BUOYANCY EFFECTS IN STRONGLY-PULSED, TURBULENT DIFFUSION FLAMES

J.C. Hermanson
University of Washington, Box 352400, Seattle, WA 98195
Ph: (206)616-2310 Fax: (206)543-0217 email jherm@aa.washington.edu

H. Johari and E. Ghaem-Maghami
Worcester Polytechnic Institute,
Worcester MA 01609

D.P. Stocker and U. G. Hegde
NASA Glenn Research Center,
Cleveland, OH 44135

The objective of this experiment is to better understand the combustion behavior of pulsed, turbulent diffusion flames by conducting experiments in microgravity. The fuel jet is fully-modulated (i.e., completely shut off between pulses) by an externally controlled valve system leading to enhanced fuel/air mixing compared to acoustically excited or partially-modulated jets[1].

Experiments are conducted both in laboratories at UW and WPI and in the GRC 2.2s Drop Tower. A single fuel nozzle with diameter d = 2 mm is centered in a combustor 20 Δ 20 cm in cross section and 67 cm in height. The gaseous fuel flow (ethylene or a 50/50 ethylene/nitrogen mixture by volume) is fully-modulated by a fast-response solenoid valve with injection times from ϑ= 4 to ϑ= 300 ms. The nominal Reynolds number based on the fuel velocity during injection, U_{jet}, is 5,000. A slow oxidizer co-flow properly ventilates the flame[2] and an electrically heated wire loop serves as a continuous ignition source. Diagnostic techniques include video imaging, fine-wire thermocouples and thermopile radiometers, and gas sampling and standard emissions instruments (the last in the laboratory only).

The normalized flame lengths of fully-modulated diffusion flames consisting of isolated, non-interacting structures at low duty cycle, ζ (i.e., low jet-on fraction) are shown in Fig. 1. The flame length scales well with the parameter $P(1+..)^{1/3}$, where $P\ \sum(U_{jet}\vartheta/d)^{1/3}$ and …is the stoichiometric air/fuel ratio[1]. The linear scaling persists to $P-\ 8$ where a transition from compact puffs to elongated flame structures begins. The visually-observed celerity of flame puffs near burn-out is generally less in microgravity than in normal gravity and the flame puffs in microgravity generally take a longer time to burn out. These two effects appear to be offsetting, with the result that the flame length of isolated, compact puffs in the linear scaling region is insensitive to buoyancy. By contrast, the mean length of flames with elongated, isolated structures ($P > 8$) does increase as buoyancy is removed.

The flame length in fully-modulated diffusion flames can also be significantly impacted by the off-time (or duty cycle) as shown in Fig. 2. Decreasing the off-time causes the discrete fuel puffs to give way to more closely-packed, interacting flame structures, which lead in turn to a longer flame length. This effect is greatest for the most compact puffs with the shortest injection time (lowest values of P). An example of a microgravity flame at a duty cycle sufficiently high to result in significant structure-structure interaction is shown in Fig. 3.

The combination of increasing flame puff size and decreasing puff celerity with downstream distance changes the separation between puffs, effectively increasing the duty cycle locally. This effect is greater in microgravity than in normal gravity due to the lower celerity in the former case, suggesting that the change in flame length with increasing injection duty cycle is correspondingly greater in microgravity. This is in qualitative agreement with the experiments.

Buoyancy appears to have a strong effect on the thermal characteristics of fully-modulated turbulent diffusion flames[3]. The cycle-averaged centerline temperatures are generally higher in the microgravity flames than in normal gravity, especially at the flame tip where the difference was as much as 200 K. The highest average centerline temperature (Fig. 4) appears to decrease, then to become roughly constant as P is increased. The transition occurs at $P - 8$ (similar to value for the transition in flame length mentioned previously).

The highest emission indices of CO and unburned hydrocarbons (UHC) were found for compact, isolated puffs and were roughly an order of magnitude higher than emissions from elongated flames[4]. The levels of CO, UHC, and NOx for all fully-modulated flames approached the low, steady-flame values for a duty cycle of approximately ζ ∅0.4, with a flame length significantly shorter than that of the steady flame. All emissions data were acquired in 1-g; the emissions levels of flames in microgravity have not yet been investigated.

This work is sponsored by NASA Glenn Research Center under Agreements NCC3-673 and NNC04AA37A.

References

[1] Hermanson, J.C., Dugnani, R., and Johari, H., *Comb. Sci. Tech.* **155**, 203-225, 2000.
[2] Hermanson, J.C., Usowicz, J., Johari, H., and Sangras, R., *AIAA Journal* **40** (7), 2002.
[3] Page, K.L., Stocker, D.P, Hegde, U.G., Hermanson, J.C. and Johari, H., *Third Joint Meeting of the U.S. Sections of The Combustion Institute*, Chicago, IL, March, 2003.
[4] Johari, H., Ghaem-Maghami, E., and Hermanson, J.C., *Combustion Science and Technology,* in press, 2004.

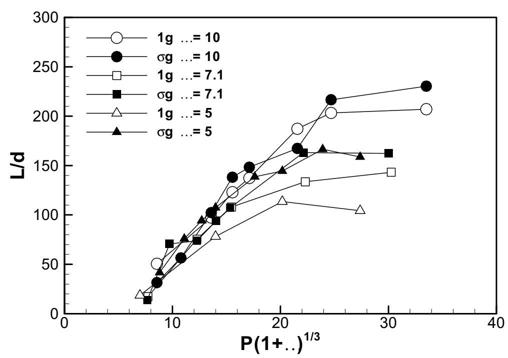

Fig. 1 Normalized flame length for fully-modulated flames.

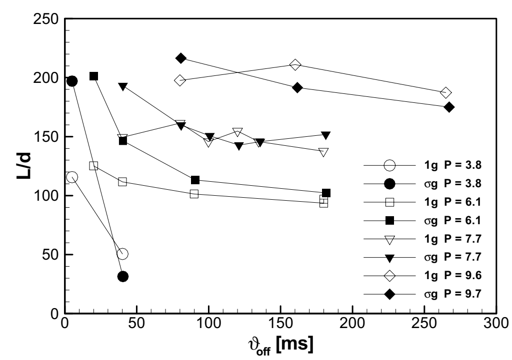

Fig. 2 Effect of injection off-time on normalized flame length for fully-modulated flames for …= 10.


Fig. 3 Sequence of fully-modulated flames in microgravity showing the merging of large-scale turbulent structures. $P = 7.6$, $\zeta = 0.5$.

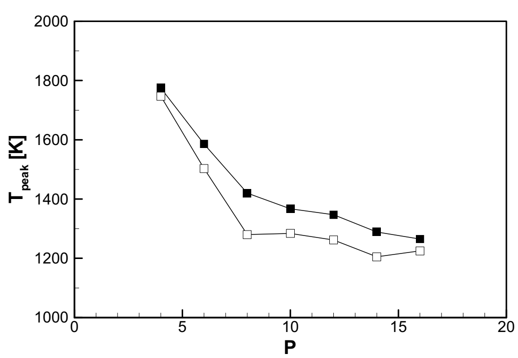

Fig. 4 Highest values of the average centerline temperature.