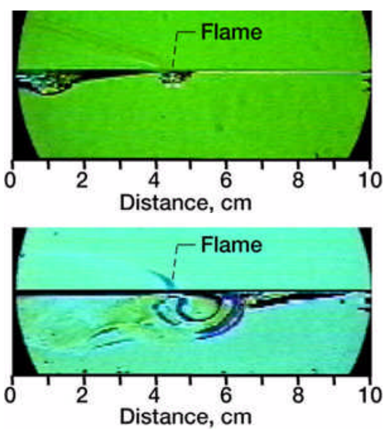
Spread Across Liquids Continues to Fly

The physics and behavior of a flame spreading across a flammable liquid is an active area of research at the NASA Glenn Research Center. Spills of fuels and other liquids often result in considerable fire hazards, and much remains unknown about the details of how a flame, once ignited, moves across a pool. The depth of the liquid or size of the spill, the temperature, and wind, if any, can all complicate the combustion processes. In addition, with the advent of the International Space Station there may be fire hazards associated with cleaning, laboratory, or other fluids in space, and it is essential to understand the role that gravity plays in such situations.

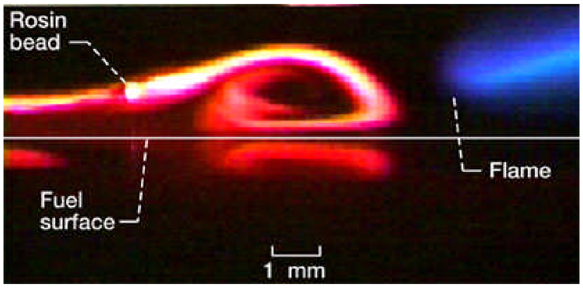
The Spread Across Liquids (SAL) experiment is an experimental and computational effort dedicated to understanding the detailed mechanisms of flame spread across a flammable liquid initially below its flashpoint temperature. The experimental research is being carried out in-house by a team of researchers from Glenn, the National Center for Microgravity Combustion, and Zin Technologies, with computer modeling being provided via a grant with the University of California, Irvine. Glenn's Zero Gravity Facility is used to achieve short microgravity periods, and normal gravity testing is done in the Space Experiments Laboratory. To achieve longer periods of microgravity, the showcase SAL hardware flies aboard a sounding rocket launched from White Sands Missile Range, New Mexico, approximately once per year. In addition to extended microgravity, this carrier allows the use of detailed diagnostics that cannot be employed in a drop tower.

SAL was first reported on in Glenn's 1995 Research & Technology report (ref. 1) when it was the first microgravity combustion experiment to have flown on a sounding rocket. Since that time, three more launches have been performed, with a fourth scheduled for December 2000.



Side view of subsurface temperature fields for a flame spreading across 1-butanol. Top: In 1g, the flame pulsates, and a new vortex forms each time it jumps. Bottom: In microgravity, the flame spreads steadily and slowly, and the vortex is much larger and travels with the flame.

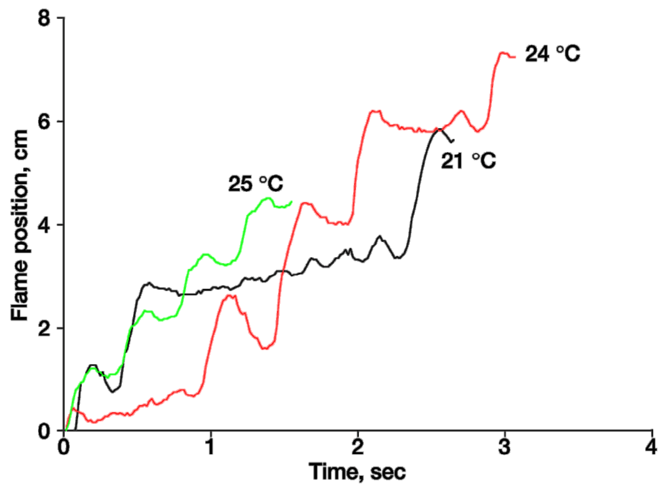
As reported in 1995, a most surprising result was obtained when the flame spread slowly and steadily across the pools, as opposed to rapidly spreading and pulsating as it does in normal gravity. Since then, this result has been further confirmed at a variety of opposed airflow velocities, ranging from 5 to 30 cm/sec. At the lowest speeds, the flame initially spread slowly and then flashed and extinguished, whereas at the higher speeds steady, complete propagation was achieved. That the flame did not spread at opposed airflows of 5 cm/sec was regarded as unusual, since even solid materials support flame spread at much lower velocities, and take much more energy to pyrolyze. It is believed the difference may be due to a large vortex that forms in the liquid and carries heat deep into the pool. In normal gravity, this vortex is kept near the surface by buoyancy, but not so in microgravity. See the preceding figures for a comparison. Using smoke tracers, a gas-phase recirculation cell that had been predicted approximately 30 years ago, but never realized, was finally visualized in both normal and microgravity (see the following image).



Side-view smoke visualization of the recirculation cell ahead of a flame spreading over 1-butanol. Flame is nearing the end of the crawl phase of the pulsation cycle. The smoke wire is perpendicular to the image at the location of the rosin bead. Note surface reflection.

Ironically, the numerical model initially predicted that the flame would pulsate in microgravity. The experimental results dictated that the model needed to be revised, and changes to the diffusion coefficient and the addition of a heat-loss term finally brought the model and experiments into alignment. For the first time the model predicts the correct flame spread behavior regardless of gravitational level without the need to adjust chemical rate parameters. This will allow parametric runs to determine the effect of several variables that cannot all be tested in flight.

In fiscal year 2000, experiments in Glenn's Zero Gravity Facility focused on much shallower pools than used previously, 2 mm rather than 25 mm.



Flame position versus time for three different liquid temperatures in a shallow tray (2 mm deep) in microgravity. Higher temperatures lead to more rapid flame pulsations and faster flame spread.

These are more realistic of a liquid spill, and have led for the first time to pulsating flame spread in microgravity (see the graph). This indicates that buoyancy is not needed for the pulsation process. A new shallow tray filling system was designed, and the next flight of SAL will test both a deep tray at elevated temperature and a shallow tray.

Reference

1. Ross, Howard D.: Spread Across Liquids: The World's First Microgravity Combustion Experiment on a Sounding Rocket. 1995 Research & Technology. NASA TM-107111, 1996, pp. 137-138. http://www.grc.nasa.gov/WWW/RT1995/6000/6711r.htm

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