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ROCKET FLAMES

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Among the important parameters which characterise the rocket flames are the (1) velocity, (2) pressure, (3) temperature of the exhaust gases and (4) the nature of chemical reactions in the flame of such gases. For the determination of these quantities ordinary methods fail because the flow of exhaust gases is supersonic in character. An introduction of a probe or any foreign body will create such strong disturbances in the supersonic flow that the readings of observing instruments will have no value. Spectroscopic methods are therefore eminently suitable because observations can be taken on the flame under running conditions.

Determination of velocity by spectroscopic method is based upon the utilization of the well known Doppler effect. For a body moving with a velocity v, towards or away from an observer, making an angle θ with the line of sight, the displacement of wave length is—

$$\frac{\delta\lambda}{\lambda} = \pm \frac{v}{c} \cos \theta$$

where c is the velocity of light. If the observations are taken in two different directions θ_1, θ_2 the difference in the two displacements will be

$$\frac{\delta\lambda}{\lambda} = \frac{v}{c} (\cos\theta_1 - \cos\theta_2)$$

For any velocity attainable on the earth v/c is so small that it is difficult to detect the shift. The stars, however, show appreciable shifts since they move with velocities ranging between 10 and 30 Km/Sec, with some as high as 300 Km/Sec.

In rockets, the velocities of exhaust gases are about 2 Km/Sec, giving a spectral shift of less than 0·1 Angstrom unit. For detection of such small shifts, instruments of highest resolving power have to be used and the one recently used is the Febry-Perot Interferometer, whose principle is as follows :

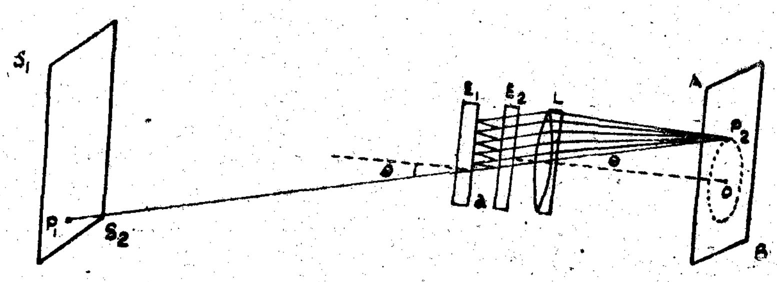

FIG. 1

* Paper read on April 24, 1952 at the Defence Science Conference held in Delhi.

E_1, E_2, are two glass plates thinly silvered on the inside. Light from a broad source S_1 S_2 suffers multiple reflections and circular fringes are produced on the screen AB. A ray from a point P_1 on the source is incident on the plate at an angle θ ; the ray suffers several reflections between the two plates and the parallel reflections are brought to the point P_2. The condition for reinforcement is $2d \cos \theta = m\lambda$. The wave-length interval between successive fringes for $\lambda = 5893 \times 10^{-8}$cms, with the interferometer set at $d = 0{\cdot}2034$ cm is 0·85 A°. If velocity of the exhaust gases is of the order of 2 Km/Sec., $\delta\lambda$ is of the order 0·06 A° ; thus the Doppler shift is less than one tenth of the fringe setting. Before these principles are applied to the determination of the velocity, it is necessary to consider briefly the characteristics of the different zones in the exhaust flames. These are shown in fig. 2.

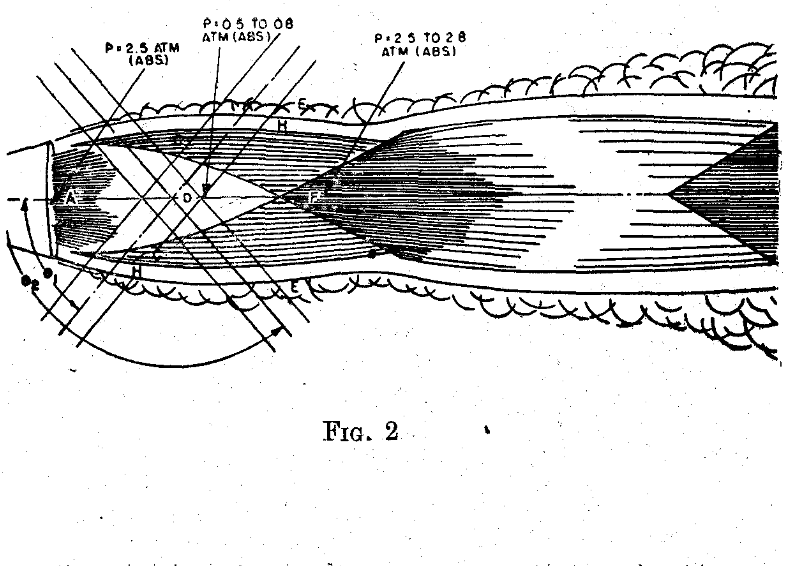

FIG. 2

If the line of sight is θ_1, the flame zones across it are, the thin subsonic boundary layer E, the relatively cool faintly luminous supersonic zone H, the hot supersonic zone C, the relatively cool overexpanded faintly luminous supersonic zone D. These are followed by repeated sections of zones C, H & E. Spectroscopically the two sections of zone C contribute the most light, zone D considerably less and zones H and E very little. The distribution of mass flow along the above zone is —— one fourth in zone H, less than half in zone C and about one third in zone D. The latter zone records highest velocity owing to overexpansion, while owing to cooling and friction by the walls, the velocity in zone H is lower than the average.

The experimental arrangements for the determination of velocities of the exhaust gases are shown in the fig. 3.

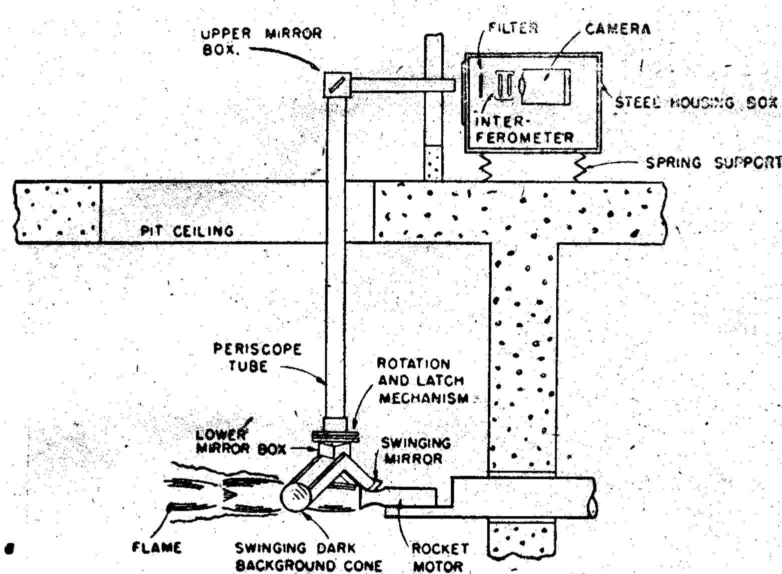

Diagram of the optical setup at the rocket test stand.

FIG. 3

Since there are strong vibrations near the rocket, the Fabry-Perot interferometer and the Camera are placed on a shock proof stand away from the rocket. Real image of the flame is focussed by the lens system of a periscope. For the velocity measurements, the periscope mirrors are so arranged that the same portion of the flame are viewed from two different angles θ_1 and θ_2 from the upstream flame axis. The Doppler shift of wave-length between these two angles of view is given by the relation,

$$\frac{\delta\lambda}{\lambda} = \frac{v}{c}(\cos\theta_1 - \cos\theta_2)$$

where v and c are the velocities of the gas and of light respectively. The interference patterns, corresponding to the two angles of view θ_1 and θ_2 are shown in fig. 4.

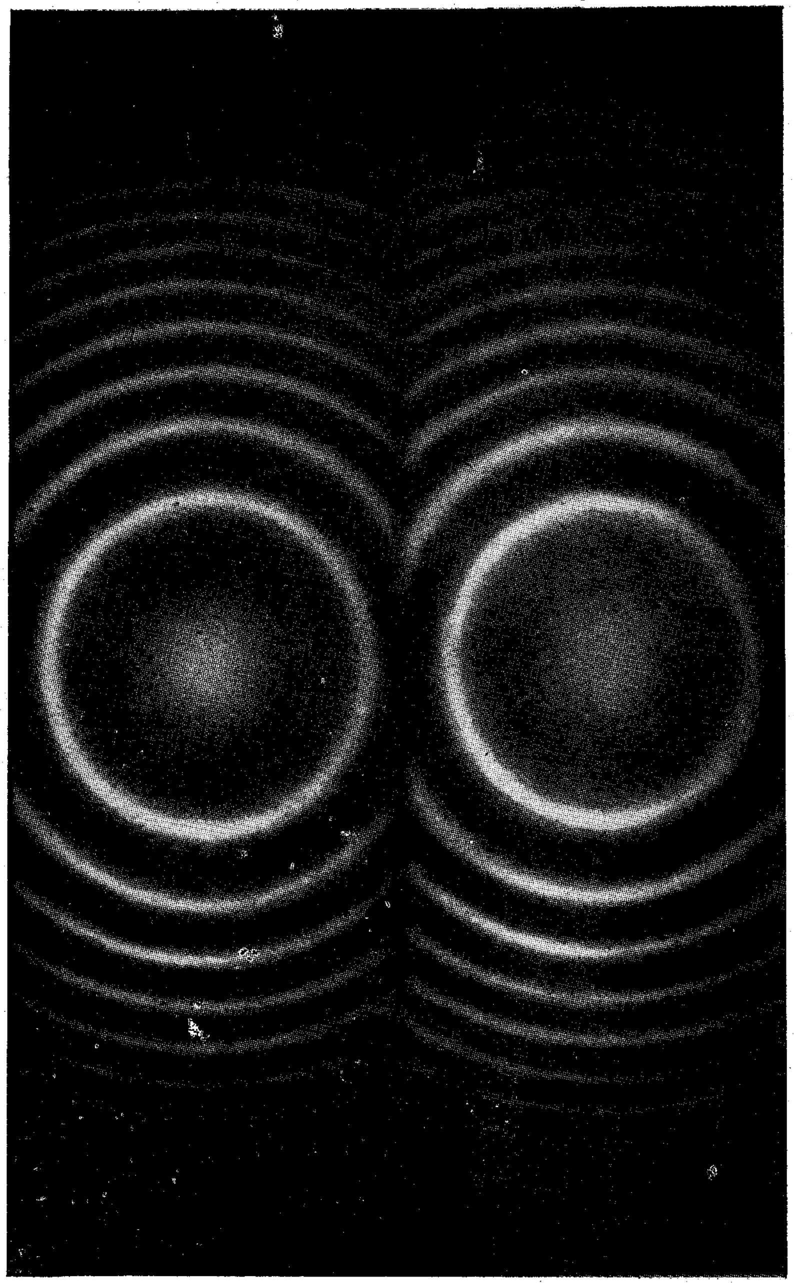

FIG. 4

For the measurement of pressure the shift of the centre of the fringe system for the D line is determined, when light is viewed at right angles to the gas-flow axis to avoid the Doppler effect. It is known that the shift is towards the red and is proportional to the absolute pressure divided by the square root of the absolute temperature and the natur e of the surrounding gas. Preliminary experiments are first carried out at known pressures and temperature and a calibration graph is drawn, between the pressure-shift $\delta\lambda$ and pressure. From the observed shift of the centre of the D lines fringe system for the rocket flames, the pressure for the latter then be calculated.

Evolution of the temperatures is much more difficult since there is no zone of uniform temperature. The central region is at a temperature higher than the outer envelope, which gives rise to dimples in the Fabry-Perot interference fringe system. Intensity contours of the fringes with the dimples have to be drawn from which temperatures can be derived.

EMISSION SPECTRA OF FLAMES

3 A
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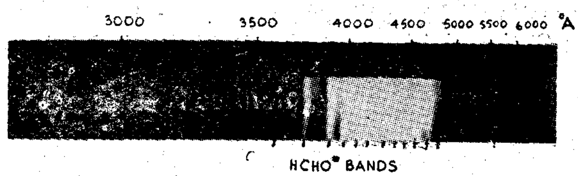
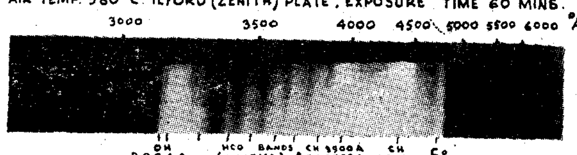


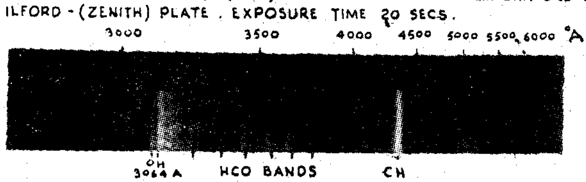
3 A. EMISSION SPECTRUM OF "COOL" FLAME NEAR JET.
KEROSENE CONTAINING 5 % (VOL.) ETHYL NITRATE PREHEATED TO 75°C.
AIR TEMP. 580°C. ILFORD (ZENITH) PLATE. EXPOSURE TIME 60 MINS.

3 B
(4 · 5 · 1945)



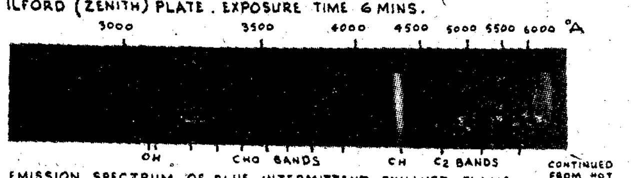
3 B EMISSION SPECTRUM OF YELLOW-LILAC EXHAUST FLAME.
KEROSENE CONTAINING 5% (VOL.) ETHYL NITRATE. AIR TEMPERATURE 970°C.
ILFORD-(ZENITH) PLATE. EXPOSURE TIME 20 SECS.

3 C
(29 5 1945)



3 C. EMISSION SPECTRUM OF LILAC EXHAUST FLAME.
DIESEL OIL. AIR TEMPERATURE 790°C.
ILFORD (ZENITH) PLATE. EXPOSURE TIME 6 MINS.

3 D
(29 · 5 · 1945)



3 D. EMISSION SPECTRUM OF BLUE INTERMITTENT EXHAUST FLAME.
KEROSENE AIR TEMPERATURE 790°C.
ILFORD (PANCHROMATIC) PLATE. EXPOSURE TIME 10 MINS.

FIG. 5.

The figures for the velocity, pressure and temperature for two different regions, D and F (See fig. 2) are

	D	F
Temperature	2200°K	2600°K
Pressure	0·8 Atm	2·6 Atm.

No data for the spectra of the exhaust flames from rockets is available, but a reproduction of the spectrum of the exhaust flame from a jet engine is given in Fig. 5.

The spectrum consists of the well known bands of C_2, CH, and OH. Besides these, there are HCO bands which were first discovered by the author in 1934. A striking feature of the spectrum is the enhanced intensity of the HCO bands. (3B, Fig. 5).

One important aspect of the study of the spectra of the exhaust flames is to understand the mechanism of production of the different radicals, which throws interesting light on the processes of combustion. Such work is in progress in the Optics Division of the National Physical Laboratory.