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
- Orbital Science's Cygnus approaching the ISS
- ESA's ATV approaching the ISS
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 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!)

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

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

S-Band Antenna

Cygnus Comm

X-Band Antenna

Ground Stations

Data Receiving and Analysis
CRC Operations

NASA Ops Engr.

VOICE

Cygnus Ops Engr.)
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 m³ 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/cm² 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.