FIRES IN SPACECRAFT?

They can happen! And have happened! On February 23rd 1997, a faulty oxygen supply unit aboard the Mir space station resulted in a fire which damaged equipment and forced astronauts to put on emergency oxygen masks and officials to consider evacuation. Minor incidents of charred electrical components have been reported in the Space Shuttle. Many cases of fires aboard aircraft have been reported. Could a fire happen aboard the new International Space Station or in manned spacecraft missions, like the Mars mission? Considering the long duration of these missions (10-20 years lifetime of the Space Station), and considering the amount of combustible materials in these facilities (circuit boards, electrical cables, packing materials, paper, trash) there is a high probability that a fire will occur sometime during the lifecycle of these facilities. Even one serious incident could be disastrous for the spacecraft and in fact, for NASA's manned space program. Whether an incipient fire turns into a catastrophe or into a triviality will depend on our collective knowledge of fire in spacecraft.

The potential for injury to humans, and damage to equipment worth billions of dollars, has prompted NASA to investigate how fires behave in a spacecraft. Fire in an enclosed compartment, like in a spacecraft, can have serious consequences – you can't open the doors, you can't call the firefighters, the smoke and toxic gases produced by the fire cannot escape or be vented, and the fire may consume the cabin oxygen very quickly. Also, detection of a fire in the absence of gravity is more difficult than on earth, because in normal gravity smoke and heat rise, making it easier to know where to put smoke detector. In spacecraft, special measures must be taken to ensure that the smoke reaches the smoke detectors.

NASA has an established fire prevention program for its space facilities that has been successful to date for the short duration missions of the Shuttle. However, flammability of materials is primarily based on testing here on earth. There is also a perception that in spacecraft, because of the absence of gravity, materials are less flammable than on earth where buoyancy helps the fire. However, recent research is indicating that in fact materials can be easier to ignite, and may burn under less stringent conditions, in the spacecraft environments (reduced gravity, low velocity air circulation) than on earth where buoyancy induces large air currents. These findings are the result of an exciting and far-reaching research program into the behavior of fire in reduced gravity environments being conducted at the NASA Glenn Research Center, working with other institutions under its sponsorship. This research encompasses studies of ignition, flame spread, smoldering, smoke evolution, and fire detection. The results from this work are bringing new light to how materials burn in air flows with velocities lower than those achievable in normal gravity. This research is addressing many of the fire-safety concerns of the space program, and is providing insight into problems in fire-safety research.

THE MICROGRAVITY COMBUSTION LABORATORY

The Microgravity Combustion Laboratory (MCL) is a NASA-funded research facility in the Department of Mechanical Engineering at the University of California, Berkeley, aiming at studying the potential onset of fire in environments encountered in spacecraft. The research goals of the MCL are to better understand and predict material flammability, combustion products, and other fire-safety related phenomena in reduced gravity environments. Research focuses on both experimental investigation, and theoretical analysis of fire-safety related physical problems in reduced gravity. Some of the experiments are conducted in NASA's microgravity facilities, including drop towers, parabolic flights (KC-135), Space Shuttle and in the future in the International Space Station.

Space shuttle cargo bay containing smoldering experiment (Mission STS-77). San Francisco Bay in background

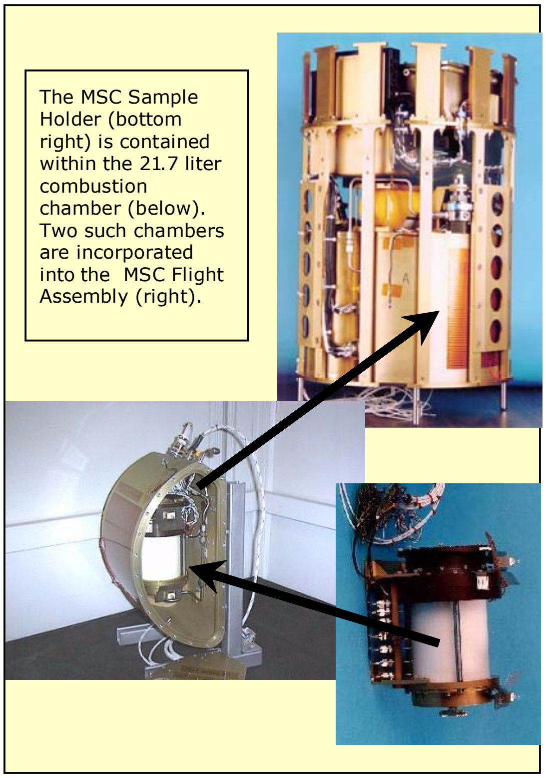
Smolder Combustion in Microgravity

Smoldering, which is a non-flaming form of combustion (as in a cigarette), is a very common cause of accidental fire. Overheating of cables due to overload, or cracks in the insulation, can initiate a smolder of adjacent combustible materials, which eventually can transition into flames (as shown in the figure below). An example of such an event in an aircraft environment is the Swissair Flight 111 fire, which is believed to have occurred by the smoldering of an insulation blanket in contact with overheated cables. Smolder combustion spreads very slowly, often through the interior of porous materials, and has very low temperatures, making it difficult to detect. Furthermore, the products of smolder combustion are highly toxic.

Under the **M**icrogravity **S**molder **C**ombustion (MSC) and the **S**molder, **T**ransition and **F**laming (STF) projects funded by NASA, researchers at the UCB MCL are studying the behavior of smolder combustion in microgravity. Emphasis is placed on the smolder of polyurethane foam (widely used as cushioning, insulation, and packing material). This research aims at discovering how smolder combustion is ignited, how fast it spreads, what products (toxic, noxious) it produces, and why and under what conditions it transitions to an open fire (rendering it a more serious potential threat to life). The MSC experiment is being carried out aboard the Space Shuttle. To date three series of experiments have been conducted in the Space Shuttle (missions STS-50, STS-69, STS-77), and two more are scheduled for this year (STS-107 - July 2001 and STS-108 - November 2001), and another three for next year.

Transition from smoldering to flaming in a slab of porous polyurethane foam

A major finding from these experiments is that smoldering in microgravity occurs at lower air flow rates than in normal gravity, and in samples of smaller size. This is due to the reduced heat losses in microgravity because of the absence of buoyant cooling. This finding has important implications because it indicates that smoldering can occur more easily in a spacecraft environment than in earth, and that consequently stricter design specifications may be needed to assure fire safety. The results from this testing are also being used to understand smoldering mechanisms in normal gravity, and to provide design guidelines for fire-safety on earth, such as the minimum heat required for ignition, minimum material size for smolder to propagate, and for flaming to occur.



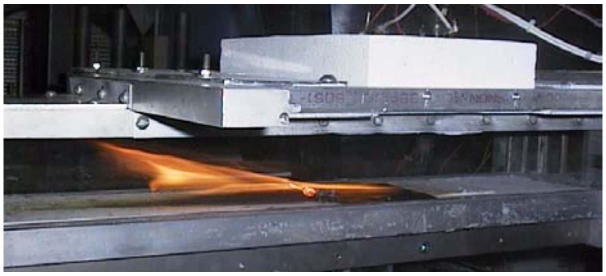
MSC apparatus carried on Space Shuttle (Missions STS-69 and STS-77)

The MSC research project uses the same experimental hardware in both earthbound and Space Shuttle tests. It consists of a sealed pressurized vessel capable of igniting smolder combustion waves in cylindrical foam samples (as shown in the figure at left). The smolder combustion is studied using thermal analysis, and using a novel ultrasound imaging technique developed with NASA engineers at the Glenn Research Center in Cleveland, Ohio, which allows for non-intrusive measurement of smolder reactions.

The MSC research project is complemented by the STF experiment, which has been manifested for the International Space Station. Pieces of foam or other materials such as wire bundles are inserted into a small-scale wind-tunnel. After air flow starts, electrical igniter wires buried in the sample ignite a smolder reaction, and as the reaction proceeds the transition to flaming is observed and studied. Like MSC, the STF experiment makes use of thermal and gas analysis, ultrasonic imaging, and laser diagnostic techniques.

Flammability Testing for Materials

Spacecraft designers need flammability data to select materials according to their potential fire exposure in the facility where they may be installed. In this project, researchers at the MCL examine and characterize the potential fire hazards of materials used aboard spacecraft, under environmental conditions expected in those facilities (reduced gravity, small air currents). For this purpose, researchers at the UCB MCL are developing a new test apparatus, **F**orced **I**gnition and **S**pread **T**est (FIST), to characterize the flammability of materials. The FIST apparatus could eventually provide NASA with a test methodology that will complement the existing protocol so as to provide a more comprehensive assessment of material flammability for space applications. FIST is based on an ASTM test method (ASTM E 1321-93)), but reflects the conditions expected in space facilities. The materials currently being tested include acrylic plastics (PMMA), and composite materials such as blended polypropylene with glass fiber commonly used for paneling in the transportation industry, and laminated epoxy/glass often used in circuit boards.



Photograph of FIST testing just after ignition of polypropylene sample has occurred (flow direction from right to left at 1m/s, heater located above sample)

The FIST apparatus consists of a small-scale wind tunnel (as shown in the figure at left), in which samples of materials are exposed to an external radiant heat flux and varied air flow velocities. The external heat flux simulates a source of heat near the material, and the flow of air simulates the circulation currents in the spacecraft. The volatile compounds that out-gas from the heated surface of the material are ignited by a hot wire placed near the surface, which simulates a hot spot adjacent to the material.

Tests are currently being conducted at UCB and on the NASA KC-135 aircraft, flying a parabolic trajectory (as shown in the figure below). The latter simulates conditions in spacecraft. A major finding from these experiments is that the time until a material ignites after being exposed to heat is significantly less in reduced gravity than here on earth. Theoretical modeling also indicates that materials will ignite at lower heat fluxes than in normal gravity. This is primarily due to the reduction in heat losses from the material surface because of the small air currents in space facilities (about ten times smaller than in normal gravity). The results have very important implications since they indicate that materials will ignite more easily under the conditions expected in space facilities, and that consequently stricter design specifications or configuration control may be needed for fire safety.

Further experiments with longer microgravity periods and varied environmental conditions are planned aboard the International Space Station to create a more extensive data bank for reduced gravity environments. The results from the experiments, and supportive theory, will be used to assess the potential fire hazards of materials considered for their use in space facilities.

Conducting microgravity combustion experiments on NASA's KC-135 parabolic flights (used by NASA to train astronauts and by the movie industry to film weightless scenes as in the movie Apollo 13)

Faculty and Staff

The principal investigator at the UCB MCL is Professor Carlos Fernandez-Pello of the Department of Mechanical Engineering. He is assisted by several graduate student researchers, pursuing Ph.D. and M.S. degrees. In addition, the laboratory hosts visiting scholars from other top universities and research centers worldwide.

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