Effects of Buoyancy on Lean Premixed Flame on a Rotating Bunsen Burner

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Introduction

In normal gravity buoyancy has a substantial impact on flame oscillations, pollutant emissions and flame stabilization limits and so its influence on flame motions is of practical importance to combustion research today. For lean premixed flames, the group at LBNL [1-4] have investigated the effect of buoyancy on flame shape and stabilization limits under a broad range of conditions including different flow velocities, equivalence ratio, and gravity levels. When the burner system is inverted (-1G), flame behaviour in normal (+1G) changes significantly. They have shown that inverse gravity (-1G) allows the lean blow-off limit to be extended to a lower equivalence ratio, compared with normal gravity.

Swirling flow is widely utilized for improving flame stabilization in practical combustion systems and it is important, therefore, to determine how the buoyancy affects the swirling flame motions. Using a rotating Bunsen burner system, we have investigated the significance of buoyancy for the dynamics of rich premixed flames [5], [6]. The flame shape of rotating flames in microgravity become broader in the radial direction, compared to that of +1G. Therefore, it would be expected that buoyancy will affect swirling flame motions in a -1G configuration. The objective of this presentation is to investigate experimentally the affect of buoyancy on swirling flame motions near lean blow off limits in +1G and -1G.

Experimental Apparatus and Method

The rotating Bunsen burner is shown schematically in Figure 1. This burner is nearly identical to that used in our earlier studies [5-7]. The burner tube has a diameter of 12 mm and is fitted on the top of a nozzle, which is vertically supported by bearings and rotated by a DC motor through a pulley and belt system. A 15 mm thick honeycomb section with grid diameter of 1.04 mm, is fitted inside the straight burner tube to create solid-body rotation of the premixed reactants at the burner tube exit [8]. CH_4/air is used as premixed reactants. The bulk flow velocity of the experiments U (= (volumetric flow rate) / (cross-sectional area of the burner tube)) was kept constant at 1.0 m/s. The rotational

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speed of the burner tube N was varied from 0 to 2500 rpm. To characterize the balance of the axial momentum and the swirl momentum, the Swirl number S is then introduced in the following equation.

$$S = \frac{2\pi \int_0^{\frac{D_0}{2}} \rho u v_\theta r^2 dr}{2\pi R \int_0^{\frac{D_0}{2}} \rho u^2 r dr} = \frac{\omega R}{2U}$$

Where, R = radius of the burner tube, u = axial velocity of reactants, v_θ = tangential velocity, ω (= πN / 30) = angular velocity of burner tube, U = bulk flow velocity of reactants, N = rotational speed of burner tube.

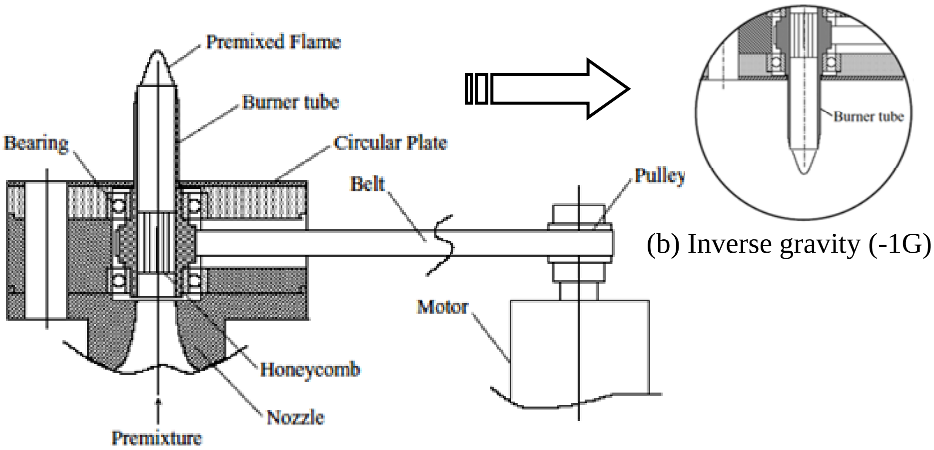

Figure 1: Experimental apparatus ((a) Normal gravity (+1G))

Results and Discussion

Photographs of flame shapes under condition of mean axial flow velocity U = 1.0 m/s, equivalence ratio ϕ = 0.75, swirl number S = 0.6 in normal gravity (+1G) and reversed gravity (–1G) are shown in Fig. 2. Note that the flame shape changes from the conical shape to the skewed shape (eccentric shape) with flame tips whirling around the rotational axis of burner tube as the swirl number is increased, and it becomes more skewed shape (tilted shape) with portions of the flame that have moved inside the burner tube [5]. As shown in Fig. 2, the flame shape in +1G changes significantly from an flat to a tilted flame when the burner system is inverted (-1G). This indicates that buoyancy affects the flame shape of rotating flames. To investigate the influence of buoyancy on the flame shapes in detail, the domains where these flame shapes exist for a constant axial flow velocity of U = 1.0 m/s are shown in Fig. 3 as functions of equivalence ratio and swirl number. Lines represent the transition boundary between the flame shapes. The transition boundary for both tilted and flat flames apparently differs in +1G and -1G. Both flames in -1G are formed at lower Swirl number, compared with those of +1G. In other words, the inverse gravity makes it easier for both flames to form compared to normal gravity. As reported in previous papers [2-4], when the burner system is inverted (-1G), the shape of interface between hot combustion products and cold ambient air becomes flat, and the hot combustion product pushes the flame front upwardly due to buoyancy. This allows the flame shape of a Bunsen flame to be flattened at low Reynolds number. Although we have not visualized the shape of interface in -1G, similar argument is applied to explain why the flat flame in -1G becomes easily to be formed compared with that of +1G. Interaction of the interface and flame motions is discussed in detail in the presentation. As shown in Fig. 3, an interesting unstable flame is observed in -1G. The effect of buoyancy on the onset of unstable flame is also discussed in the presentation.

Summary

The effect of buoyancy on lean swirling flame motions has been experimentally investigated, using a rotating Bunsen burner. The transition boundary for all flames in +1G significantly changes when turned the burner system upside down (-1G). This result indicates that buoyancy has substantial impact on changes in flame shape of swirling flame motions.

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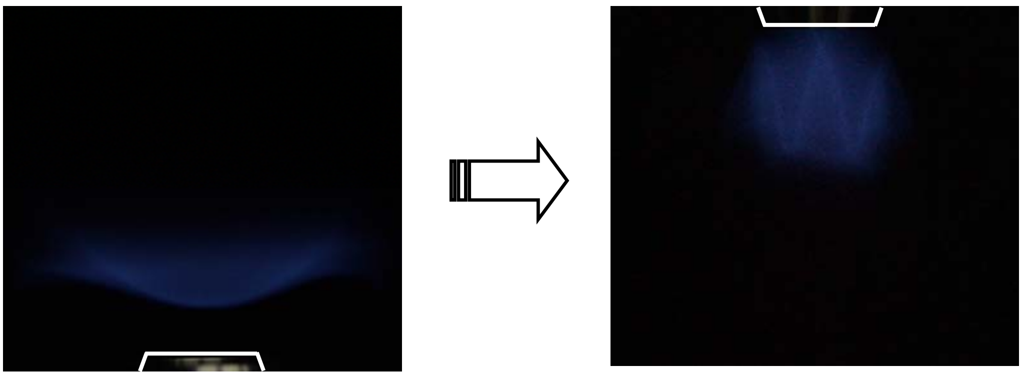

(a) Normal gravity (+1G) (b) Inversed gravity (-1G)

Figure 2: Flame shape of rotating flames under condition of U = 1.0 m/s, ϕ = 0.75, S = 0.6 in normal gravity (+1G) and inversed gravity (–1G)

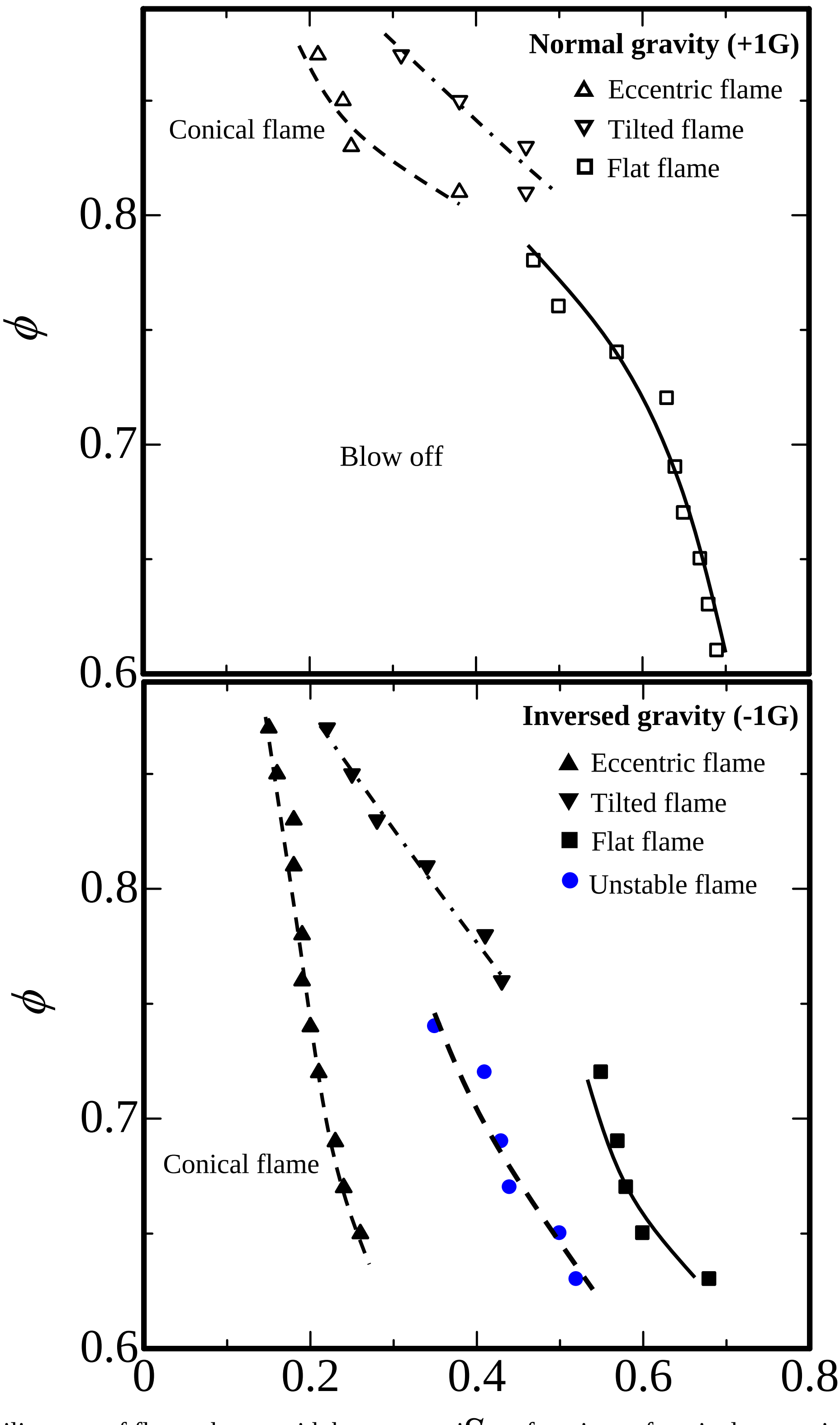

Figure 3: Stability map of flame shapes with burner rotation as functions of equivalence ratio ϕ and swirl number S for a constant axial flow velocity of U = 1.0 m/s in normal gravity (+1G) and Inversed gravity (–1G)