and of the benefits both to industry and to the university staff. Special mention was made of the close contact between the Ministry of Supply and university departments of aeronautical engineering and also of the Ministry's scheme for employing university teachers as vacation consultants. Suggestions were made for better methods of communicating information about the results of research, and about research in progress. Higher-degree theses are quite unsuitable for general publication, and the results should be re-written at different levels to suit the different kinds of readers to whom the results would be useful. It was suggested that abstracts of all higher-degree theses should be deposited with a central organization, such as the Department of Scientific and Industrial Research, which would bring the work to the notice of interested people.

Postgraduate courses for men in industry provide an effective research contact between industry and universities. The courses might be of long or short duration, but should include some experience in the investigation of problems relevant to the industry. On the other hand, it was pointed out that many of the students attending such courses, and indeed a large proportion of the students engaged on research for higher degrees, come from overseas countries, with the financial support of their governments, and will bring no direct benefit to industry in Britain. If industry were really convinced of the benefits of research and postgraduate courses as a training for its young engineers, it should send more of them back to the universities, either full-time or part-time; this in itself would be a valuable method of maintaining closer contact and promoting co-operation between industry and educational institutions.

AIRFLOW OVER MOUNTAINS

A DISCUSSION meeting was held on the subject of the "Airflow over Mountains" in the rooms of the Royal Meteorological Society on January 19. The subject poses an interesting problem in hydrodynamics, and also has implications of considerable importance to aviation; accordingly, many visitors having an interest in the aviation aspects attended. The discussion was opened by Mr. G. A. Corby, of the Meteorological Office, who gave a summary of the state of knowledge of the subject.

Stationary lenticular clouds can often be seen both over and to the lee of hills and mountains, strongly suggesting that systems of waves can be initiated in an airstream by topography. Cirrus clouds at 20,000 ft. or more, too, are believed to be due sometimes to the topography below; while over the Norwegian mountains so-called 'mother of pearl' clouds can be seen on rare occasions at some 70,000–80,000 ft. Clearly, the influence of mountains on the airflow above can be much more than an intensification of turbulence. Glider pilots have contributed much useful observational evidence of these special airflow effects, and their experience leads to a certain conception of what an atmospheric lee wave system is like. By exploiting the up currents in such waves, gliders have exceeded 15,000 ft. over hills of moderate size in Britain, while they have penetrated well into the stratosphere in the powerful wave systems of the Sierra Nevada in California. Powered aircraft also are affected by these vertical currents, which occasionally may be sufficiently intense to con-

stitute a hazard. Aircraft flying over or near mountains sometimes pass through alternate regions of lift and sink; these regions may not be accompanied by any significant turbulence and, indeed, remarkable smoothness is sometimes reported. Vertical currents of a few hundred feet per minute are, apparently, quite common, while on extreme occasions smooth vertical currents exceeding 2,000 ft./min. have been encountered by aircraft in Europe.

The hydrodynamical problem of the laminar, frictionless and isentropic flow over an idealized two-dimensional ridge has been studied by several workers, using perturbation theory. Prof. P. Queney confined himself to a uniform airstream, that is, one in which the static stability and wind in the undisturbed stream were constant, and found that the nature of the flow depended very much on the scale of the problem. For a very small hill, neither stability nor geostrophic forces were relevant, and his solution gave a single smooth disturbance over the hill. For a hill of a few kilometres in width, the stability became important, and a more complicated disturbance affected the flow above the hill throughout the depth of the airstream. For a large mountain ridge of about 100 km. in width, his solutions predicted a lee wave system. On examination, this wave system proves to be mainly a horizontal oscillation about the geostrophic wind, having a long wave-length of some hundreds of kilometres. Although such waves probably occur in the atmosphere, they cannot be responsible for the vertical currents which embarrass aircraft and are exploited by gliders.

In Dr. R. S. Scorer's theoretical work, provision was made for variations of static stability and wind in the vertical. A certain function of the wind and stability proved to be a parameter of fundamental importance in the problem, and Scorer has shown that for realistic lee waves to be possible in an airstream, a decrease in this parameter with height is necessary. The condition can be fulfilled in practice by the presence of a layer of marked stability (or an inversion) at middle levels, with less stable air above, or by a substantial increase in wind with height, or by some combination of these two effects. Perturbation theory calculations for the flow of such an airstream over a mountain predict a system of lee waves which accords well with observational data. The waves have a wave-length of a few kilometres, and after attaining a maximum amplitude at some level, they die away at greater heights, sometimes slowly, sometimes quickly. An example of the theoretical streamlines calculated for a particular case is given in Fig. 1; the relevant temperature and wind profiles are indicated at the left of the diagram. Examination of the characteristics of the airstreams in which mountain waves have been encountered by aircraft shows that the conditions are consistent with those deduced theoretically by Scorer. The theory could be exploited qualitatively for the preparation of advice to aviation interests; but it would be difficult to apply the theory with any precision because of the complications of the atmosphere and of mountainous terrain in general.

Dr. J. Förchtgott, an expert Czech mountain glider pilot, has carried out a series of field investigations over several mountain ridges of Central Europe, using teams of gliders, light aircraft and special ground observations. He found that no organized pattern of airflow could be discerned unless the airstream had stable or neutral stability, and the wind direction was fairly constant with height and

Fig. 1. Theoretical stream-lines for the flow over a mountain ridge under conditions favourable for lee waves

roughly perpendicular to the mountain ridge. Subject to these conditions, the type of flow depended on the wind. For moderate winds, a large semi-permanent standing eddy was often observed in the lee, with reversed flow up the lee slope. With stronger winds increasing with height, a lee wave system developed, often with lenticular (wave) clouds aloft and rotating clouds in the wave crests at heights comparable with that of the mountain top. With very strong winds extending through a restricted vertical depth, that is, when, above the friction layer, there was reversed wind shear in the vertical, Förchtgott found that heavy turbulence occurred, due, he believed, to the formation of a system of vortices rotating in opposite directions and having features similar to the Kármán vortex street of hydrodynamics. He named the latter flow type 'rotor streaming'. Theory can as yet make no predictions as to the nature of such non-laminar flow patterns.

Mr. A. Yates described more recent work by Dr. Förchtgott in which he has elaborated his diagnosis of the flow types. From observations of lenticular clouds he has concluded that mountain waves sometimes move slowly downstream, to be followed sometimes by apparent rapid movements upstream. During the course of the meeting it was suggested that complicated interference must occur between the wave trains from separate orographic features, and this, coupled with random or systematic changes in the airstream characteristics, might well account for apparently erratic changes in the wave-length and amplitude of atmospheric wave systems.

Mr. C. E. Wallington gave an account of a calculation of the flow over a section of the Derbyshire countryside on an occasion when a marked wave system was encountered during a glider flight. A close approximation to the topography was achieved using five Fourier integrals, and the profiles of static stability and wind were obtained from meteorological upper air data. Synthesis of the five flow patterns obtained by perturbation theory gave the theoretical flow over the actual topography. A useful measure of agreement between the observed and calculated flows was demonstrated.

Prof. G. Manley described some observations of the striking wave phenomena which sometimes occur with strong easterly winds over the Crossfell escarpment in Cumberland. The question of separation of the flow and the formation of eddies was discussed by Dr. R. S. Scorer, who demonstrated the part played by viscosity in encouraging eddy formation. Katabatic winds and such effects would discourage eddies; but on the whole it appeared that the shape

and steepness of the lee slope were the most important factors in determining separation. Such effects near the surface could have a profound effect on the flow at much greater heights, because the effective shape of a hill becomes completely changed by the presence of a lee eddy.

Research into the possibility of exploiting wind-power for the generation of electricity has stimulated the collection of wind data from hill tops in Britain. Mr. H. H. Rosenbrock reported that an increase of up to 40 or 50 per cent in wind speed is to be expected over hill crests, and as the power available from wind varies as the cube of the speed, the increase is important. In the case of a long ridge, the increase in speed arises from the compression of the streamlines over the crest; but a similar increase is also attained over an isolated hill because much of the flow at low levels passes around the hill, and accordingly the crest-level flow is derived from a higher level.

Mr. K. W. V. Townsend discussed the distribution of tree damage from gales in hilly country. Although this is complicated because of the variation of tree growth with altitude and soil properties, nevertheless the distribution was clearly dominated by the local distortion and intensification of the wind-flow by the terrain.

The closely related subject of orographic rainfall was discussed by Mr. J. S. Sawyer, who pointed out that rainfall totals over 12 or 24 hr. were on much too coarse a time-scale to reveal the effects on rainfall of complicated and changing atmospheric waves. However, it was clear that the increase in rainfall over hilly terrain was often significant to the lee as well as over the crests and windward slopes. He had noted also that the increase was commonly much more marked to the south of depression tracks than to the north; an explanation could be that the wind structure to the south (normally an increase with height) would be more favourable for orographic disturbances to the airstream than to the north (where there would normally be reverse wind shear).

Mr. H. S. Turner put forward the suggestion that there might be an association on some occasions between high-altitude clear air turbulence, sometimes encountered by high-flying aircraft, and topography. The idea is gaining favour, and Dr. Scorer has pointed out that mountain waves could provide the mechanism for the generation and maintenance of the large shears of wind which appears to be necessary for such turbulence.

Some pilots of British European Airways described their experiences in flying through mountain waves and turbulence, and Mr. R. K. Pilsbury, of the meteorological office, Northolt Airport, gave brief details of an analysis of such aircraft observations.

G. A. CORBY

THE BRITISH COUNCIL ANNUAL REPORT

A PART from the chapter dealing with the welfare of overseas students, the portions in the report on the work of the British Council for the year ended March 31, 1954*, of most direct interest to the scientist are those discussing university interchange and the written and recorded word.

* Report on the work of the British Council for the year ending 31st March 1954. Pp. v+105. (London: British Council, 1954.) 2s. 6d.