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AERODYNAMIC FEATURES OF FLAMES IN PREMIXED GASES

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A variety of experimentally established flame phenomena in premixed gases are interpreted by relating them to basic aerodynamic properties of the flow field. On this basis the essential mechanism of some well known characteristic features of flames stabilized in the wake of a bluff-body or propagating in ducts are revealed. Elementary components of the flame propagation process are shown to be: (1) rotary motion, (2) self-advancement, and (3) expansion.

Their consequences are analyzed under a most strict set of idealizations that permit the flow field to be treated as potential in character while the flame is modelled as a Stefan-like interface capable of exerting a feed-back effect upon the flow field. The results provide an insight into the fundamental fluid-mechanical reasons for the experimentally observed distortions of the flame front, rationalizing in particular its ability to sustain relatively high flow velocities at amazingly low normal burning speeds.

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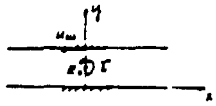
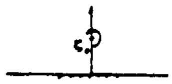
Schwarz-Christoffel Transformation:

(i) channel with open ends



z - plane



ζ - plane

$$F(\zeta) = \frac{d\zeta}{dz} = \pi\zeta$$

$$\zeta = e^{\pi z}$$

Location of vortex center in the physical plane $z_0 = \frac{1}{2}i$,

in the transformed plane $\zeta_0 = e^{\pi z_0} = i$

Complex velocity in the transformed plane

$$w(\zeta) = -i\Gamma\left(\frac{1}{\zeta-\zeta_0} - \frac{1}{\zeta+\zeta_0}\right) = \frac{2\Gamma}{\zeta^2+1}$$

Complex velocity in the physical plane

$$w(z) = u - iv = w(\zeta)F(\zeta)$$

$$= \frac{2\Gamma}{\zeta^2+1}\ \pi\zeta$$

$$= \frac{2\pi\Gamma}{\zeta+\zeta^{-1}} = \frac{2\pi\Gamma}{e^{\pi z}+e^{-\pi z}}$$

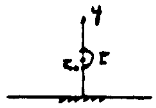
at $z_w = i$ (i.e. $x=0$, $y=1$)

if $\Gamma = 1/\pi \Rightarrow w(z_w) = -1 = u_w$

$|u_w| = 1$ is thus taken as the reference velocity.

(ii) channel with one closed end

z - plane



ζ - plane

$$F(\zeta) = \frac{d\zeta}{dz} = -\pi\sqrt{\zeta^2-1}$$

$$\zeta = \cosh(\pi(i-z))$$

location of vortex center in the physical plane: $z_0 = -x + \frac{1}{2}i$,

in the transformed plane: $\zeta_0 = \cosh(\pi(i - z_0))$

$$= \cosh(\pi(x+\tfrac{1}{2}i))$$

$$= i\sinh x\pi$$

complex velocity in the transformed plane:

$$w(\zeta) = -i\Gamma\left(\frac{1}{\zeta-\zeta_0} - \frac{1}{\zeta+\zeta_0}\right) = -i\Gamma\frac{2\zeta_0}{\zeta^2-\zeta_0^2}$$

complex velocity in the physical plane:

$$w(z) = w(\zeta)F(\zeta)$$

$$= -\frac{i2\Gamma\zeta_0}{\zeta^2-\zeta_0^2} \cdot -\pi\sqrt{\zeta^2-1}$$

$$= \mp\frac{2\pi\Gamma \sinh x\pi \sinh \pi z}{(\cosh \pi z)^2+(\sinh x\pi)^2}$$

If $\Gamma = -1/\pi$ and $x = 3$

at $z_w = -3+i$, $w(z_w) = 1 = u_w$

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Case 1 Deformation of Flame fronts due to effects of three elementary components of flame propagation mechanism

* initial interface · straight line
* vortex is located at the center of the interface with circulation $\Gamma = 1/\pi$ and core radius $r_0 = 0.05$
* flame propagation speed $S_u = 0.4$
* density ratio $\beta = 3.0$
* time step $\Delta t = 1.7857 \times 10^{-3}$

Fig. 1 Deformed flame fronts and velocity field in the physical plane at 80th time step

Fig. 2 Deformed flame fronts and velocity field in the transformed plane at 80th time step

Fig. 3 Enlargement of inner portion of Fig 2

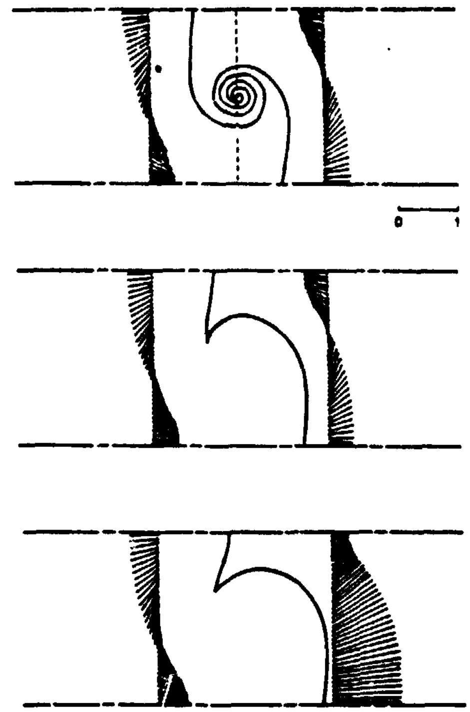

Fig 1

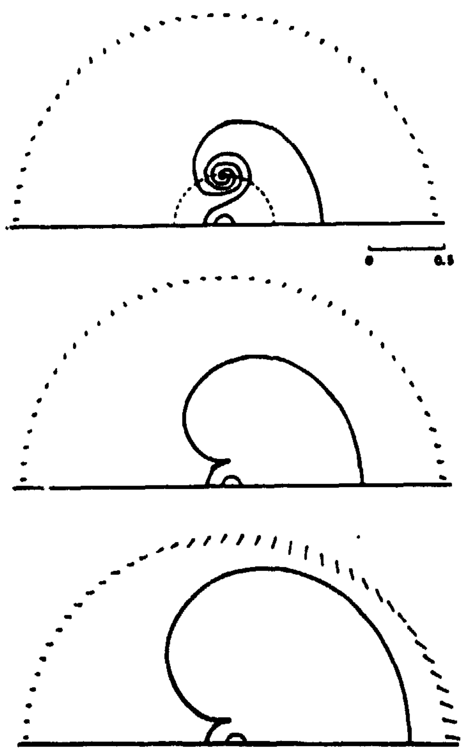

Fig 2

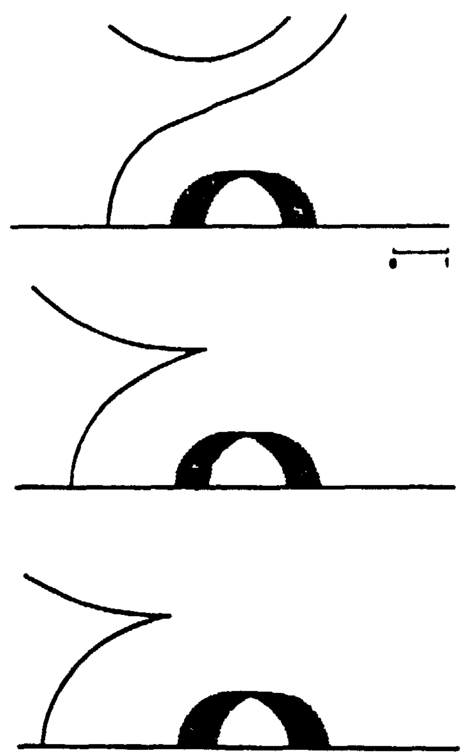

Fig 3

Case 2: Turbulent Flame propagation in a channel

* initial interface straight line
* vortex with circulation $\Gamma = 1/\pi$ is located at the center of the channel and 0.5 to the left of the interface — stays stationary
* flame propagation speed $S_u = S_u(r_f)$ with $S_{u_{max}} = 0.4$
* density ratio $\beta = 3.0$
* time step $\Delta t = 1.7857 \times 10^{-2}$

Fig. 4 Deforming flame fronts at every 40 time steps.

Fig. 5 Flame fronts and velocity field in the physical plane at 120^{th} time step

Fig. 6 Flame fronts and velocity field in the transformed plane at 120^{th} time step

Fig. 7 Enlargement of the inner portion of Fig 6

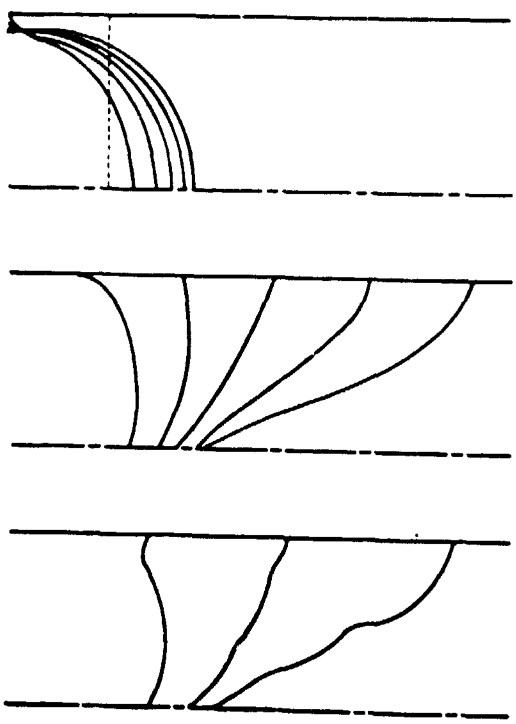

Fig 4

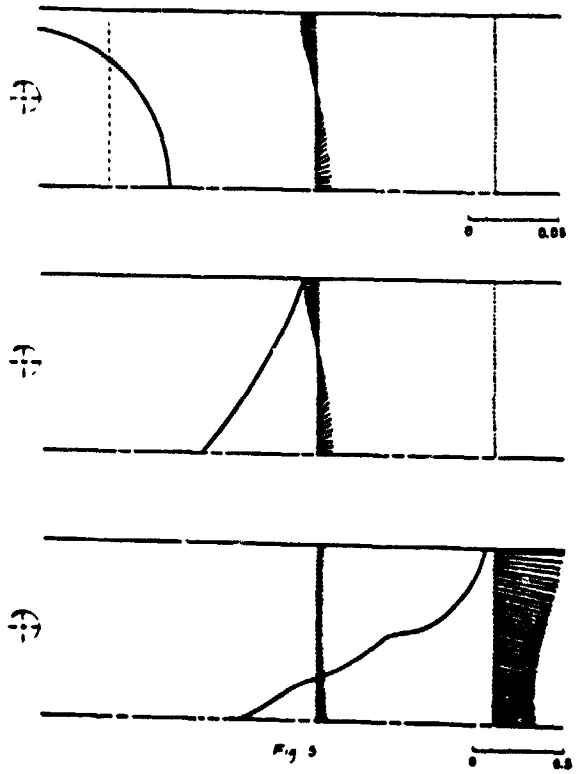

Fig 5

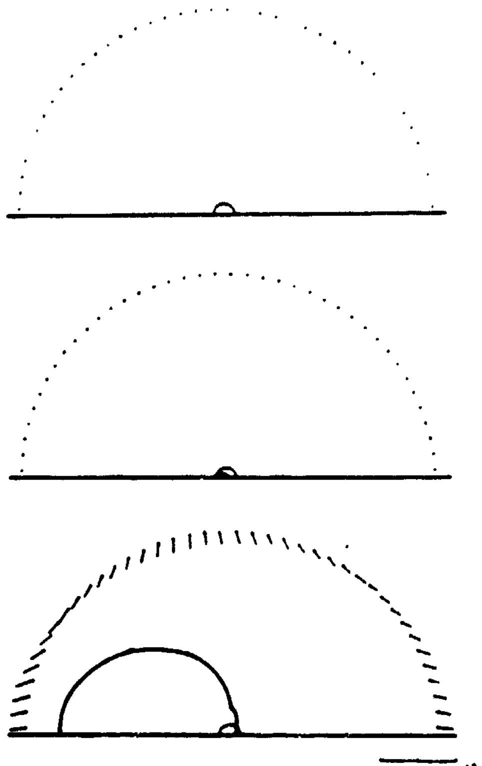

Fig 6

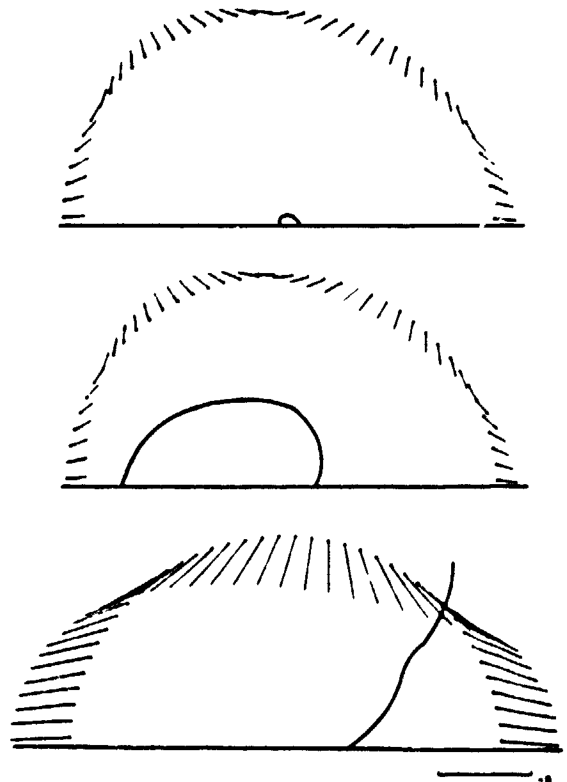

Fig 7

Case 3. Laminar flame propagation in a channel

* initial interface: straight line
* vortex is also located 0.5 to the left of the interface with circulation $\Gamma = -1/\pi$ and moving to the right at constant speed 0.0075
* flame propagation speed $S_u = 0.4$
* density ratio $\beta = 3.0$
* time step $\Delta t = 1.7857 \times 10^{-2}$

Fig 8 Flame fronts and locations of vortices at 40th, 120th and 200th time step

Fig 9 Flame fronts and velocity fields in the physical plane at 200th time step

Fig 10 Flame fronts and velocity field at different location in the physical plane

Fig 11 Flame fronts and velocity field in the transformed plane at 200th time step

Fig 12 Enlargement of inner portion of Fig 11.

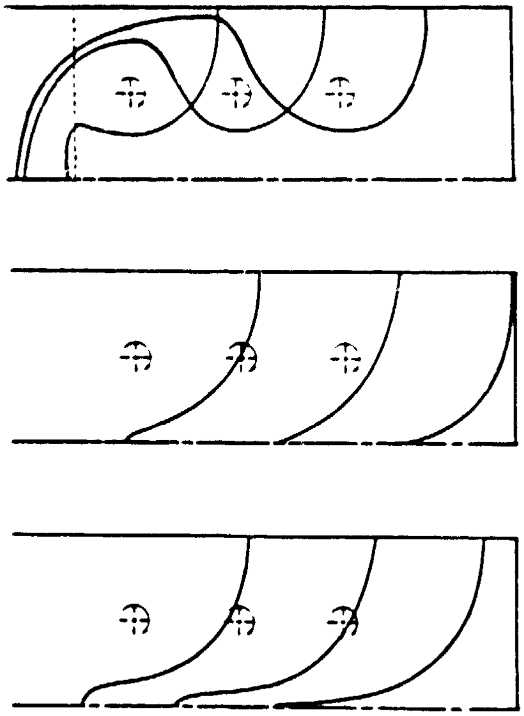

Fig. 8

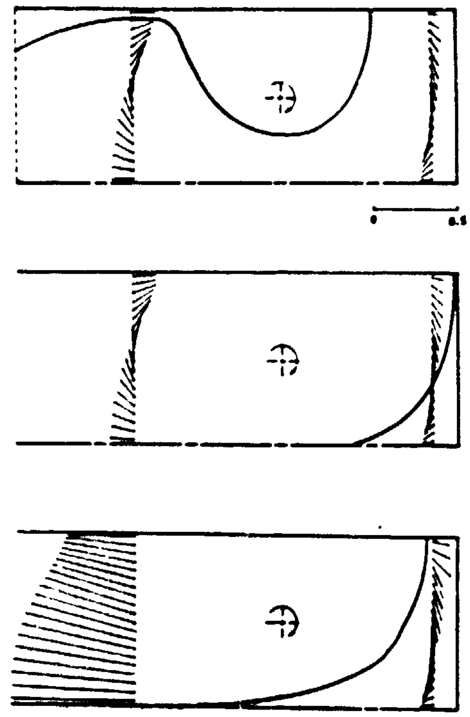

Fig. 9

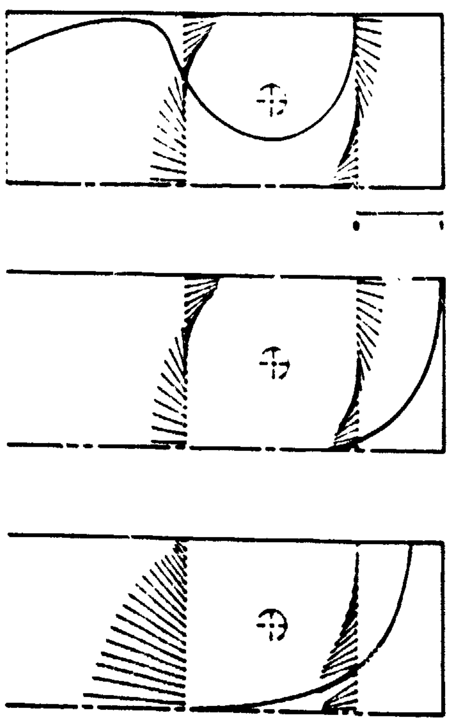

Fig. 10

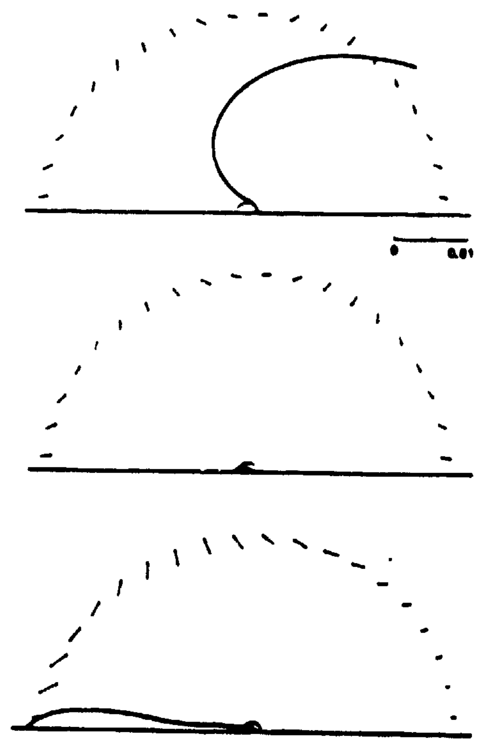

Fig. 11

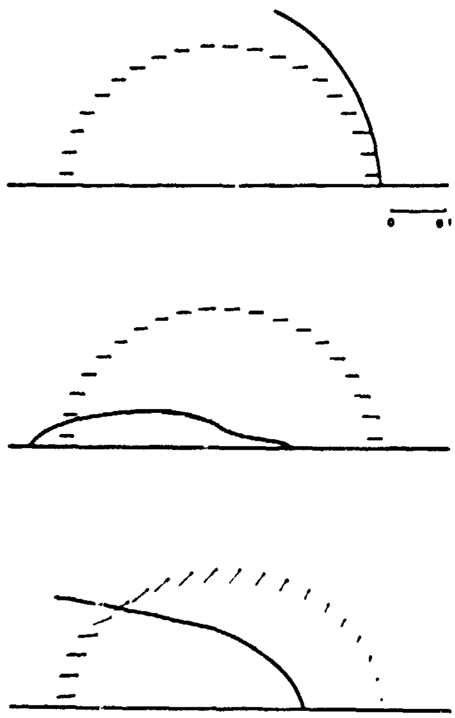

Fig 12