AERODYNAMIC AND AEROSTATIC STUDIES.

EXPERIMENTS WITH MODELS OF AIRSHIPS AND AEROPLANES.

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It is now almost the universal practice of ship-builders to test new forms of hulls by towing models, usually made of paraffin and a few yards in length, through the water and measuring the resistance opposed to their motion. No large ocean steamer is now constructed without such preliminary experiments. Experiments with models of airships are still more necessary, because in the air we have not the practical experience that we have in the water. In both cases one of the chief objects of study is the total resistance to motion and the discovery of the form which will make this resistance a minimum. Other important questions concern the distribution of pressure and skin friction in their dependence upon the form and character of the surface. The investigation of stability and steering qualities also requires experiments with model which may likewise give interesting information of the lifting power, or kite action, of the airship when inclined to the horizontal. In the case of aeroplanes it is necessary to study thoroughly the magnitude and direction of the resultant force on single surfaces of various forms, on combinations of surfaces, and finally on complete aeroplanes, and the stability and steering qualities must be determined as in the case of the airship. The question of power and

FIG. 1.—CURVED GUIDES AT CORNERS OF AIR CHANNEL.

propelling mechanism is the same for both classes of vessels, and may also be studied by means of models. It is more convenient, simpler, and cheaper to learn from models all that they can teach us, than to make the experiments with large and expensive vessels. The question, however, suggests itself, how far the results obtained from models can be applied to the large vessels. It must be admitted that here, as in the case of nautical vessels, this applicability is not perfect, on account of the peculiarities of the so-called skin friction. If the skin friction is neglected, the results obtained from the model can be applied to the large vessel if the following simple rule is observed:

Forces are proportional to areas and to the squares of velocities.

Experiments with models can be conducted accord-

FIG. 2.—PLAN OF GOETTINGEN LABORATORY.

ing to several very different systems. The first system corresponds to that employed for nautical vessels, in which the model is towed by a carriage running on rails. This method is not suitable for aerial vessels because, as everything is surrounded by the same medium, the carriage would generally create a greater disturbance in the air than the model would produce—a disturbance sufficiently great to make exact meas-

urement impossible. By replacing the towing carriage with a cord wound on a windlass this objection is removed, but it remains very difficult to distinguish sharply the comparatively small air resistances from the great forces of inertia of the heavy model. For

FIG. 3.—MOUTH OF FINE EQUALIZER.

the sake of completeness we may also mention experiments of the free fall of a body through the air, from which very good results can be obtained by a skilled experimenter. The frequently employed method of carrying the model round in a circle by means of a long rotating arm is open to the objection that the model is always moving in air which has been disturbed by its last passage.

In great contrast to all these methods, in which the model moves in approximately still air, is the method of maintaining the model at rest in a current of air produced, for example, by a ventilating fan. The mutual action between the model and the air is here exactly the same as in the former system, if the condition of the moving air before it strikes the model is as uniform as that of still air. The trustworthiness of results obtained by this method depends, therefore,

FIG. 4.—CURVES OF DISTRIBUTION OF PRESSURE IN FRONT OF (LEFT CURVE) AND BEHIND (RIGHT CURVE) THE EQUALIZERS.

upon obtaining a uniform current, free from eddies. This can be secured by the employment of various appliances. When a uniform current has been secured, the advantages of this method are great and obvious. The duration of the experiment is unlimited, and the model can be attached to its support much more easily and securely than if it were in motion. Furthermore, the difficulties produced by the acceleration and inertia of the model and the measuring apparatus are here avoided, and the model is continuously in sight, so that any irregularities can be at once detected and corrected.

Two systems of construction, the open and the closed, are possible. In the open system the air is drawn from the atmosphere through the experimental channel and expelled at the farther end. In the closed system a confined body of air is kept moving in an annular closed channel. The unavoidable formation of eddies forms an obvious objection to the closed system, but careful comparison proves that it is, on the whole, far superior to the open system, which is exposed to serious disturbances caused by wind. The necessity of reducing again to uniformity the current of air disturbed by the ventilating fan, and the loss of energy in this operation, are small disadvantages in comparison with the advantage of being independent of the weather.

The Goettingen experimental institute has been designed in accordance with this system. As a member of the technical committee of the Aeronautical Society, the writer, in January, 1907, designed an experimental

laboratory which was completed in the summer of 1908. The internal equipment is now nearly finished. The air channel is square in section, measuring 6½ feet each way. This form was adopted for convenience in construction and inspection. The current of air is produced by a screw propeller, which was adopted on account of simplicity and cheapness, although a centrifugal blower produces a more uniform current and consumes less power. For the sake of simplicity, also, the canal follows the sides of a rectangle, but the air is guided round each corner in a number of small streams by means of curved fixed surfaces, as shown in Fig. 1. The apparatus by which the air disturbed by the fan is quieted and made uniform consists of a large system of guiding surfaces immediately behind the fan, which distribute the current over the whole cross section of the canal, and of a coarse and a fine equalizer, of which the former contains 400, and the latter about 100,000 parallel channels. Finally, the air passes through a sieve of 1/12-inch mesh. Fig. 2 shows the ground plan of the laboratory.

The fan *V* is driven by a 30-horse-power electric

FIG. 5.—ARRANGEMENT FOR MEASURING LONGITUDINAL RESISTANCE.

motor *E*. Near the fan is the distributor *L*. The coarse equalizer *G*₁ is a little distance farther on, while the fine equalizer *G*₂ is on the opposite side of the rectangle. The curved blades at the upper corners of the figures are 20 in number. Those at the other corners, between the two equalizers, number 40 and 80, respectively.

Fig. 4 illustrates the distribution of velocities before and after passing through the distributor and equalizers. The model *M* is suspended in the branch of the channel opposite the fan and can be observed conveniently through the glass windows which separate the channel from the observation room on the left, where all the measuring and regulating mechanism is installed. The speed of the fan can be modified within the ratio 1 to 4. Hence the velocity of the air current can be varied in the same proportion and, as the air pressure is proportional to the square of the velocity, the pressure can be varied in the ratio 1 to 16, which is a sufficiently wide range for practical purposes. The

FIG. 6.—ARRANGEMENT WHICH ALLOWS THE AXIS OF THE MODEL TO BE INCLINED TO THE CURRENT.

velocity of the current is measured by means of a modified Pitot tube, in conjunction with a micro-manometer. (The Pitot tube, as used for the measurement of the velocity of water currents, is an L-shaped tube, the short leg of which is immersed and directed against the current. The strength of the current is measured by the height to which the water rises in the vertical branch.) One of these instruments is

placed in front of, and another behind the model. Each is so arranged that it can be moved to any point of the cross section of the channel. The manometers are provided with registering apparatus. In order to avoid interference with the current, the suspension of the model and the transmission of power are effected as far as possible by the use of wires. For the measurement of the simple longitudinal resistance the arrangement shown in Fig. 5 has been adopted. The model is attached to a thin rod *O*, suspended by the four wires 1, 2, 3, 4. The longitudinal force exerted along wire 5 is transmitted with undiminished strength to the wires 6 and 7, each of which makes an angle of 120 degrees with wire 5. This force is measured by the balance attached to the end of wire 7. Wires 8, 9, and 10, the last of which is loaded with a weight, form a tension system which serves to maintain the position of the model when not exposed to the air current. In making a measurement the bal-

ances are first adjusted to equilibrium when the air is at rest. The ventilator is then started, the balances again adjusted, and the weights recorded. The difference of the weights gives the force exerted by the current upon the model and the suspension system combined.

The force exerted upon the suspension system can be measured separately by repeating the experiment after removal of the model. The velocity of the air current is meanwhile recorded by the self-registering apparatus described above. This measurement is taken at a place in the channel behind the model and beyond the influence of its wake. The problem of determining the magnitude and direction of the resultant effect of an air current which has any given direction in the vertical longitudinal plane is solved by adding to the foregoing measurements the tensions produced in wires 1, 2, 3, and 4. The force which tends to turn the vessel can be measured by an additional

wire and balance. For example, in Fig. 6 the horizontal longitudinal component is measured by balance *I*, the vertical component by the mean of the readings of *II* and *III*, and the deflecting force by a fourth balance (not shown). In order to measure with the utmost generality the six components of the forces acting upon an unsymmetrical body, the body, after the first measurement, must be turned through a right angle and the measurement repeated. As it is often necessary to investigate the dependence of the force upon the angle between the axis of the object and the direction of the current, the apparatus is so arranged that the balance *III* can be raised and lowered, by which means the model is turned round a horizontal transverse axis.

An extensive programme of work has been arranged for the laboratory and new problems will continually arise for solution.—Translated for SCIENTIFIC AMERICAN SUPPLEMENT from Umschau.

THE PARIS AVIATION EXHIBITION.—II.*

PARTICULARS OF SOME OF THE AERONAUTIC MOTORS SHOWN.

Continued from Supplement No. 1765, page 283.

In addition to the aeroplanes shown there are numerous engines specially designed for use in them, and in the structural points of these there is very much more diversity than in the aeroplanes themselves. The number of cylinders varies from two to sixteen, and these are arranged in every conceivable manner. The essential object is, of course, to reduce the weight as far as possible, consistent with reliability over the time which a flight is likely to occupy—a period which has, so far, not much exceeded three hours. Durability, in the ordinary sense of the word, is not necessary. Weight is, of course, of the greatest importance in every motor which moves itself, such as a motor-car engine or a marine motor. Hence such apparatus are made as light as possible consistent with due reliability, durability, and accessibility; and in the racing motor-car and launch-engines the weight has been made as small as is consistent with their maintaining their power with certainty over the period of a race, which is never more than a few hours.

In producing a motor still lighter than these there are several courses open. The simplest is to take an engine of fairly ordinary and substantial construction, and to increase the power developed by cylinders of a given size. This can be done by raising the compression and increasing the rate of revolutions, the valves being made of suitable size. That is to say, we have a substantially-built engine, which is run very hard. The second plan is to retain the ordinary vertical type of engine, but to reduce the weight for a given cylinder capacity by the use of thin steel cylinders, and very light construction of all the parts. The third plan is to reduce the weight of the crank-case and other parts by putting more than one connecting-rod to each crank. The simplest form of this is the diagonal type, in which two cylinders work on to each crank. The most usual form is the eight-cylinder diagonal with four cranks, though several examples are shown of four-cylinder engines with two cranks. The extreme form is that in which several cylinders are grouped round a crank-case of the length usual for one cylinder, all working on to one crank.

A further way of reducing the weight is to do away with the water-cooling, and substitute air-cooling. In this case the whole of the weight of the radiators and the contained water is saved, but, on the other hand, it is doubtful whether it will be possible to maintain the same horse-power for a given cylinder capacity. The question of air-cooling vs. water-cooling may depend on many factors, and we shall refer to this matter later. Meanwhile it may be remarked that, although the cross-Channel flight, and the record for distance have been performed with air-cooled motors, the water-cooled engines are in a very large majority at the exhibition.

The table annexed gives the particulars of several engines exhibited, and will give a fair idea of the lines on which the various constructors are working.

It will be seen that much the lightest engine per horse-power is the "Gnome." This engine was fitted to the Farman aeroplane which holds the record for the longest flight, and was illustrated in SCIENTIFIC AMERICAN SUPPLEMENT No. 1729. It is of the extreme radial type, as the whole of the cylinders are grouped round one crank-case, and attached to one crank, the crank in this case being fixed and the crank-case and cylinders revolving. The success of the engine does not, however, depend entirely on the general outlines of the design, but is largely due to the extreme care taken in the construction, the cylinders and crank-

case, every part, in fact, being machined out of high-grade steel. The rotary cylinders lend themselves admirably to air-cooling, as their rapid motion through the air helps to cool them, and the engine is in every way apparently well adapted to experimental purposes; but it may be doubted whether it will be so well suited to practical work when the aeroplane gets out of the experimental stage. The inlet-valves

water-pump at the other. No exhaust-pipe is provided, and there is a row of holes in the cylinder, which the piston uncovers at the bottom of the stroke to provide a freer exhaust. There is no fly-wheel, the engine being coupled direct to the propeller. An engine of almost identical construction is used by Santos Dumont. As his is the lightest and fastest aeroplane in existence, it appears that if the engine

TABLE GIVING CHIEF PARTICULARS OF AEROPLANE ENGINES.

TYPE.	Horse-Power.	Air or Water Cooled.	CYLINDERS.			Cylinder Capacity.	Weight.	Cylinder Capacity per Horse-Power.	Weight per Horse-Power.	Weight per Cubic Inch of Cylinder Capacity.
			Diameter.	Stroke.	No.					
Gnome.....	50	Air	mm.	mm.	7	cu. in.	lb.	cu. in.	lb.	lb.
Anzani.....	100	"	110	120	14	487	168	9.7	3.4	0.35
".....	30	"	110	120	3	974	220	9.7	2.2	0.23
".....	40	"	105	130	3	307	145	6.9	4.8	0.69
".....	50	"	120	140	3	230	187	7.3	4.7	0.65
".....	35	Water	135	150	3	391	232	7.8	4.6	0.59
Darracq.....	70	"	100	120	4	522	182	6.6	5.2	0.79
".....	30	"	135	150	4	232	206	7.4	4.2	0.57
".....	40	"	130	120	2	194	121	6.5	4	0.62
Panhard.....	40	"	130	120	4	388	242	6.5	4	0.62
Bayard.....	40	"	110	140	4	323	198	8.1	4.9	0.61
Aster.....	50	"	100	120	4	230	242	5.8	6.1	1.05
Renault.....	50	"	130	140	4	455	242	9.1	4.8	0.53
".....	50	"	110	160	4	370	286	7.4	5.7	0.74
Mors.....	50	Air	90	120	8	372	374	7.4	7.5	1.05
".....	45	Water	110	130	4	301	203	6.7	4.5	0.68

are automatic, and placed in the pistons, and therefore very inaccessible, while the centrifugal force of the exhaust-valves has to be balanced by a system of rocking levers. There are also difficulties in distributing the necessary current to the sparking-plugs without undue complication, and at present there is no attempt at any silencer. Even with the very complete cooling the cylinders get it will be seen from the table annexed that the power claimed is very low in proportion to the size of the cylinders.

Among the other engines, of which particulars are given in the table, there is not a very great difference in the weight per horse-power, this ranging from 4 pounds per horse-power to 7.5 pounds, the lightest being the Darracq, water-cooled, and the heaviest the Renault, air-cooled. It may, however, be observed that, with the exception of the Renault, the weights of the water-cooled engines do not, as a rule, include the radiator and water, and this will add from 10 per cent to 20 per cent to their weights in most cases. On the other hand, it is not clear how long the air-cooled engines will maintain their power. It is usual for makers of air- and water-cooled engines to claim the same power for equal-sized engines, whether air- or water-cooled, while in practice the power of the air-cooled falls very rapidly in use as the cylinder gets hot. The Renault air-cooled engine is provided with a fan for cooling the cylinders, and it is understood that its maintained power has been officially tested, but in this case the weight per horse-power is greater than that of the water-cooled engine with radiator, by the same makers. Both of these engines were illustrated in SUPPLEMENT No. 1728.

One of the most interesting engines at the show is undoubtedly the two-cylinder Darracq. This engine is of extremely simple construction, as it has only two cylinders, and these are placed horizontally at opposite sides of the crank-case. The diameter of the cylinders is 130 millimeters (5 1/8 inches), the stroke 120 millimeters (4 3/4 inches), and the power is stated to be 25 to 30 horse-power. Both inlet and exhaust valves are placed in the cylinder-head, and are driven by means of rocking-levers. There is an inclined camshaft, which drives the magneto at one end and the

is light enough for it, it should be light enough for most things, and the advantage of very numerous cylinders for reducing weight is very doubtful in practice. Messrs. Darracq also show a vertical engine with separate cylinders, 170 by 140 millimeters (6 3/4 inches by 5 1/2 inches), having the valves in the cylinder-heads, and giving 100 to 120 horse-power. This engine was illustrated in our last issue.

Next simplest to the two-cylinder engine is naturally the three-cylinder. Of this the Anzani, the type used by M. Bleriot in his flight across the Channel, is naturally the most interesting example. This can be seen in the picture of the Bleriot monoplane. In this case the three cylinders are placed radially around the crank-case at angles of 60 deg. The engine is directly coupled to the propeller, and the draft from this blows on the cylinders, the arrangement of which allows of its striking directly on all of them, while the heads are so far apart as to have no tendency to heat each other. The valves are arranged with the inlet over the exhaust, the former being automatic, and there are holes in the cylinder walls which the pistons overrun to secure a free exhaust.

An air-cooled engine of a totally different type is exhibited by Messrs. Renault Frères. This engine (which, as well as the water-cooled one of the same maker, was illustrated in SUPPLEMENT No. 1728) has eight cylinders disposed diagonally on a four-throw crankshaft. Naturally, with cylinders so arranged the draft caused by the aeroplane going through the air would not be enough to keep them cool, as the cylinders would screen each other. Further, the cylinders are so close together that their heads will radiate a considerable amount of heat to each other. Accordingly a powerful fan is provided, running at the engine speed, which blows a strong draft of air past the cylinders. The latter are 90 by 120 millimeters (3 1/2 by 4 3/4 inches), and have the valves placed over each other, the inlet-valves being driven by rocking-levers. A feature of this engine is that the cam-shaft is driven by gearing capable of transmitting the whole power of the engine, and is prolonged so that the propeller can be mounted on it if desired, and therefore run at half the engine speed. Messrs. Renault also exhibit a

* Engineering.