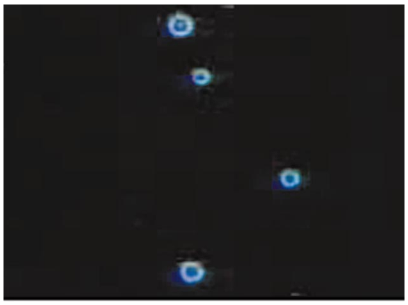
Great (Flame) Balls of Fire!

Structure of Flame Balls a t Low Lewis-number–2 (SOFBALL–2)

Everyone knows that an automobile engine wastes fuel and energy when it runs with a fuel-rich mixture. "Lean" burning, mixing in more air and less fuel, is better for the environment. But lean mixtures also lead to engine misfiring and rough operation. No one knows the ultimate limits for lean operation, for "weak" combustion that is friendly to the environment while still moving us around.



Flame balls (seen in a 1997 space experiment) seem to shine bright as stars, but only because they are observed in the dark by a video camera with an image intensifier. Under normal lighting in a space module, the flame balls would be invisible — to the eye and to fire detectors — and thus potentially hazardous.

This is where the accidental verification of a decades-old prediction may have strong implications for designing and running low-emissions engines in the 21st century. In 1944, Soviet physicist Yakov Zeldovich predicted that stationary, spherical flames are possible under limited conditions in lean fuel-air mixtures.

Dr. Paul Ronney of the University of Southern California accidentally discovered such "flame balls" in experiments with lean hydrogen-air mixtures in 1984 during drop-tower experiments that provided just 2.2 seconds of near weightlessness. Experiments aboard NASA's low-g aircraft confirmed the results, but a thorough investigation was hampered by the aircraft's bumpy ride. And stable flame balls can only exist in microgravity.

The potential for investigating combustion at the limits of flammability, and the implications for spacecraft fire safety, led to the Structure of Flame Balls at Low Lewis-number (SOFBALL) experiment flown twice aboard the Space Shuttle on the Microgravity Sciences Laboratory–1 (MSL–1) in 1997. Success there led to the planned reflight on STS–107.

Flame balls are the weakest fires yet produced in space or on Earth. Typically each flame ball produced only 1 watt of thermal power. By comparison, a birthday candle produces 50 watts.

The Lewis-number measures the rate of diffusion of fuel into the flame ball relative to the rate of diffusion of heat away from the flame ball. Lewis-number mixtures conduct heat poorly. Hydrogen and methane are the only fuels that provide low enough Lewis-numbers to produce stable flame balls, and even then only for very weak, barely flammable mixtures. Nevertheless, under these conditions flame balls give scientists the opportunity to test models in one of the simplest combustion experiments possible. SOFBALL–2 science objectives include:

- Improving our understanding of the flame ball phenomenon,
- Determining the conditions under which flame balls exist,
- Testing predictions of flame ball lifetimes, and
- Acquiring more precise data for critical model comparison.

Applications

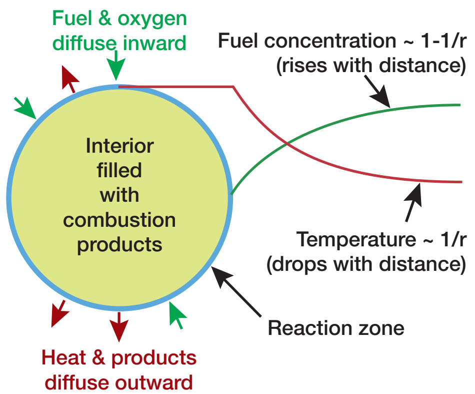
- Lean-burning car engines under consideration to meet California's ultra low emissions standards, or natural-gas powered cars, like the test model (above) in New York.
- Assessment of fire and explosion hazards in mine shafts, oil refineries, and chemical plants.
- Spacecraft safety where gases from waste systems or fuel cells could provide a fuel source for long-lived flame balls.

Principal Investigator: Dr. Paul Ronney, University of Southern California, Los Angeles
Project Scientist: Dr. Karen J. Weiland, NASA Glenn Research Center, Cleveland, OH
Project Manager: Ann Over, NASA Glenn Research Center, Cleveland, OH

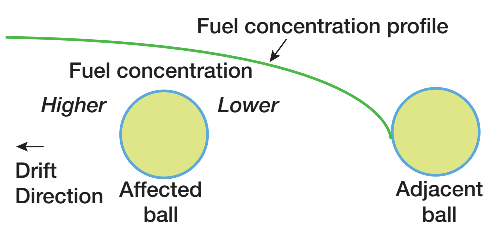
Background Information

Science

SOFBALL burns extremely lean fuel-air mixtures that are near the lower limit of combustion. Because the mixture is lean and has a low Lewis-number, the flame does not spread across the mixture. It forms a spherical shell filled with combustion products. Fuel and oxygen diffuse inward while heat and combustion products diffuse outward. This diffusion-controlled combustion process produces the weakest known flames and provides a mechanism to study the limits of lean combustion. This works only in the microgravity environment, in the absence of buoyant flow that would otherwise overwhelm diffusion.



All the combustion in a flame ball takes place in a razor-thin reaction zone that depends on diffusion to keep the ball alive (above). Such a fragile balance is impossible on Earth. Flame balls always drift away from each other (below) at a continually decreasing rate, indicating that they move into areas of greater fuel concentration.



Hardware

SOFBALL–2 experiments will be conducted inside the Combustion Module–2 (CM–2) facility flown on Spacelab in 1997 and modified for flight on SPACEHAB. CM–2 will also host the Laminar Soot Processes (LSP) and Water Mist experiments. CM–2 is described in a separate fact sheet.

The SOFBALL–2 Experiment Mounting Structure in CM–2 is a cylinder about 62 cm long and 40 cm in diameter (24.4 × 15.7 in), and weighs approximately 39 kg (87 lb). The main components are the spark igniter; temperature sensors, arranged as a rake of six thin thermocouple wires; two pairs of radiometers; a mixing fan; and volume compensators to reduce the amount of gas needed for each test. Improvements for SOFBALL–2 include longer tests times, two new gas mixtures, addition of a close-up camera, and using an accelerometer for real-time decisions during tests.

Affected Fields

Combustion physics: Study the simplest interaction of chemistry and transport.

Spacecraft design: Systems that handle hydrogen or biological products (food, waste, lab animals) that produce hydrogen and other combustible gases.

Automotive engineering: Design of lean-burning engines using pure hydrogen or using hydrocarbon fuels in which hydrogen combustion is a significant component.

On-Orbit Operations

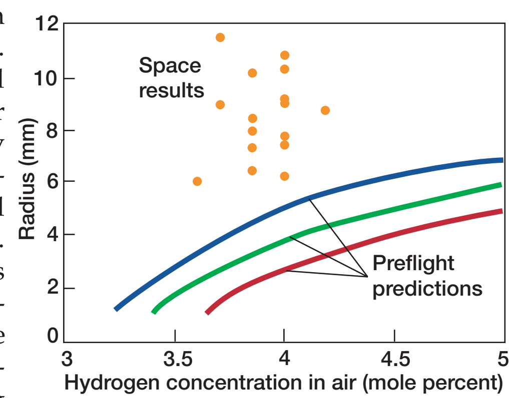
The flight crew will run the first three test points through the CM–2 laptop computer. The SOFBALL science team on Earth will adjust conditions from one burn to the next, but the flight crew will initiate combustion, determine whether flame balls exist, adjust and monitor instruments, terminate the experiment, and initiate a reburn if needed. SOFBALL operations will take about 160 hours of flight time. Key science measurements include: flame ball size, brightness, temperature, radiant emission, lifetime, and combustion product composition.

Dr. Janice Voss, a mission specialist services the CM during MSL–1 in 1997.

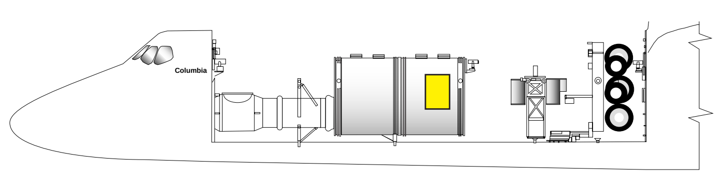
SOFBALL test points will use five gas combinations — hydrogen-air, hydrogen-oxygen-sulfur hexafluoride, hydrogen-oxygen-carbon dioxide, hydrogen-oxygen-carbon dioxide-helium, and methane-oxygen-sulfur hexafluoride — at 1 to 3 atmospheres, each with varying concentrations. Flame balls will burn for 1,500 to 10,000 seconds (almost 2.8 hours) depending on experiment objectives.

Previous Results

The biggest discovery from the first SOFBALL flights (MSL–1 and 1R) was the long life of flame balls. Scientists expected that flame balls would extinguish or drift into the chamber walls in a few minutes. Instead, most could have burned for hours had they not been automatically terminated at 500 seconds. The experiments also provided conclusive evidence about the limitations of existing computer models of lean combustion, and demonstrated the effects of flames reabsorbing their own radiation, which can also affect large engines and industrial boilers.



Theory does not always predict behavior. Predictions for hydrogen-air flame balls were quite different from SOFBALL tests on MSL–1.



Approximate location of this payload aboard STS–107.

Photos. NASA, New York State Dept. of Transportation (auto); University of Southern California (diagrams).