FLAMES AND COMBUSTION

DURING recent years the approach to combustion research has undergone a marked change from the domain of chemistry towards that of the physical sciences. This swing has been closely associated with the changing aspect of engineering requirements. The upper limit of performance of the internal combustion engine is largely set by the maximum compression ratio that can be employed without the onset of knock. Accordingly, much of the research was directed towards a better understanding of oxidation reactions in stationary systems—an essentially chemical problem. The advent of various types of jet and rocket engines, however, has emphasized the importance of heat and mass transfer in reacting flow systems, of the fundamental mechanism of flame propagation, and of the stability and structure of flame fronts. It therefore seems appropriate that, at the meeting in Bristol this year of the British Association, a series of papers on flames and combustion was included in the programme of Section A (Physics).

Dr. S. Whitehead acted as chairman of the session. The four contributions were divided equally between academic and applied research.

In general, flames can be subdivided into those which occur in the interface of the fuel and oxidant (diffusion flames), and those in which the flame front advances into a mixture of the reactants (premixed flames). In the latter case, the flame advances at a uniform velocity characteristic of the medium and can be stabilized on a burner by a suitable rate of counter-flow; in the former, the rate of burning is in general controlled by the rate of mixing. According to the flow conditions, both types of flame can be either laminar or turbulent.

The first speaker, Dr. A. G. Gaydon (Imperial College of Science and Technology, London), dealt with laminar flows in a paper entitled "The Structure of Flames". The mainly physical techniques available for the study of stabilized flames, such as measurements of temperature, spectra, ionization and others, are most effective when applied to flames of simple geometrical shape. During recent years much progress has been made in the design of special burners, and Dr. Gaydon gave a summary of the techniques now available for the stabilization of two-dimensional flame fronts both of the diffusion and of the premixed type.

The processes of heat release in the flame can be studied by the measurement of temperature distribution, by sampling and subsequent analyses, and by the study of emission and absorption spectra. The spectra, as well as indicating the presence of some short-lived chemical species, such as OH, C₂, CH and HCO, also give information about the energy distribution, and Dr. Gaydon discussed studies of effective translational, rotational, vibrational and electronic excitation temperatures. These are often quite abnormal in reaction zones, and similar anomalies are indicated by ionization measurements. Dr. Gaydon concluded his remarks by a brief summary of the main deductions from such measurements, with reference to the general structure of flames.

The second speaker, Dr. F. J. Weinberg (Imperial College of Science and Technology, London), discussed "The Study of Flames by Optical Means". It may perhaps seem rather incongruous that,

although combustion in one of its forms was probably the first type of chemical reaction consciously put to use by man, the fundamental mechanism by which flame is propagated has still not been solved completely. The reason for this lies not only in the inherent complexity of the phenomena, but is also due, to a large extent, to the extreme conditions prevailing in combustion zones. Large temperature and composition changes occurring over extremely small intervals of space and time give rise to exceedingly large gradients of temperature and concentrations and to accelerations of the order of 10^6 cm./sec.⁻². Since extrapolation of available physical and chemical data to such extreme conditions is unreliable, it is desirable to confine all studies to actual flame *in situ*, and optical methods, that is methods based on refractive index changes attendant upon combustion, constitute a most powerful tool in such studies.

After a brief outline of the underlying theory, Dr. Weinberg discussed the methods available and illustrated their use by slides. The luminous zone of a flame is not necessarily the most important nor the most informative region, and flame records using extraneous light give a more relevant, and in some cases the only reliable, account of flame events. As occasion demands, an instantaneous record or an exposure of any extended duration can be produced by photographic means, and can be used for visualization or for exact measurements. Dr. Weinberg concluded by showing examples of a complete analysis of the relevant variables across a flame front, obtained by a mathematical analysis of the distribution of deflexions produced by the flame from an initially parallel beam of light.

The more practical aspects of turbulent flames were discussed by Dr. B. P. Mullins (National Gas Turbine Establishment) in a paper entitled "Combustion and the Gas Turbine". Dr. Mullins stated that "... a new science, 'Combustion' has emerged in the past decade ...". While it may perhaps seem a little premature to reject so much of the valuable earlier work, the new trend in approach, already referred to earlier in this article, has certainly become manifest during this period. Dr. Mullins, who illustrated his lecture by many spectacular demonstrations, aimed at correlating turbine combustion-chamber performance with fuel properties and other fundamental factors. The dependence of such desirable requirements as high combustion efficiency and intensity, ease of ignition and wide range of stable burning, minimum fire risk and freedom from carbon formation, on fuel properties such as calorific value, limits of inflammability, flash point, viscosity and vapour pressure, is obviously manifold and complex. Dr. Mullins outlined much valuable work aiming at making such dependence of behaviour on initial variables understood and predictable.

The last paper, by Prof. M. W. Thring and Dr. C. Hulse (University of Sheffield) and read by Dr. Hulse, dealt with "The Part played by Luminous Radiation in Furnace Heat Transfer". Luminous radiation emanates largely from soot particles which are the product of incomplete combustion in large turbulent diffusion flames. The paper dealt with parts of the work carried out by the International

Flame Radiation Committee on experimental furnaces at Ijmuiden in Holland and at Stockholm. Two types of trial are carried out. In 'performance trials' the effect of input variables on the distribution of emissivity is investigated by radiation pyrometry, while in 'combustion mechanism trials' probe methods are used to determine distributions of the more fundamental variables, such as suction pyrometer temperature, fraction of combustion, Pitot velocity and soot content. Such experiments provide much valuable information on furnace heat transfer, and general correlations are already emerging of the dependence of flame characteristics, such as flame length, temperatures and emissivities in various parts of the flame, on input variables such as nozzle design, atomizing agent, preheat temperatures and type and quantity of fuel.

Subsequent discussion reflected the diversity of the topics raised by the original contributions which may perhaps have seemed a little bewildering to the uninitiated. Such diversity, however, enables the newcomer to the field to form a balanced impression of current trends in combustion research and often gives rise to valuable cross-fertilization of ideas among workers in the various branches of the subject. In fulfilling these aims, the meeting was thoroughly successful. F. J. WEINBERG

ANIMAL MIGRATION

SECTION D (Zoology) of the British Association held a symposium on "Migration" in Bristol on September 2, with Mr. Peter Scott, vice-president of the Section, in the chair. A paper on "Recent Data on Movements of Desert Locust Swarms", by Dr. R. C. Rainey, Z. Waloff and H. Sayer, was read by Dr. Rainey. Recently some reasonably accurate estimates of the numbers of individuals in a locust swarm have been made by taking out samples obtained by spraying portions of the swarms with insecticides. A density of 70 locusts per square yard has been found, so that a swarm 8 square miles in area would contain some three thousand tons of locusts. These eat their own weight of food every day, and it is thus easy to understand how the recent invasion of Morocco has caused damage estimated at £4½ million.

Studies of orientation within the swarms have been made by taking photographs vertically upwards, coupled with pilot balloon observations of local wind conditions. It is found that individual locusts are orientated at random within the swarm. But this does not mean that the individual's flight is wholly independent of its neighbours'. The swarms show marked cohesion in turbulent air, and there is a strong 'edge effect' which causes locusts leaving the swarm to turn back into it. The movement of the swarm as a whole tends to be downwind, a conclusion agreeing with previous work in which the recorded tracks of locust swarms were correlated with weather charts. This downwind movement of the swarms will in the course of time inevitably lead them to the 'zones of convergence' where winds from different directions meet. The air in such zones must necessarily rise, leading to condensation, rain and moist ground conditions. The very lack of positive orientation of the swarm will thus ensure its arrival in an area which is suitable ecologically. The so-called 'intertropical fronts' are examples of such

zones. Occasionally there may be a carrying-over beyond the zone in the downwind drift, as occurred last October when desert locusts appeared at several points in Britain. A film of locust swarms seen from the ground and the air was then shown.

In the discussion, Dr. Rainey said that it seems that the locusts maintain contact with one another within the swarm by visual means. Their auditory sensitivity is insufficient for this purpose. The fact that a swarm was once picked up by a ship's radar four hours after sunset cannot be cited as evidence for non-visual orientation, because the swarm was so large that there would not have been sufficient time for it to have become dispersed. While there is a possibility that the locusts appearing in England were brought by a ship, this is unlikely because of the simultaneous appearances at scattered points and the precise correlation with weather conditions. Large numbers of dead locusts were found at sea up to the latitude of Lisbon on the same day. It is impossible for locusts to keep flying actively for the thirty hours or so needed to reach England, but they can remain airborne for such periods by gliding at intervals, a habit Mr. Scott had noticed in Morocco. In 1865 substantial numbers of locusts came aboard a ship 1,200 miles off West Africa.

Mr. T. A. Stuart next spoke on "The Local Migrations of Brown Trout". He said that sea trout make local movements—the resulting concentrations being exploited by fishermen—as well as their true migrations to and from the sea. The benefit of this behaviour to the species is that far more fish can grow to maturity on the plentiful food of the sea than could if they remained in the home brook. The brown trout was originally thought to be non-migratory; but it has now been shown, by catching and marking samples of the fish, that there is a definite movement downstream to the lochs, where the fish matures. The adult fish migrates back up the streams at about the same time, though the two movements do not necessarily coincide. Occasionally precocious young males will stay and fertilize incoming females before starting on their own migration, but young females always require the extra year in the loch to lay in sufficient reserves for egg production.

The trout has a strong homing tendency, and, of many hundreds marked, none has afterwards been recovered in a stream other than that in which it was originally captured, except when the latter has been blocked. From 1952 the fry has been marked in this way, so that it is definitely known that the individual was born in a particular stream. Again strong homing tendencies have been demonstrated. Experiments have been made in which ripe fish moving up a stream are removed and released in streams on the opposite side of a large reservoir into which the streams emptied, a distance of more than a mile. No fish was recaptured in the stream to which it had been transferred; but about half those released were recovered and all save two were back in the original stream from which they had been removed. The successful homers did not only have to detect the mouth of the home stream once they were in the reservoir, but also actively to leave the foreign stream, swimming downstream against the mass of incoming fish for whom that particular stream was home. Mr. Stuart could not offer any explanation for the way in which the fish could re-orientate themselves in this manner. He thought it unlikely to be based on the detection of chemical