Tackling a Hot Paradox

Laminar Soot Processes–2 (LSP–2)

The last place you want to be in traffic is behind the bus or truck that is belching large clouds of soot onto your freshly washed car. Besides looking and smelling bad, soot is a health hazard. Particles range from big enough to see to microscopic and can accumulate in the lungs, potentially leading to debilitating or fatal lung diseases.

Soot is wasted energy, and therein lies an interesting paradox: Soot forms in a flame's hottest regions where you would expect complete combustion and no waste. Soot enhances the emissions of other pollutants (carbon monoxide and polyaromatic hydrocarbons, etc.) from flames and radiates unwanted heat to combustion chambers (a candle's yellowish glow is soot radiating heat), among other effects.

Soot belched by a diesel engine is more than ugly — it's dangerous. While the largest particles may wash out of the air when it rains, smaller particles linger and possibly endanger human health and the environment.

The mechanisms of soot formation are among the most important unresolved problems of combustion science because soot affects contemporary life in so many ways. Although we have used fire for centuries, many fundamental aspects of combustion remain elusive, in part because of limits imposed by the effects of gravity on Earth. Hot or warm air rises quickly and draws in fresh cold air behind it, thus giving flames the classical teardrop shape. Reactions occur in a very small zone, too fast for scientists to observe, in detail, what is happening inside the flame.

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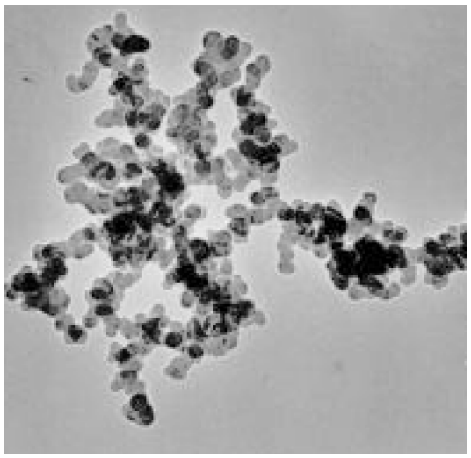
The Laminar Soot Processes (LSP–2) experiments aboard STS–107 will use the microgravity environment of space to eliminate buoyancy effects and thus slow the reactions inside a flame so they can be more readily studied. "Laminar" means a simple, smooth fuel jet burning in air, somewhat like a butane lighter. This classical flame approximates combustion in diesel engines, aircraft jet propulsion engines, and furnaces and other devices.

LSP–2 will expand on surprising results developed from its first two flights in 1997. The data suggest the existence of a universal relationship, the soot paradigm, that, if proven, will be used to model and control combustion systems on Earth. STS–107 experiments also will help set the stage for extended combustion experiments aboard the *International Space Station*.



Soot particles from MSL–1 experiments (top) are about 10 to 60 nm across and formed aggregates 1,000 nm (1 micron) wide. This is similar to soot formed in terrestrial sources.

Applications

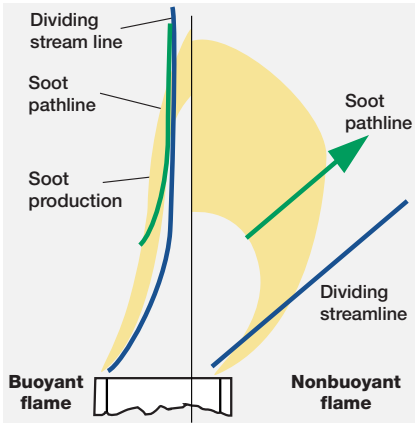
Fine-tune burner design and operation to:

- Control soot production in combustion processes,
- Reduce radiative heat transfer from soot particles that can damage engines
- Improve electric power generation efficiency by increasing radiative transfer from soot in flame to furnace walls while maintaining complete soot burnout (no emission),
- Enhance soot production in processes for carbon black used in tires and applications,
- Enhance computational combustion studies to design new systems that are optimized at the start, and retrofit existing systems.

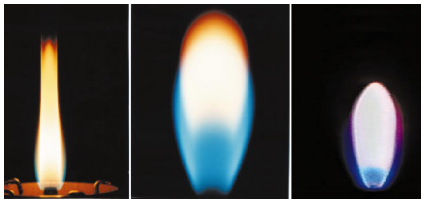
Background Information

Science

Microgravity provides an unprecedented opportunity to investigate soot processes relevant to practical flames. The chemical pathways that form soot are highly controversial in the science community. When the flame temperature falls below about 1300 °K (1900 °F), no soot is formed. Above that, hydrocarbon fuels pyrolyze or break down, even as most of the reactions form carbon dioxide and water vapor. These molecular fragments produce other molecules, including polycyclic aromatic hydrocarbons (PAH's) that coalesce into solid carbonaceous particles — soot — that are linked to human cancers in a number of studies.



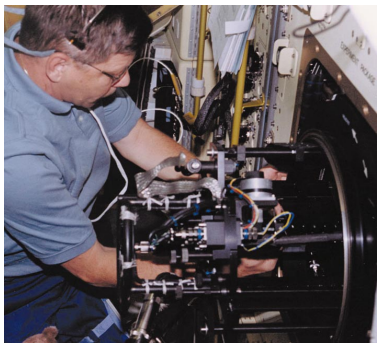
In buoyant flames (bottom left), soot mainly nucleates at the outer boundary of the soot production region, then moves inward before approaching the flame sheet once again near the flame tip. In nonbuoyant flames (bottom center and right), soot mainly nucleates near the inner boundary of the soot production region, and then is drawn directly toward the flame sheet.



The LSP investigation observes soot processes within laminar jet diffusion flames where a hydrocarbon jet burns in still air. Microgravity produces nonbuoyant laminar jet flames which allow observations of soot processes that cannot be duplicated on Earth. Normal gravity generates buoyant motion due to the large variations of gas densities in flames. These motions introduce soot particle motions that do not represent most practical flame environments where local effects of buoyancy are small.

Hardware

LSP–2 experiments will be conducted inside the Combustion Module (CM–2) facility flown in 1997 and modified for SPACEHAB. CM-2 will also host the Structure of Flame Balls at Low-Lewis number –2 (SOFBALL–2) and Water Mist experiments. CM–2 is detailed in a separate fact sheet. Diagnostic instruments for LSP include a color camera, a soot volume fraction system (using the dimming of a laser shining through the flame), and a soot temperature measurement system. An Experiment Mounting Structure provides a large volume to allow laminar flames to form on one of two burners with diameters of 0.4 mm (0.016 in.) and 0.8 mm (0.0315 in). They produce a flame 20 to 60 mm long (0.8 to 2.4 in). Soot samplers (for six test points) snap through the flame to capture particles for post-flight analysis.



Dr. Roger Crouch, a payload specialist on MSL–1, services the LSP experiment.

Affected Fields

Transportation: Internal combustion engines on aircraft (jet and piston), rail, ships, trucks, buses.
Industry: Power plants, process plants that use combustion heating.
Safety: Reduced loss of life and property due to improved understanding of building fires.

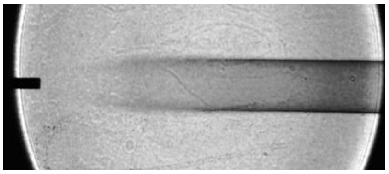
On-Orbit Operations

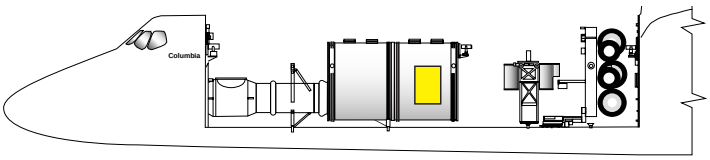
LSP–2 science operations will last almost 42 hours and cover 15 test points using ethylene or propane fuel in air. LSP–2 is operated by the flight crew through a laptop computer connected to the CM–2. Setting the smoke height will require guidance from the science team at Johnson Space Center.

Previous Results

On the Microgravity Sciences Lab–1 mission in 1997, LSP yielded several surprises. The LSP team discovered a new mechanism of flame extinction caused by radiation from soot. The mechanism is unusual because the flame quenches near its tip, unlike conventional extinction of buoyant flames where the flame quenches near its base. This phenomenon has significant implications for spacecraft fire safety and for selecting test conditions for future studies of nonbuoyant soot containing flames. The team also made the first observations of steady soot-containing nonbuoyant flames both with and without soot emissions. These provided textbook examples of soot formation processes in practical flames that are invaluable for developing methods for controlling the emissions of pollutant soot.

LSP uses a small jet burner, similar to a classroom butane lighter, that produces flames up to 60 mm (2.3 in) long. Measurements include color TV imagery (above), and laser shadowgraphs whose dimming indicates the quantity of soot produced in the flame (below).





Approximate location of this payload aboard STS–107.

Photos. NASA, University of Michigan at Ann Arbor.

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