

Figure 1

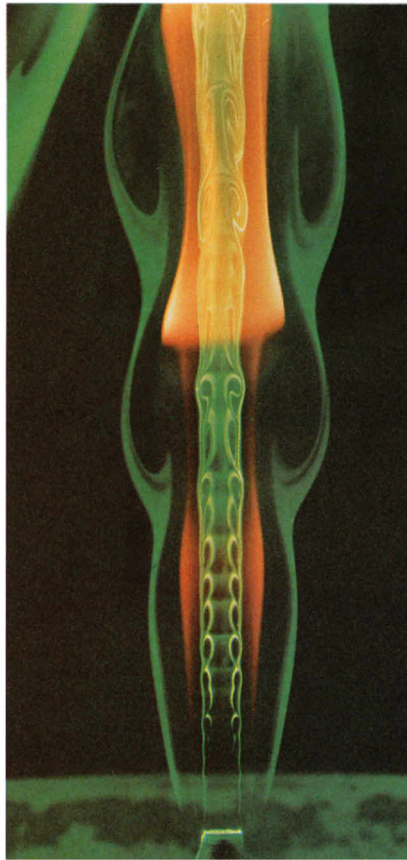


Figure 2



Figure 3

## JET DIFFUSION FLAME TRANSITION TO TURBULENCE

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Figures 1–3 illustrate the detail with which a novel laser sheet-lighting technique can be used to visualize processes occurring inside and outside of jet diffusion flames.<sup>1</sup> The test configuration consists of a 1 cm diam methane jet surrounded by a 15 cm/sec annulus air flow. Dry fuel and coannular air are seeded with  $\text{TiCl}_4$  vapor. The  $\text{TiCl}_4$  reacts spontaneously and nearly instantaneously with the water product to form micron-size  $\text{TiO}_2$  particles. Mie scattering from the  $\text{TiO}_2$  particles is observed at right angles to a sheet of laser light passing vertically through the center of the flame. This provides a view of the flow field where the water product mixes with the air outside the flame and with the fuel inside the flame surface. The exposure time for the green laser light in the photographs is 10 nsec and is 2 msec for the sooting yellow flame.

The laminar to turbulent transition in jet diffusion flames is shown in Figs. 1–3. At low and intermediate fuel velocities, the toroidal vortices observed outside the visible

flame surface play a dominating role in determining the flame structure. The rotation of the toroidal vortices pulls the flame radially outward forming a flame bulge as shown in Fig. 1. As the fuel velocity is increased, the flame has less time to be affected by the rotation of the outer vortices and the flame bulge is reduced in size (Fig. 2). The frequency of the outer vortices (same as that of the flame bulge) corresponds to the flame flicker frequency of about 12 Hz. The outer structures are believed to be established by a buoyancy driven shear layer.

The turbulent characteristics of jet diffusion flames are most clearly illustrated by the fuel/water product interface occurring inside the flame surface. An initial instability wave is shown in Fig. 1. This inner instability develops into coherent vortices as the fuel velocity is increased (Fig. 2). At higher fuel flow rates, the inner vortices lose their coherence through a coalescence process and, at some distance downstream, small scale, unorganized vortex structures are formed (Fig. 3). We believe that flamelets (small protrusions of the flame surface) are the result of localized collisions of the small scale vortices with the flame surface. When a vortex, with a very large radial velocity component, collides with the flame surface, the flame can stretch and quench so that a localized hole appears. If the hole is formed near the jet exit, where the flame is already highly stressed, the hole will open up and the flame will lift.