FLAME PROPAGATION IN LOW-INTENSITY TURBULENCE UNDER MICROGRAVITY CONDITIONS

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INTRODUCTION

The goal of the research is to understand the influences of the hydrodynamic instability on premixed-flame propagation. It is known that coupling between flame and flow-field dynamics in association with the hydrodynamic instability may lead to flame-generated turbulence, flame acceleration and enhancement of burning rates [1]. As a result of such hydrodynamic coupling the transition from initially planar or wrinkled laminar flames to fast turbulent flames or detonations is possible, even when diffusive-thermal effects associated with non-unity reactant Lewis numbers are not destabilizing. It is important to identify methods of suppressing the hydrodynamic instability so as to insure fire safety, particularly in space.

Under normal-gravity conditions, it is generally possible to suppress the hydrodynamic instability by sufficient reduction of the flow cross-sectional area, thereby restricting flow disturbances to wavelengths below the unstable range, or by dilution of the reactants so as to limit the heat released by the flame [2]. However, these approaches are at the expense of increased heat loss and decreased reactant consumption rates. Furthermore, the effectiveness of these approaches may be severely limited in space, since under microgravity conditions there is no stabilizing influence of buoyancy and, as a result, the influence of the hydrodynamic instability may be stronger.

It has been demonstrated recently that one-dimensional acoustic waves can suppress the hydrodynamic instability and prevent the growth of flame-surface wrinkles under normal-gravity conditions [3]. An objective of the present work is to determine the effectiveness of such acoustic waves in suppressing the influence of the hydrodynamic instability on planar and weakly wrinkled flames under microgravity conditions, where the instability is expected to be stronger. Another objective of the work is to examine the influence of the hydrodynamic instability on flame propagation in low-intensity turbulent flow. In particular, it is of interest to determine the relationship between the burning rate and the intensity of turbulence and how this relationship is influenced by the hydrodynamic instability. Theoretical analyses neglecting hydrodynamic coupling have predicted two fundamentally different relationships, depending on the extent of randomness of the velocity fluctuations [4,5]. A third objective of the proposed work is to examine the effectiveness of low-intensity turbulence in suppressing the hydrodynamic instability. It is expected that high-intensity velocity fluctuations in the reactant flow, relative to the laminar burning speed, will suppress the influence of the hydrodynamic instability. It is of interest to determine the level of intensity required and if low levels of intensity could be used to enhance burning rates while also providing flame stability.

BACKGROUND

Freely propagating planar flames are known to be unstable to large-scale flow-field fluctuations, such that small-amplitude wrinkles that develop in the flame surface will grow and result in acceleration of the flame [6]. This is because the reactant flow speed decreases (increases) along streamlines approaching the flame in regions where the flame surface is convex (concave) toward the reactants, and as the motion of the flame is governed primarily by the local reactant flow speed, the flame will tend to become more wrinkled, as both convex and concave bulges grow in amplitude and variations in the local reactant flow speed increase over time. Acceleration of the flame is a consequence of the resulting increase in flame surface area. This instability associated with coupling between the dynamics of the flame and the incompressible reactant flow was discovered independently by Darrieus [7] and Landau [8].

A planar flame will be unstable to reactant-flow fluctuations and undergo wrinkling and acceleration if the Darrieus-Landau hydrodynamic instability is weaker than any existing stabilizing influences which act to suppress flame wrinkling. Two stabilizing mechanisms are well known, those associated with thermal-diffusive effects and buoyancy [6], and a third mechanism associated with one-dimensional acoustic waves has been recently established [3,9]. Small-wavelength wrinkles are stabilized by thermal-diffusive effects for sufficiently large reactant Lewis numbers, while large-wavelength wrinkles are stabilized by buoyancy for downward flame propagation. Acoustic waves propagating along the axis of flame propagation act similarly to buoyancy-induced gravity waves, by inducing a local oscillating acceleration field which dampens flame wrinkles [10]. Unlike buoyancy, however, the influence of these one-dimensional acoustic waves is expected to be stabilizing even for flames that are not propagating downward and, thus, is independent of the presence of or direction of a gravitational field [10]. The strength of the hydrodynamic instability itself increases with the strength of the reactant mixture, as represented by the amount of heat released per mass of reactants or the value of the planar, laminar flame speed. Therefore, whether flame propagation in a given reactant mixture will be stable or not depends on the strength of the mixture, as determined by the equivalence ratio and the extent of heat loss to the burner walls, as well as the size of the combustor and the presence of a gravitational or acoustic acceleration field.

RESEARCH PLAN

Fig. 1 shows a schematic diagram of the Taylor-Couette (TC) combustor to be used for the experiments. It is a modified version of a TC combustor that has been used in our laboratory to study flame propagation under normal gravity conditions. It will consist of two vertically oriented, concentric cylinders capable of independent rotation in either direction. The inner cylinder will be made of aluminum, with an anodized outer surface, and the outer cylinder made of glass to allow optical access to the annulus gap separating the two cylinders. The annulus gap is sealed at the bottom of the combustor and open to the atmosphere at the top. Reactants are introduced into the annulus through many small holes in the bottom of the inner cylinder and flow upward toward the top of the combustor where the flame is ignited. The flame will be first stabilized in the top section of the combustor by weak straining of the flow, in the region of changing annulus area, while the hydrodynamic instability is suppressed with longitudinal acoustic waves introduced into the annulus by an array of loud speakers above the combustor. In this way, a planar or weakly wrinkled stable flame can be established in the upper section of the combustor before downward propagation through the smaller-area region and development of

the hydrodynamic instability under microgravity conditions occurs. Pre-ignition turbulence intensities will be controlled by counter rotation of the TC cylinders, and the propagation of the flame through the combustor will be measured with a high-speed film or CCD camera. The flame speed will be measured from video records and correlated with levels of pre-ignition turbulence intensity and reactant-mixture properties which determine the strength of the hydrodynamic instability, such as heat released per mass of reactants and reactant Lewis numbers. Experiments will be conducted with and without acoustic-wave suppression of the hydrodynamic instability during propagation in order to evaluate the influence of hydrodynamic coupling.
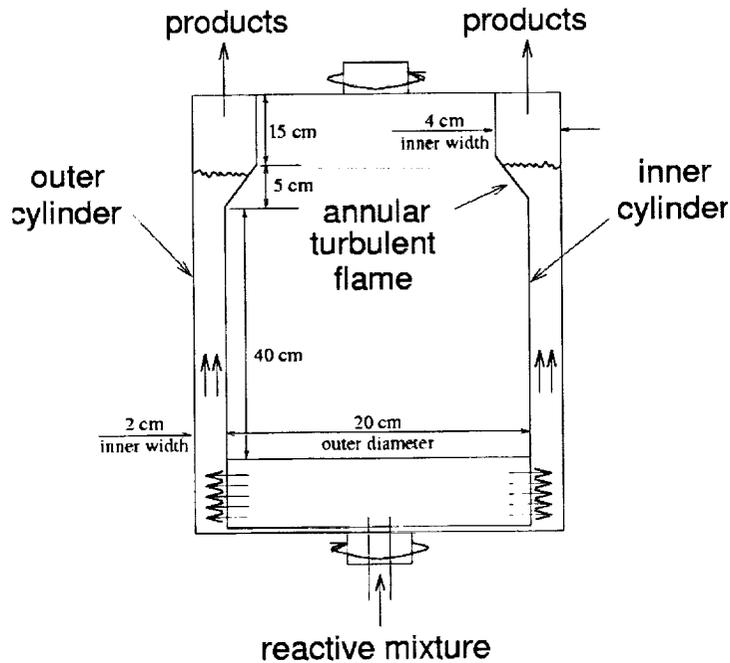

FIG. 1

With the dimensions chosen for the TC combustor, as represented in Fig. 1, the time required for a flame to propagate through the lower section of the combustor will be no longer than about 4 sec for the weakest methane-air and propane-air mixtures to be considered (having burning speeds as low as 10 cm/s), but less than 1 sec for flame propagation in stronger mixtures; stabilization of the flame in the variable-area section of the combustor will be accomplished prior to attaining microgravity conditions. Therefore, many of the experiments can be conducted in the 2.2-sec NASA drop tower, although the 5.18-sec drop tower will be necessary for a few with weak reactant mixtures and no appreciable flame-wrinkling.

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