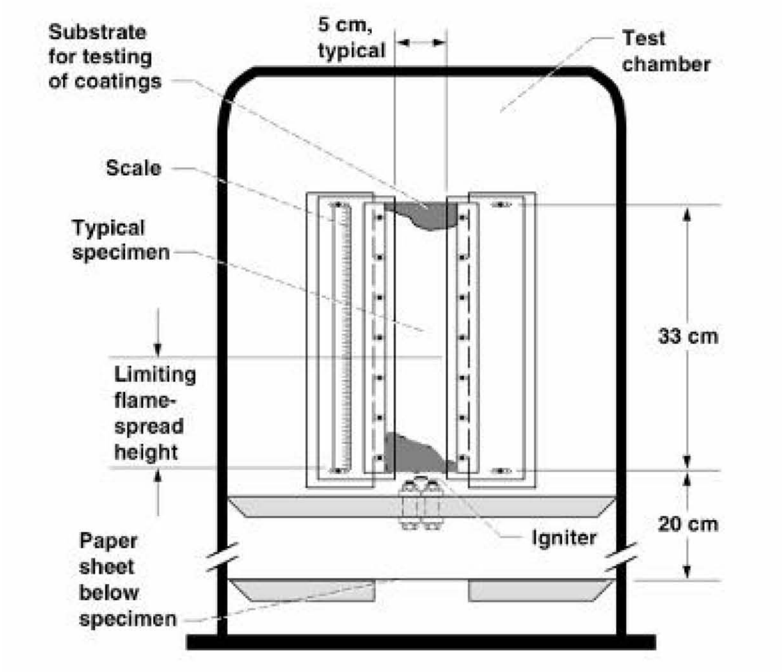
Implications of Fire Growth Rate

- Almost no information exists on large-scale fire growth in microgravity
- CO_2 concentration approximately scales with mass of material consumed
- Safety-critical parameters such as temperature and pressure scale with mass consumed *and* rate of mass consumption
- Growth rate information is needed to make informed decisions on safety equipment and crew response
  - Pressure relief valve sizing
  - Extinguisher size
  - Consumables for cabin cleanup
  - Crew response times (fight-or-flee decisions)
- Data will validate modeling of spacecraft fire response scenarios



Material Flammability Testing

- NASA-STD-6001 describes the test methods used to qualify materials for use in space vehicles.
- The tests cover flammability, odor, off-gassing, and compatibility.
- The primary test to assess material flammability is Test 1: Upward Flame Propagation



Test 1 Apparatus

- 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 fraction at which material passes Test 1
- Flammability limits determined by this test are strongly influenced by natural convection
- Samples are 5 cm wide x 33 cm long and rigidly held in a frame

➢ *Flammability samples*

Low- and Partial-g Flammability Limits

- **Tests were conducted at WSTF (normal-g) and GRC (low- and partial-g) to quantify changes in the flammability limit for Nomex, Mylar, and Ultem at low (with convective flow), Martian, and Lunar gravity levels.**

- **Data on right shows Oxygen Margin of Safety** ***(negative means material burns at lower O2 compared to normal gravity!)***

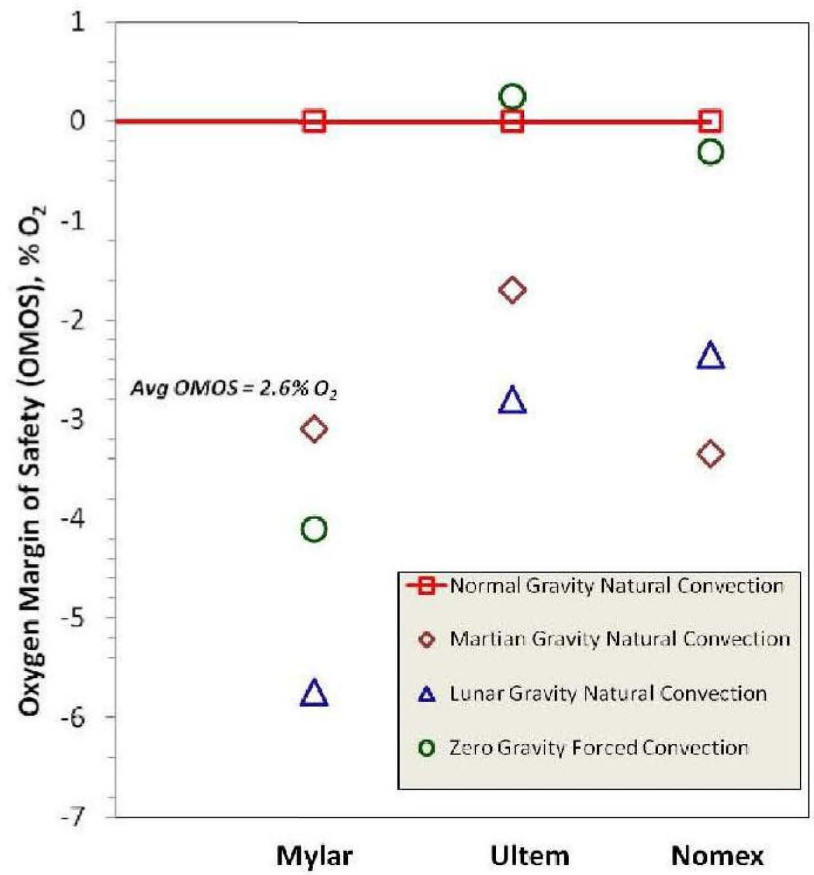
$$(\text{OMOS} = \text{MOC})_{0\text{-g}} - \text{MOC})_{1\text{-g}})$$

Centrifuge drop rig being prepared for a drop in the Zero Gravity Facility

Dome

Experiment support plate

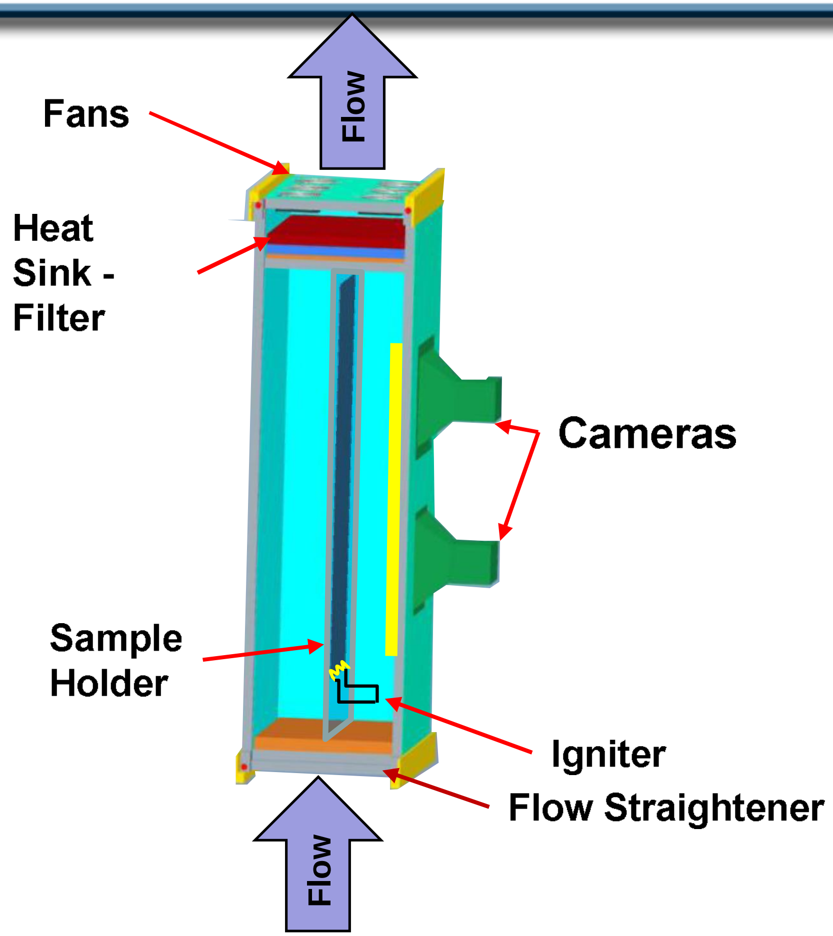
Control hardware and electronics



- Flammability limit samples in the Spacecraft Fire Safety Demonstration Experiment will evaluate NASA-STD-6001 Test 1 in low-g and validate drop tower results.

Experiment Concept

- **Project is developing an experimental concept for the Cygnus vehicle**
- **Current objective is to produce a "simple" modular test facility that could be replicated and fly on multiple flights**
  - Achieve additional spacecraft fire safety demonstration objectives while achieving a lower cost per flight
- **Multiple, single-objective experiments on three flights**
  1. Single, large sample – large-scale flame spread
  2. Flammability limit samples – verify oxygen flammability limits in low gravity
  3. Repeat 1. or 2. at different conditions/post-fire clean-up

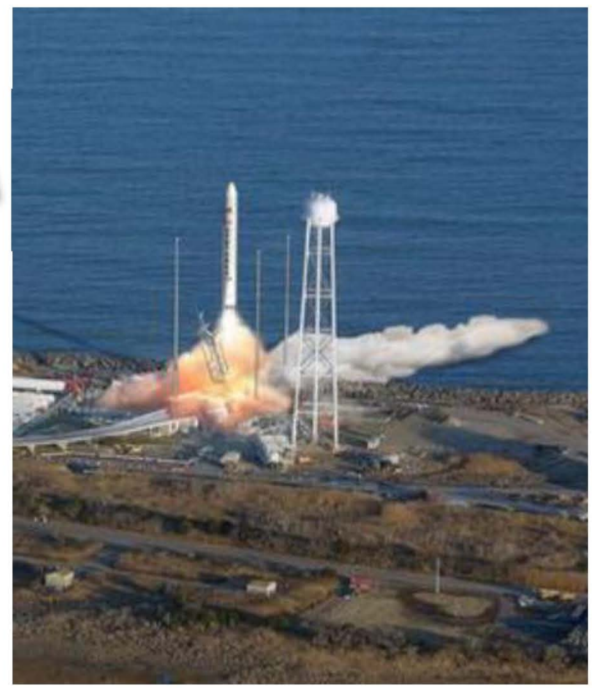


Experiment flow duct concept
Interior of flow duct is 20" x 20" x 48"

Mission Concept

Load experiment into Cygnus PCM

Cygnus mounted in the shroud
of the Antares vehicle



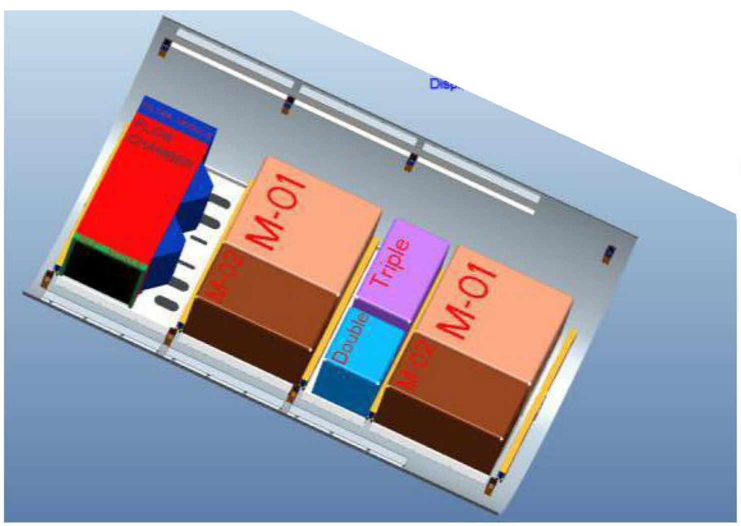
Antares (Taures 2) V launch

Mission Concept

Cygnus approaching ISS

Unpack cargo, reload with trash

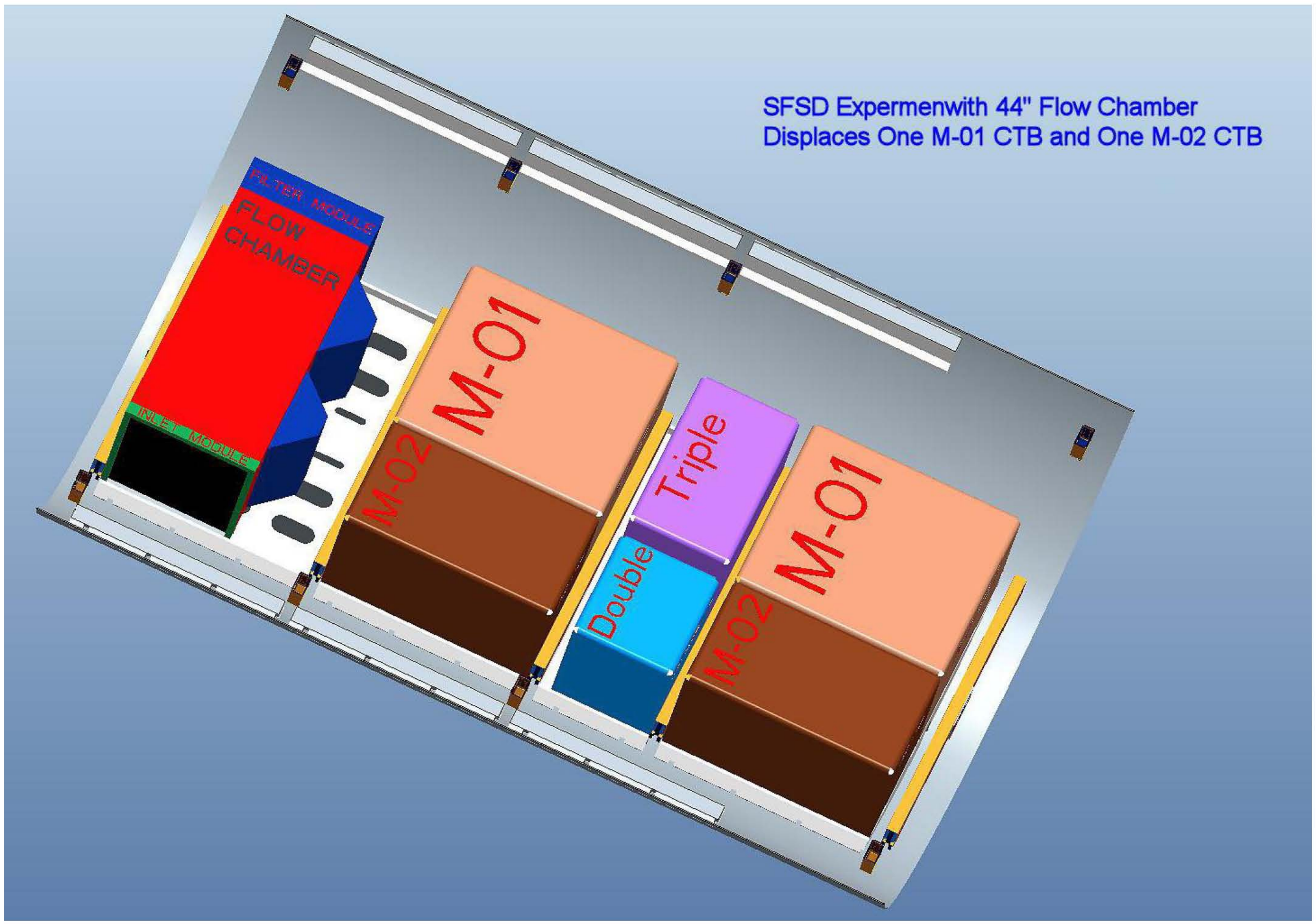
Proposed location of the SFS Demo experiment (back of vehicle)



Check-out SFS Demo experiment

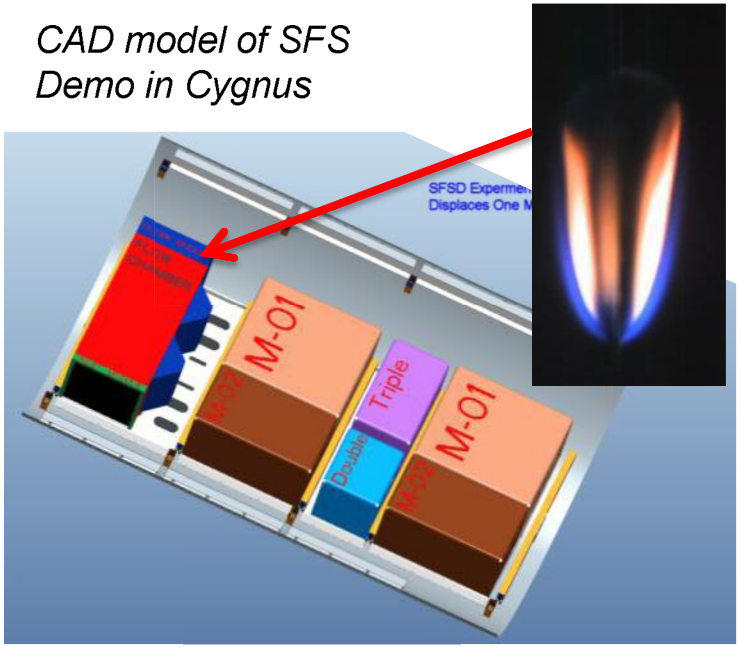
SFS Demo Experiment Configuration

- Experiment remains on AFT wall but rotated to lie between the rails
- Sample spacing requirements met
- Length of flow chamber reduced from 48” to 44“
- Camera enclosures facing M-01/M-02 bags on AFT wall

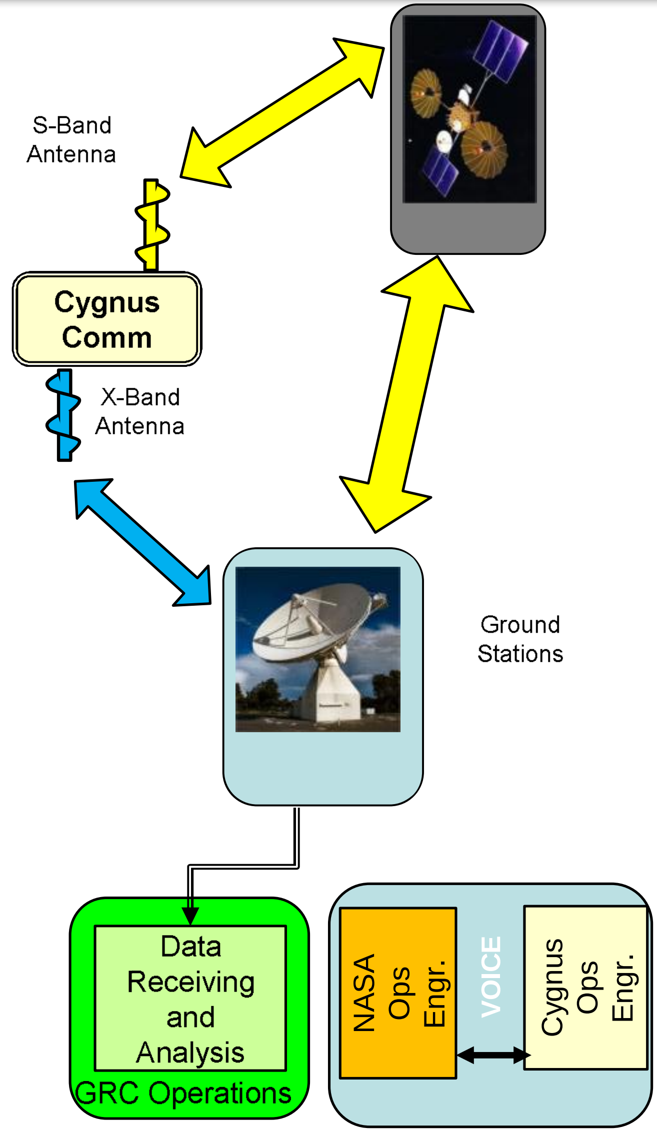


Mission Concept

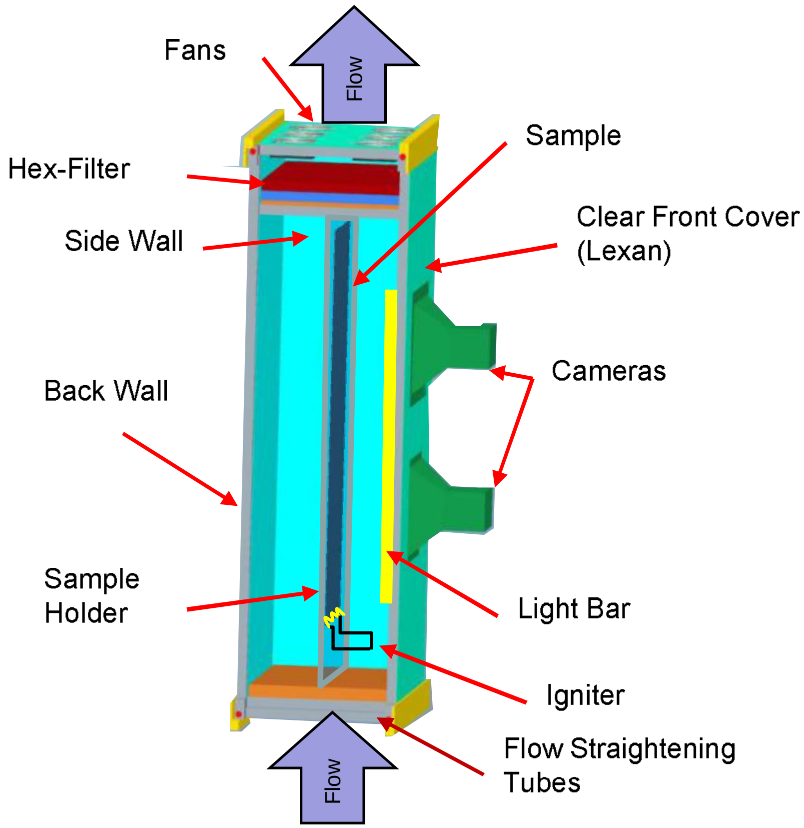
CAD model of SFS Demo in Cygnus



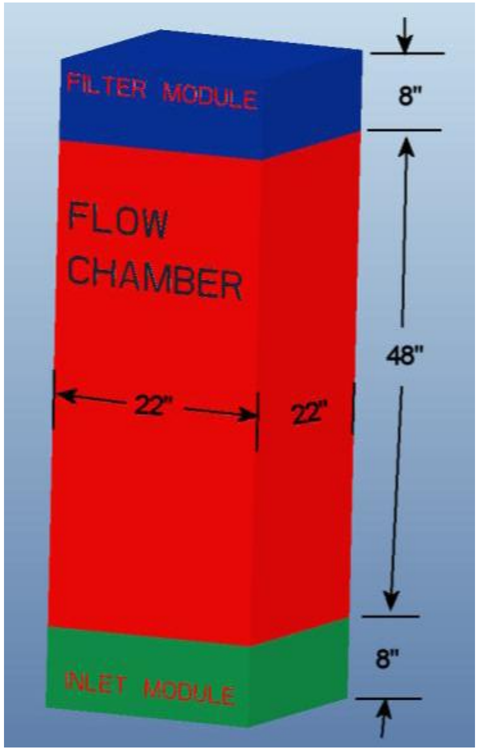
Side view of a low-g flame on a thin paper sample in a convective flow



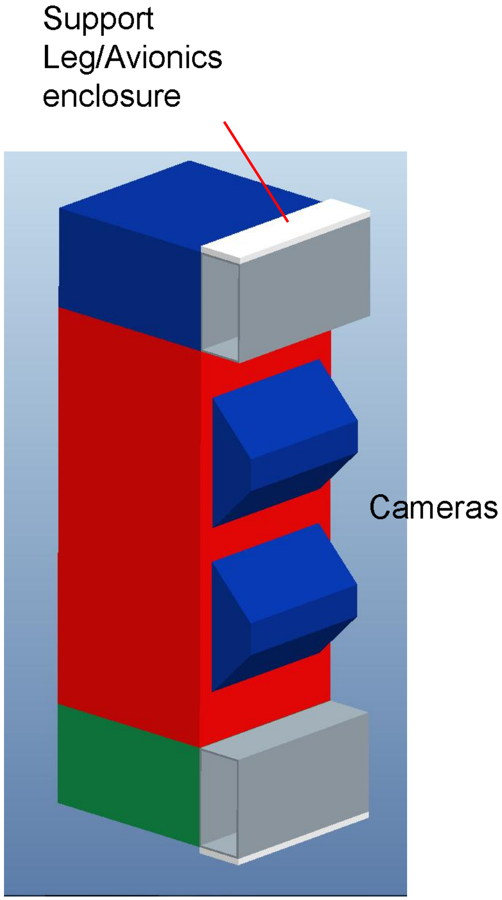
Spacecraft Fire Safety Demo Mission Concepts



Details of experiment flow duct (draft)



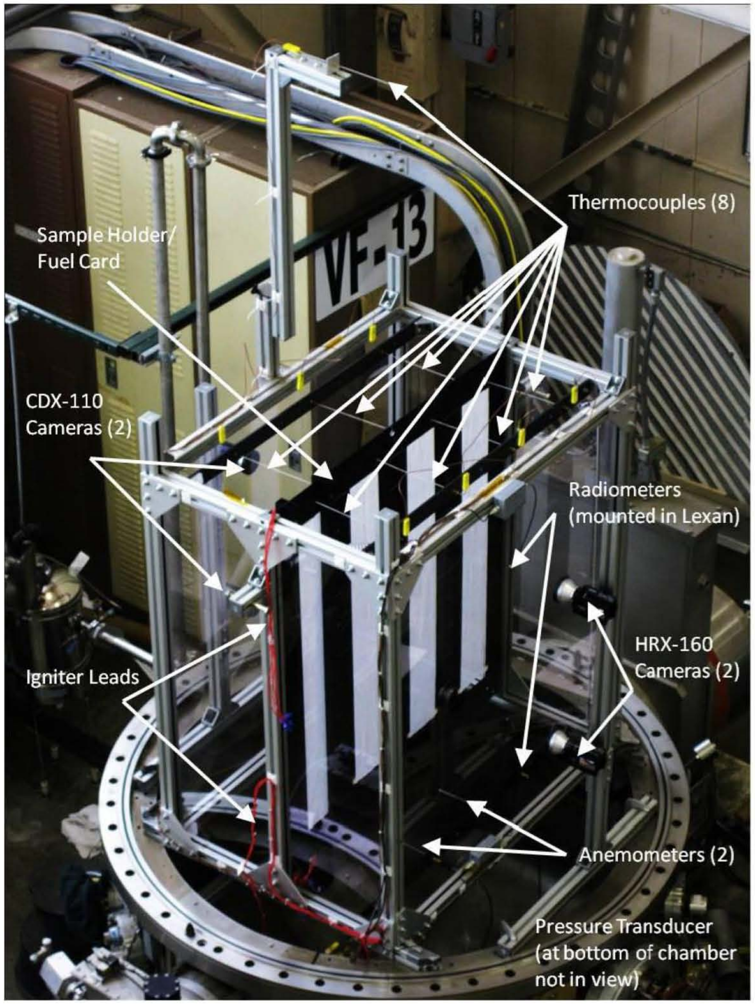
Outer dimensions of experiment hardware *(Interior of flow chamber is 20" x 20" x 48")*



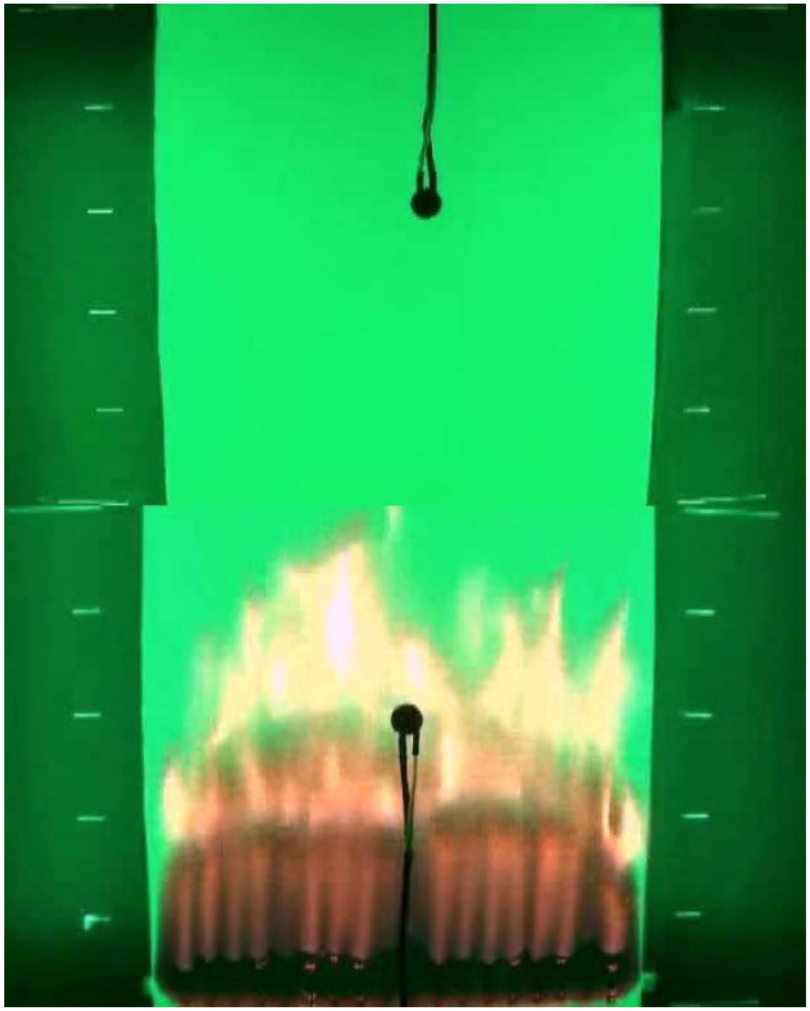
Block configuration of Cygnus experiment concept

Safety Considerations - Overpressure testing

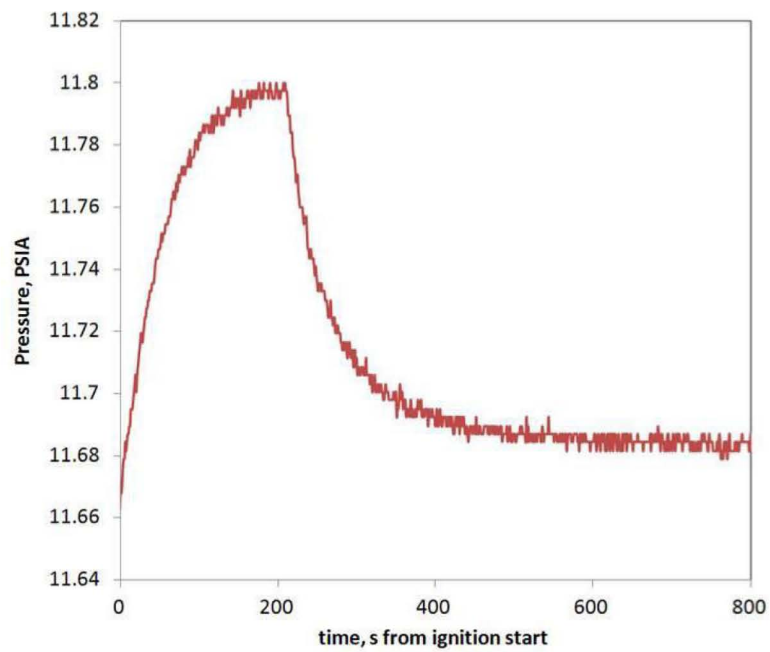
Vacuum Faculty (VF)-13)
149.9 cm ID, 360 cm high, 6.35 m^3 volume



Safety Considerations - Overpressure testing

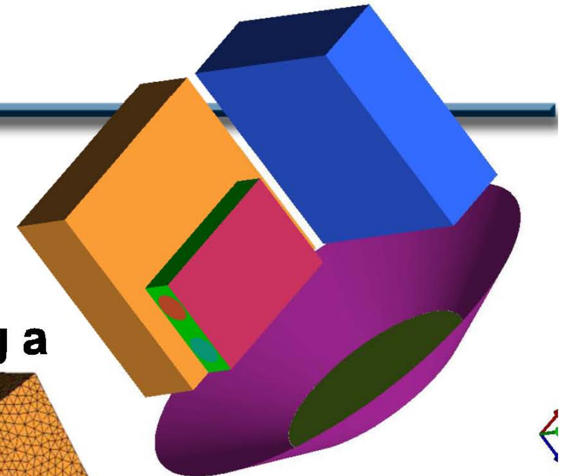


SIBAL Cloth, upward 1-g

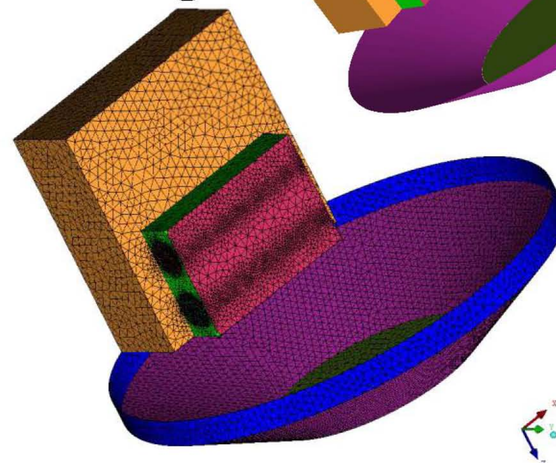


Pressure trace for Single 12.5- by 100-cm sample ignited at the top.
The fuel is 90 grade cotton cheese-cloth with a 4.92 mg/cm^2 density.

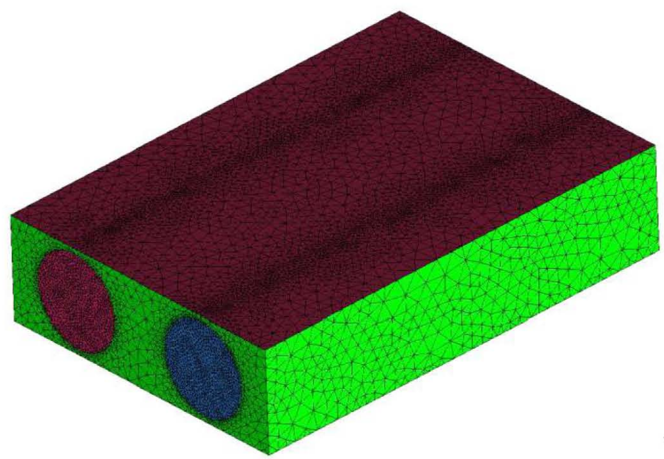
Calculation initialization



- **Calculations are initialized with a steady state flow generated by the fans at constant temperature following a classic strategy:**
  - Flow initialization
  - Full multigrid initialization
  - Few thousand iterations with first order solver
  - Few thousand iterations with second order solver

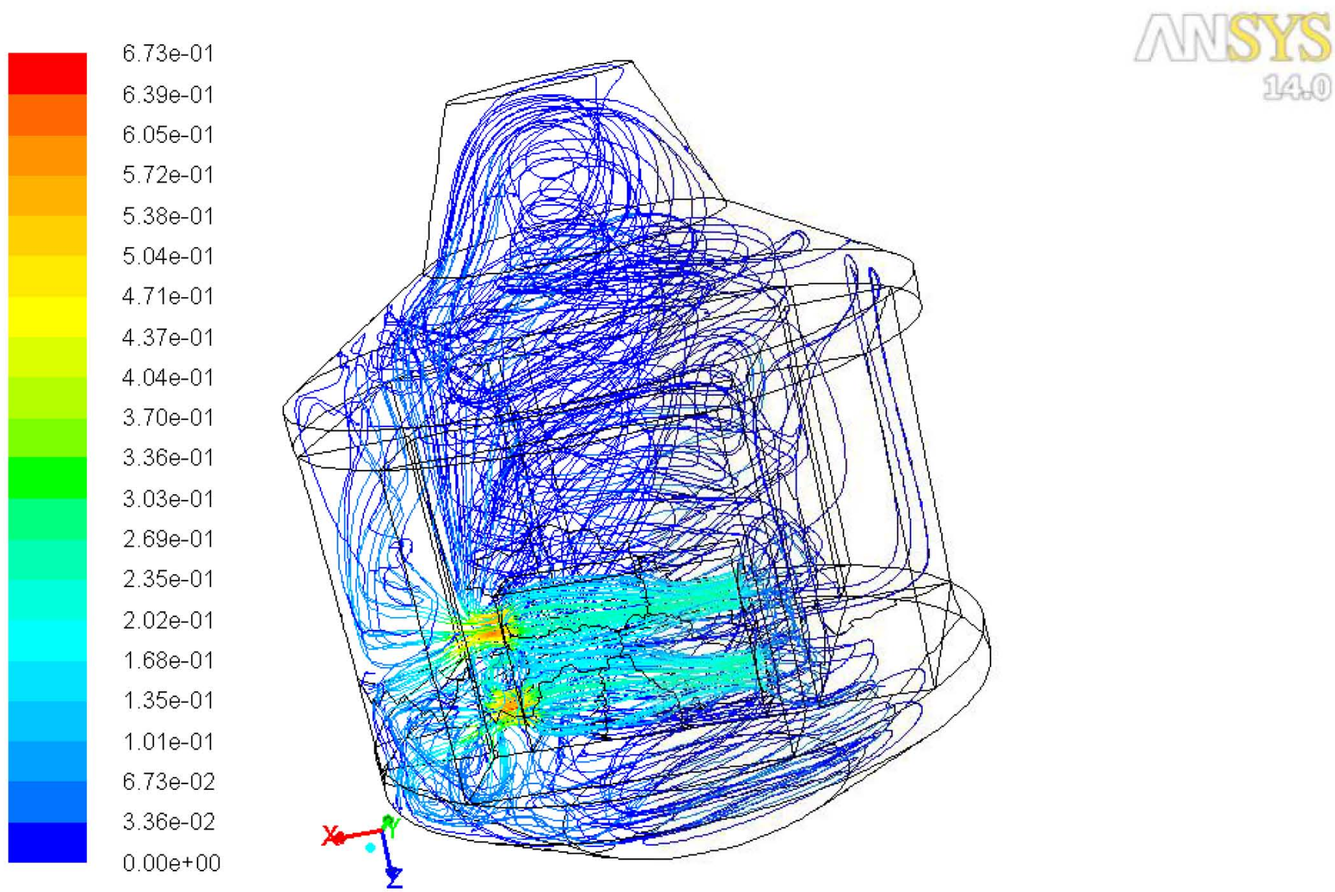


- **Flow modelling main parameters:**
  - Energy equation turned on
  - Turbulence model: Ke-RNG
  - Air as ideal gas for density calculation
  - Sutherland model for viscosity
  - Initial temperature: 300k
  - Initial pressure: 1013 hPa
  - All walls are adiabatic



Calculation with heat release : ATV configuration

- **1- ATV configuration after 1 minute of heat release**
  - Pathlines
  - Velocity field

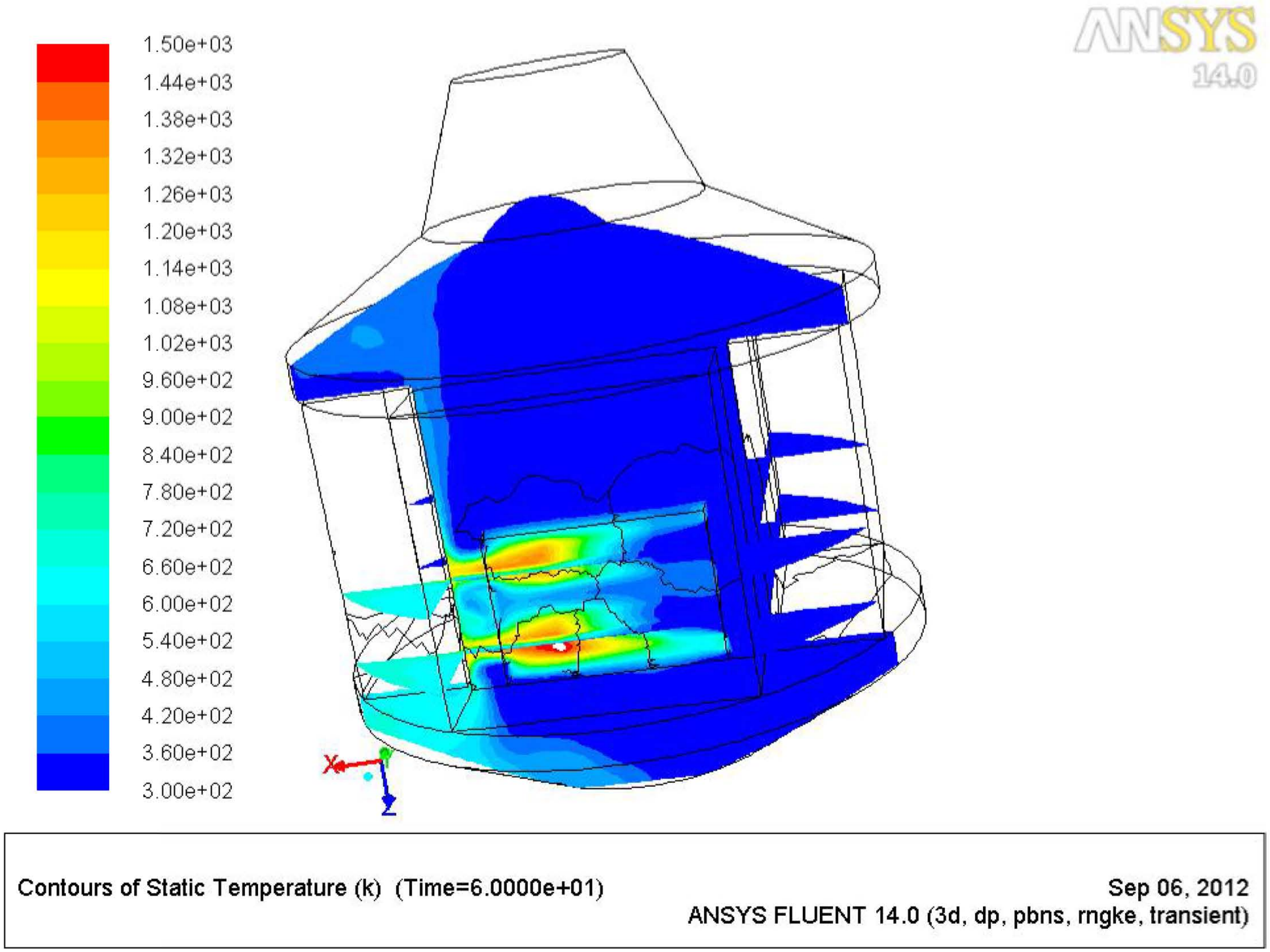


Pathlines Colored by Velocity Magnitude (m/s) (Time=6.0000e+01) Sep 06, 2012
ANSYS FLUENT 14.0 (3d, dp, pbns, rngke, transient)

Calculation with heat release : ATV configuration

◆ **1- ATV configuration after 1 minute of heat release**

- Temperature field



Conclusions

- **Microgravity fire behaviour remains poorly understood and a significant risk for spaceflight**

- **An experiment is underdevelopment that will provide the first real opportunity to examine this issue focussing on two objectives**
  - Flame Spread
  - Material Flammability

- **This experiment has been shown to be feasible on both ESA's ATV and Orbital Science's Cygnus vehicles with the Cygnus as the current base-line carrier.**

- **An international topical team has been formed to develop concepts for that experiment and support its implementation.**
  - Pressure Rise prediction
  - Sample Material Selection

- **This experiment would be a landmark for spacecraft fire safety with the data and subsequent analysis providing much needed verification of spacecraft fire safety protocols for the crews of future exploration vehicles and habitats.**