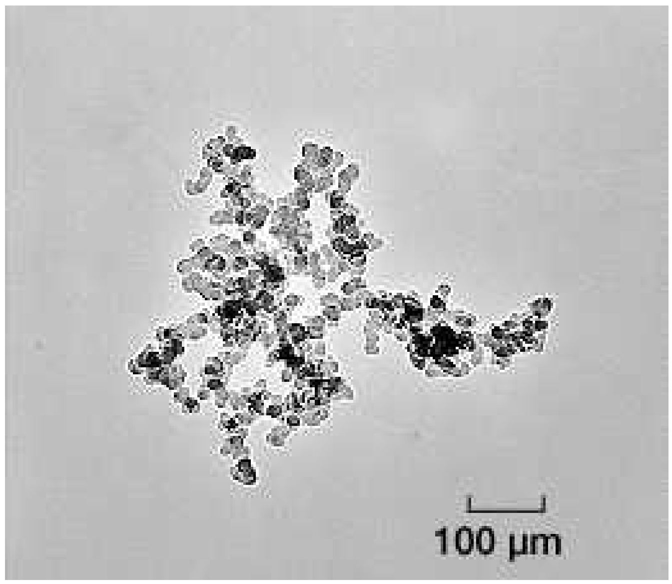
Laminar Soot Processes Experiment Shedding Light on Flame Radiation

The Laminar Soot Processes (LSP) experiment investigated soot processes in nonturbulent, round gas jet diffusion flames in still air. The soot processes within these flames are relevant to practical combustion in aircraft propulsion systems, diesel engines, and furnaces. However, for the LSP experiment, the flames were slowed and spread out to allow measurements that are not tractable for practical, Earth-bound flames.



Transmission electron micrograph of soot from STS-83.

It is a remarkable paradox of nature that flames, which are widely recognized to consume solid fuels and create gaseous combustion products, also create new solid materials--soot--in their highest-temperature regions (as shown in the photomicrograph). The mechanisms that produce soot in flames are among the most important unknowns of combustion science because soot affects contemporary life in many ways. Even though the production of soot as carbon black is important for numerous ordinary industrial products, soot contributes to many serious problems: pollution, undesirable radiative heat loads to combustion chambers, and the spread of unwanted fires via radiant emission. The peer-reviewed LSP experiment was developed to enhance our understanding of this critical combustion product. It was conceived at the University of Michigan by Professor Gerard M. Faeth and developed by the NASA Lewis Research Center in collaboration with Analex Corporation and Aerospace Design & Fabrication (ADF).

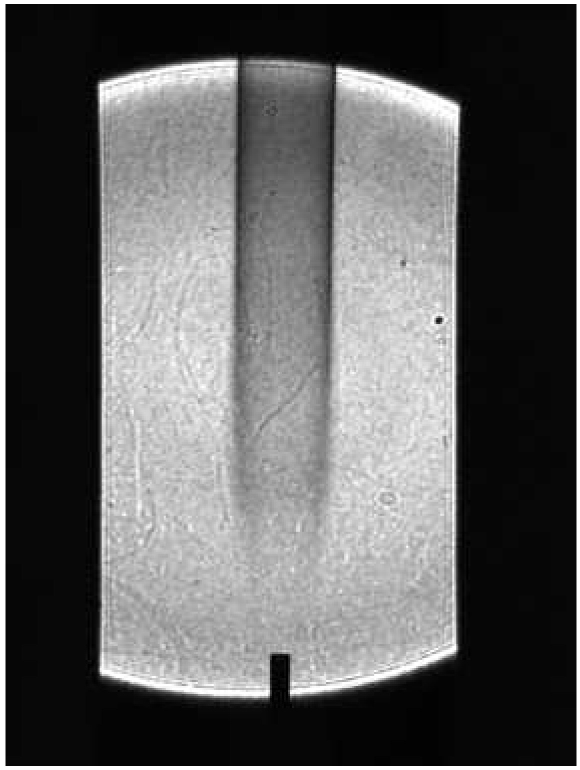
LSP flew as scheduled on April 4, 1997, on the STS-83 space shuttle mission. Because STS-83 had to be shortened, LSP flew again on STS-94. LSP is a complex experiment; nevertheless, it functioned flawlessly on both flights and yielded new results well beyond expectations. In fact, with the cooperation of the crew, we successfully completed 2 tests on STS-83 and 19 on STS-94, which is 7 more than originally planned. Major findings are summarized in the following paragraphs.

The new measurements demonstrated for the first time that the propensity of nonbuoyant flames to contain large concentrations of soot is not related to their propensity to emit soot. This finding is relevant to both practical nonbuoyant flames and spacecraft fire safety. It also is important in the selection of test conditions for future testing of nonbuoyant, soot-containing flames. This result had not been demonstrated previously because of the limited test times available in ground-based low-gravity facilities.

Most importantly, our initial analysis of the new measurements suggests that universal relationships exist between the soot processes and the degree of mixing within nonbuoyant flames. These relationships are known as the soot paradigm, a controversial hypothesis based on indirect observations of practical nonbuoyant flames. If the paradigm proves to be true--after further analysis of this unique data set of "steady," soot-containing, nonbuoyant flames with and without soot emissions--it offers simple ways to control and model soot processes in practical flames.

The mechanism of flame extinction caused by radiative heat loss, in this case from soot, was quantified for the first time by direct measurements of soot temperatures. This mechanism is unusual because a microgravity flame quenches near its tip, unlike a buoyant flame on Earth, which quenches near its base. The new measurements also yielded the first observations of the simultaneous emission of soot and unburned hydrocarbons from steady nonbuoyant flames and the first-ever observation of a smoke point (minimum flame height for soot emission) from steady, nonbuoyant flames.

Finally, the nonbuoyant flames are larger and emit soot at lower flame heights than flames observed in ground-based microgravity facilities because testing during orbit allows truly steady flames to be observed. These flames were 100-percent larger than weakly buoyant flames on Earth and were 50-percent larger than flames observed in transient tests in Lewis' ground-based microgravity facilities. The following figure shows soot in a steady microgravity flame.



Shadow image of soot in a microgravity ethylene flame on STS-83. The bright area is illuminated by the laser, the "notch" at the bottom is the shadow of the nozzle, and the soot shadow is above the "notch."

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