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

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?

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
- ESA’s ATV approaching the ISS
- Orbital Science’s Cygnus approaching ISS
Implications of Fire Growth Rate

- Almost no information exists on large-scale fire growth in microgravity
- CO₂ 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

- 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 strongly influenced by natural convection
- 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!)

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

- 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

SFSD Experiment with 44” Flow Chamber
Displaces One M-01 CTB and One M-02 CTB
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”)

Support Leg/Avionics enclosure

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.
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 focusing 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.