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LARGE SCALE EXPERIMENTS ON SPACECRAFT FIRE SAFETY

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Spacecraft Fire Safety Demonstration

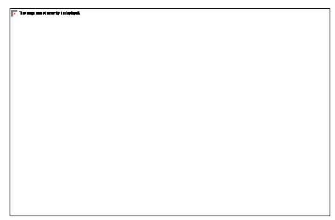
Project Objective:

- Advance spacecraft fire safety technologies identified as gaps by the Constellation Program and in the Exploration Technology Roadmaps
- Demonstrate performance of these technologies in a large-scale, low-gravity spacecraft fire safety test aboard an unmanned re-entry vehicle
  – Demonstration of this operational concept could allow future experiments to investigate additional fire safety technologies and protocols

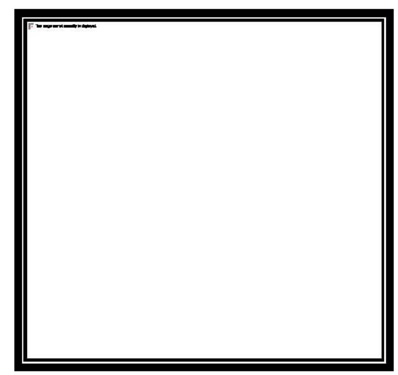
Most U.S. agencies responsible for large transportation systems conduct full-scale fire tests to address gaps in fire safety knowledge and prove equipment and protocols.

FAA full scale aircraft test

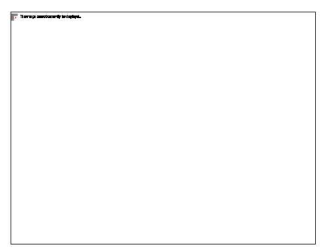
Controlled burns of structures



Naval Research Laboratory Ex-USS Shadwell



Orbital Science’s Cygnus approaching ISS



ESA’s ATV approaching the ISS

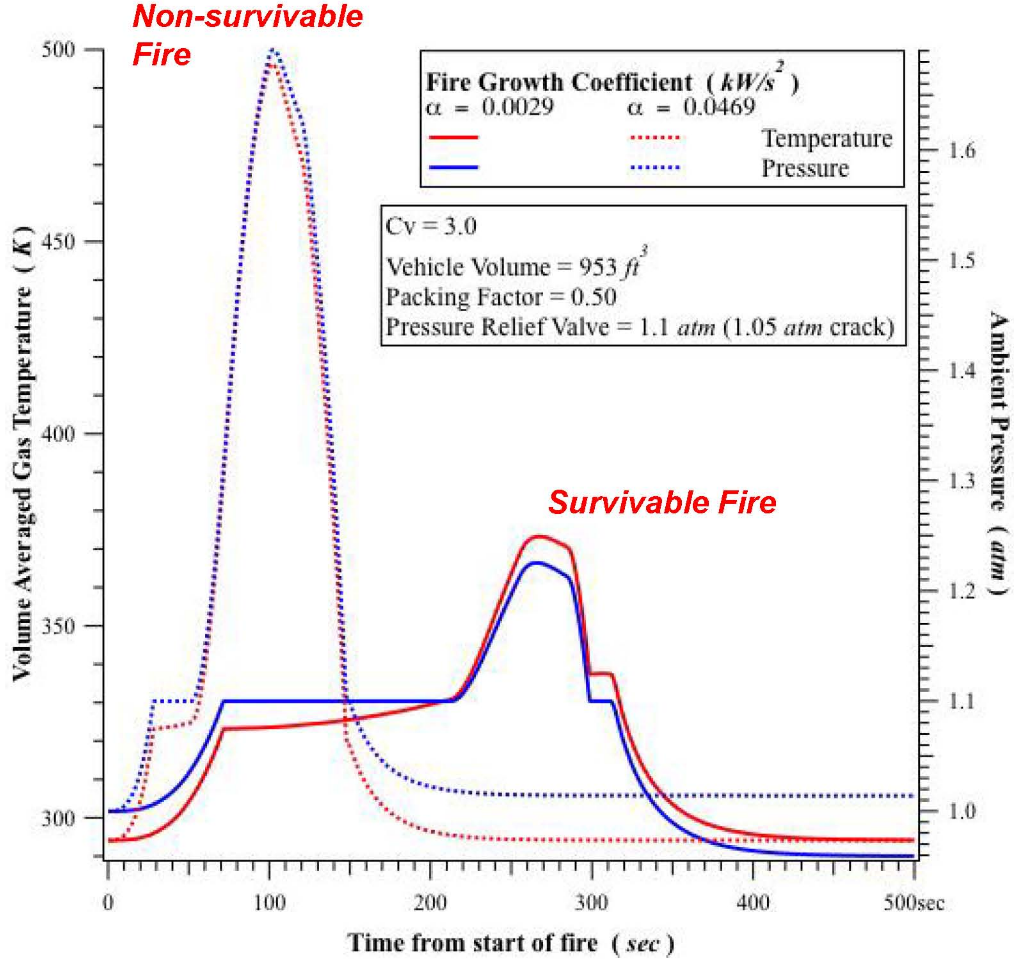
Experiment Objective:

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- and partial-g flammability limits are less than those in normal gravity
   - *Are drop tower results correct?*

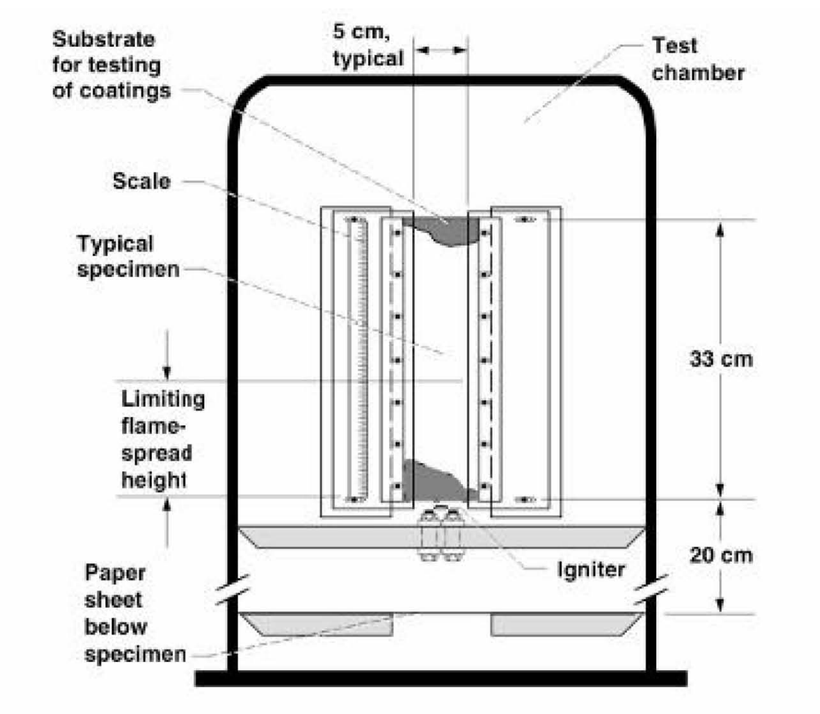
Implications of Fire Growth Rate

- 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



Experiment Justification

- 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



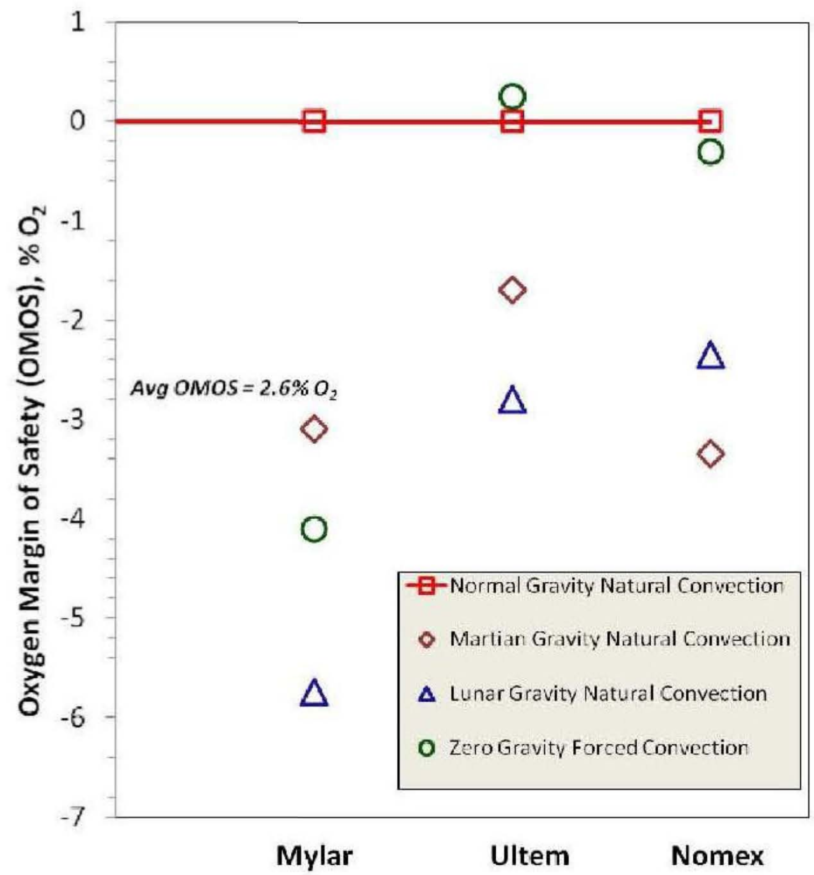
Test 1 Apparatus

- 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 at which material passes Test 1
- Flammability limits determined by this test are <u>strongly influenced by natural convection</u>
- Drop tower data shows that flammability limits are lower in low- and partial-gravity!
- *Do NASA's flammability standards result in higher flammability limits than actually found in low-gravity?*

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!)*

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

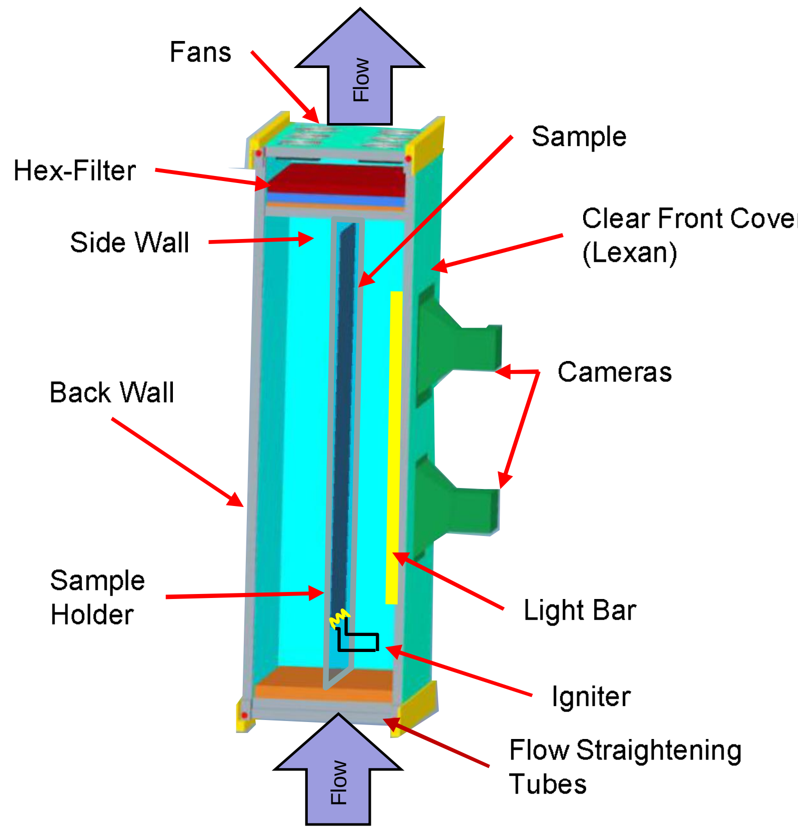


Centrifuge drop rig being prepared for a drop in the Zero Gravity Facility

- 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**
  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

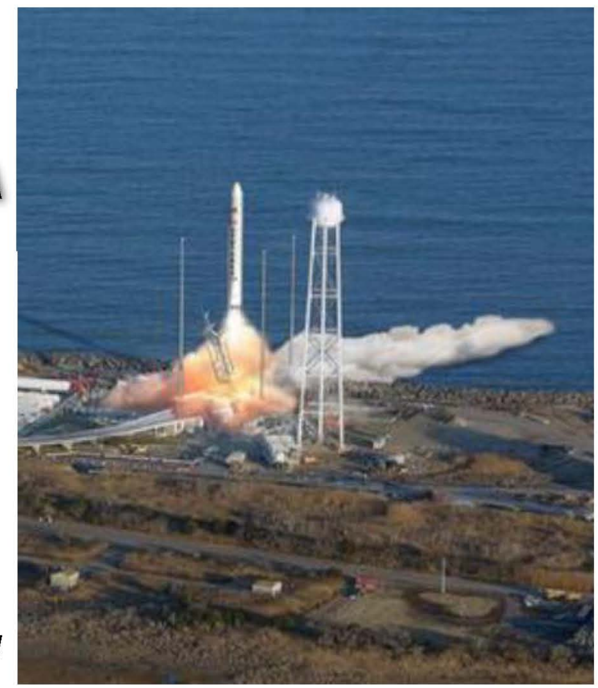


Details of experiment flow duct (tentative).
Interior of flow duct is 20" x 20" x 48"

Mission Concept

Load experiment into Cygnus PCM

Cygnus mounted in the shroud of the Antares vehicle



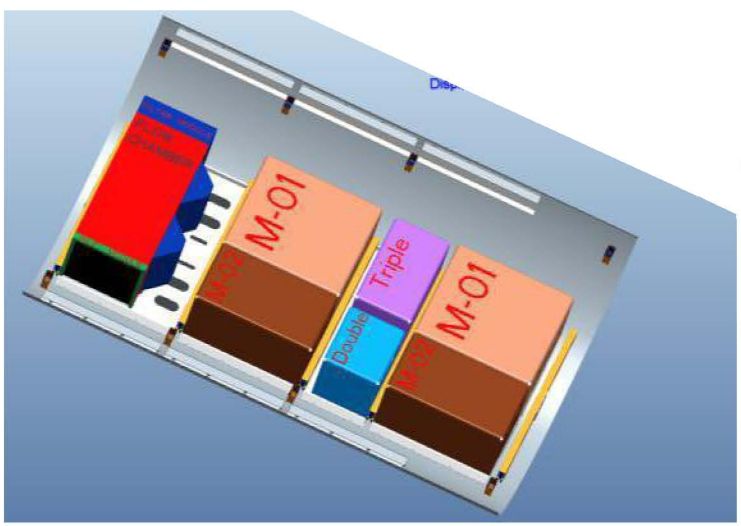
Antares (Taures 2) V launch

Mission Concept

Cygnus approaching ISS

Unpack cargo, reload with trash

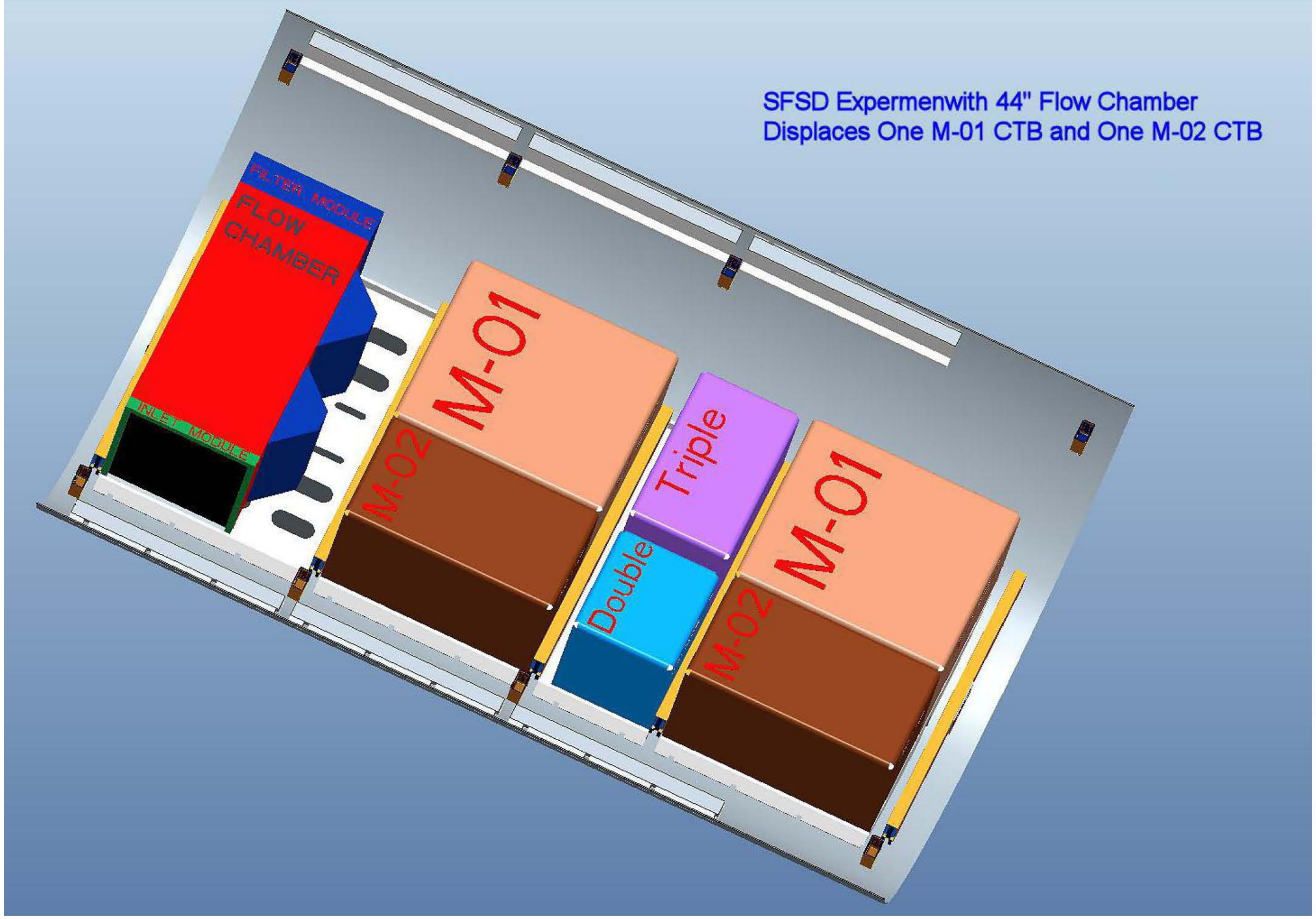
Proposed location of the SFS Demo experiment (back of vehicle)



Check-out SFS Demo experiment

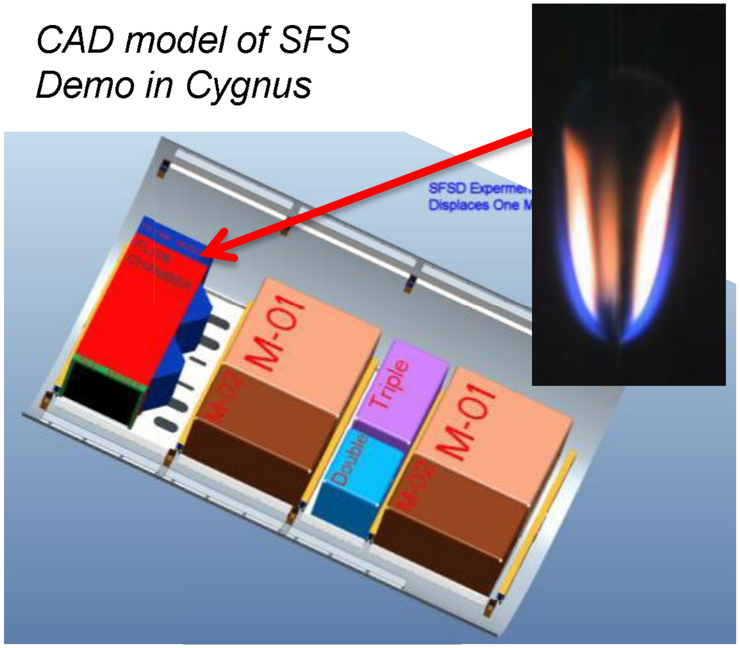
SFS Demo Experiment Configuration

- 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

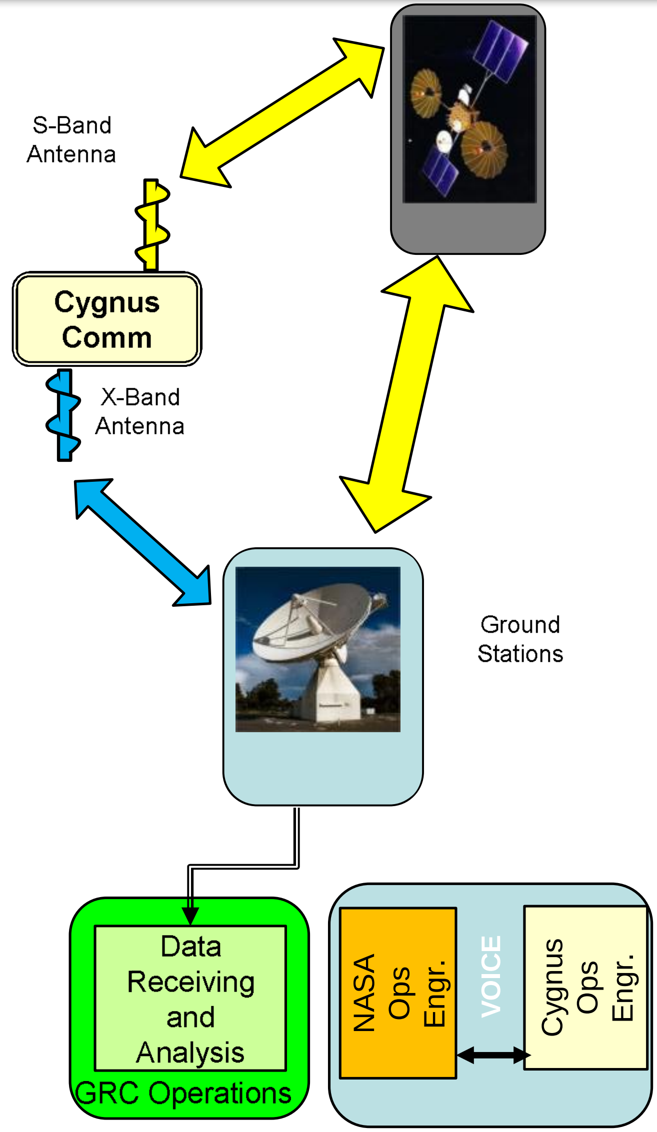


Mission Concept

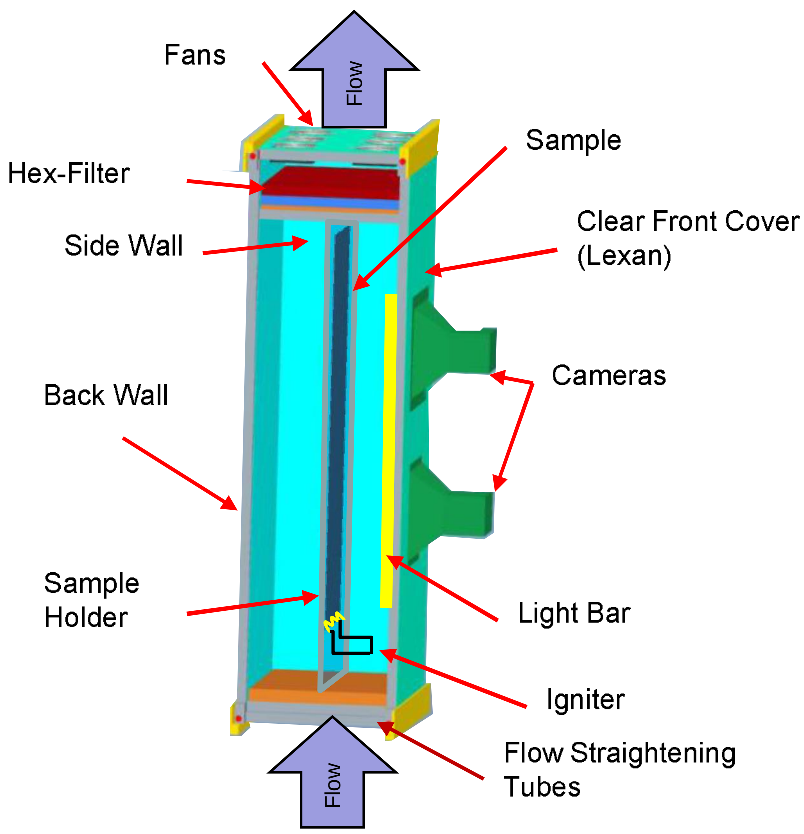
CAD model of SFS Demo in Cygnus



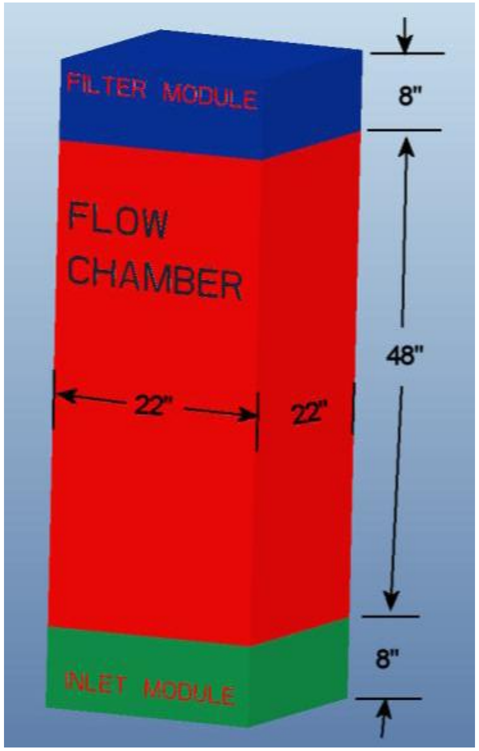
Side view of a low-g flame on a thin paper sample in a convective flow



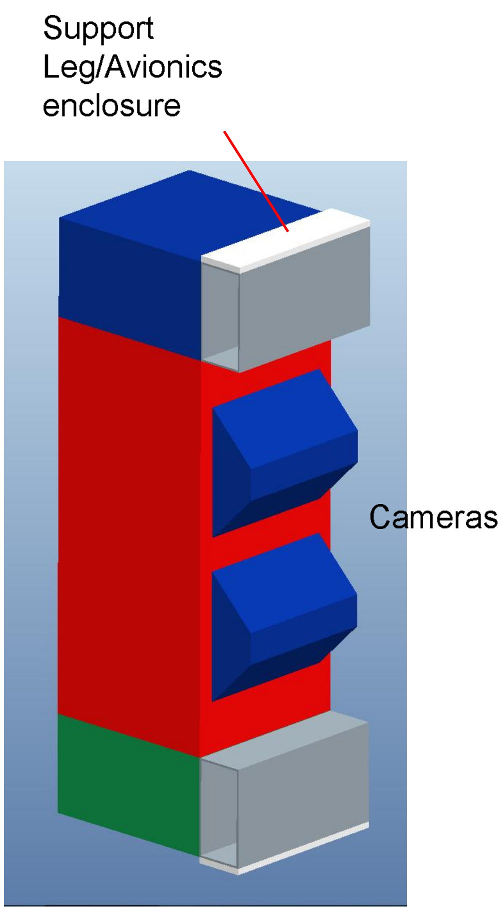
Spacecraft Fire Safety Demo Mission Concepts



Details of experiment flow duct (draft)



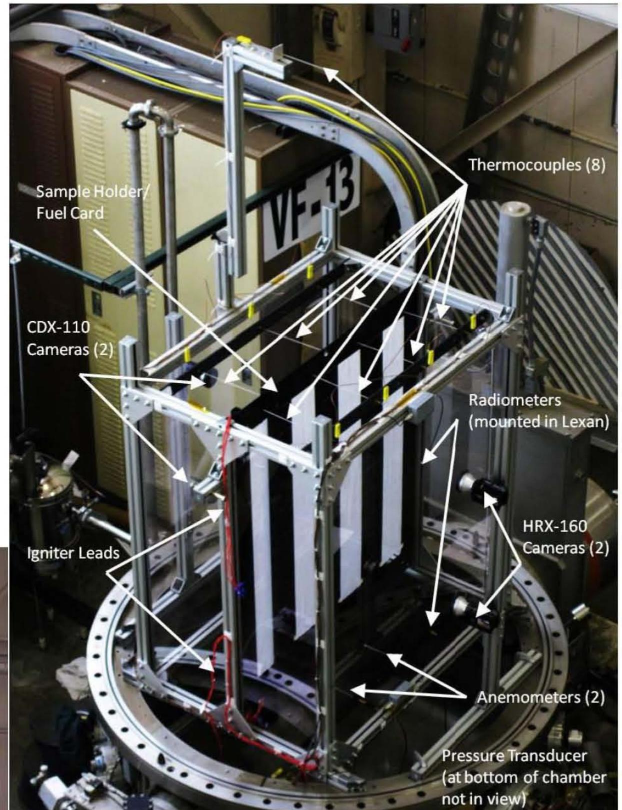
Outer dimensions of experiment hardware *(Interior of flow chamber is 20” x 20” x 48”)*

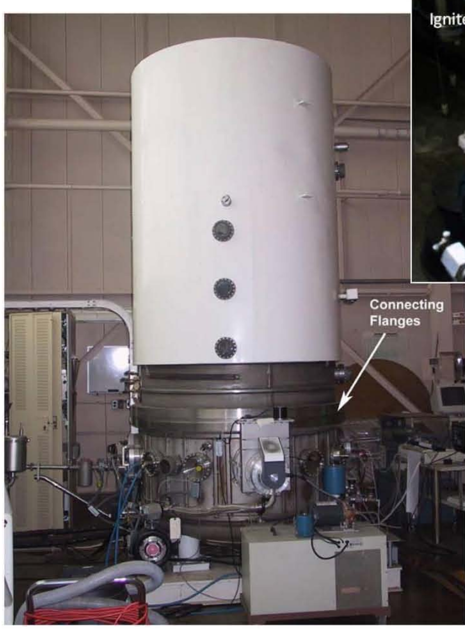


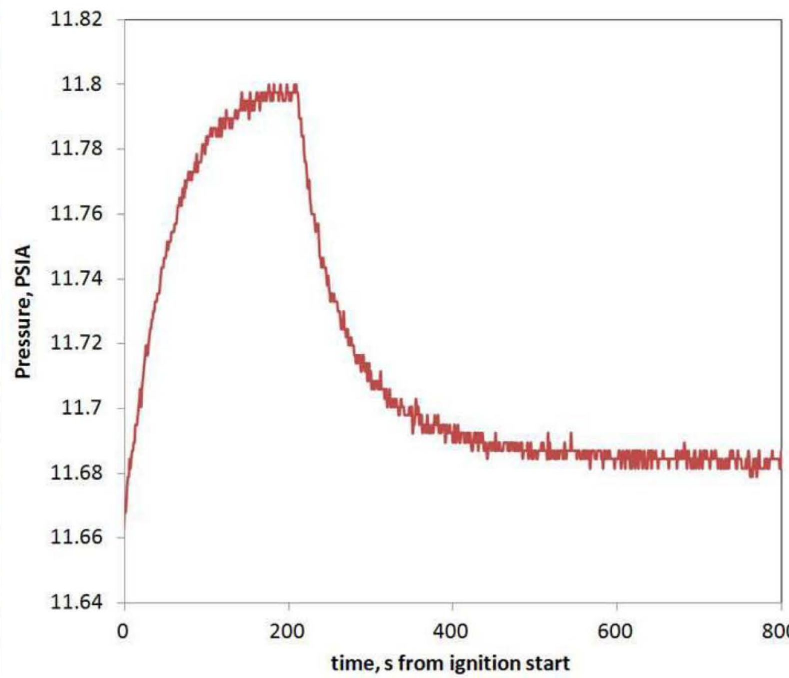
Block configuration of Cygnus experiment concept

Safety Considerations - Overpressure testing

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

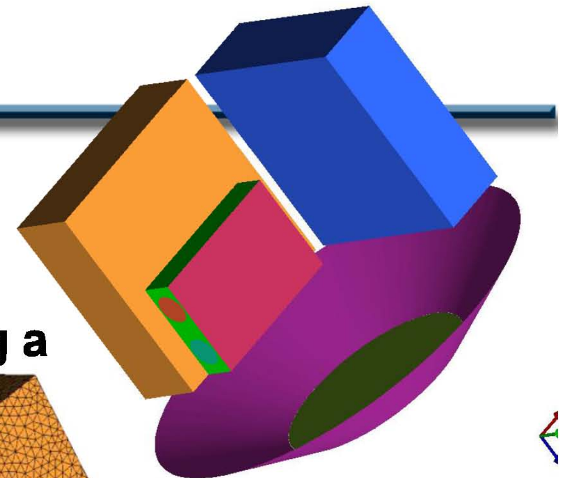




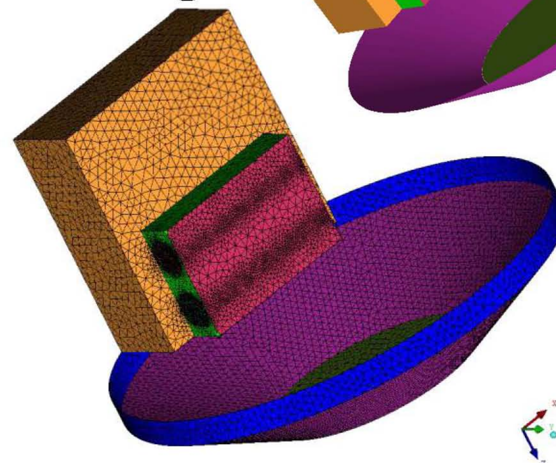


Pressure trace for Single 12.5- by 100-cm sample ignited at the top. The fuel is 90 grade cotton cheese-cloth with a 4.92 mg/cm^2 density.

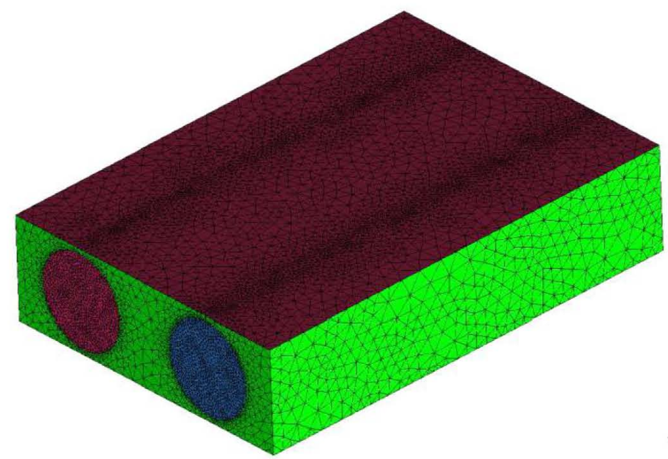
Calculation initialization



- **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 thousands iterations with first order solver
  - Few thousands iterations with second order solver

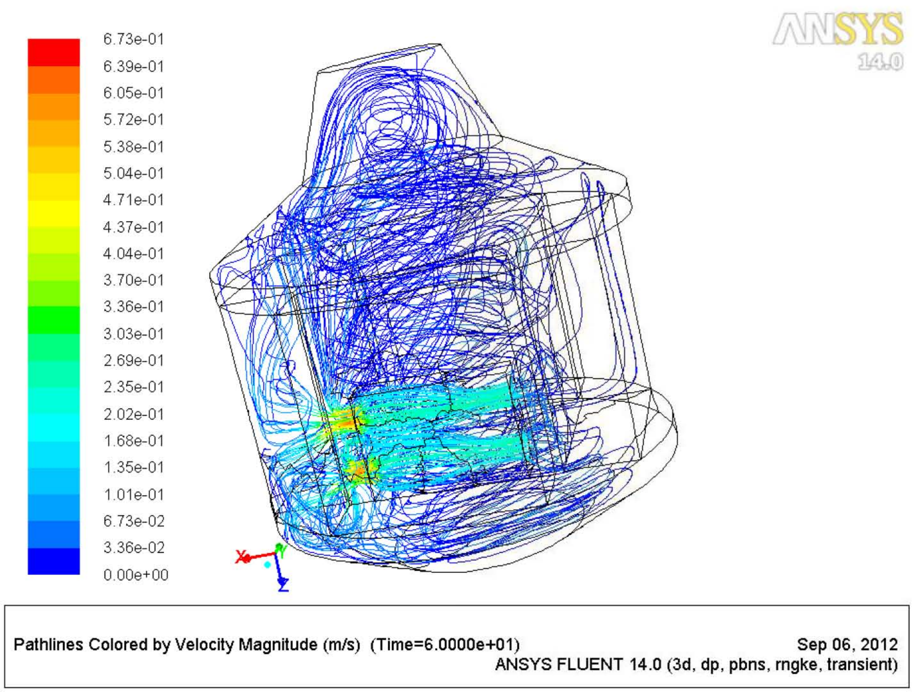


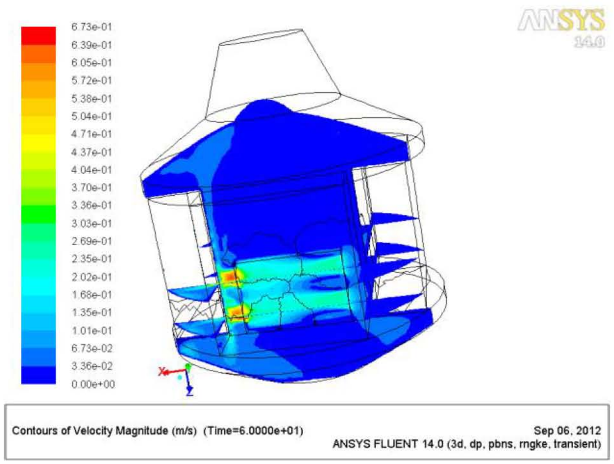
- **Flow modelling main parameters:**
  - Energy equation turned on
  - Turbulence model: Ke-RNG
  - Air as ideal gas for density calculation
  - sutherland model for viscosity
  - Initial temperature: 300k
  - Initial pressure: 1013 hPa
  - All walls are adiabatic

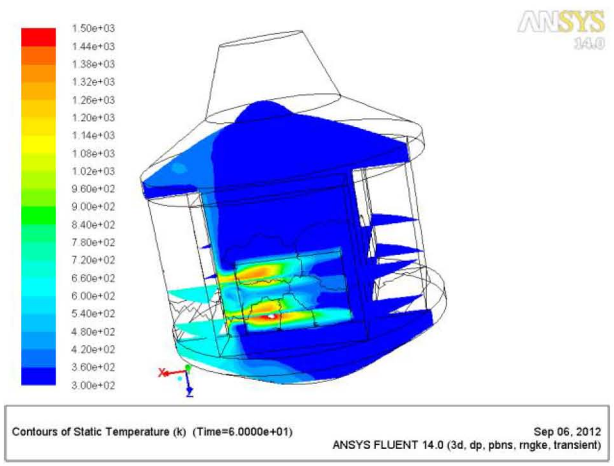


Calculation with heat release : ATV configuration

- **1- ATV configuration after 1 minute of heat release**
  - Pathlines
  - Velocity field
  - 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 work towards 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 verifications of spacecraft fire safety protocol for the crews of future exploration vehicles and habitats.**