aerodynamic blockage (q_b) yields a net heat flux input which is slightly greater over the first half of the cycle, but not enough to account fully for the trend in q_L. The apparent dominant factor is the heat flux reradiated from the surface (q_{rr}) which is seen to be appreciably greater over the second half of the cycle. A similar result is obtained for the inverted heating cycle Thus, reradiation from the char surface appears to be the main reason for the average pyrolysis mass-loss rate being greater during the first half of the heating cycle. This result might be anticipated if one notes that the surface temperature is greater over the last half of the heating cycle than over the first half. This observation is true for both the theoretical and experimental results.

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Response of a Low-Speed Flame to Flame-Holder Vibration

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Nomenclature

A/F = air-fuel ratio
D = flame-holder diameter
L = flame-front characteristic length
V = air-fuel mixture velocity
ϵ = density ratio across flame front
λ = wavelength
φ = Markstein parameter

Introduction

EXPERIMENTAL observations have shown that the small disturbances produced by a vibrating flame-holder may, under certain conditions, be transmitted along the flame front. This response appears on schlieren flame photographs as evenly spaced wrinkles along the flame front. This phenomenon has been the object of several analytical and experimental studies. In general, these studies have attempted to predict the regime of "flame stability." Flame stability, generally associated with lean and rich mixture flammability limits, in the present context deals with the flame response to disturbances in the flow. A stable condition exists when these disturbances decay with time and are not transmitted along the flame front.

Markstein's[1] classic work on the subject of flame stability predicts that a flame will be stable to disturbances of short wavelengths (high frequencies) and unstable to long wavelengths (low frequencies). The wavelength at which this transition occurs is known as the cutoff wavelength ($\lambda_{c.o.}$). In the development of flame stability theories, the presence of a flame-holder is not considered. The purpose of this work was to determine experimentally the effect of flame-holder diameter on cutoff wavelength, and thus flame stability, of a low-speed air-propane flame. To accomplish this, various air-fuel ratios, mixture velocities, and flame-holder sizes were used in the experiments. The range of air-fuel ratios, from 10 to 22, gave a wide spread of rich and lean mixtures. Mixture velocities of 8, 12, and 16 fps were used and flame-holder diameters were varied from $\frac{1}{8}$ in. to $\frac{3}{4}$ in. The range of Reynolds number based on flame-holder diameter and mixture speed was 600–3000.

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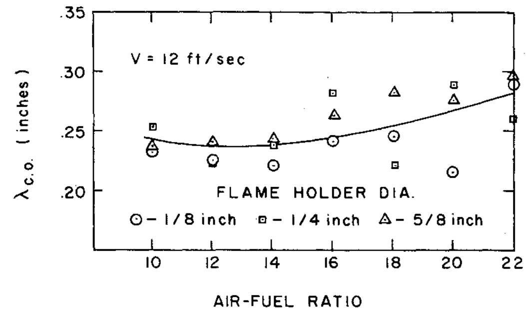

Fig. 1 Cutoff wavelength vs air-fuel ratio and flame-holder diameter.

Analysis

Analytical studies of flame stability have been carried out by applying the small perturbation technique to the governing nonlinear differential equations. Various stability theories have been developed by Landau, Markstein, Eckhaus, Einbinder, and Parlange and Chu. These theories are discussed in detail in Ref. 2. Markstein's stability theory has been verified over the lean A/F range by Petersen,[3] and the results of the present work are correlated on the basis of the Markstein theory.

This theory predicts the cutoff wavelength to be

$$\lambda_{c.o.} = 4\pi\mu L\epsilon/(\epsilon - 1) \quad (1)$$

The density ratio ϵ can be calculated and thus a measurement of the cutoff wavelength can be used to determine μL. This quantity can also be determined from a measurement of the natural wavelength which appears on the flame front with no external excitation by making use of the Markstein maximum theory.[3]

Experimental Results

The experiments[4] were performed in the University of Oklahoma Combustion Tunnel. The flame-holder was linked

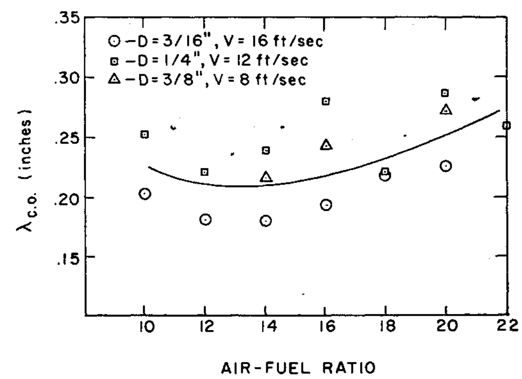

Fig. 2 Cutoff wavelength vs air-fuel ratio at constant Reynolds number (1300).

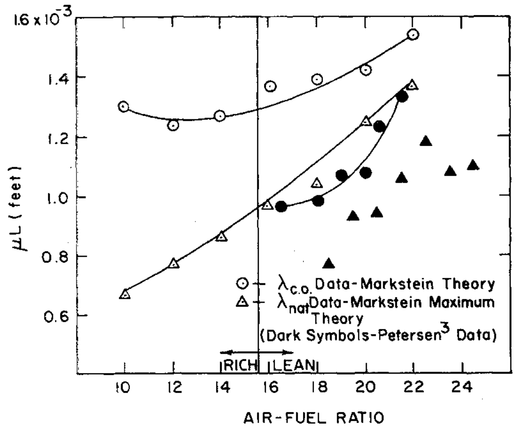

Fig. 3 μL **vs air-fuel ratio.**

mechanically to an electromagnetic vibration exciter. Thus the flame-holder could be held stationary or vibrated over a range of frequencies to determine the response of the flame. A schlieren system was used to photograph the flame front at various frequency intervals as the forcing frequency at the flame-holder was increased from zero. The length of the flame-front wrinkles (wavelength) correspondingly decreased to a minimum. This point corresponded to the cutoff wavelength. As the forcing frequency was further increased, the wavelength returned to the natural wavelength value for all higher frequencies. This, then, was the region of flame stability.

The first set of tests were run at a constant mixture velocity with various size flame-holders (see Fig. 1). There is a general trend toward increasing cutoff wavelength with increasing air-fuel ratio. The slight increase in $\lambda_{c.o.}$ with increasing flame-holder diameter is not considered significant since the maximum spread of data points at any air-fuel ratio is within the range of the experimental error. Figure 2 shows $\lambda_{c.o.}$ vs A/F ratio for mixture-speed-flame-holder combinations having the same Reynolds number ($\sim$1300). The product VD was thus held constant. In light of the previous conclusion (no dependence on flame holder size), no correlation between $\lambda_{c.o.}$ and mixture velocity was found. The experimental values of μL are shown in Fig. 3. The calculations were based on average $\lambda_{c.o.}$ and λ_{nat}, values found in this experiment. Similar data by Petersen are shown in this figure.

Conclusions

Of primary interest in this experiment was the effect of flame-holder size on flame stability. For the three sizes tested there was no significant effect on cutoff or natural wavelengths. The set of data at constant Reynolds number indicated that mixture velocity does not affect flame stability. The cutoff and natural wavelengths increased with increasing air-fuel ratio with minimum values occurring between A/F ratios of 10–14. The average cutoff data and the values of μL found in this experiment show good agreement with other reported experimental data. Thus, the presence of the flame-holder appears to have no significant effect on flame stability.

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Drag of Streamers at Subsonic Speeds

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Nomenclature

A = surface area of one side of streamer
C_D = drag coefficient based on the surface area
f = frequency
g = gravitational constant
l = streamer length or chord
s = streamer width or span
U = ambient stream velocity
w = streamer weight per unit area
ρ = ambient stream density

1. Introduction

PROJECTILES are normally either stabilized gyroscopically or aerodynamically by the use of fins. For certain types of subprojectiles dispensed from a parent container, drag stabilizers may also be used since a high drag is not necessarily a disadvantage. Drag devices may also assist packing and be better able to withstand the severe loads applied during the launching of the parent container. One such drag device is a streamer or flag. Before studying the complex motion of a projectile stabilized by streamers a number of preliminary tests were undertaken to measure the drag of streamers alone to determine the drag dependence on parameters such as size, weight, shape, and velocity. These preliminary experiments are reported in this Note. They were deemed necessary because the only relevant information in the literature was aimed at the drag of advertising streamers towed behind light aircraft in 1930.[1]

2. Apparatus

The tests were undertaken in a small subsonic tunnel with a working section 0.46 m square. The speed range was 14–37 m/sec giving Reynolds numbers of 0.95–2.32 × 10^6 per meter.

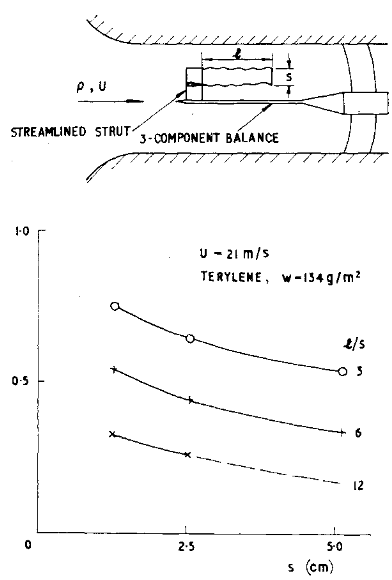

Fig. 1 Streamer drag as a function of width.

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