which are for the most part contained in *The Journal of Agricultural Science*.

The report is accompanied by a circular of the society for extending the Rothamsted experiments, which gives details of the financial position of the trust. Subscriptions are invited for the rebuilding of the old laboratory, which must shortly be undertaken, and for the maintenance of the permanent plots, which entails very considerable annual expenditure.

DESIGN AND USE OF SCIENTIFIC INSTRUMENTS IN AERONAUTICS.[1]

AFTER expressing his admiration for the character of Wilbur Wright, his brilliant engineering work, and the scientific method by which he obtained his results, the lecturer considered the resemblance and differences of the manufactured aëroplane and the living bird. The resemblance may be simply the result of copying the bird, or it may be that similar designs have been arrived at independently by birds and men. The wings of both are roughly the same shape: of wide span, and narrow in the direction in which the bird flies; both have concave wings with thick leading edges. In many aëroplanes hollow spars are used like bones and like the quills of the feathers of birds. We copy plants also in this respect, for they too have learnt the economy of material in the use of hollow spars.

These resemblances are remarkable, but there are great differences. The Wright brothers found no biplane bird to copy and did not flap their wings. No flying animal uses a continuously rotating propeller to drive him forward on soaring wings, and it is perhaps scarcely too much to say that if birds only knew how, they would now copy the Wright brothers. Muscular action and the circulation of the blood, however, put supreme difficulties in the way of the development of the continuous rotation of a part of an animal.

Instruments Used in Aëroplanes.

It is important to realise beforehand the difficulties of using instruments on aëroplanes during flight and the errors that may be introduced in the readings. The aëroplane shakes, it does not remain level, and is subject to acceleration in all directions. The instrument should be so designed as not to be affected by any of these disturbances. A vertical acceleration has the same effect as a change in the amount of the downward pull due to gravity; the tilting of the aëroplane changes the direction of the downward pull with regard to the instrument. A lateral or longitudinal acceleration has the effect of altering both the direction and the amount of gravity. But vibration is a greater difficulty still. The hand of an instrument may move so much and so rapidly that it is difficult to estimate the mean reading on the scale, and sometimes it is quite impossible to do so. And this may happen when the quantity which is indicated by the position of the hand only varies slowly and by small amounts. The moving part of an instrument should be well balanced. This reduces the vibration from the shaking of the aëroplane as well as the error caused by its tilting or want of level.

In a compass as ordinarily made, the condition of balance cannot be fulfilled. The magnet rests on a steel point and is horizontal, and its centre of gravity is below the steel point. The force on the north pole acts in a downward direction towards the north, and the force on the south pole in an upward direction towards the south, and the magnet is made to rest in a horizontal position by arranging that the centre of gravity of the magnet is between its south end and its centre. It is below and to one side of the point about which rotation takes place. Hence a sideways movement must start it swinging. The magnet and card in aëroplane and ship compasses are usually surrounded by a liquid, so that any vibration which may be caused by its want of balance is rapidly reduced.

Instruments on aëroplanes should be damped, using the word to damp in the sense of "to dull" or "to abate the motion of." This damping is specially important if it should happen that the rate of vibration of the whole instrument should agree with the natural rate of vibration of the moving part. When this happens with an undamped instrument, the vibration is excessive. Damping is also required in cases where the fluctuations in the quantity to be measured are rapid; it may then be difficult to read the instrument, and the excursions of the hand may indicate a much greater amount of variation of the quantity than really takes place. If the mean reading is required the instrument must be damped, and the damping should be of a particular kind.

The essential features of satisfactory damping are that no force should be applied to the moving part whilst it is at rest, but that as soon as it moves a force should act opposing the movement. Friction at the joint does damp the instrument, but does not fulfil these conditions, and is bad. The force should be small when the movement is slow, and it should increase when the movement becomes more rapid. The most usual method is to immerse the moving part, or a paddle fixed to it, in a liquid more or less viscous, or the paddle can be replaced by a fan in the air. Another method is to damp by the movement of a copper plate between the poles of a magnet. If a Pitot tube is used, the flow of air through the connecting tubes damps the instrument.

Mr. A. Mallock has pointed out that in order to obtain a true mean reading with an instrument the damping force should be proportional to the velocity of movement of its index. When the damping force varies as the square of the velocity there may be no error or there may be a considerable error. Suppose that the quantity to be measured remains at 80 for 2/10 second, and then suddenly increases to 140 and remains at that amount for 1/10 second, and then it goes back to 80 and remains at that amount for 2/10 second, and that this rapid oscillation goes on indefinitely. Suppose also that the instrument is damped by a force which varies as the square of the velocity of the index, and that it is so much damped that the hand appears to remain at rest. The reading of the instrument will be 92 and the true mean in reality is 100, so that we have an error amounting to 8 per cent., by no means a small error. The diagram (Fig. 1) gives the supposed variations of the quantity as it would be recorded on a moving sheet of paper, and gives the true mean and the instrument reading.

In the magnetic method of damping, the force varies as the velocity and the true mean is obtained. With liquid and air damping the force varies as the square of the velocity, unless the movement is extremely slow, when it varies nearly as the velocity.

Speed of Aëroplanes.

The speed of the aëroplane through the air is often measured by a Pitot tube and a manometer.

The principle of the Pitot tube is very simple. If the open end of a tube faces the wind, the air wants to pass down the tube; if the tube is closed at

[1] From the first Wilbur Wright memorial lecture delivered before the Aëronautical Society of Great Britain on May 21, by Mr. Horace Darwin, F.R.S.

the other end the air pressure is increased in the tube, and this increase of pressure is a remarkably accurate means of measuring the velocity of the wind. This method is used in Dines's anemometer, and for measuring the velocity of the air in the wind channel at the National Physical Laboratory. In 1903 Dr. Stanton read a paper before the Institution of Civil Engineers (Proc. Inst. C.E., vol. clvi., p. 78) proving the accuracy of this method of measuring air velocity, and improvements have recently been made which give even more satisfactory results. The delicate measurement of the air pressure necessary for the most refined work is made by the tilting water gauge designed by Prof. A. P. Chattock and Mr. J. D. Fry. This is a laboratory instrument of the highest order of precision, and is far too delicate and accurate to be used on a flying machine. It is a difference of pressure that has to be measured—the increase of pressure in the tube, above the air pressure outside—and a second tube transmits this pressure (the static pressure) to the manometer. It is found by experiment that changes in the size of the opening of the Pitot tube, or the thickness of the tube, or the bevelling of its edge, make little or no difference in the pressure. With the opening of

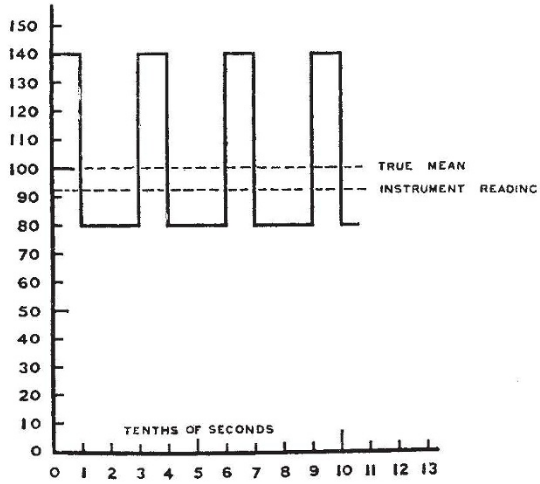

FIG. 1.

the static tube it is different, and its design is important. In the design now adopted at the National Physical Laboratory the pressure obtained is almost exactly what we should expect from theoretical considerations. This is an advantageous simplification, and this form of Pitot tube should be used for all the most refined measurements. But the static tube can be so made that it will give a pressure below the true static pressure, and the Royal Aircraft Factory has made use of this and has increased the manometer readings by 20 per cent. in order to give a more open scale.

The tubes transmitting the pressure can be carried a considerable distance to allow the manometer to be placed in a convenient position for reading; this is often of great importance. If it is found advisable to have a large amount of damping in the manometer it is best to have long tubes of large diameter. This gives the correct form of damping. Short tubes of small diameter will also give a large amount of damping, but in this case the damping force will vary as the square of the velocity of the air in the tube, and the reading will not necessarily be the true mean. For the same reason it is inadvisable to cause damping by throttling the passage of the air by closing a valve, or by means of letting it pass through a small hole in a plate.

If a Pitot tube speed-meter gives the correct speed when flying near the ground level, it will not be correct when flying at a great altitude. The error is caused by the change in the density of the air. As you mount the air becomes less dense because the atmospheric pressure is reduced, and more dense because the temperature falls, and an error of 7 per cent. may be expected at an altitude of 5000 ft.

The simplest form of manometer is a U-tube containing a liquid. The difference of the level of the liquid is then a measure of the difference of the air pressure in the two tubes. For use on an aëroplane this has two drawbacks: the scale is not open enough to read the speed easily and accurately, and tilting of the aëroplane causes an error. Mr. Short, of the Royal Aircraft Factory, has designed a manometer which overcomes both these objections. It is in effect a U-tube manometer; he uses two liquids of different densities, which do not mix, and thus obtains a more open scale. One tube is placed inside the other, and this overcomes the chief error due to the tilting of the aëroplane, leaving only a small secondary error amounting to $1\frac{1}{2}$ per cent. for a displacement of 10° out of the vertical.

If the aëroplane has an upward or downward acceleration or is changing its direction there is an error.

If a Pitot tube is fixed to the tips of the wings of an aëroplane and it is flying in a circle, the speed of the outer wing tip is greater than the speed of the inner wing tip. If these Pitot tubes are joined together by a tube there will be a greater pressure at one end of the tube than at the other, and at first sight we should expect that there would be a flow of air through the tube from the outer to the inner wing tip. But this is not the case, because the aëroplane is moving in a circle and there will be centrifugal force acting on the air in the tube. This will tend to make it flow outwards, and will exactly balance the tendency of the air to flow inwards due to the excess pressure in the Pitot tube on the outer wing tip, and there will be no flow through the tube. If there is a side-slip this statement is only approximately true. For accurate speed measurements at the Royal Aircraft Factory two Pitot tubes are used, one at each wing tip, both are connected to the manometer and the mean speed is given.

An instrument called a yaw-meter was described. It measures the direction in which the air is moving relatively to an aëroplane, and its action depends on the fact that the pressure in a Pitot tube becomes less if it does not directly face the wind. Two Pitot tubes are used, and the indication is independent of the speed of flight.

A method of indicating the speed of ascent or descent was also described.

The Principle of Geometrical Design.

Clerk Maxwell writes:—

"Each solid piece of an instrument is intended to be either fixed or movable, and to have a certain definite shape. It is acted on by its own weight, and other forces, but it ought not to be subjected to unnecessary stresses, for these not only diminish its strength, but (what for scientific purposes may be much more injurious) they alter its figure, and may, by their unexpected changes during the course of an experiment, produce disturbance or confusion in the observations we have to make.

"We have, therefore, to consider the methods of relieving the pieces of an instrument from unnecessary strain, of securing for the fixed parts a determinate position, and of ensuring that the movable parts shall move freely, yet without shake.

"This we may do by attending to the well-known fact in kinematics—'*A rigid body has six degrees of freedom.*'"

Designs in which this principle is carried out may be called geometrical designs. A three-legged table is a geometrical design, and a four-legged table is not. A four-legged table either rocks on two legs, or bends so that all legs touch the floor, and the amount of bending and the pressure of each foot on the floor depends on the stiffness of the table and the evenness of the floor. Every time an ordinary chair is placed in a new position, it takes a new shape. A surface plate is a familiar example of the importance of three supports, and nearly all scientific instruments rest on three feet. Other examples of geometric design were also given.

Good Design and Bad Workmanship.

A most important consideration in a good design is that the instrument shall still work well when the rubbing surfaces get worn or parts get bent, or if the workmanship is not good. With perfect workmanship and a bad design, you may get jamming in the moving pieces and bending of parts which should not bend, and the results obtained will be liable to error and the working unsatisfactory. This consideration brings out most forcibly the advantage of geometrical designs, but also it is a valuable test to all designs. It is a long way from being the only test, but it is always well worth while to consider separately the effects of imperfect workmanship, or the bending of each part and wearing of the rubbing surfaces. Take the case of wear in a wheelbarrow. The axle of the wheel usually consists of two round iron pins running in holes in wooden rails forming the frame of the wheelbarrow. Both the wood and the pins wear; the pin gets smaller but keeps circular, and wears its way into the wood and always fits it properly on the side where pressure is taken. The wheel will work perfectly until either the holes break out of the wood or the pin wears down very small and itself gives way. But sometimes the axle is made differently; an iron rod is fixed to the two wooden rails and passes through a hole bored along the centre of the wheel. With use the iron rod wears on the under side and does not remain circular, the hole in the wheel gets larger; the result is increased friction and a loose and shaky bearing.

The following test was applied to the Rocking Microtome, which has been designed so far as possible on the geometrical method. The iron castings of which it is chiefly made were taken as they left the foundry, were put together with as little work as possible, and it at once cut good sections. This was a severe ordeal, but sections as thin as 0·003 mm. were cut, proving that the instrument still worked with considerable precision.

This test for good design is not the only test, and it may fail. Ball bearings are much used, and when once used for any purpose they continue to be used more and more; this is the best test of a really good mechanical device. All must admire their design, but first-rate workmanship is essential; in this must be included the composition of the steel, the skill in hardening, as well as the accuracy of the figure of the working parts. A ball bearing, however, would be a better thing even than it is at present if it did not require such fine workmanship. It also requires careful mounting, and it is interesting to notice that the recent improvements in ball-bearing design are in the direction of allowing it to work satisfactorily on shafting which may be considerably bent.

The Advantage of Reversing the Parts of a Machine.

An improvement in the design of a machine can often be made by reversing the relative position of two parts of it, or the part that moved can be fixed and the part that was fixed can be made to move. This reversal makes it possible to compare two or more methods, and it is then easy to see which is best. It is advantageous that "the survival of the fittest" should take place early in the life of the machine, and by this means, in fact, it takes place before the design is completed.

In the before-mentioned wheelbarrow it is easy to see which is the best design, and if the designer had deliberately considered whether the iron pins should turn in the wooden rails or whether the iron bar should be fixed, the bad design would never have been made. It is surprising how often this reversal is possible and advantageous, and how difficult it is to realise that it is possible. We are so familiar with a clock in which the frame remains at rest and the hands move that it requires a considerable mental wrench to realise that it is possible and in some cases better that the clock itself should revolve and the hour hand remain at rest. But in recording apparatus it is usual to fix the clockwork in the rotating drum carrying the paper, and to prevent rotation of the hour-hand spindle.

The lecturer concluded:—"I have spoken as a manufacturer of scientific instruments, but my remarks apply equally or even more to the home-made or rather laboratory-made type of instruments. And it is with these that the greatest advances in knowledge have been made. If I could believe that what I have said would be any help to the makers of the wire, cork, and sealing-wax class of instruments, or to the orthodox instrument-maker, I should be glad to think I had done something to advance knowledge."

THE STANDARDISATION OF HYDROMETERS.

WE have received from the director of the National Physical Laboratory the following memorandum for publication in NATURE:—

At the present time there appears to be considerable ambiguity as to the bases of standardisation of hydrometers graduated to read directly in specific gravity.

Three different methods have been brought to the notice of the National Physical Laboratory, and it seems desirable to determine which of these three should be considered as standard.

The instruments are in all cases graduated for use in a liquid at a definite temperature—we call this the standard temperature of the instrument—and give the specific gravity of this liquid at some definite temperature, which may or may not be the standard temperature of the instrument, referred to water at the same or at some other temperature.

The following cases have arisen in practice:—

I. (α) The liquid to be tested must be at the standard temperature of the instrument.

(β) The water to which the specific gravity is referred must also be at the standard temperature of the instrument. Thus, if 85° F. be the standard temperature of the instrument[1] the liquid must be at 85° F. when tested, and its specific gravity is referred to water also at 85° F.

II. (α) The liquid to be tested must be at the standard temperature of the instrument.

[1] A more usual value for this temperature of the instrument would be 60° F. or 62° F. The temperature 85° F. is chosen here as an example so as to bring out the differences arising from the various methods of standardisation.