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STABILIZATION AND BLOWOUT OF
GASEOUS- AND SPRAY-JET FLAMES

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SUMMARY/OVERVIEW:

A research program to focus on experimental work in lifted flames (gaseous and spray) has been initiated. In particular, the group is interested in the similarities of spray and gaseous lifted-flame structures, similarities and differences in apparent stabilization phenomena, the role of mixing in each and blowout phenomena. Discussed in this report are the details of experimental findings in gaseous combustion and proposed experiments primarily in spray combustion and how the information and data to be obtained aids in understanding the physics of flame stabilization in general.

TECHNICAL DISCUSSION:

GASEOUS COMBUSTION. A sufficient understanding of the concepts governing the stability of turbulent diffusion flames is essential because of their widespread appearance in combustion applications (Schefer and Goix 1998). Examining the lifted diffusion flame, from both spray and gaseous sources, provides a meaningful system in which to develop this understanding. Simultaneous velocity and concentration field measurements in reacting flows are desirable because they provide a deeper understanding of the flow behavior, including stabilization and local extinction. Experiments have been performed by our group to measure the instantaneous velocity and CH radical concentration fields in a lifted methane jet diffusion flame.

CH is an excellent radical for marking the reaction zone of hydrocarbon flames. The short-lived transient nature of CH at an intermediate stage of combustion makes it an accurate Planar Laser-Induced Fluorescence (PLIF) imaging tool for indicating flame front location and thus the region of stabilization. Additionally, the well-defined reaction surface indicated by the fluorescence signals of CH provide a excellent means for evaluating the role of local extinction in lifted flames. Instantaneous velocity field measurements, indicated by Particle Image Velocimetry (PIV), in conjunction with CH images present an improved indicator of the flowfield behavior near these regions.

The simultaneous PIV/CH-PLIF measurements provide an accurate method for determining the location of the stabilization point and the flow velocity at this critical location. While previous studies have estimated the stabilization point velocity by assuming the flame stabilizes in the region of low seed particle density indicated by the PIV images, the CH profiles of this study provide a more accurate indication of the flame front location. An important conclusion that supports previous findings is that the flame is stabilized against the incoming unburned gas in a region of relatively low velocity (1.18 m/s) that is comparable to the premixed laminar burning velocity ($\sim 3S_L$).

The extent of premixing at the flame front and its role as a stabilization mechanism is a common source of disagreement among current theories. Recently, triple, or tribrachial, flames have received substantial consideration as the anchoring mechanism for lifted flames (Kioni et al 1999). Triple flames consist of an ordinary diffusion flame surrounded by two premixed flames, one fuel-rich and one fuel-lean, which join at the triple point. The two premixed zones allow for flame propagation against the incoming unburned flow while the trailing diffusion flame extends downstream from the premixed regions.

Our group at N.C. State, in collaboration with the Air Force Research Laboratory, recently reported some of the first experimental evidence for the "leading edge" flame as a primary stabilization mechanism in lifted diffusion flames. CH is an excellent radical for marking the reaction zone of hydrocarbon flames. The "leading edge" flame phenomenon refers to the outward-extending branch of CH fluorescence at the base of the streamwise CH zones. The "leading edge" flame is regarded as a source of thermal energy which anchors the trailing diffusion flame. Whether the "leading edge" flame is a special case of the more general triple flame is a question which remains unanswered. It is evident from previous computational studies that the triple flame, when interacting with a vortex or pair of vortices, can take on characteristics of the "leading edge" flames introduced in the present study. Several diagnostic studies involving lifted flames present the lifted flame structure as a continuous flame surface, similar to a distorted cylindrical object, emanating from a ring-shaped structure where the flame is stabilized. Most previous work, however, does not give experimental evidence of the *mechanism* of lifted flame stabilization. Shown in Fig 1 (see Watson et al 1999) are several CH-PLIF images from our work which provide such evidence. Each image was collected from the same spatial location and represents an instantaneous realization of the flame zone. The images clearly show a continuous vertical distribution of CH which represents the primary diffusion flame reported in many previous studies.. In addition to the vertical trailing diffusion flame, a structure is witnessed near the flame base which curls toward the outside, or fuel-lean, portion of the reaction zone. In comparison to ideal, laminar tribrachial structures, evidence of both rich and lean branches of premixed flame are not present, only the one branch extending outward near the jet edge. However, the rich branch on the fuel side of the diffusion flame may be overlapped into the diffusion flame by the flowfield. It is believed that the branch in the CH zone is a "leading edge" flame, stabilized by opposing the flow in the relatively low speed region (approx. 1.0 m/s) near the outside edge of the jet.

The extent of mixing and the entrainment of ambient air into the fuel is of central importance to this problem. Based on comparisons with mixture fraction images, which illustrate that the portion at the base of a lifted methane flame has a flammable composition, the PI is confident that the leading edge flame lies in a flammable mixture fraction region (Kelman et al 1998). Furthermore, fluctuations in the axial location of the leading edge, along with its orientation relative to the trailing diffusion flame, imply propagation into the unburned gas region. Together, these facts support the notion of premixing as a primary mechanism of lifted flame stabilization even for flames in the near-field.

SPRAY COMBUSTION. The current work in spray flame stabilization is motivated by the results discussed earlier on observation of leading edge phenomena in gaseous jet flames. There have been many studies published on bluff-body stabilization of flames that attempt to account for flame stabilization. In the context of spray flames (Stepowski et al 1994, Cessou et al 1999), these studies have been largely geared toward understanding phenomena in gas turbine combustion and other systems where fuel is injected as a spray. If one views the combustion zone down from a flame holder (bluff body) as a homogeneous chemical reactor (homogeneous composition and temperature), then flame extinction is thought to occur when the amount of heat needed to ignite the fresh reactants exceeds that amount received by local combustion. Central to this picture is the recirculation zone and the need for entrainment into the wake region, whether spray or gaseous combustion is considered. As is true of earlier work in gaseous lifted-flame combustion, the lack of appendages in the flow to create recirculation zones in our geometries makes it difficult to apply results from previous flameholding studies. Thus our main reason for continued interest in the lifted spray flame is to acquire experimental data indicative of the nature of the flamefront in lifted spray flames and contrast the structures with our gaseous flame results. For example, it is not clear if the leading edge phenomena witnessed in our gaseous studies correspond with the dual fronts witnessed in the vaporization regime of spray combustion or if the phenomena are fundamentally different. The nature of the flamefront in the stabilization region of a corresponding *spray-jet flame* is currently unknown. Whether spray flames exhibit "leading edge" flame structures as shown by our group for the gaseous case is a major question to be addressed by this research. Detailed study of spray jet flames (see typical experimental setup in Figure 2) is being currently initiated in order to illuminate the features common to both systems and show differences in the flame structure and dynamics of the spray and gaseous systems.

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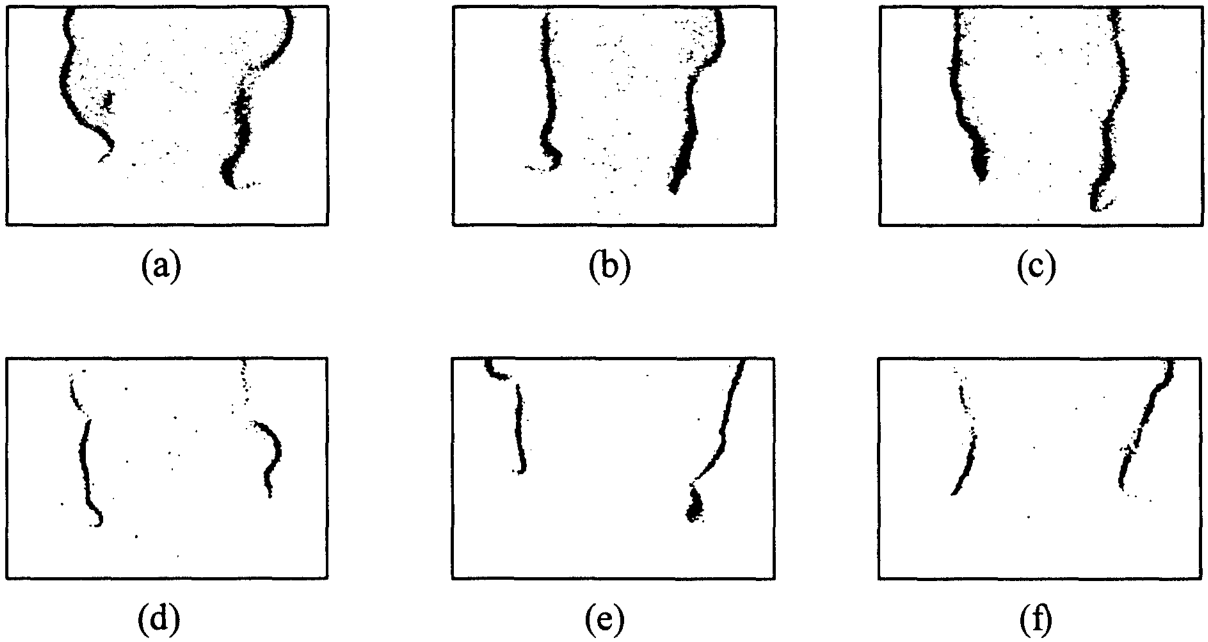

Figure 1 – Shown are the leading edge flame structures (CH) near the stabilization zone in a lifted gaseous methane flame. These observations help drive our interest in examining spray flames for the presence of similar structures.

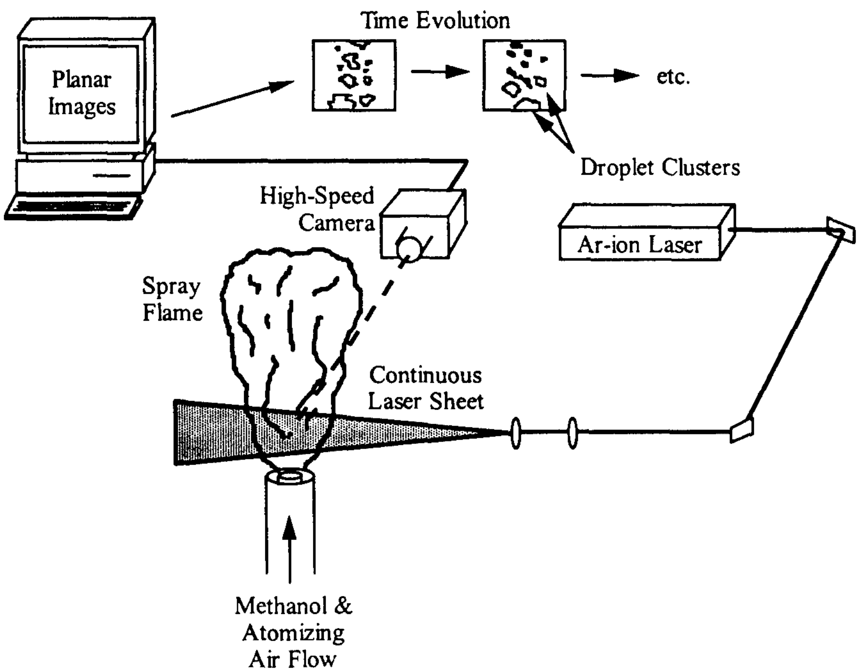

Figure 2 – Schematic of typical experimental setup for examining spray flames