Large-scale Spacecraft Fire Safety Tests

David L. Urban, Gary A Ruff, Paul Ferkul and Sandra Olson: NASA Glenn Research Center, Cleveland, OH, USA
A. Carlos Fernandez-Pello: UC Berkeley, Berkeley, CA, USA
James S. T'ien: Case Western Reserve University, Cleveland, OH, USA
Jose L. Torero University of Queensland, Brisbane, Australia
Adam Cowlard: University of Edinburgh, Edinburgh, UK
Sebastien Rouvreau: Belisama R&D, Toulouse, France

Olivier Minster and Balazs Toth: ESA ESTEC, Noordwijk, Netherlands
Guillaume Legros: Université Pierre et Marie Curie, Paris, France
Christian Eigenbrod: University of Bremen (ZARM), Bremen, Germany
Nickolay Smirnov: Moscow Lomonosov State University, Moscow, Russia
Osamu Fujita: Hokkaido University, Sapporo, Japan
Grunde Jomaas: Technical University of Denmark, Kgs. Lyngby, Denmark

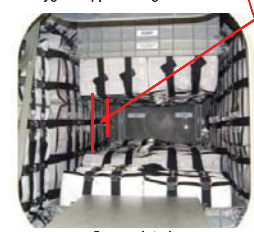
International Topical Team

The experiment is an international collaboration between numerous space agencies. The collaboration is managed by an International Topical Team including participation by NASA and ESA, plus a **group of international scientists (pictures below)**, that aims to revolutionize spacecraft fire safety designs for next-generation space vehicles and habitats. It will feature a validation experiment in the pressurized interior environment of the unmanned Cygnus vehicle (Orbital Sciences) after it has completed its supply mission to the International Space Station. Currently, three flights are scheduled (Saffire I-III, corresponding to Orbital 5-7).

Vehicle Configuration

Cygnus approaching the ISS

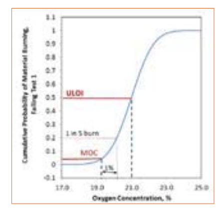
Cutaway view of the flow duct and avionics enclosure



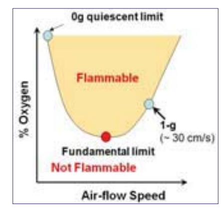
Cygnus interior

Problem Identification

Full scale fire testing complemented by computer modeling has substantially improved our understanding of the risk, prevention and suppression of fire in terrestrial systems (cars, ships, planes, buildings, mines, and tunnels). In comparison, no such testing has been carried out for manned spacecraft due to the complexity, cost and risk associated with operating a **material flammability experiment of a relevant size and duration in microgravity**. Therefore, there is currently a gap in knowledge of fire behavior in spacecraft.



NASA Test1 challenges



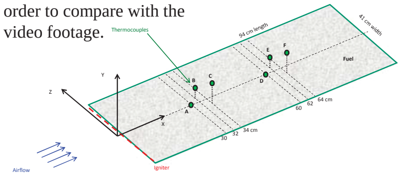
Flammability limits differ

Sample Layout Flights I and III

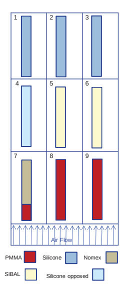
The samples in Saffire I and III will be 40.6 cm by 94.0 cm of cotton / fiberglass blend (Sibal cloth) 75% cotton by weight (18.05 mg/cm^2)

Embedded thermocouples at 0, 0.3 and 0.8 cm above the surface in 2 locations to estimate the flame position and the standoff distance in order to compare with the video footage.

1-g experiment



Sample Layout Flight II



Sample Layout for Saffire II

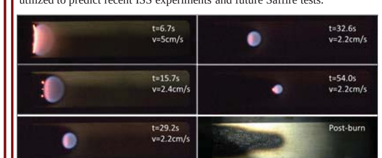
Samples are 5 cm x 30 cm

Saffire II Samples

Material	Sample Thickness	Air Flow (cm/s)	Igniter Position
Silicone (Flammability limit 1)	0.25 mm (0.010")	20	Bottom
Silicone (Flammability limit 2)	0.61 mm (0.024")	20	Bottom
Silicone (Flammability limit 3)	1.02 mm (0.040")	20	Bottom
Silicone (Downward burn 1)	0.36 mm (0.014")	20	Top
SIBAL fabric (SIBAL 1)	0.33 mm (0.013")	20	Bottom
SIBAL fabric (SIBAL 2)	0.33 mm (0.013")	30	Bottom
PMMA to Nomex (Transition 1)	0.33 mm (0.013")	20	Bottom
Structured PMMA (Thick 1)	10 mm with tapered edge for ignition	20	Bottom
Flat PMMA (Thick 2)	10 mm with tapered edge for ignition	30	Bottom

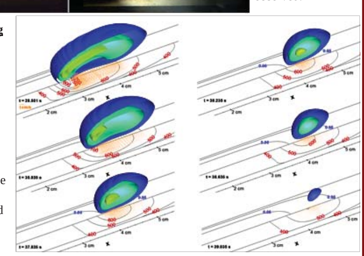
Numerical Modeling

A detailed three-dimensional transient concurrent flame spread model, featuring an adaptive mesh refinement method that will resolve in detail the spreading flame base and pyrolysis front, will be utilized to predict recent ISS experiments and future Saffire tests.



ISS Experiment
Flame spread over a thin-solid sample (10 cm x 2.2 cm), 1 atm., 18.7% O_2. Ignite at 5 cm/s flow, reduce to 2.2 cm/s. Quenching extinction is observed.

Numerical Modeling
Same sample as above, 1 atm., 17.5% O_2. Ignite at 10 cm/s flow, reduced to 4 cm/s. Quenching extinction is observed.
Plot:
3D reaction rate contours, solid surface temperature (K), fuel injection velocity, and pyrolysis front/base.

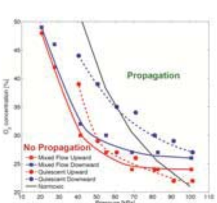


The Road Ahead

The large-scale material flammability demonstration will facilitate the understanding of the long-term consequences of a potential spacecraft fire and provide data not only for the verification of detailed numerical models of such an event, but also for the development of predictive models that can assist and optimise fire prevention, response and mitigation.

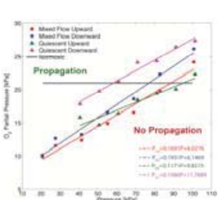
The first step is to provide a predictive tools that will integrate fire safety into design and management of space vehicles. Such tools will integrate a wide range of design issues including, but not limited to, material selection, emergency response, crew training, post-fire clean-up, fire detection, fire suppression, environmental control and life support (ECLS) system design, and even atmosphere selection to provide a globally optimised solution.

Nomex Ignition Testing

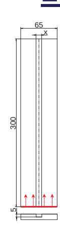


Tests have been conducted with Nomex HT90-40 to find the limiting oxygen concentration (LOC) for flame spread as a function of ambient pressure in a quiescent environment.
The igniter was a hot wire: 18 V at %5A
The results with Nomex HT90-40 revealed that having a forced flow, or mixed flow over the fabric surface versus a quiescent environment resulted in different LOC values.
The strong dependence on pressure suggests either kinetic effects or flow effects.

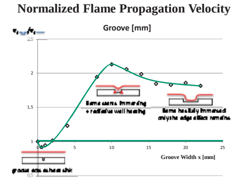
When the results are plotted in terms of the oxygen partial pressure, the flammability boundary follows a nearly linear relationship with respect to ambient pressure. The non-zero intercept corresponds to the curvature seen on the O_2 concentration versus pressure graph. The decreasing nature raises an important issue in reduced ambient pressure environments. For a constant oxygen partial pressure, such as in normoxic equivalent atmospheres, it is possible that a fire resistant material can become flammable depending on the ambient pressure.



Effect of Surface Structures



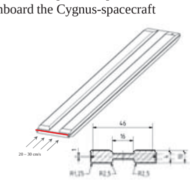
Normalized Flame Propagation Velocity

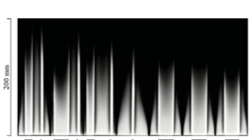


As compared to a flat plate, a sharp edged groove can retard or enhance flame propagation - dependent on width

PMMA-sample to be processed onboard the Cygnus-spacecraft

Effect of different surface structures on flame propagation (PMMA, 1g)





IR-images after 60 s each

Contact David Urban (david.urban@nasa.gov) and / or Grunde Jomaas (grujo@byg.dtu.dk) for more information or to express interest in participation.