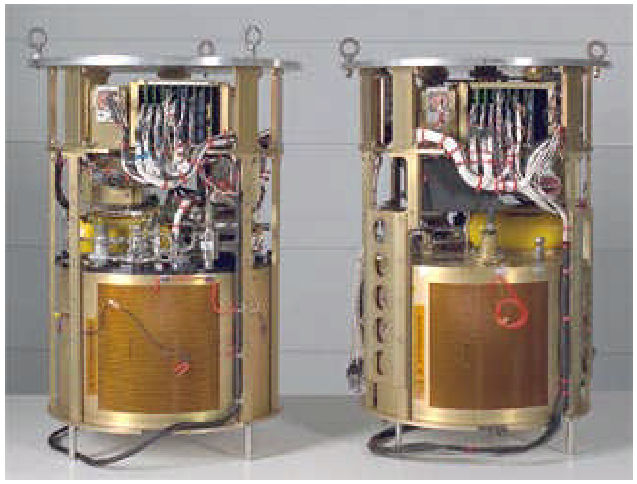
Experiments Developed to Study Microgravity Smoldering Combustion

The overall objective of the Microgravity Smoldering Combustion (MSC) research program is to understand and predict smoldering combustion under normal and microgravity (near-zero-gravity) conditions to help prevent and control smolder-originated fires, in both environments. Smoldering is defined as a nonflaming, self-sustaining, propagating, exothermic surface reaction. If a material is sufficiently permeable, smoldering is not confined to its outer surface, but can propagate as a reaction wave through the interior of the material. The MSC program will accomplish its goals by conducting smolder experiments on the ground and in a space-based laboratory, and developing theoretical models of the process. Space-based experiments are necessary because smoldering is a very slow process and, consequently, its study in a microgravity environment requires extended periods of time that can only be achieved in space. Smoldering can occur in a variety of processes ranging from the smolder of porous insulating materials to underground coal combustion. Many materials can sustain smoldering, including wood, cloth, foams, tobacco, other dry organic materials, and charcoal. The ignition, propagation, transition to flaming, and extinction of the smolder reaction are controlled by complex, thermochemical mechanisms that are not well understood. As with many forms of combustion, gravity affects the availability of the oxidizer and the transport of heat, and therefore, the rate of combustion.

The smoldering combustion of porous materials has been studied both experimentally and theoretically, usually in the context of fire safety. Smoldering encompasses a number of fundamental processes, including heat and mass transfer in a porous media; endothermic pyrolysis of combustible material; ignition, propagation, and extinction of heterogeneous exothermic reactions at the solid-gas pore interface; and the onset of gas phase reactions (flaming) from existing surface reactions. Smoldering presents a serious fire risk because the combustion can propagate slowly in a material's interior and go undetected for long periods of time. It typically yields a substantially higher conversion of fuel to toxic compounds than does flaming (though more slowly), and may undergo a sudden transition to flaming.



Microgravity smoldering combustion. Left: After modification. Right: Before modification.

Common examples of smoldering hazards are the initiation of forest fires by smoldering embers and of building fires from undetected smoldering in packing material insulation and furniture cushioning. Various studies since the early 1970's have shown that more than 40 percent of U.S. fire deaths can be attributed to smoldering household furniture. Smolder of cable insulation, another common fire hazard, is of particular concern in the space program--to date there have been a few minor incidents of overheated and charred cables and electrical components reported on space shuttle flights. Recently, with the establishment of the International Space Station and other planned space facilities, there has been an increased interest in the study of smoldering in microgravity to prevent or minimize the effect of a smolder-initiated fire.

The complexity of the smolder process requires the use of approximations in theoretical models and simplifications in experiments. The removal of gravity substantially simplifies smolder investigations because the influence of buoyancy on the heat and mass transport processes is removed. Instabilities induced by density stratification and problems related to sedimentation and collapse of the porous fuel and char are absent in microgravity. Furthermore, such experiments as well as a complementary theoretical foundation are necessary to assess the fire risk of a space-based installation.

The MSC investigation is being led by Professor A.C. Fernandez-Pello, the principal investigator, of the University of California at Berkeley. Dr. David L. Urban, of the NASA Glenn Research Center, is the project scientist. Two flight units have been built at Glenn by a team of civil servants and contractors, and have flown on the space shuttle: one on STS-69 and one on STS-77. The smoldering test material on both flights was unretarded urethane furniture foam. Each unit contained two test sections. Unit one had one test section with opposed (to the direction of burn) flow, and one with quiescent conditions. Unit two tested another opposed case (a different flow rate), and another quiescent case, the latter at higher oxygen content.

All tests were with oxygen-nitrogen mixtures. On the basis of these results, the project improved the smolder tracking system for reflight. The first units employed a video system, but the data were not as useful in low gravity as in Earth gravity. However, the experiment was able to track the combustion progress because the fuel sample included 10 thermocouples that provide an axial and radial temperature history of the smolder propagation. The modified units use an ultrasonic imaging system (UIS), which was developed and tested by the Glenn team. The UIS uses arrays of speakers and receivers on opposite sides of the foam test piece test sections to track the progress of the flame front. The original hardware design used a clear quartz cylinder to hold the foam fuel test sample to permit imaging of the smolder process, but this material is brittle and not amenable to the machining necessary to mount the speakers and receivers. After much searching and testing, the team located a polyimide resin material that could both withstand the high temperatures and had the toughness to be machined to the necessary tolerances. In addition to the UIS, the reflight experiment hardware comprises the main structure, two aluminum combustion chambers, an igniter power unit, a common igniter, two flow systems to deliver the oxidizer gas mixture, a battery, a data acquisition and control system, and a power control unit. Other hardware improvements, especially to the oxidizer gas delivery system, have been incorporated in the latest MSC reflight design. The first unit has been completed, and the second is now in the final testing process. Both are in line to fly on the shuttle as "Get-Away-Specials," as did the previous units. The experiments are based on what was learned on the previous flights. They are opposed and forward flows on the first reflight payload, and forward flows and quiescent conditions on the second, with changes in various parameters. It is expected that the results of these studies will provide new insights into the mechanisms involved in the smoldering process and result in specific recommendations for reducing the risk of fires both on Earth and in space.

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