The Relationship of Physics to Aeronautical Research.[1]

By H. E. Wimperis, Director of Scientific Research, Air Ministry.

Aviation is now entering upon a new and intensely interesting phase—one which will call for every scientific resource at our command. The materials of construction are changing: wood is giving place to metal. The engine proves to have most unexpected possibilities ahead of it through the increase of intake pressure; whilst the very lifting structure itself may possibly change, for some purposes at least, from linear motion to rotary. Now in aeronautical work there can be no doubt that scientific studies have been considerably stimulated by problems which have arisen directly from aeronautical engineering. The thought of those physicists who have in recent years done such brilliant work on the mathematical theory of fluid motion was stimulated in no small degree by the results obtained either in the wind channels of our aerodynamic laboratories or in free flight on the full scale.

Aeronautics by its youth escaped the medievalism of the old-time practical engineer; it was launched well in the modern scientific path by the formation some seventeen years ago of the Advisory Committee for Aeronautics, which after two phases of re-adjustment is still with us as the Aeronautical Research Committee. When I first knew it, it was presided over by that kindly and gracious being the late Lord Rayleigh; in those days the field of work was small enough for all matters to be dealt with by the single Committee. Now the scale is so much greater that many subcommittees and panels have to share its responsibilities. The latest phase is the organisation under the Air Ministry of a separate scientific research department to ensure that scientific investigations shall receive their due, and be vigilantly guarded against any competition for money, staff or facilities by the seemingly urgent claims coming from other quarters.

The scientific research staff of the Air Ministry closely resembles the corresponding staff at the National Physical Laboratory in its method of recruiting, its scales of pay, and its conditions of work. This staff is about eighty in number, and of this general 'pool' some four-fifths work in the laboratories at Farnborough and the rest at such stations as Martlesham, where the performance of new airplanes is studied, Felixstowe, where corresponding work is done for seaplanes, and the Air Ministry Laboratory in the Imperial College of Science, where special problems, mainly physical and chemical, are studied.

The examination of the flow around aerofoils and of the fluid forces brought into play has naturally formed one of the chief items of physical research in the wind channels of the aerodynamic laboratories throughout the world. The simpler measurements usually made on aerofoils are the lift and drag coefficients and the motion of the centre of pressure. These, the ordinary methods of classical hydrodynamics, are not capable of predicting from theoretical considerations alone, since the mathematics deal only with the motion of a fluid in which viscosity plays no part.

In the case of a simple mathematical shape, such as a cylinder placed at right angles to the flow, the positions of the streamlines, as determined for an inviscid fluid, differ appreciably from those which would arise in a viscous medium such as air. In the former fluid, moreover, no resultant force acts upon the cylinder, whereas measurements made in an air channel show that considerable forces are brought into play. Indeed, without such forces flying would not be possible.

If now to the streaming of the inviscid fluid past the cylinder there be arbitrarily added a 'circulation' of the fluid around the cylinder, there at once comes into existence a resultant force at right angles to the stream. This has an immediate analogy with the lift force experienced by an aerofoil, and with the propulsive force produced by the action of the wind on the rotating cylinder of the Flettner rotor ship.

It is seen, therefore, that by the addition of the idea of a 'circulation' around the body, a possible explanation is given for the existence of lift forces, and in recent years, by the employment of this convention, successful efforts have been made actually to predict the lift of certain forms of wing section. Naturally, a theory such as this has had to face much criticism, but some years of experience with it have enabled comparisons to be made with data obtained in the laboratory, and such comparisons have shown that it affords a close approximation to what actually happens. The theory itself was built upon the work of many investigators, and among that many I would like specially to refer to the work of Lanchester, Joukowsky and Prandtl. As a result of the work of these and other pioneers, therefore, we find it useful in aerofoil design to study the effect of imposing upon the motion of an inviscid fluid a 'circulation,' of unknown origin, around the aerofoil of sufficient amount to carry what is known as the 'stagnation point' to the trailing edge of the wing. 'Circulation' must have a physical existence, since the velocity is greater above the wing than it is below, though this real circulation is a circulation with no slip, whereas the mathematical circulation has slip. Hence the rather amusing situation arises of adding to the mathematical study of streamlines a conventional motion which could not really arise in an inviscid fluid! So long, however, as the limitations to the theory are borne in mind no harm can be done, whilst the results of such mathematical work are of the greatest utility as a first approximation as to what is happening.

One great merit of Prandtl's work is that his theory enables the lift of a wing of limited span to be deduced from the known performance of a wing of the same cross-section but of unlimited span; in other words, that the results of three-dimensional flow can be deduced from the known two-dimensional. The two-dimensional flow can be studied in two ways: experimentally, by means of a model wing-section stretching

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[1] From a lecture delivered before the Institute of Physics, at the Royal College of Science, South Kensington, on June 7.

right across the wind channel; and mathematically, by the method initiated by Joukowsky, who found a way of predicting these forces by the mathematical step of converting a circle into the desired aerofoil shape by means of a suitable conformal transformation. For a limited number of aerofoil shapes it is therefore possible to deduce theoretically the performance for two-dimensional flow, whilst by the Prandtl theory it is possible to convert these results from two-dimensional to three-dimensional conditions. This work has been put to use by the Air Ministry scientific research staff, and some six aerofoil sections have been designed on this basis with the object of obtaining in the first instance a good thick wing, and in the second, a good racing wing. This theoretical work has been fully confirmed by subsequent experimental results on such aerofoils, whilst on certain of these wings full-scale work in free flight has been put in hand.

Many attempts have been made to build a type of aircraft known as a helicopter, which is fitted with rotating wings driven by one or more engines. Little success has, however, been met with in spite of considerable expenditure. But in the last year or two, real success has been achieved by Señor de la Cierva with his 'autogiro'; this machine is not strictly a helicopter, however, since the windmill is not power driven. But I think there is little doubt that it is through the autogiro, or, in English, the gyroplane, that we have the best means of studying the performance of all rotating wing machines. One of the difficulties with a rotating wing is that the part which is moving in the direction of flight has a higher airspeed than the retiring part, and this leads to greater lift on one side of the machine than the other. Mechanisms to balance these forces mechanically are most complicated to build and still more complicated to control. Cierva cut the knot of this difficulty by hinging his blades close up to the vertical shaft. This meant that the advancing blade merely lifted a little above its average position while the retiring blade fell a little below that level; thus the wings oscillated in a vertical plane during each rotation and presented some analogy to the flapping flight of birds. Centrifugal force prevents the wings from folding up about their hinges.

Owing to wall interference in the wind-channel tests that have previously been made on such windmills, or for some other reason, their capacity for slow descent under load was underestimated. This underestimate was first realised as a result of the tests carried out at Farnborough last summer with a Cierva gyroplane in which the vertical velocity was some 15 feet per second only, about half the speed of fall of a parachute carrying the same load and having a diameter equal to that of the windmill.

Full-scale tests on aircraft components usually require a greater space than can be given in a laboratory, and in consequence the physical investigations arising therefrom need to be carried out through the medium of models. It is no difficult matter to make an accurate scale model of any form of aircraft, and to provide a wind channel of such dimensions as will make the test reasonably representative. That is relatively simple, but a difficulty soon arises through what is known as 'scale effect.' The study of scale effect is intricate and much work has yet to be done. But it has been proved that model tests in the wind channel would represent what happens on the full scale if a certain physical ratio were preserved; this ratio is the product of length by velocity and divided by the kinematic coefficient of viscosity. This ratio is a non-dimensional one and it is coming to be known as the 'Reynolds' Number.' Model tests in wind channels as we at present know them give a value of the Reynolds' Number of but one-tenth of that appropriate to full scale. This is unfortunate, since it means that within the range of velocities available in the ordinary wind channel only a very small portion of the correction for the change of the characteristic under measurement with the Reynolds' Number can be studied: hence to deduce full-scale results from wind-channel experiments may mean extrapolation in the ratio of something like 10 : 1.

A limit to the air velocity in the channel is imposed by the considerable increase of horse-power for such operation; there is also an obvious limit to the dimensions of channels, and it follows that the only opportunity of obtaining a Reynolds' Number comparable with that applicable to full-scale conditions is by means of an increase in density of the air, or else of its replacement by some fluid having a higher specific gravity. Much interest has been taken in the pressure channel recently built at Washington, which is capable of being operated at an internal pressure of 20 atmospheres, so realising a Reynolds' Number equal to that of full-scale work, when allowance is made for the fact that a pressure tunnel is best run at about half the airspeed of an atmospheric tunnel, so that the amount of the forces acting upon the model may be kept within bounds. It is too early to say whether this channel has entirely fulfilled its constructors' hopes, but from such tests as have been reported it seems that the method of testing rendered possible by its use will prove to be of great utility.

Another form of model-testing is that carried out in the Yarrow tank at the National Physical Laboratory. This tank was originally built for the testing of ship models, but in recent years it has also been used for work on models of seaplanes. Investigations of this sort become specially necessary when the seaworthy characteristics of seaplanes need study. These craft have to be designed in relationship not only to their performance as flying machines, but also as to their habits when travelling on the surface of the water before they become entirely air-borne. For the aerodynamic characteristics the wind channel suffices, but for the study of the period prior to flight the tank is necessary. When considering the size and speed of a tank for this purpose one is faced with the consideration that the model must run at what naval architects term the 'corresponding speed' to that of the full-scale machine; speeds are said to be corresponding when the ratio of the velocity to the square root of the length of the model is equal to the velocity of the ship divided by the square root of its length. This ratio, it will be seen, is quite different from the Reynolds' Number above mentioned and it leads to totally different design requirements.

It might be thought from what has been said that the main purpose of the tank is to make accurate quantitative measurements. This, however, is not the case, since probably the chief use of such tests is a qualitative examination of the wave motion created by the hull, particularly in relationship to the position in which the engines and propellers are proposed to be placed.

The physical problems presented by the aero engine are for the most part not peculiar to aeronautics, but are part of the general study of the internal combustion engine. The use of this type of prime mover for aircraft does, however, present special problems owing to the urgent demand for 'reliability' on one hand and lightness on the other. Moreover, there is always the tenuity of the air at altitude to be reckoned with.

As a matter of fact, the aero engine has improved enormously in recent years—not so much perhaps as the result of scientific study as by sheer hard efficient work on the part of the engineering staffs of the engine-builders. As witness to this remarkable success, I would specially mention the performance of the Napier water-cooled engine on the flight to South America, the excellent behaviour of the air-cooled Jaguar engine on Mr. Cobham's flight to South Africa and back, and by no means least, the remarkable achievement of an air-cooled Jupiter engine in flying 25,000 miles without any overhaul.

Need for lightness of construction brings in quite other considerations. For high output, high efficiency is necessary, and this calls for increased compression pressures and a consequent liability to the troubles induced by detonation. The study of detonation and the means of avoiding it are fitting studies for physicists. Equally fitting are the investigations necessary to ascertain whether the output of the engine in relation to its weight can be increased by what is known as supercharging, and if so, how far in that direction it is expedient to go. All the while it has to be borne in mind that the engine must not only be capable of operating in a normal atmosphere such as that in which most internal-combustion engines work, but also in conditions in which the pressure may be only one-third of that at sea level and in which the atmospheric temperature may be no less than 50° Centigrade below zero.

This sensitivity of the engine to atmospheric pressure has led naturally to attempts to create an artificial atmosphere of increased density in the engine intake. A scheme of this sort was indeed mooted by Sir Dugald Clerk more than twenty years ago, and was called by him 'super-compression.' It is now known as 'supercharging' when the effort is to maintain an intake pressure at all altitudes equal to that at ground level, or 'boosting' when the effort is to increase the intake pressure by a constant fraction at all heights. These developments present an infinitude of problems most of which are now beginning to be seriously tackled—their close relationship to detonation is a complicating phenomenon. There are such great possibilities in this direction that a material decrease in weight per horse-power at altitude may confidently be looked for in the not distant future.

We live in a wonderful age. Just as in the thirteenth century the splendour of life must have seemed most to surround the work of the architect, or in the fifteenth century that of the painter, so it appears to me in the present age does it crown the labour and achievement of the physicist.

Iron in Antiquity.[1]

By Dr. J. NEWTON FRIEND.

IT would be difficult to find a subject of greater interest than the study of iron in antiquity. Man's first acquaintance with the metal undoubtedly dates back, in certain districts, to the Stone Age. At that time meteoric iron would be much more common than now, and primitive man would soon observe that the metal was more malleable than ordinary stone, and could be cold worked, by repeated hammering, into simple shapes for ornament or for personal use. Probably this was the origin of the metal beads, the oxidised remains of which have been found in predynastic tombs in Egypt, dating back to about 4000 B.C. But it was not until man had progressed slowly upwards through ages of unremitting toil that he learned of the connexion between metallic iron and certain of the stones around him, and succeeded in reducing the metal from its ores.

Iron appears to have been manufactured in the Near East at a fairly early date. The Hittites were beginning to use iron weapons for military purposes about 1300 B.C., and Rameses II., King of Egypt, is known to have applied to the Hittite king for a supply of the metal. Whether he obtained it or not is unknown, but a mutilated letter has been found, possibly addressed to Rameses II., in which the Hittite king states that he is sending an iron dagger, and promises to forward a supply of iron.

The Philistines are believed to have introduced the general use of iron into Palestine, although the metal was known many years prior to that. It is clear from references in the Old Testament (see 1 Sam. xiii. 19-22) that the Philistines retained the monopoly of working iron, with the result that at first there was no smith in Israel, and the only Hebrew persons possessing iron swords were Saul and Jonathan. In other words, the Philistines had already entered upon their iron age when the Israelites were still in their bronze age. By the time that David ascended the throne, however, the use of iron was becoming more general. Nevertheless, it is interesting to note that no iron tool was allowed to be used in the construction of Solomon's temple at Jerusalem. The employment of iron would have been offensive to God, who had in previous years spoken against the use of metal, and had ordered (Ex. xx. 25) any altars erected to Him to be made of unhewn stone. In view of this the following tradition is interesting. Whilst the present writer was in Jerusalem last year, his dragoman informed him of a curious belief prevalent amongst the Jews to the effect that if the crevices in the ancient wall at the famous Wailing Place are completely filled with

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[1] Substance of a lecture delivered at the Royal Institution on June 3