New Species of Fire Discovered: Fingering Flamelets Form a Dynamic Population

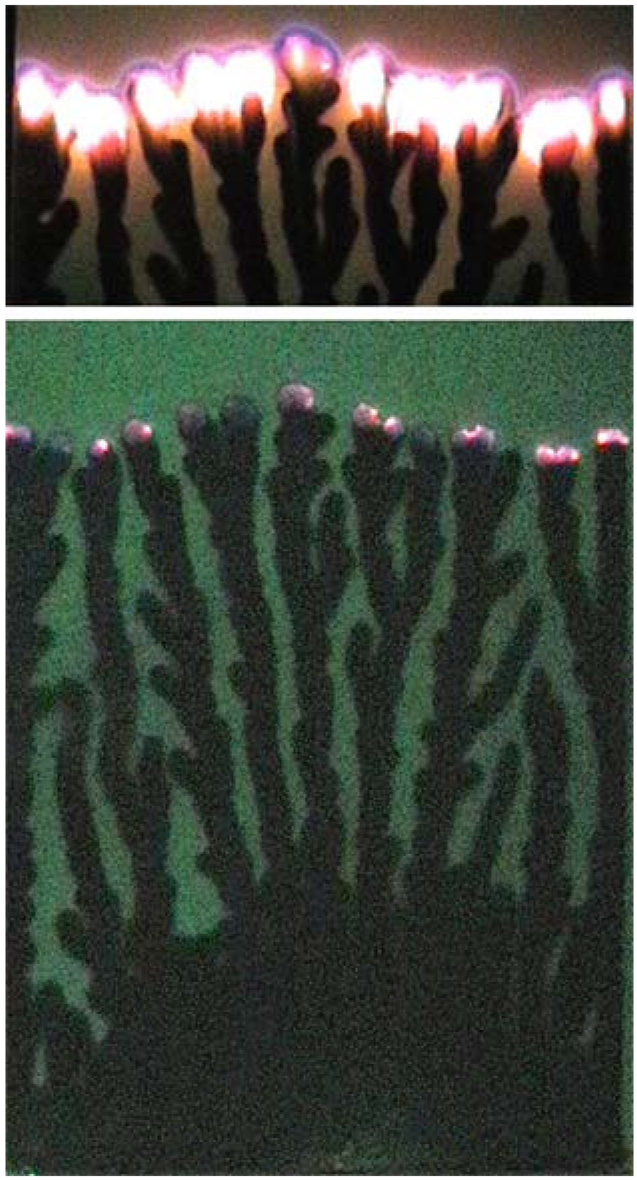
"To me the fire is a splendid metaphor for life. Sometimes raging and fervent, sometimes glowing softly and evenly, other times reduced to struggling embers."
--Jean Carnahan

Poets and artists have long used fire as a metaphor for life. At the NASA Glenn Research Center, recent experiments in a subcritical Rayleigh number flow channel demonstrated that this analogy holds up surprisingly well when tools developed to characterize a biological population are applied to a class of fire that occurs in near-extinction, weakly convective environments (such as microgravity) or in vertically confined spaces (such as our apparatus). Under these conditions, the flame breaks into numerous "flamelets" that form a Turing-type reaction-diffusion fingering pattern as they spread across the fuel.

It is standard practice on U.S. spacecraft for the astronaut crew to turn off the ventilation to help extinguish a fire, both to eliminate the fresh oxygen supply and to reduce the distribution of the smoke. When crew members think that the fire is fully extinguished, they reactivate the ventilation system to clear the smoke. However, some flamelets can survive, and our experiments have demonstrated that flamelets quickly grow into a large fire when ventilation increases.

A similar event already happened aboard Russia's Mir space station on October 15, 1994. Cosmonaut Valery Polyakov was the first to reach a small fire and put it out using a jumpsuit belonging to crewmate Yuri Malenchenko. Later, however, the cosmonauts discovered that the jumpsuit was still burning and the flames had burned a hole through the chest area of the suit. Had the crew not noticed this fire, it could have grown undetected into a large damaging fire. Because of the apparently fractal nature of this phenomenon, enhanced understanding of centimeter-scale fingering flame spread may be relevant not only to spacecraft fire safety, but to kilometer-scale fingering wildfire spread on Earth. The fractal nature of wildfire burn patterns has been noted. It also has been noted that the least damaging wildfires are those that burn in a mosaic pattern that leaves many random, irregular unburned fingers and islands. A better understanding of the dynamics of these kinds of fires could help control prescribed burns to achieve the desired mosaic burn patterns that appear to benefit both flora and fauna.

Flamelets form a dynamic population whose members interact competitively for the limited available oxygen. They reproduce through bifurcation and die either at the birth of the next generation or through extinction without bifurcation. Flamelets show many of the characteristics found in biological populations, such as a Type II age structure and a uniform pattern of dispersion. We utilized the continuous logistic model with a time lag to describe the flamelet population growth and fluctuation around a stable population characterized by the carrying capacity based on environmental limitations. This flame "adaptation" to adverse environmental conditions extends the flammability range to lower opposed flow velocities, lower oxygen concentrations, or higher heat loss by increasing the multidimensionality of the flame and, thus, enhancing oxygen transport to the flame zone.



Top: At the end of the test, the airflow is increased to see if the flamelets can be blown out. Instead, they flare up and remerge into a full flame front. Bottom: Green light illuminates the end of a fingering flame spread test, revealing the black char fingering patterns left behind on the paper once the flame breaks into flamelets. The black (bottom) section of the sample was entirely consumed during flame spread prior to airflow ramp down. As the airflow was reduced (air came from the top to the bottom of the image), the flame became starved for oxygen and broke into flamelets that survived by drawing oxygen from the sides as well as the front. The blue flamelets at the tips of the "fingers" formed a dynamic population that reproduced through bifurcation (branches in the black *fingers) and died through quenching extinction (end of black fingers). The steady-state size that the population reached depended on how much oxygen was provided. In this case, the airflow was 2 cm/sec past the sample and the population was about 13.*

Bibliography

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Find out more about this research:
Analysis of Thermal and Hydrodynamic Instabilities in Near-limit Atmospheres (ATHINA) at: http://microgravity.grc.nasa.gov/combustion/athina/athina_index.htm
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