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Technical Notes

Fluidic Flame Stabilization in a Planar Combustor Using a Transverse Slot Jet

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I. Introduction

THE stabilization of a premixed flame in a high-speed internal environment has received a considerable amount of interest from many researchers, for example, [1–3]. Flame stabilization behind a bluff body represents the most common strategy for flame anchoring [4–8]. Bluff bodies and rearward-facing step flows stabilize the flame by introducing a low-velocity recirculation zone containing combustion products that act as a continuous ignition source. Although these flame-holding devices provide an environment suitable for flame holding, a drag penalty is incurred. An alternative fluidic-based approach using a transverse slot jet to generate a "virtual bluff body" would reduce the thrust penalties through the removal of form drag while producing a flowfield with flame-holding potential. Figure 1 shows two schematics for combustors employing bluff body and fluidic methods for flame holding. The dashed box in the figure represents the control volume that will be used to demonstrate that form drag imposes a penalty. A momentum balance in the streamwise direction for the two situations, employing the assumption of negligible viscous shear, indicates that the drag force on the bluff body F_D will result in a loss in either streamwise momentum or an increased pressure drop across the burner. For the fluidic case, a balance will be maintained between pressure drop and an increase in streamwise momentum. A simple one-dimensional analysis of the systems, shown in Fig. 1, using a drag coefficient based on the inlet flow properties was conducted to determine the additional total pressure losses due to flame-holder drag. The calculation employs constant specific heats, models the fluid as air, and employs conservation of mass, momentum, the ideal gas equation, Mach number definition, and stagnation relations. Figure 2 shows the additional total pressure loss due to form drag on the flame holder as a function of inlet Mach number and drag coefficient.

In addition to thrust penalty reduction, the fluidic flame holder allows active control of the recirculation zone size, providing dynamic control of the stabilization characteristics that will allow a broader operating envelope and improved off-design performance. Dynamic control would allow for optimization of the tradeoff between combustion efficiency and flame stability. The cost of the fluidic actuation is considered in terms of the required mass flow rate to achieve the necessary recirculation zone. For the present experiments, the fluidic flow rate was nominally 7% of the main flow rate.

The objective of the current note is to document the operating characteristics of a fluidic flame holder consisting of a planar transverse jet issuing into a channel flow. The influence of the test chamber initial conditions on the scaling of the induced recirculation zone will be shown. It will also be shown that the jet equivalence ratio can be used to manipulate the rich and lean blowout limits.

II. Experimental Setup

The experiments were conducted in the Combustion Laboratory in the Mechanical and Aerospace Engineering Department at the University at Buffalo, State University of New York. The schematic of the ramjet model is shown in Fig. 3. The figure shows three sections of the experiment: the nozzle, the diffuser, and the combustion section. The diffuser is present in the experiment to produce combustor initial conditions that would be present for a ramjet engine, for which the diffuser is required for thrust production due to the projected area in the streamwise direction. The analogous sudden expansion burner would have the same area ratio as the diffuser, but would also incur higher total pressure losses due to the flowpath geometry.

The air for the main channel flow is generated using a blowdown-type facility, in which pressurized air is regulated and metered before delivery to the plenum of the ramjet model facility. The plenum of the test rig contains flow conditioning in the form of two coarse screens, a 1 in. section of a $1/8$ in. aluminum honeycomb, followed by a fine mesh screen. The Reynolds number based on the mean velocity at the combustor inlet U_o and the combustor height H was varied up to approximately 32,000. The combustion section has a short dimension height H of 45 mm and a cross-sectional aspect ratio of 2.8:1. The diffuser has an expansion ratio of 3:1, with a total angle of 7.5 deg and a length of 229 mm that produces a quasi-parabolic exit mean streamwise velocity as shown in Fig. 4a. Note that the diffuser did not have separated flow although the fluctuation levels were quite high, as indicated in Fig. 4b. An additional flow conditioning section, consisting of three axially spaced fine mesh screens, was employed for some measurements to investigate the role of the combustor inlet conditions. The additional screens resulted in nominally uniform flow with low turbulence levels, as shown in Figs. 4c and 4d. Measurements have been made with both initial conditions.

A slot jet is situated one channel height H downstream of the diffuser exit on the bottom wall of the combustion channel. The slot spans the full channel spanwise depth. The slot jet has a short dimension of 0.254 mm. Compressed air is first passed through a Laskin nozzle for seeding the airstream with nominally 1-μm-diam olive oil droplets before delivery to the plenum for the nonreacting

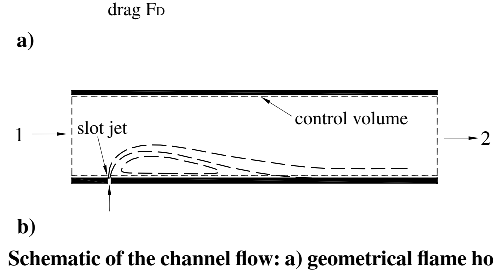

Fig. 1 Schematic of the channel flow: a) geometrical flame holder, and b) fluidic flame holder.

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