NASA/CP—2004-213205/VOL2

Understanding Material Property Impacts on Co-Current Flame Spread: Improving Understanding Crucial for Fire Safety

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NASA/CP—2004-213205/VOL2

Introduction

The prospect of long-term manned space flight brings fresh urgency to the development of an integrated and fundamental approach to the study of material flammability. Currently, NASA uses two tests, the upward flame propagation test and heat and visible smoke release rate test, to assess the flammability properties of materials to be used in space under microgravity conditions. The upward flame propagation test can be considered in the context of the 2-D analysis of Emmons (1956)[1]. This solution incorporates material properties by a "mass transfer number," B in the boundary conditions, given by.

$$B = \frac{(1-\chi)(\Delta H_C Y_{O_2,\infty}) - Cp_\infty (T_{ig} - T_\infty)}{\Delta H_P + Q_C}$$

In this expression for B, the numerator denotes the amount of heat release and the denominator represents the amount of heat needed to gasify the fuel; hence larger values of B represent a greater potential driving force for combustion and a greater potential flammability. Experimental and theoretical calculations of the B number, however, don't give similar results. The primary reason for this appears to be air entrainment, which is not accounted for in the Emmons 2-D model. Current experimental and analysis work aims to provide a more solid foundation for the prediction of material property influence on flammability.

[1] H. Emmons, Z. angew. Math. Mech. 36 (1-2) (1956) 60-71.

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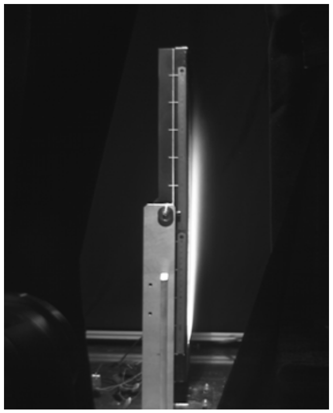
Experiment

- Measurements of flame stand-off distance and pyrolysis length enable determination of B in a configuration analogous to NASA's flame spread test (Figures 1, 2, 5)
- Particle image velocimetry measurements illustrate air entrainment from the 3rd dimension, this has been verified using the Fire Dynamic Simulator Code from NIST (Figure 3, 4).

Experimental setup



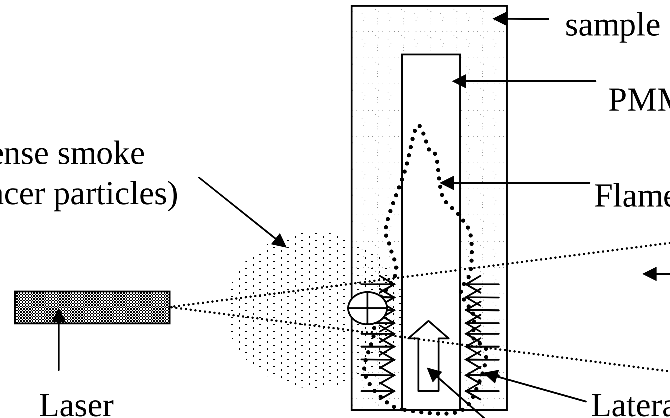
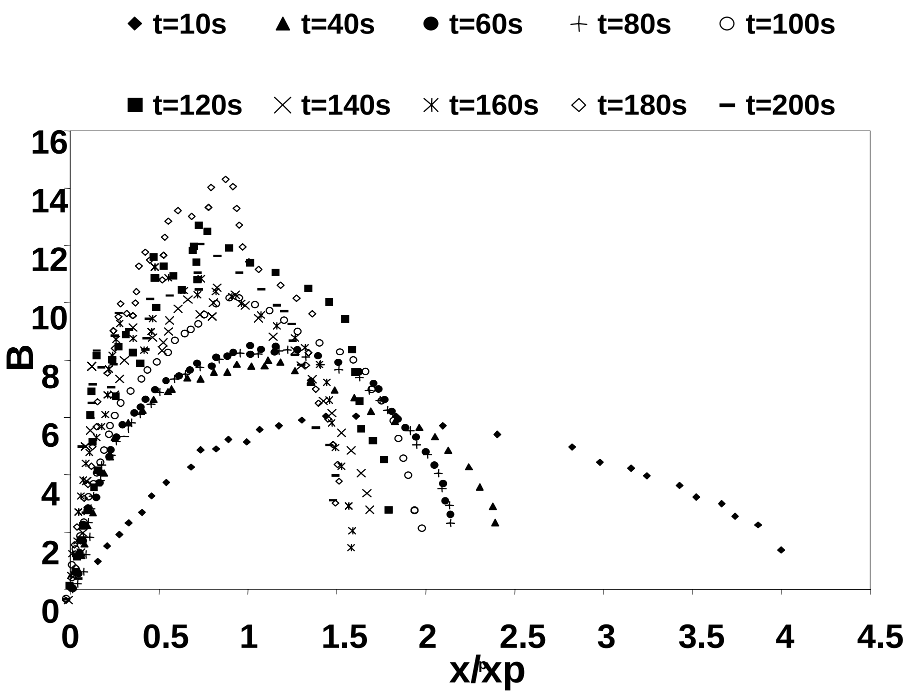
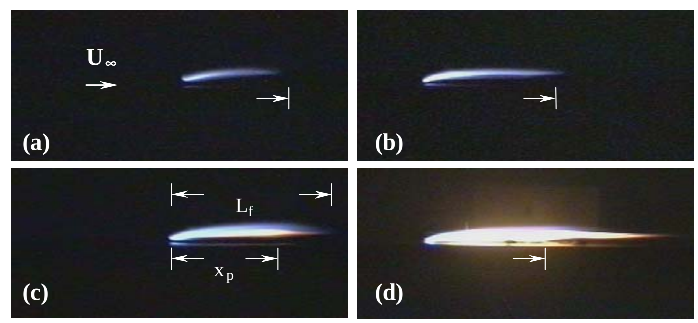


***Fig 1, 2*:** Experimental set up to measure stand off distance is shown by the picture on left hand side. The right hand side above shows the particle image velocimetry (PIV) set up.

Typical stand-off distances measured as a function of time





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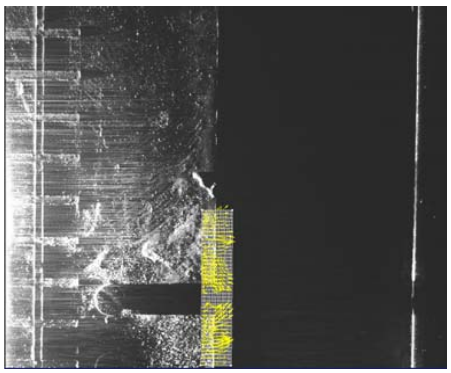
Significance/Findings

The two-dimensional classical boundary layer solution of Emmons[1] is insufficient to describe the buoyantly-driven flame propagation investigated here due to the influence of air entrainment in the 3rd dimension. However, this does not invalidate the significance of the B number or the importance of material properties on flame spread.



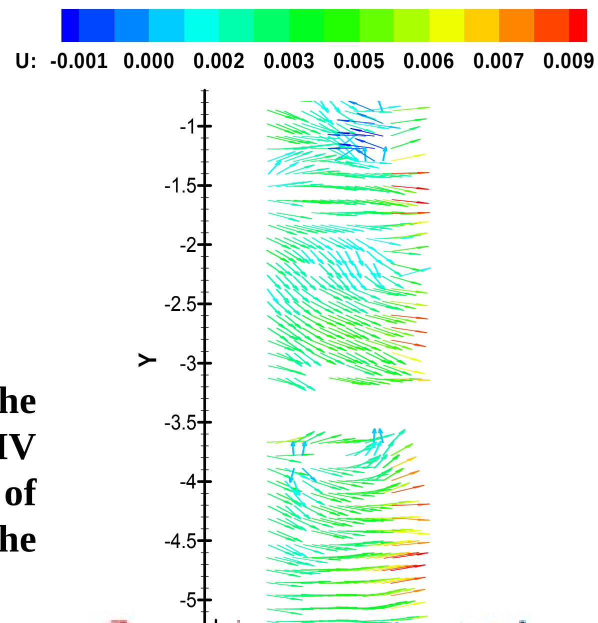


***Fig 3*: Above: the fuel, with the yellow square on the edge of the fuel showing the location of the PIV measurements. The PIV measurements (right) illustrate entrainment from the side of the fuel: Average velocity is 7-10 mm/s at 4 to 5 mm from the surface of the fuel.**

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Experimental and FDS results

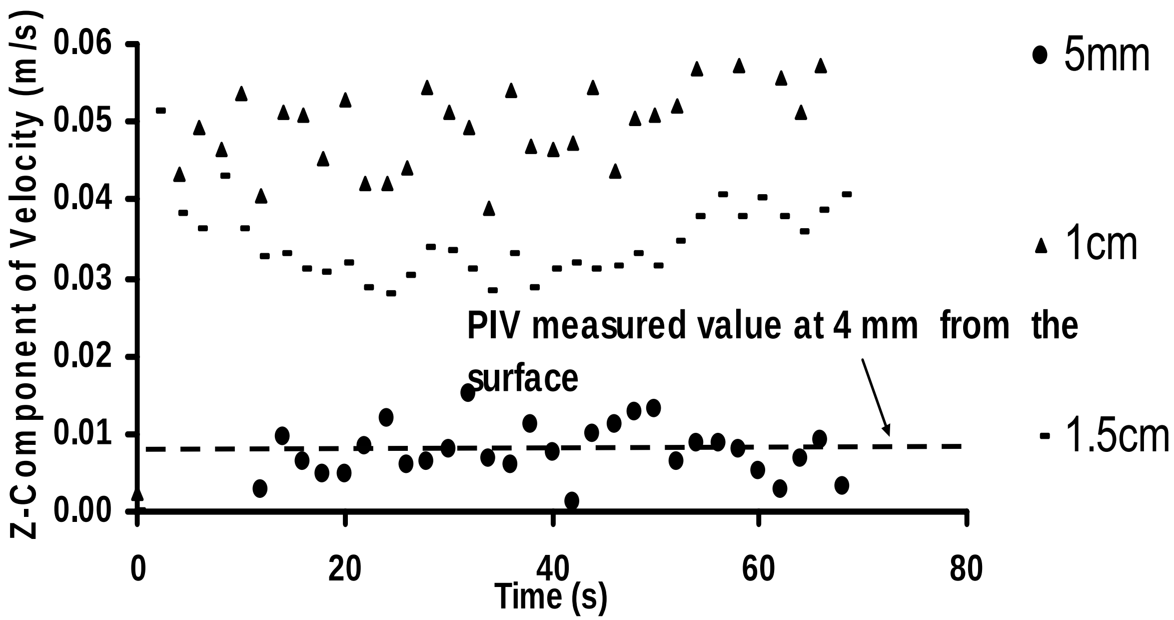
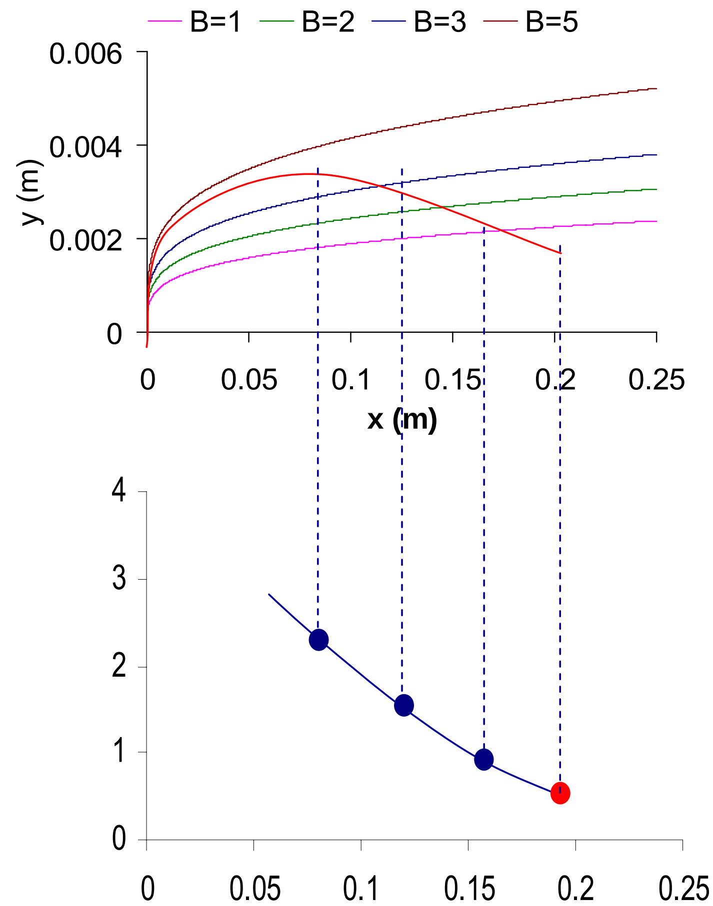


***Fig 4*: The lateral entrainment velocity predicted by FDS (fire dynamic simulator). As the distance from the surface increases the lateral entrainment velocity increases, reaching a maximum value at about 1 cm from the surface before decreasing. The entrainment velocity of 7-10 mm/s we measured from our experiments was a distance of between 4 to 5 mm from the surface of the fuel in good agreement with FDS.**

Fig 5: **The flame shape has a direct relationship with the B number. Four of the curves with similar shapes are from theory, while the red curve shows the experimentally measured flame shape. The experimentally-determined B number should be a constant, but it is not. The evolution of the B number obtained from the stand off distance shows that theory and experiment don't match.**



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Conclusions to date

- **Lateral flame spread has a significant impact on the upward flame spread problem under study. The traditional Emmons solution is not able to capture the impact of flow in this 3rd dimension and thus modifications are required to apply theory to this problem.**
- **Material properties, such as those embodied in the mass transfer number B, should play a vital role in our understanding of flammability and flame spread**

Continuing Work

- New experiments are planned to better examine the linkage between the material properties, B number, and flammability.
- Direct numerical modeling of the experiments to better quantify flow field.
- Analytical solution of the flow in the third dimension

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Acknowledgements

NASA Fire Safety Program of the Bioastronautics Initiative: Grant #NAG-32568

NASA technical contact: Dr. Gary Ruff

Experimental assistance: Dr. Mickey Coutin

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