MULTIDIMENSIONAL EFFECTS ON IGNITION, TRANSITION, AND FLAME SPREAD IN MICROGRAVITY

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INTRODUCTION

Localized ignition is initiated by an external radiant source at the middle of a thermally thin sample under external slow flow, simulating fire initiation in a spacecraft with a slow ventilation flow. Two ignition configurations are simulated, one across the sample surface creating a line shaped flame front (two-dimensional, 2-D, configuration) and the other a small circular ignition (three-dimensional, 3-D, configuration). Ignition, subsequent transition to simultaneously upstream and downstream flame spread, and flame growth behavior are studied experimentally and theoretically. Details of our theoretical models and numerical techniques can be found in previous publications [1,2].

The effects of the sample width on the transition and subsequent flame spread, and flame spread along open edges of a thermally thin paper sample are determined. Experimental observations of flame spread phenomena were conducted in the 10 s drop tower and also on the space shuttle STS-75 flight to determine the effects of oxygen concentration and external flow velocity on flame spread rate and flame growth pattern. Finally, effects of confinement in a small test chamber on the transition and subsequent flame spread are examined. The results of these studies are briefly reported.

EFFECTS OF SAMPLE WIDTH

Many flame spread studies over a solid fuel surface in microgravity, by necessity, were conducted in spatially limited experimental volumes which resulted in relatively narrow samples despite the original intention of a 2-D experimental configuration. It is, therefore, critically important to determine whether these sample widths will produce truly 2-D flame spread behavior. In this study, our 2-D and 3-D numerical simulation codes were used to investigate the effects of sample width on flame spread. Heat loss effects at the interface of the sample and the sample holder were tested by varying the thermal properties of the sample holder. It was found that heat losses to the sample holder affected the flame spread rate in the case of the narrower sample with slower external flow velocity as shown in Figure 1. Sample width effects were most significant when the external flow was relatively small (limited oxygen supply case) as shown in Figure 2. The incoming flow speed towards the flame front was dramatically reduced by thermal expansion (the flame acts as an obstacle to the incoming flow). In such environments, the net inflow of oxygen is reduced enough to significantly affect flame spread behavior. Since a full 2-D flame generates more heat release (larger thermal expansion) than a narrow 2-D flame (a smaller flame with less heat release), the net inflow of oxygen for the full 2-D flame is less than for the narrow 2-D flame[3]. This is the reason why flame spread rate of a narrow sample is faster than that of a wider sample. The results shown in Figure 1 indicate that attainment of a truly 2-D flame configuration tends to be difficult at external flow velocities less than 5 cm/s.
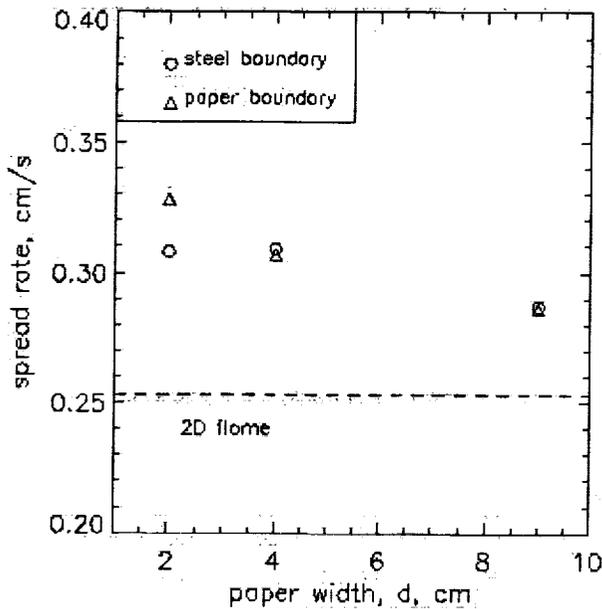
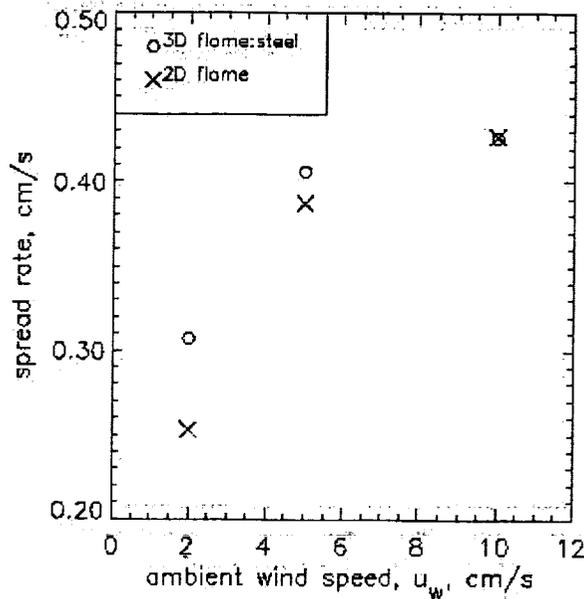Figure 1. An external flow of 2 cm/s.

Figure 2. 9 cm width for 3-D with steel holder
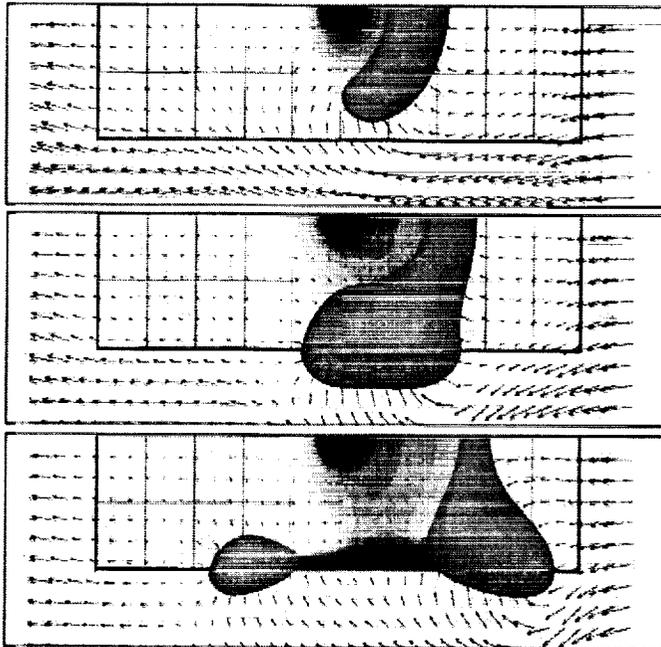
FLAME SPREAD ALONG FREE EDGES

Figure 3 Calculated sequence images of isosurface of gas phase reaction rate with net oxygen mass flux vectors at flow of 2 cm/s from right to left .

In this theoretical and experimental study, the sample is ignited locally at the middle of the 4 cm wide sample and the subsequent flame spread reaches both open edges of the sample oriented along the direction of the flow. Figure 3 shows the flame is more or less semicircular shortly after ignition, and slightly extended upstream (top figure). Later the flame spreads to free edges (middle figure) and starts to spread both upstream and downstream. The following trends are observed in the experiments and predicted by the numerical calculation[4] in the order of increasing imposed flow velocity; (1) ignition but subsequent flame spread is not attained, (2) flame spreads upstream (opposed mode) without any downstream flame, and (3) the upstream flame and downstream flames separately travel simultaneously along the two open edges. For the upstream edge flame, the flame spread rate is nearly independent

of, or decreases gradually, with the imposed flow velocity as shown in Figure 4. The spread rate of the downstream edge flame, however, increases significantly with the imposed flow velocity. Generally, the upstream and downstream edge flame spread rates are faster than the central flame spread rate for an imposed flow velocity of up to 5 cm/s as shown in Figure 3. This is due to greater oxygen supply from the outer free stream to the edge flames shown in Figure 3 and more efficient heat transfer from the edge flames to the sample surface than the central flames.

SPOT RADIATIVE IGNITION AND SUBSEQUENT 3D FLAME SPREAD

It was experimentally observed that non-piloted radiative ignition of the paper occurred more easily in microgravity than in normal gravity. The ignition delay time was a much stronger function of flow at low oxygen concentrations. After ignition, the flame spread only upstream, in a fan-shaped pattern. The fan angle increased with increasing external flow velocity and oxygen concentration from zero angle (narrow flame with width of the beam diameter) at the limiting 0.5 cm/s external air flow, to 90 degrees (semicircular flame) for external flow velocities at and above 5 cm/s and higher oxygen concentrations as shown in Figure 5[5]. Predicted fan angles based on a simple analysis that estimates the air flow normal to the flame front including the effects of diffusion qualitatively agree with the experimentally obtained results as shown in the figure. A surface energy balance using the measured surface temperature histories from fine thermocouples reveals the heat feedback rate from the upstream flame to the surface decreases with decreasing oxygen mass transport to the flame via either imposed flow velocity or ambient oxygen concentration[5]. Despite the convective heating from
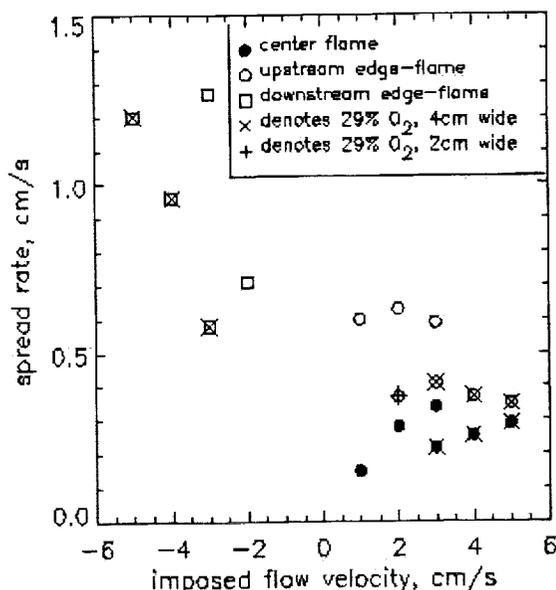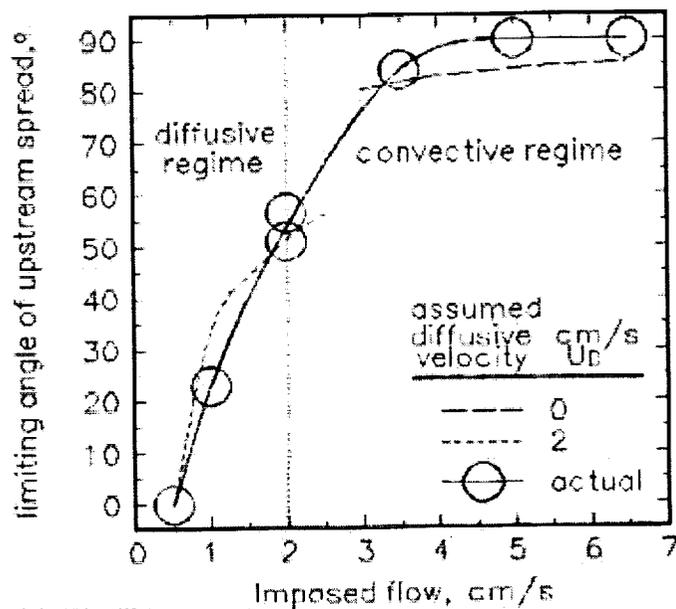

Figure 4. Calculated flame spread rates.

Figure 5. Measured fan angle with circle vs. calculated results with lines.

the upstream flame, the downstream flame spread did not occur due to lack of oxygen caused by the upstream flame, 'oxygen shadow', for the flow conditions studied.

EFFECTS OF TEST CHAMBER CONFINEMENT

Generally, the size of many test chambers for microgravity combustion experiments is due to low flow velocities. It is quite possible that surrounding test chamber walls might have significant effects on flame behavior. In this study, the confinement effects are determined by comparing the calculated results obtained from the open, unconfined case with the results with the confinement of the test chamber used in our experiments. The effects of the confinement on flame spread rate in the 2-D configuration are shown in Figure 6. Since the fan used in the
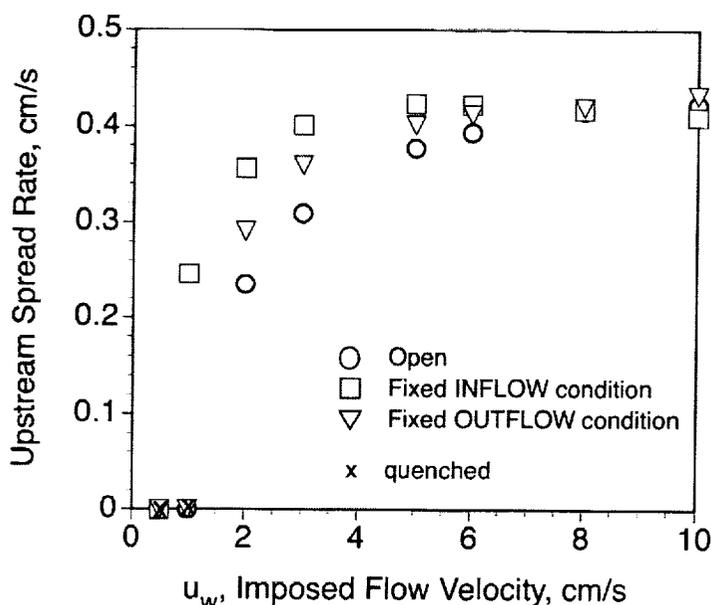

Figure 6. Effects of confinement on flame spread rate in 40% oxygen Concentration.

experiment was calibrated without any combustion in the test chamber, the effects of heat and mass addition to the performance of the fan could not be determined. Therefore, two different boundary conditions for the flow field were selected; specifying a constant inflow condition and fixing a constant outflow condition. The results show significant acceleration of flow and subsequent increase in flame spread rate compared to that without any confinement (open) at low imposed flow velocities. The length of flame is more extended and flame gets closer to the sample surface with the confined case. Since the size of flame is initially small in the 3-D configuration, the effects of the confinement on flame behavior are initially less than in the 2-D configuration.

ACKNOWLEDGMENTS

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