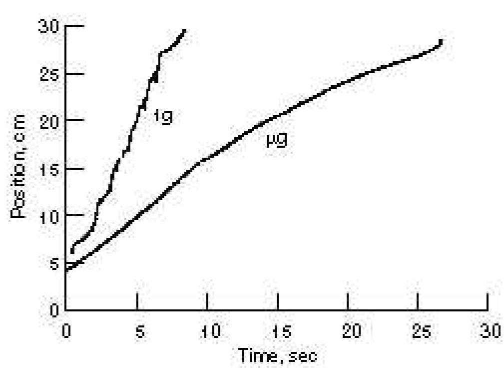
Spread Across Liquids: The World's First Microgravity Combustion Experiment on a Sounding Rocket

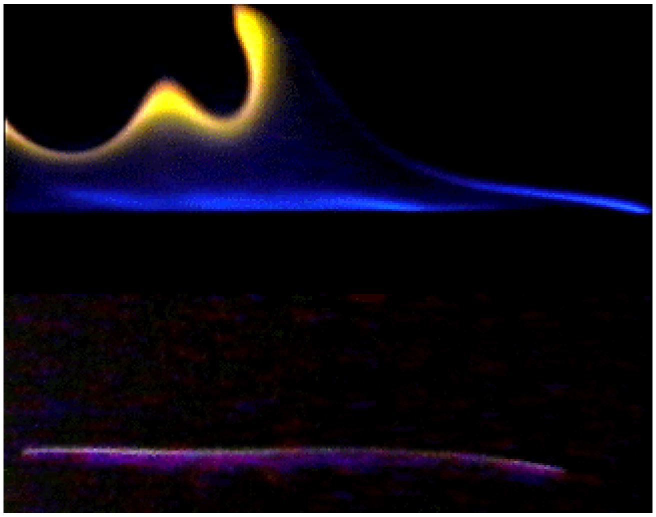
The Spread Across Liquids (SAL) experiment characterizes how flames spread over liquid pools in a low-gravity environment in comparison to test data at Earth's gravity and with numerical models. The modeling and experimental data provide a more complete understanding of flame spread, an area of textbook interest, and add to our knowledge about on-orbit and Earthbound fire behavior and fire hazards. The experiment was performed on a sounding rocket to obtain the necessary microgravity period. Such crewless sounding rockets provide a comparatively inexpensive means to fly very complex, and potentially hazardous, experiments and perform reflights at a very low additional cost. SAL was the first sounding-rocket-based, microgravity combustion experiment in the world.

It was expected that gravity would affect ignition susceptibility and flame spread through buoyant convection in both the liquid pool and the gas above the pool. Prior to these sounding rocket tests, however, it was not clear whether the fuel would ignite readily and whether a flame would be sustained in microgravity. It also was not clear whether the flame spread rate would be faster or slower than in Earth's gravity.

The SAL experiment flew twice in the past year, and both flights were highly successful, revealing new flame-spread behavior attributable to the absence of gravitational effects and also proving the feasibility in microgravity of several novel, advanced diagnostics and fluid management technologies. The diagnostic instruments, which performed flawlessly, included four flame-imaging cameras, two side-viewing particle image velocimetry (PIV) systems that recorded liquid fuel-flow patterns, an infrared camera that determined the liquid surface temperature field ahead of the flame, and a rainbow schlieren deflectometer that imaged the subsurface-liquid temperature gradients.

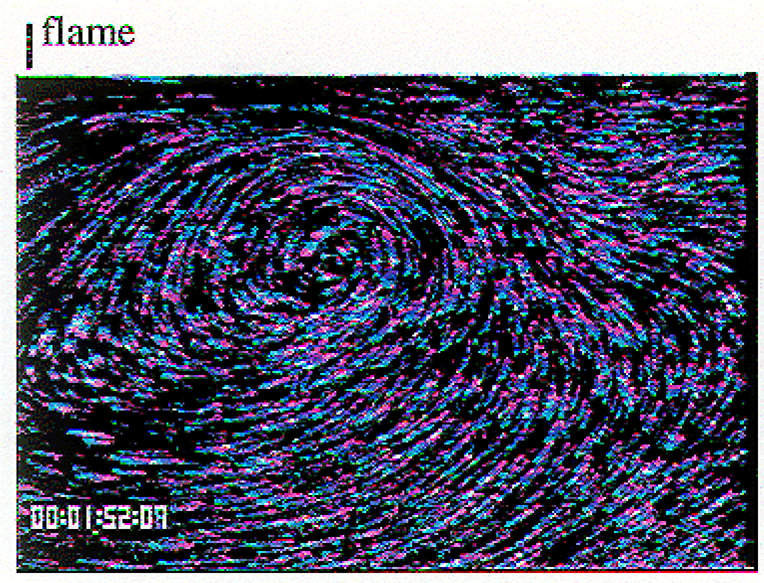


Flame position versus time for a 2.5-cm-deep butanol pool in an opposed airflow of 30 cm/sec.



Flame spread. Top (or left): At 1g (normal gravity). Bottom (or right): In microgravity.

In Earth's gravity (1g), flames spread in a regularly pulsating manner. In these microgravity tests, however, flames spread very slowly and uniformly across the entire length of the pool (see the graph). Unlike flames in 1g, the microgravity (ug) flame was completely blue (soot-free), without any noticeable plume or wavering. (See the comparative photos (above) of a flame in 1g and in microgravity.) The diagnostic instruments showed a large liquid-phase vortical flow extending deep into the pool ahead of the flame (see the following photo for the PIV liquid phase velocity field), very different from the stratified liquid flow that occurs in 1g. These observations showed conclusively that (1) flame spread can persist in microgravity, (2) it is substantially different from that at Earth's gravity, and (3) liquid buoyancy plays a major role in flame spread over flammable liquids. For the past two to three decades prior to these tests, research literature had debated this last point. The acquired data will allow detailed verification of the numerical models in areas such as liquid-phase velocity and temperatures, as well as the flame-spread rate.



Vortical liquid phase velocity field below the flame leading edge.

The peer-reviewed SAL experiment was conceived and developed by the NASA Lewis Research Center in collaboration with Case Western Reserve University and Aerospace Design & Fabrication (ADF). Experiments are being modeled by the University of California at Irvine.