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Modern Aerial Navigation

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No. 173.

[Monthly Issue.]

Friday, May 13, 1892.

MAJOR-GENERAL R. N. DAWSON-SCOTT, Commandant, School of Military Engineering, Chatham, Member of Council, in the Chair.

MODERN AERIAL NAVIGATION.

By Captain J. D. FULLERTON, R.E.

SYLLABUS.

Introductory remarks and division of the subject.

SECTION I.—*Ballooning or Aerial Navigation by means of Machines lighter than the Air.*

Characteristics of this system.—Successful attempts at propelling balloons.—Giffard's dirigible balloon.—Dupuy de Lôme's dirigible balloon.—The dirigible balloon designed by the brothers Tissaudier.—"La France."—Campbell's air ship.—Professor Carl Meyer's aerial bicycle.—Proposed balloon for war purposes.—The method of calculating the power, speed, &c., of dirigible balloons.—General remarks on dirigible balloons.

SECTION II.—*Aviation or Aerial Navigation by means of Machines heavier than the Air.*

Characteristics of this system.—The theory of aeroplanes.—The motion of an aeroplane through the air.—Longitudinal stability.—Crosswise stability.—Remarks on large aeroplanes.—The bird, and theories of its flight.—Wing motion.—Movements during flight.—Power, speed, &c., of a bird in motion.—Mons. Marey's views.—Mr. Chanute's views.—Mons. Richet's views.—Possibilities of flight in man.—Successful flying machines.—Hargraves model.—Mons. Adler's machine.—Machine proposed by Mr. Maxim.—Motors and methods of propulsion.—The method of calculating the speed, power, &c., of machines of the aeroplane type.—General remarks on aviation.

Concluding remarks.

Introductory Remarks.

THE subject which I propose to bring to your notice to-day, viz., "Aerial Navigation," is one of the very greatest importance to mankind in general, as there can be no possible doubt that if the power of moving safely and expeditiously through the air be successfully attained, great changes affecting all classes and all interests will take place.

Hitherto, unfortunately, in this country aerial navigation has been looked upon, to put it mildly, with the deepest suspicion, and it is no exaggeration to say that the terms "aeronaut" and "lunatic" are at present considered as more or less synonymous.

My object to-day is to show you that the science of aeronautics is based upon simple rules and common sense, and not upon wild and vague theories opposed to all principles of nature. It is only within the last few years that the subject has been scientifically studied, and I believe that, as the result of that study, the long wished for solution of the problem is at last within our reach.

What I particularly wish to do to-day is not so much to advocate any particular system of flight, as to explain the latest ideas on the subject, and to leave you to judge for yourselves as to their possible application for practical purposes.

Division of the Subject.

Aerial navigation is divided into two distinct branches, viz.:—

1. Ballooning, or navigation by means of machines lighter than air;

2. Aviation, or navigation by means of machines heavier than air;

and as these two branches depend upon different principles, I propose to explain them separately.

SECTION I. BALLOONING, OR AERIAL NAVIGATION BY MEANS OF MACHINES LIGHTER THAN THE AIR.

Characteristics of this System.

The chief characteristics of this system are:—

1. That the weight to be moved is floated in the air, by means of a balloon or envelope, filled with a gas lighter than the air—the principle being, of course, exactly the same as that by which a ship floats on the water.

2. That the forms of the balloon, car, &c., are such as to offer the smallest possible resistance. For this reason the envelope is usually made spindle-shaped.

3. That owing to the weight being taken, as above explained, it is only necessary to provide a propulsive force sufficient to overcome the horizontal resistance.

Fig. 8 shows an ordinary type of dirigible balloon. It will be seen

MODERN AERIAL NAVIGATION.

FIG. 1. GIFFARD'S BALLOON.

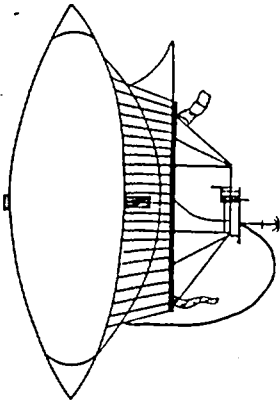


FIG. 2. BALLOON OF DUJUY DE LÔME.

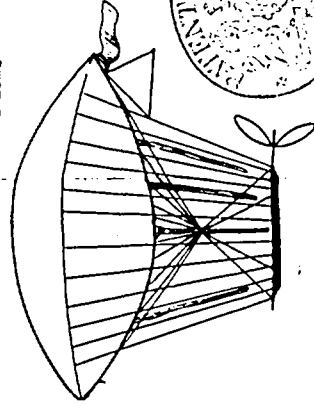


FIG. 3. TISSAUDIER'S BALLOON.

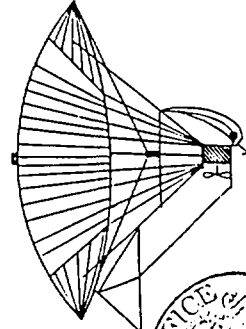


FIG. 4. "LA FRANCE."

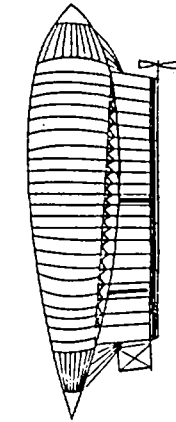


FIG. 5. SCREW OF "LA FRANCE." FROM "REVUE DE L'AERONAUTIQUE."

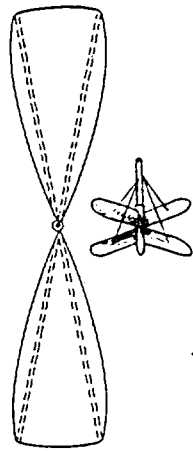


FIG. 6. CAMPBELL'S AIR SHIP. FROM "SCIENTIFIC AMERICAN."

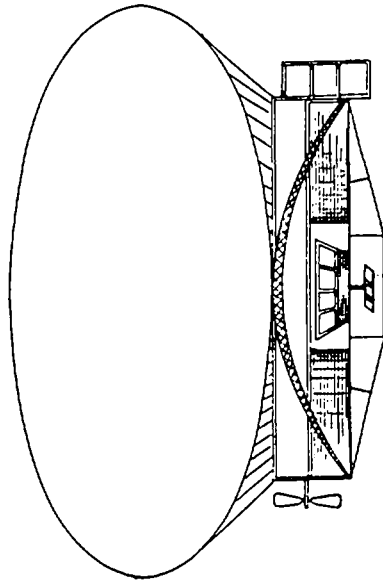


FIG. 7. PROFESSOR C. MEYER'S AERIAL BICYCLE.

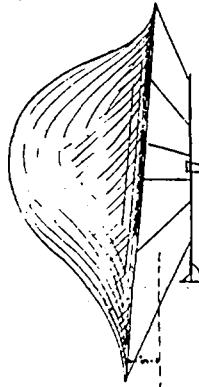


FIG. 8. PROPOSED WAR BALLOON.

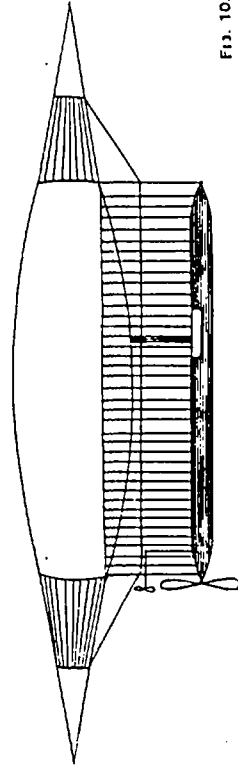


FIG. 9. THEORY OF AEROPLANES.

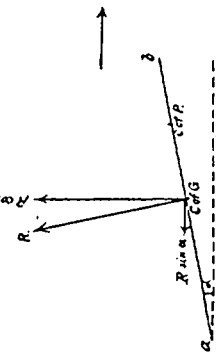


FIG. 10. CROSSWISE STABILITY OF AEROPLANES.



FIG. 12. TRAJECTORY OF THE POINT OF THE WING OF THE BUZZARD.

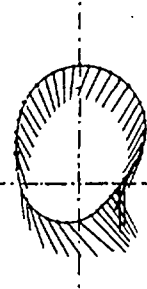


FIG. 11. THEORY OF BIRD MOTION.

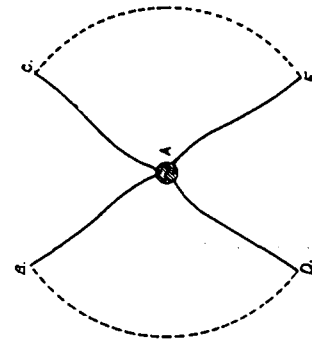


FIG. 16. DIAGRAM OF GULL'S MOVEMENTS.

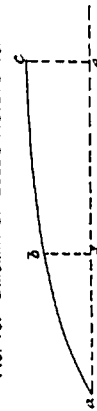


FIG. 14. ROWING FLIGHT OF THE GULL.

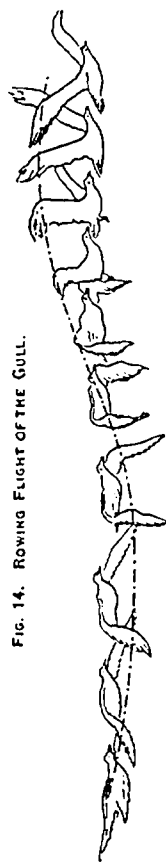


FIG. 15. PART OF TRAJECTORY OF A GULL.

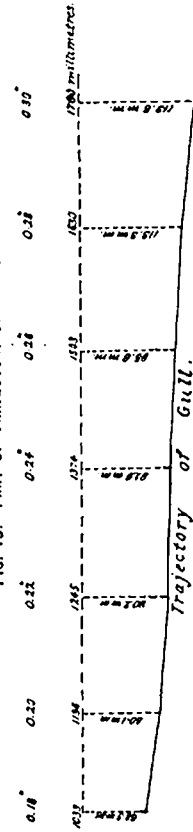


FIG. 18. ADER'S FLYING MACHINE. FROM "RAILROAD AND ENGINEERING JOURNAL."

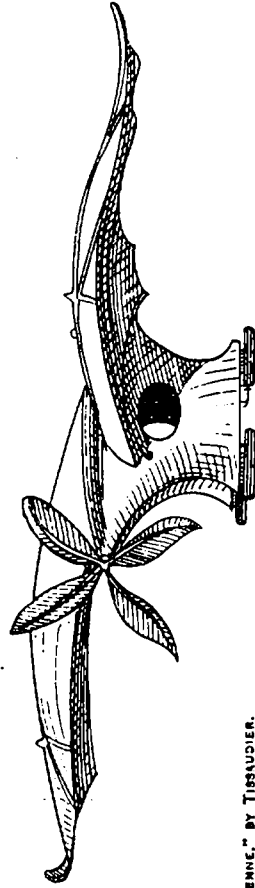


FIG. 17. HARGREAVES' FLYING MACHINE. FROM "ENGINEERING, 1891."

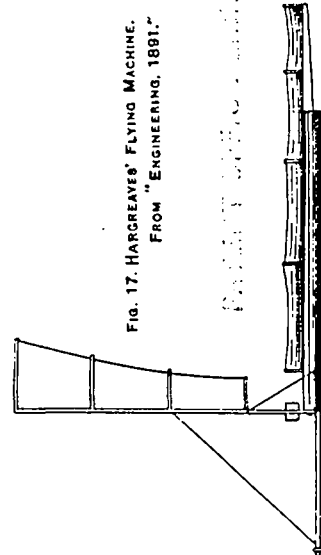
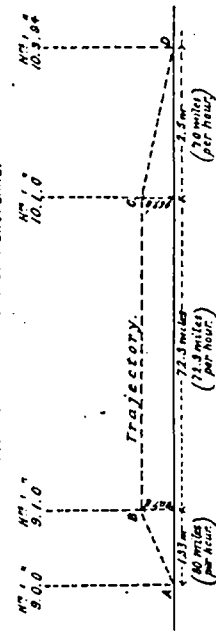


FIG. 19. TRAJECTORY OF AEROPLANE.



FIGS. 1, 2, 3, AND 4 FROM "LA NAVIGATION AERIENNE," BY TISSAUDIER.

FIGS. 12, 13, 14, AND 15 FROM "LE VOL DES OISEAUX," BY M. MAREY.

that the envelope is spindle-shaped, and that the car is attached to it by means of a specially-designed jacket with rope attachments, &c.

Successful Attempts at Propelling Balloons.

From time to time various persons have constructed small model balloons, and worked them successfully at a slow pace.

In 1833 Rufus Porter, an American, constructed a model 22 feet long, and 4 feet in diameter. The propulsive power was a compact little steam engine, and it appears that the machine actually moved at a somewhat rapid rate when exhibited at New York and Washington. In 1850 Mons. Jullien exhibited a model at the Hippodrome in Paris; it was fish-shaped, and weighed 1,160 grams, the content of the envelope being 1,203 c.dm. The gas employed was pure hydrogen, and the machine was forced along by a spring working two small screws. It appears to have been fairly successful, but eventually broke down from being overweighted. The first really successful attempt, however, on a large scale, appears to have been that of Mons. Henri Giffard, shown in Fig. 1.

Giffard's Balloon.

The principal dimensions were; length 44 m., largest diameter 12 m., cubic content 2,500 c.m., giving for pure hydrogen a lifting power of 2,800 kilos., and for coal-gas (which was actually used) 1,800 kilos. There was a long wooden bar, 20 m. in length, to which the car and its appurtenances was hung 6 m. lower down. The car itself was little more than a wooden platform with wheels, so as to allow of the machine running easily along the ground, if it came down with any horizontal velocity. The boiler was vertical, and surrounded with a sheet-iron casing to prevent any flame reaching the coal-gas. The funnel pointed downwards, and the whole apparatus was very ingeniously designed.

The screw had 3 blades and a diameter of 3.40 m.; with 110 revolutions it gave 3 F.H.P. The weights were as follows:—envelope with valve, 320 kilos.; net, 150 kilos.; beam, suspending ropes, &c., 300 kilos.; machine and boiler empty, 150 kilos.; water and coke in boiler at time of starting, 60 kilos.; car with wheels, coal and water tanks, 420 kilos.; anchor rope, 80 kilos.; one passenger, 70 kilos.; spare, 258 kilos.; total, 1,800 kilos. The ascensional force was 10 kilos., the remainder of the spare 258 kilos. being utilized for coal and water.

A trial was made on the 24th September, 1852; there was a strong wind blowing at the time, and although the machine could not overcome the wind resistance, it managed to keep fairly well up to it, and there was no difficulty in steering in any direction. To Mons. Giffard undoubtedly belongs the credit of having been the first person to manœuvre a balloon in the air, with any sort of success:

The next successful attempt was that of

Dupuy de Lôme.

This balloon is shown in Fig. 2. During the siege of Paris in October, 1870, the Government of National Defence entrusted the construction of a dirigible balloon to Mons. Dupuy de Lôme, but unfortunately it was not completed until the siege was over. The principal dimensions were: length, 36 m.; largest diameter, 14·84 m.; cubic content, 3,400 c.m.; screw, 9 m. in diameter. Pure hydrogen was used for inflating the envelope; the motive power was furnished by eight men. There was a very ingenious arrangement for causing the balloon to rise or fall, and for keeping the envelope to its proper form, in the shape of a small balloon inside the large one. This small balloon was filled with atmospheric air, and had a capacity of about $\frac{1}{10}$ th of the large one. To raise the machine, air was drawn out of this balloon, thus making the whole affair lighter, while to lower it, air was forced in. In this manner a rising power of 864 m. was obtained. Another point about the balloon was the manner in which the car was hung; all the suspending ropes were collected at a point above the car, the idea being to render the machine more stable, and to stop swaying about.

A trial took place on 2nd February, 1872, and was successful, a speed of about 2·82 m. per second, or $10\frac{1}{4}$ km. per hour, having been attained, on a still day, with $27\frac{1}{2}$ revolutions per minute of the screw. It was of course obvious that man power was not sufficient for practical work, and Mons. de Lôme proposed using an 8 F.H.P. engine, but the French Government does not appear to have done anything further in the matter.

The Balloons designed by the Brothers Tissaudier.

At the Paris Exhibition of 1881, the brothers Tissaudier showed a small dirigible balloon, of a type very similar to that of Giffard's. This balloon had a small electric motor and attained a speed of 3 m. per second. Encouraged by these results, they constructed a large balloon shown in Fig. 3, the principal dimensions of which were: length, 28 m.; largest diameter, 9·20 m.; cubic content, 1,060 c.m. There was an automatic valve in the lower part of the envelope. The screw had two blades, diameter 2·80 m., and made 180 to 200 revolutions per minute. The motor was a Siemens' dynamo, having a force of 100 kilogram-meters, and a weight of 45 kilos.; the battery being a bichromate one of special construction. The weights were: envelope with valve, 170 kilos.; jacket, rudder, suspending cords, 70 kilos.; braces, 34 kilos.; car (made of bamboo and wickerwork) 100 kilos.; motor screw and battery with materials for $2\frac{1}{2}$ hours' consumption, 280 kilos.; anchor and guide rope, 50 kilos.; two passengers with instruments, 150 kilos.; ballast and spare, 396 kilos.; total lift, 1,250 kilos. The balloon was inflated with hydrogen. Ascents were made in 1883 and 1884, with very fair success; there was no difficulty in steering, but the highest speed attained did not probably exceed

4 m. per second. With such a small H.P., viz., $1\frac{1}{2}$ F.H.P., this was not surprising. Want of funds seems to have prevented the brothers Tissaudier from doing any further work in the ballooning line.

"La France."

Fig. 4 shows "*La France*," the large dirigible balloon built by the French Military Engineers Captains Renaud and Krebs at Chalais-Meudon. The principal dimensions were: length, 50.42 m.; diameter, 8.40 m.; content, 1,864 c.m. The largest diameter was at a point about $\frac{1}{2}$ length from the front of the balloon, instead of being at the centre. The screw, which had a diameter of 7 m. (see Fig. 5), was placed in front, and the 12 F.H.P. engine gave a force of $8\frac{1}{2}$ F.H.P. on the shaft of the screw. There was a small balloon inside the envelope, as in Dupuy de Lôme's machine, and a movable weight was used for adjusting the equilibrium of the whole apparatus. The car was 33 m. long, and 2 m. high; the object of the great length being to ensure stability. The weights were as follows:—Envelope and small balloon, 369 kilos.; jacket and net, 127 kilos.; car complete, 452 kilos.; rudder, 46 kilos.; screw, 41 kilos.; motor, 98 kilos.; other gear, 47 kilos.; shaft of motor, 30.5 kilos.; battery, &c., 435.5 kilos.; passengers, 140 kilos.; ballast, 214 kilos.; total, 2,000 kilos.

Ascents were made in 1884 and 1885 as follows:—

9th August, 1884.—Speed 4.58 m. per second; 42 revolutions of screw per minute. The balloon returned safely to Chalais-Meudon.

12th September, 1884.—Speed 4.43 m. per second; 50 revolutions.

On this occasion there was a breakdown of the battery, and the descent was made at Velizy.

8th November, 1884.—Speed 6.00 m. per second; 55 revolutions.

The balloon returned safely to Chalais-Meudon.

8th November, 1884.—Speed 3.82 m. per second; 35 revolutions.

25th August, 1885.—Speed 6.00 m. per second; 55 revolutions.

Wind was too strong; descent at Villacoublay.

22nd September, 1885.—Speed 6.00 m. per second; 55 revolutions.

The balloon returned safely to Chalais.

23rd September, 1885.—Speed 6.22 m. per second; 57 revolutions.

The balloon returned safely to Chalais.

The general results were fairly successful, but no great speed could be obtained.

Captain Renaud states that the resistance to horizontal motion was much more than he had calculated, it having reached 22.8 kilos. for a speed of 5.50 m. per second. There was no difficulty in steering the machine; but on the first trial it pitched slightly; there does not appear to have been any difficulty about this afterwards. The speeds given above are, of course, for calm weather only.

Campbell's Air Ship.

In 1889, Mr. Campbell, an American, invented the air ship shown in Fig. 6. The length of the balloon was 60 feet, and, although spindle-shaped, the points were blunted. The rising and falling of the machine was managed by the vertical screw in the centre, there being not quite sufficient gas to lift the weight. One man could work both the vertical and horizontal propellers. The preliminary trials were successful, the machine moving forward at a slow pace; but on 16th July, 1889, when Professor Hogan went up in it, the vertical screw fell off, and entirely disarranged the equilibrium. This, of course, ruined the machine, which drifted out to sea and was never heard of again. The principle of the machine was good enough, but it could never have gone any pace, as the shape was bad and the power insufficient to drive it.

Professor C. Meyer's Aerial Bicycle.

The rather extraordinary looking machine represented in Fig. 7 is the aerial bicycle designed by Professor Carl Meyer. The figure is only a rough sketch, but will show the general principle of the apparatus. A short account of it appears in Fores' "Sporting Magazine," 1890 and 1891, and the "Graphic" had a picture of it in August last.

The envelope is something in the shape of a cocked hat, the lower part of which is inclined at an angle of about 5° with the horizon. The propeller is rather a peculiar one, with a right and left, instead of a circular motion. The whole machine is made very light, the bicycle framework weighing, I believe, only 29 lbs.

The mode of starting is as follows:—The amount of gas in the envelope not being quite sufficient to raise the weight, the rider gets on the seat, and pushes himself up into the air, by pressing against the ground with his foot; he then works the pedals as hard as he can, and the machine moves upwards and forwards.

The explanation given in the article above quoted is that the back pressure of air from the propeller strikes the under surface of the balloon and forces it up. This, in my opinion, is incorrect; what I think really happens is that the under surface of the envelope acts as an aeroplane, and the moment any speed is got up the air furnishes a pressure, which forces the machine up. If this is the case, it is a most ingeniously designed apparatus. The steering is done by throwing the weight of the body to the left or right, something after the fashion of a bird. I will explain further on the theory of the action of an aeroplane.

It is of course very difficult, without having the exact dimensions, to calculate the power required to drive this machine; but from rough calculations I have made, I think the resistance for a speed of about 10 miles per hour would be about 3 lbs. A two-bladed screw propeller about 3 feet in diameter would give this thrust, if the power was about $\frac{1}{10}$ H.P. Such a force is just about what a man can

conveniently exert for several hours consecutively; for shorter periods he can, of course, do much more.

The upward pressure on the aeroplane would be about 3 lbs., quite sufficient for the purpose. As far as I can see, there is no reason why the machine should not work. Professor Meyer says he can go 10 miles an hour, without undue exertion.

I think a less eccentric form of envelope would be better; if it was spindle-shaped, and had a light aeroplane of bamboo and canvas over the head of the rider, the apparatus would probably be more manageable.

The next subject to be considered is the type of dirigible balloon likely to be suitable for war purposes.

Description of proposed War Balloon.

The requirements of such a balloon are:—

1. That it should be able to carry three or four passengers, a supply of explosive shells, and a machine gun or two.
2. That it should be able to travel at the rate of about 30 miles an hour on a still day; this speed would enable it to keep up with almost any war-ship now afloat, on more than half the days of the year.

Fig. 8 shows a balloon which would, I think, meet the above requirements.

The Envelope.—Spindle-shaped, 30 feet in largest diameter; length, 240 feet. General shape, a trachoid of revolution, the object being to get easy "entrance curves." The valves for letting out gas should be so arranged as to be easily opened and shut from the car.

Jacket and Netting.—This should be light, but strong, and should be very carefully designed, as the stability of the balloon depends very much upon it.

Car.—Length, 120 feet; breadth and height, 6 feet; ends pointed so as to offer less resistance.

Propeller.—Two screws 18 feet in diameter.

Engines.—These would have to be very carefully designed, great attention being paid to lightness.

Rudder.—This should be a small screw in rear, above the propellers. It should be so arranged that its shaft can be moved from left to right. The thrust of the screw can thus be utilized to change the direction of the balloon.

Equilibrium Adjuster.—An arrangement similar to that used by Captains Renaud and Krebs in "La France" might be used with advantage.

Ballast.—Instead of using sand, air might be compressed in a tank. When it is required to ascend, air could be let out; while in descending, air could be pumped in.

The Method of Calculating the Dimensions, Speed, &c.

In the "Proceedings of the Institute of Civil Engineers," vols. lxxvii and lxxxii, are two papers on "Aerial Navigation," by W. Pole, Esq.,

F.R.S., M.I.C.E. These are most important, as they are, as far as I can ascertain, the first attempt to calculate the speed, &c., upon really scientific principles. The whole theory of the subject is most carefully gone into, and I strongly recommend their perusal to any-one interested in the matter.

As regards the balloon shown in Fig. 8, I have worked out a set of formulæ, based, more or less, on Pole's paper, suited to the particular shape I advocate, and an account of them can be found in the "R.E. Journal" for February, 1891. The example calculated is as follows (see Fig. 8):—

Conditions.

Total weight, 5,400 lbs., approximately; general form as shown in the figure. Required the dimensions of the balloon, its speed, H.P., &c.

(a.) Assuming a diameter of 30 feet, and length 240 feet, the weight which the balloon can lift is found to be 5,437·26 lbs. This might be distributed as follows:—

	Lbs.
Envelope.....	700
Jacket and netting.....	300
Car, lines, rudder, &c.	600
Propeller and screw	200
Engines, water, fuel, &c.	1,800
Instruments	100
Anchor, spare ropes, &c.	150
Passengers	500
Explosives, ballast, &c.	1,087
	<hr/>
	5,437

(b.) The cubic content is 72,403 cubic feet.

(c.) The maximum theoretical height to which the balloon can rise = 5,425·47 feet.

(d.) The resistance to motion through the air is = 230 lbs. at 26·927 miles per hour.

(e.) The gross horse power required would be 20 H.P.; efficiency taken at 0·8.

(f.) The speed would be 26·9 miles per hour.

(g.) The weight of the engines would be about 90 lbs. per H.P. with four hours' coal and water. I will allude to the subject of weight of engines further on; at present I will only say that there should be no difficulty in building engines at this weight.

Remarks on Dirigible Balloons.

The above calculations give rather startling results, but I believe they give a very fair statement of the case as it now stands. I will, however, leave you to draw your own conclusions, and merely point out some of the advantages and disadvantages of balloons, from a

mechanical point of view, it being, I think, generally admitted that for military purposes a balloon capable of moving safely and expeditiously through the air would be most useful.

Advantages.

1. Ascending and descending can be very easily managed by letting out ballast in the shape of compressed air. This air can be obtained at any height without difficulty.

2. No lifting power is required from the engines, only a propelling power; consequently very much less powerful and less expensive engines can be used. This is, of course, a very important matter.

Disadvantages.

1. Floating about in the air, entirely dependent on a bag of gas, is not a very safe proceeding.

2. It is doubtful whether, at very high speeds, the form of the balloon would not be altered, and consequently pace lost, owing to the pressure of the air. I think, however, that at speeds like 30 or 40 miles per hour this might be obviated, either by using a small balloon inside the large one, as before explained, or by making use of bamboo stiffeners, as proposed by General Hutchinson.

3. The difficulty of getting sufficiently light motors. This, of course, applies to all methods of aerial navigation.

4. The expense. This no doubt would be fairly heavy, but it must be recollected that a war balloon of the above type, if it was at all successful, would save its cost over and over again.

With these remarks I shall conclude the consideration of aerial navigation by means of machines lighter than air, and proceed to discuss "aviation," which I myself believe to be the most important of the two branches of the subject.

SECTION II.—AVIATION, OR NAVIGATION BY MEANS OF MACHINES HEAVIER THAN THE AIR.

Characteristics of this System.

The chief characteristics of this system are:—

1. That the machine used is heavier than the air.

2. That a large supporting surface, either in the form of wings, or in the form of an aeroplane, is used to carry the weight.

3. That the lifting or supporting power of this surface is dependent upon its velocity and the angle of inclination which it makes with the horizon, increasing as the velocity or angle increases, and decreasing as they decrease.

4. That the horizontal resistance to motion depends upon the velocity and angle of inclination, in the same manner as the lifting power does.

From these 3rd and 4th characteristics, the following very impor-

tant fact is deduced, viz.: that the higher the speed, the less the power required to drive the machine. For, by reducing the angle of inclination, the horizontal resistance and, consequently, the power is reduced, while, by using a high speed, loss of lifting power is compensated for.

Thus, a plane and car, weighing, say, 15,000 lbs., with a 4° inclination, moving at about 62 miles per hour, has to overcome a horizontal resistance = about 1,000 lbs. The same plane, with an inclination of 3° and a speed of 72 miles an hour, meets with a resistance = about 800 lbs. In other words, less power is required to drive it at 72 miles an hour than at 62 miles an hour. These figures are taken from the example worked out later on.

5. That the means of propulsion is either by wing movements, as in the case of a bird, or by a screw propeller, jet propulsion, or some such mechanical arrangement.

Before discussing possible flying machines of the aeroplane type, it is necessary to understand

The Theory of Aeroplanes.

Our knowledge of the principles governing the motion of planes through the air has, till the last two years or so, been somewhat vague; the fact being that the subject has, until quite recently, received little or no attention. As regards planes moving vertically through the air, numerous experiments have been made by Hutton, Newton, and others, the general result being that, for small speeds, the pressure per square foot on a surface moved vertically through the air varies as some function of the square of the velocity. Different formulæ have been proposed, but for the purposes of this lecture I will take the well-known one of Smeaton, viz.,

$$p = \frac{v^2}{200},$$

where p = pressure per square foot in lbs., and v = velocity of plane in miles per hour.

Next, as regards planes moving through the air at an angle.

Various experiments have been made, but the first really satisfactory formula appears to be that of Colonel Duchemin, of the French Engineers, who found that

$$P_a = p \frac{2 \sin \alpha}{1 + \sin^2 \alpha},$$

where P_a = normal pressure per square foot on the inclined plane,

α = angle of inclination of the plane with the horizon.

During the last few years, Professor Langley, of America, has, by means of very carefully-constructed apparatus, thoroughly investigated the subject, and his results agree almost exactly with those of Duchemin. A very interesting account of these experiments is given

in "Experiments in Aerodynamics," recently published, and I think we may take it that the subject has now been fairly well threshed out. Assuming Langley and Duchemin's formulæ to be fairly correct, I will now explain

The Motion of an Aeroplane through the Air.

Let *ab*, Fig. 9, represent the aeroplane or thin rectangular plate, inclined to the horizon at an angle α , and moving with any given velocity, in the direction shown by the arrow. Then *R* is the normal resistance of the air = $SP\alpha$, where *S* is the number of square feet of surface of the aeroplane.

Now *R* can be resolved into two components: $R \cos \alpha$ opposing the weight *W*, and $R \sin \alpha$ resisting the advance of the aeroplane. Leaving aside, for the moment, the fact that the forces *R* and *W* act at different points in the plane, we have:—

If $R \cos \alpha$ is less than *W*, the aeroplane will move downwards, with the velocity due to the pressure $W - R \cos \alpha$.

If $R \cos \alpha$ is greater than *W*, the aeroplane will move upwards, with the velocity due to the pressure $R \cos \alpha - W$.

If $R \cos \alpha = W$, the weight will be just supported and the aeroplane will move along, on the level, with the velocity corresponding to the value of *R*.

From the above it will be seen that it is easy to find out the weight which a given aeroplane, moving at a given velocity, will carry; for example, aeroplane 1 square foot, $\alpha = 2^\circ$, velocity 60 miles per hour. By Langley and Smeaton's formulæ, the normal pressure $R = 1.26$ lbs., and resolving

$$R \cos \alpha = 1.26 \text{ lbs. (since } \cos 2^\circ = 1 \text{ nearly);}$$

and, consequently, the plane will carry 1.26 lbs., including its own weight.

Also the resistance $R \sin \alpha = 0.043$ lb.; and, consequently, the horse power required to drive the plane = $\frac{0.043 \times 5,280}{33,000} = 0.00688$ H.P.

Longitudinal Stability.

I noticed above that the forces *R* and *W* were not applied at the same point. The reason of this is, that the centre of pressure of an inclined plane moving through a fluid does not coincide with the centre of gravity of the plane. The rules for finding the position of pressure in cases of this sort are given very clearly by Mons. Dezewiecki, in a paper read by him before the Aeronautical Society of Paris in 1889. This very important paper, to which I shall allude further on, states that, for planes of this description, moving at very small angles of inclination, the centre of pressure is at a distance from the front edge of the plane equal to two-tenths of its length. In the case above quoted, therefore, the distance between

the centres of pressure and gravity will be $\frac{3}{16} \times 12'' = 3.6''$, and must, of course, be taken into consideration. The best plan to do this appears to be, to shift the weights forward so that the vertical line through the centre of gravity coincides with the vertical line through the centre of pressure; in this way the machine will be longitudinally stable, and there will not be any tendency to tip back.

Crosswise Stability.

This is also important, and can be secured by making the plane in cross section somewhat as shown in Fig. 10.

Large Aeroplanes.

As regards large aeroplanes, such as those 50 feet by 100 feet in size, it cannot be said for certain that the pressures found by the above rules will be strictly in proportion to the extent of the surfaces, but they most probably are, and such will be considered to be the case in the calculations drawn up further on.

In the above remarks, I have only touched generally upon the more important parts of this subject. For further details, I must refer you to Professor Langley's "Experiments in Aerodynamics," and Monsieur Dezewiecki's paper, published in "L'Aéronaut," 1889.

I will now proceed to explain the motion of the best known flying machine at present, viz. :—

The Bird.

Up till quite recently, the generally accepted theory of the bird's motion has been that by flapping its wings it produced a force which lifted it and drove it along, somewhat as follows (Fig. 11) :—

Let A be a cross section of the body of the bird, AB, AC, the position of the wings when at the beginning of the stroke; AD, AE, the positions at the end of the stroke; then it was considered that the wings acted as aeroplanes, moving with a velocity equal to that of the down stroke, the air pressures generated in this manner counterbalancing the weight, as soon as they were strong enough. It was admitted that the up strokes also produced air pressures, which would on this theory drive the birds down, but it was pointed out that there was a great difference between the strength of the upward and downward strokes, owing to the wing being in the former case convex, and in the latter concave. Speaking generally, it was the difference between the up and down air pressures which was the real motive power. The actual propulsion was supposed to be due to the fact that the forces above mentioned did not act in a vertical line, and that consequently there was a horizontal component which drove the bird along, and a vertical component which sustained it in the air.

This theory, however, does not appear to be correct. Mons. Dezewiecki's theory is as follows :—

1. A bird is simply an aeroplane of a peculiar shape, and having a peculiar kind of motor, and it is sustained in the air in exactly the same way as an aeroplane is.

2. A bird in full flight carries its plane, generally speaking, at an angle of about 2° or 3° .

3. The rules for aeroplanes apply generally to birds, making allowance for size of wings, &c.

4. At small angles, such as 2° , the resistance to horizontal motion (for small bodies) is very small indeed. The aeroplane alluded to above weighed about $1\frac{1}{4}$ lbs., and only required 0.006 H.P. to drive it at the rate of 60 miles an hour.

5. At the lower velocities, just after starting, owing to the steeper angle of inclination, greater power must be exerted by the bird, its object being to get up a high speed as quickly as possible, so as to utilize the air pressure as a lifting force.

6. The propelling force is due to the air escaping, or rather being forced under the wings backward. These streams of air act against the atmosphere, and propel the bird along.

I should add that Mons. Dezewiecki shows from an example that the usually accepted theory is quite wrong in the case of large birds, and that they cannot possibly work up sufficient air resistance to sustain their own weight.

Wing Motion.

There are probably few subjects which have been so much disputed over as the motion of a bird's wing in "rowing" or ordinary flight. The great difficulty in connection with the matter is to find out what really does occur, as the speeds of the birds and wings are so great that the eye does not readily grasp the motions. An immense amount of thought and labour has been spent by Mons. Marey, in making experiments on this subject, and in his most interesting book, called "*Le Vol des Oiseaux*," he has given us the results of these labours.

Fig. 12 shows the trajectory of the point of the wing of a buzzard in rowing flight (medium speed) and the approximate positions which the plane of the wing assumes during an up and down stroke. It will be noticed that the trajectory is elliptical, with the longer axis of the ellipse inclined downwards and forwards, and that in the second quarter of the ellipse the wing is distinctly driving the air backwards.

When a bird is in full flight, it is found, as might be expected, that the larger axis of the ellipse approaches more nearly to the vertical as the speed increases; while, on the other hand, at the commencement of flight, the axis is nearly horizontal.

Movements during Flight.

Our knowledge of the movements of birds during flight is by no means satisfactory, and many points in connection with the subject

are still much disputed. As regards "starting," it is pretty well certain that the smaller birds either give a vigorous jump in the air, so as to get clear of the ground, and then violently flap their wings, or throw themselves off a height, the object in both cases being the same, viz., to get up speed as quickly as possible, so as to get the benefit of the vertical component of the air pressure. Larger birds either throw themselves off a height, or run rapidly along the ground, jump into the air, and beat their wings violently.

"Stopping."—Fig. 13 shows a duck coming down. The method of using the wings, to prevent stopping too quickly, is well illustrated.

"Rowing Flight."—Fig. 14 shows the different positions of a gull, practising this kind of flight. Instantaneous photographs of their positions were taken by Mons. Marey, at intervals of $\frac{1}{50}$ th second.

"Floating Flight."—I do not know exactly what name to give this description of flight, but I think "floating" expresses the facts of the case. It is practised when a bird suddenly stops "rowing," and is carried forward by the impetus left in it. Usually, the bird glides down an inclined plane of about 7° or 8° , with his wings held out horizontal; as long as he has any energy left, he can, by altering the plane of his wings, rise, fall, move right or left, &c.

"Sailing Flight."—There is a great deal of difference of opinion as regards "Sailing Flight," but all authorities seem to agree upon one point, viz., that it can only be practised in a high wind. The usual idea seems to be that the vertical component of the high wind (against the bird) forms a supporting force to hold the bird in the air; later theories are against this, and it is difficult to say which is correct.

"Turning Movements."—This is done by throwing the weight of the body towards the side to which it is intended to turn.

The Power, Speed, &c., of a Bird in Flight.

Numerous attempts have been made to estimate the power required to move a bird at any given velocity, and the estimates are most conflicting. Years ago, one author considered that a goose in full flight expended 200 H.P., whilst a recent calculation by Mr. Maxim shows that the goose would only expend 0.083 H.P. When "doctors differ" to such an extent as this, it is a little difficult to get at the truth; but I think, by describing to you the methods used by some of the abler modern experimentalists, you can get a very fair idea of the approximate power required for the different kinds of flight.

Mons. Marey's System.

The first really careful, scientific calculations appear to be those of Mons. Marey, who was assisted by Captain de Labouret, of the French Engineers. In his book, "*Le Vol des Oiseaux*," he goes very thoroughly into the subject, and his general method of investigation may be described as follows:—

A gull, carrying a small bright bead on his head, was made to fly

in front of a specially-constructed camera, and photographs of the bird in flight were taken at intervals of $\frac{1}{30}$ th second. From the photographs the trajectory of the bead was made out. A very elaborate correction was made for the position of the centre of gravity of the bird, taking into account the differences of the position of this point, due to the up and down motion of the wings. From these data the true trajectory of the centre of gravity of the bird was calculated. Fig. 15 shows this line for a part of Example I in Mons. Marey's book; the gull was at the time flying slowly, viz., at the rate of about 15 miles per hour.

The method of calculating the forces exerted by the bird during each interval of $\frac{1}{30}$ th second, is best shown in Fig. 16.

Let a, b, c , be the trajectory of the centre of gravity of the bird, a, b , and c being the positions occupied by the bird at the 0.18-inch, 0.20-inch, and 0.22-inch respectively. Let ae be a horizontal line; then ad represents the horizontal space passed over between the 0.18-inch and the 0.20-inch, de the similar space between the 0.20-inch and the 0.22-inch, and so on. Similarly, bd and ce represent the vertical rise (or fall). Now, since $\frac{1}{30}$ -inch is a very short period, we may take

$$\text{force} = \text{acceleration per } \frac{1}{30}'' \times \text{mass of the bird};$$

consequently, if we know the trajectory, the forces can be calculated. As an example, let $ad = 103$ mm., $de = 119$ mm.; then

$$\text{acceleration per } \frac{1}{30}'' = 16 \text{ mm.}$$

$$\text{acceleration} = 0.8 \text{ m. per second,}$$

$$\therefore \text{acceleration per } \frac{1}{30} \text{ in metres} = 40,$$

$$\text{and force} = 40 \times 0.0637, \text{ when mass} = 0.0637 \\ = 2.548.$$

The vertical forces can be found in a similar manner.

The estimation of the horse power, &c., has been very neatly worked out by Captain de Labourat for the forces, as calculated above, but, as the details are rather long, I must refer you to Mons. Marey's book for them. The general result, however, is—

$$\text{1st example, } \frac{7.046}{75} = 0.094 \text{ F.H.P.}$$

$$\text{2nd example, } \frac{7.495}{75} = 0.1 \text{ F.H.P. nearly,}$$

as the H.P. required to move the bird at the speed of about 15 miles an hour. For full flight Mons. Marey considers that about one-fifth of the above would be necessary

$$= 0.02 \text{ F.H.P.}$$

Mr. Chanute's Method.

In the "Railroad and Engineering Journal" for February (and previous numbers), 1891, are some interesting articles on "Progress in Flying Machines," by Mr. Chanute. This gentleman considers a bird as an aeroplane, and calculates the power expended in the manner explained above for an aeroplane, making allowance for the concavity of the wings, &c. The two pigeons experimented on by him were of the following dimensions: largest cross section of body, 4.9 square inches and 5.3 square inches; largest cross section of edge of wings 5.02 and 4.88 square inches; weight of birds 1 lb. and 0.969 lb.; total surface of spread wings, projected body, and spread tail, 132.56 square inches and 151.04 square inches.

Corrections have to be applied to all the above.

Cross Section of the Body.—As explained for balloons, the resistance of a fair-shaped body may be taken as $\frac{1}{16}$ of that of its cross section; consequently the area for body resistance may be considered = 0.05 square foot.

Area of the Wings.—This is about 1 square foot, and allowing for concavity, may be taken as 1.3 square foot.

Resistance of the Edge of the Wings.—This is equal to the area $\times 0.15$ as a reasonable coefficient.

Now to find the power required at various speeds; find by the usual aeroplane formula an angle which gives a lifting power approximately equal to the weight of the bird. The following examples show the power required at different speeds.

Speed, 20 miles per hour.

Normal resistance = 2 lbs.

Lifting power at $12^\circ = 1.3 \times 2 \times 0.39 = 1.014$ lbs.

Horizontal resistance at $12^\circ = 1.3 \times 2 \times 0.0828 = 378.7$ ft.-lbs.

Body resistance = $0.03472 \times 2 \times 0.05 = 6.1$ "

Edge of wings = $0.03472 \times 2 \times 0.15 = 18.3$ "

403.1 "

\therefore H.P. required = 0.0122 H.P.

For other speeds—

5° and 30 miles per hour	317.2 ft.-lbs.
3° and 40	"	394.2 "
2° and 50	"	556.5 "
1½° and 60	"	827.3 "

The reason why more power is required at 40 miles an hour than at 30 miles per hour is that the body resistance increases as the square of the velocity. This body resistance is a very important element in the case of a bird or small object, and has to be taken into consideration, especially in large flying machines.

According to Mr. Chanute, a bird usually carries its plane at an angle of about 3° , and this is the angle where the resistance is about a minimum. He has added to the table of bird dimensions, &c., in Mons. Mouillard's "*L'Empire de l'Air*," a column showing the speed which each bird would fly at, supposing the angle of its plane to be 3° . The following are a few examples:—

Bat.....	15.9 miles per hour.
Swallow	23.1 "
Kingfisher.....	30.3 "
Rook	33.3 "
Quail	42.3 "
Gray pelican.....	51.3 "
Male duck	66.2 "

Mons. Richet's Views.

Mons. Richet, the editor of the "*Revue Scientifique*," endeavours to find the work done by a bird by the use of chemical formulae, and the investigation is interesting as being an entirely different method of approaching the subject. It is based upon the following principles: a bird when in repose produces a certain amount of carbonic acid gas per kilogram of its weight per hour. Now if we can ascertain the amount produced when the bird is in motion, the difference will give us a basis from which to calculate the work done in flight.

Mons. Richet considers, from his own experiments and from those of other experimentalists, that a pigeon weighing 320 grams will produce 3.3 grams of carbonic acid gas per kilogram of its weight per hour, when in repose. Now we have no means of ascertaining exactly the amount that the bird will produce when in motion, but it seems probable that the increase will bear a similar ratio to that found by experiment to be the one for men and animals. This when a fair amount of exertion is being put out is about three times the amount when in repose. Assuming this to be correct, the bird would give out 3×3.3 grams, say 10 grams per kilogram of its weight per hour when in full flight. Now deduct the amount given when in repose, and 6.6 grams is left as a basis for farther calculations. By chemical experiment it has been found that 1. gram of carbonic acid gas is equivalent to 2.575 calories; consequently the 6.6 grams are equivalent to 17 calories. Now since the ratio of chemical to mechanical work is about 4 to 1, we may consider the mechanical work done as

$$= 4 \text{ calories} = 4 \times 423.985 \text{ kilos.}$$

$$= 1,700 \text{ kilos. per hour.}$$

$$= \frac{1}{2} \text{ kilo. per second per kilo. of weight.}$$

This formula, if applied to the gull experimented on by Mons. Marey, would give about twice as much power required for full flight, but Mons. Richet states that $\frac{1}{2}$ kilogram is probably too high.

In concluding this part of the subject I may mention that Mons.

Tatin, in his paper in the "Revue Scientifique," makes the power very much lower, viz., about 0.0025 F.H.P. as a minimum and 0.0150 F.H.P. as a maximum.

Possibilities of Flight in Man.

For centuries it has been the ambition of man to fly in the air with the speed of a bird, and the number of flying machines which have been invented is almost countless. I do not believe that it is possible for a man to fly by means of wings, without some assisting power. For suppose a large bird-shaped machine to be built, having a wing-surface of 200 square feet, inclination of plane 2° . Now using the aeroplane formula, and considering the weight of the man to be 150 lbs., then for a speed of v miles per hour the

$$\begin{aligned}\text{lifting power} &= 200 \times \frac{v^2}{200} \times 0.07, \\ &= 150 \text{ lbs.};\end{aligned}$$

$$v = 46 \text{ miles per hour};$$

and the resistance would be

$$200 \times \frac{46^2}{200} \times 0.0025 = 5.3 \text{ lbs.},$$

$$\text{giving a H.P.} = 0.65 \text{ E.H.P.}$$

Now in the above calculations no allowance has been made for the weight of the machine, or the body resistance of the man. Both of these would very largely increase the power required, and, as a man can only conveniently exert $\frac{1}{10}$ th H.P., it seems pretty certain that some extra power will be required to move him through the air.

Successful Flying Machines.

Up to the present (with the exception of Mons. Ader's machine) no full-sized apparatus has flown in the air. A good number of flying models have been constructed, such as the butterfly toy, de Pichancourt's bird, &c. One very good example is Mr. Hargraves' model shown in Fig. 17. The motor is compressed air, stored in the tube which forms the backbone of the apparatus. This tube is 2 inches in diameter and $48\frac{1}{2}$ inches long; its weight being $19\frac{1}{2}$ ounces. The air pressure is 230 lbs. to the square inch. The engine weighs $6\frac{1}{2}$ ounces, its cylinder being $1\frac{1}{2}$ inches in diameter; stroke $1\frac{1}{4}$ inch. The piston rod is fastened to the tube, the cylinder working up and down, moving the wings. The wings are of paper and weigh 3 ozs.; their area is 216 square inches, and that of the body is 2,128 square inches. This model flew 368 feet on a calm day.

Ader's Flying Machine.

Fig. 18 shows Mons. Ader's flying machine. He is reported to have risen 60 feet in the air, and taken short flights of some 300 yards or 400 yards; but all details of the machinery are kept a secret. The real moving power is the screw in front, though I believe the wings are used to assist in rising from the ground.

Maxim's Flying Machine.

Constant mention is made in the public press of Mr. Maxim's flying machine. In the "Century Magazine" for October, 1891, he has written an article entitled "Aerial Navigation," the power required, describing the results of some of his experiments, and giving some information about the machine. It appears to be an aeroplane, with a car attached underneath; the supporting surface being about 5,500 square feet, and the angle of inclination 1 in 14, or $5^{\circ} 43'$. It is not quite clear from the article whether the angle can be varied, but presumably it can. The weight of the machine, engines, passengers, fuel, &c., is 5,000 lbs., and as he can carry 14,000 lbs., there is some 9,000 lbs. of weight to spare. The engines are extraordinarily light, weighing only about 13 lbs., and perhaps less, to the H.P. The push of the two screws is 1,000 lbs. when 120 H.P. is used; this would, with a $5^{\circ} 43'$ inclination, give a speed of about 45 miles per hour for motion on a level. The steam generator is self-regulating, has 48,000 brazen joints, and is heated by 45,000 gas jets, the gas being made from petroleum. Mr. Maxim is very sanguine as to its success. One doubtful point has been noticed by Mr. Brearey, in the "Proceedings of the Aeronautical Society," viz., that we do not at present know whether the rules for aeroplanes moving on a whirling table are strictly applicable to aeroplanes moving freely through the air. This is, of course, a very important point, but it can only be settled by making the experiment.

Motors and Methods of Propulsion.

The great difficulty, both in "Ballooning" and "Aviation" is to get a sufficiently light motor. At present, owing to the fact that such articles are not much in demand, 40 lbs. per H.P., is looked upon as a small weight; but there does not appear to be any reason why this should not be very largely reduced. Mr. Stringfellow's engine (1868) weighed only 13 lbs. per H.P., and an engine lately invented by the Rev. T. Jones comes to only about 14 lbs. per H.P. A description of this latter engine is given in General Hutchinson's "Navigable Balloons in War and Peace." Mr. Maxim's engine is probably a good deal lighter than either of the above, and, I believe, that when the matter is thoroughly gone into, it will be found possible to very largely reduce the present weights. I may add that as far as can be seen at present, a steam engine appears to be a more promising motor than an electrical one.

Next, as regards methods of propulsion, I do not think that any form of wing action is desirable, as the machinery for this kind of motion must be complicated, and will require very nice adjustment. At present a fine-pitched screw propeller, revolving at a rapid rate, appears to be the best, but probably in the future some form of jet propulsion will come into general use, as we cannot allow the enormous power given out by the explosion of gun-cotton or powder to be wasted for ever.

The Method of Calculating the Power Speed of Machines of the Aeroplane Type.

We have now to examine the general method of calculating the power, speed, &c., of a machine of the aeroplane type, and this will be best shown by an example.

Conditions.

Aeroplane.—110 ft. \times 50 ft. = 5,500 sq. ft. of surface; angle of inclination, variable at will.

Car.—About 70 ft. long, fair shaped, largest cross. section, $7\frac{1}{2}$ ft. \times 10 ft.

Weights.—Aeroplane, car, &c., about 5,000 lbs., engines, fuel, &c., about 10,000 lbs.; 300 G.H.P., or about 33 lbs. per G.H.P.

Propelling Machinery.—Two two-bladed screws.

Method of Starting.—Either by running along a line of rails and rising in the air when the air pressure lifts the machine, or by holding the machine firmly to the ground, and allowing it to rise when there is sufficient air pressure to maintain it. Proper arrival and departure stations would have to be built.

Method of Descending.—Speed of descent to be checked by auxiliary planes, and suitable horizontal velocities to be chosen from the calculated tables, which will allow of the rate of fall being not greater than 22 ft. per second.

Calculations.

The general theory of aeroplanes has already been gone into. The calculations now required may be conveniently arranged as follows:—

1. Lifting power, and rising and falling velocities.
2. Horizontal resistances and the powers required to overcome them.
3. Convenient speeds, &c., and the power required.
4. The trajectory of the machine in the air under given conditions.

Lifting Power, &c.

(1.) From the aeroplane formulæ:—

$$\text{Lifting power} = 5,500 \cos \alpha \times \frac{v^2}{200} \times \frac{2 \sin \alpha}{1 + \sin^2 \alpha}.$$

Hence by assuming any convenient angle, and substituting values of v , such as 10 miles per hour, 20 miles, 30 miles, and so on, a table can be drawn up, as shown below, giving the lifting power for any given speed.

2. Rising and falling velocities. As already explained, the aeroplane will rise when

$$SR \cos \alpha > \text{the total weight,}$$

and it will fall when it is less. Let the rising or falling velocity = v' , then

$$v' = \sqrt{\left(\frac{\text{lifting power} \pm 15,000}{S}\right)} 200 \text{ miles per hour.}$$

It should be noticed, when considering these rising and falling movements, that the pressures are practically speaking those on a horizontal plane; for, when the angle of inclination of the aeroplane is very small, $R \cos \alpha = R = \text{weight}$.

The table below gives the lifting power and the rising and falling velocities for an angle of inclination of 3° .

TABLE I.

Velocity in miles per hour.	Lifting power.	Downward velocity.	Upward velocity.
	lbs.	ft. per sec.	ft. per sec.
0	0	31.24	0
10	286	33.83	..
20	1,144	32.85	..
30	2,574	31.09	..
40	4,576	29.45	..
50	7,150	24.79	..
60	10,296	19.21	..
70	14,014	7.48	..
80	18,304	..	16.13
90	23,166	..	23.61
100	28,600	..	32.70
110	34,606	..	39.16

N.B.—When the machine has a horizontal velocity of 72.3 miles per hour, it will just move along in the air on a level.

Horizontal Resistances and G.H.P.

(1.) The horizontal resistances to be overcome are—

- Air resistance to aeroplane.
- Air resistance to body of car, ropes, &c.
- Rail resistance while the machine is on the ground.

(a.) The air resistance to aeroplane is found

$$= 5,500 \sin \alpha \frac{v^2}{200} \times \frac{2 \sin \alpha}{1 + \sin^2 \alpha},$$

and can be tabulated in the same manner as the lift.

(b.) The body resistance may in this case be taken

$$= 75 \times \frac{1}{15} \times \frac{v^2}{200}.$$

(c.) Rail resistance. From Forney's "Catechism of the Locomotive" this is found to be—

Speeds.	Resistances per ton of 2,000 lbs.
10	6.6 lbs.
20	8.3 "
30	11.2 "
40	15.3 "
50	20.6 "
60	27.0 "
70	34.6 "

The following table shows all these resistances for the various speeds:—

TABLE II.

Velocity in miles per hour.	Resistance in lbs.					Gross horse power required to drive the machine through the air.
	Air.	Body.	Rail.	Total.		
				Without rail.	With rail.	
0	0	0	0	0	0	0
10	14.85	2.5	49.70	17.35	67.05	0.60
20	59.40	10	62.25	69.40	131.65	4.69
30	133.65	22.5	84.00	156.15	240.15	14.98
40	237.60	40	114.75	277.60	392.35	42.27
50	371.25	62	151.50	433.25	587.75	64.71
60	534.60	90	202.50	624.60	827.10	108.96
70	727.65	122	259.50	840.65	1,109.15	171.33
80	950.40	160	..	1,110.40	..	253.52
90	1,202.85	202	..	1,404.85	..	357.46
100	1,485.00	250	..	1,735.00	..	485.91
110	1,796.85	302	..	2,098.85	..	640.42

N.B.—The gross horse power required to drive the machine on a level through the air at 72.3 miles per hour = 189.75 G.H.P.

(2.) The G.H.P. required to overcome the resistances is—

$$= \frac{\text{Resistance in lbs.} \times \text{speed in ft. per minute}}{33,000}$$

To find the G.H.P., a percentage must be added for slip of the screw; the amount of this is not well known, but I have taken it as follows:—

Speed in miles per hour.	Percentage of slip.
10	30
20	24
30	20
40	16
50	12
60	9
70	8
80	7
90	6
100	5
110	4

Table II, above, shows the above calculated resistances and G.H.P.

Speed, Power, &c.

An inspection of the above tables for 3° inclination shows—

1. That the machine will move on a level in the air at a speed of 72·3 miles per hour.
2. That the G.H.P. required to so move it is 189·75 G.H.P.
3. That a convenient rising velocity is about 16·13 feet per second, and that this would be attained when the machine had a horizontal velocity of 80 miles per hour.
4. That a convenient descending velocity, leaving out of consideration auxiliary aeroplanes, would be 7·48 feet per second, which is attained when the horizontal velocity is 70 miles per hour. It must be understood that these results only apply to a 3° inclination; a lower inclination of the aeroplane would, of course, be much more favourable to rapid motion.

Trajectory of the Machine in the Air under given Conditions.

From the above tables we can work out the trajectory of the machine (see Fig. 19). Starting from A at 9 A.M. with a velocity of 80 miles per hour, in one minute the machine would be at B, 967·8 feet above the ground. C would be reached at 10 hours 1 minute, 72·3 miles having been covered in one hour. In coming down (leaving out of consideration the use of auxiliary planes), the falling velocity might be 7·48 feet per second, and the ground would be reached at 10 hours 3 minutes 9·4 seconds.

The above calculations are, of course, very general, simply to give you an idea of the method employed.

General Remarks on Aviation.

Apart from the military value of such machines, from the mechanical point of view, the advantages and disadvantages of this class of apparatus appear to be:—

Advantages.

1. Very high speeds, with small expenditure of force.

Disadvantages.

1. As regards any wing-motion machines, the difficulty of producing the wing motion satisfactorily.

2. Owing to the high speeds and enormous differences of pressure caused by very slight alterations in the inclination of the aeroplane, great skill and watchfulness will be required on the part of those responsible for the working of the apparatus.

3. The difficulty of getting a sufficiently light motor. This affects any form of flying machine more than it does a balloon, as a flying machine is entirely dependent on a high speed, to supply the lifting force.

4. The danger in coming down with a high horizontal velocity. This can, I think, be arranged for by using auxiliary planes, and thus increasing the lifting power. It will not then be necessary to maintain a high horizontal velocity, in order to get a convenient vertical speed.

5. The difficulty of keeping the aeroplane at any particular angle. Until a trial has been made, it is hard to say whether this difficulty really exists or not.

Concluding Remarks.

In concluding, I wish to specially bring to notice the following points:—

1. The very great importance of "aerial navigation" to this country. The success of aerial machines will enormously affect the position of the United Kingdom; in fact, there is no country in the world which will be so much affected. A total change will have to be made in our defensive system; the value of our Navy will be very much reduced, and the "silver streak," of which we hear so constantly, will, for all practical purposes, disappear. An aerial navy of the very first class will be an absolute necessity, if we are to maintain our position as one of the leading Powers in the world.

2. The importance of making really careful and scientific experiments on the subject, so as to obtain thoroughly satisfactory data to work from.

Hitherto, the most absurd mistakes have been made about air-pres-

sure, &c., simply because proper experiments were not carried out. For instance, it has for years been supposed that if a plane were projected horizontally with any velocity, however high, it would always reach the ground in the same time that it would do if it were let fall without any horizontal velocity at all. Professor Langley's experiments show that this is not the case, and that the time of fall is very largely increased by giving a high horizontal velocity.

I mention this case, because such a very simple matter as this, one of enormous importance to aerial navigation, has apparently only been discovered in 1891!

In conclusion, I will quote a remark said to have been made by Mr. Maxim, who is now constructing a flying machine of the aeroplane type:—

"If I can rise from the coast of France, sail through the air across the Channel, and drop half a ton of nitro-glycerine upon an English city, I can revolutionize the world. I believe I can do it if I live long enough. If I die, someone will come after me, who will be successful if I fail. . . . It can be done as sure as fate. I have spent 45,000 dollars already upon it, and I did not enter upon the work until I was convinced that the idea was practical."

LIST OF BOOKS, PAPERS, &c.

- "Proceedings of the Institute of Civil Engineers," vols. lxxvii and lxxxi.
 - "Navigable Balloons in War and Peace," by General Hutchinson.
 - "Aerial Navigation," 1891, Chanute.
 - "Railroad and Engineering Journal," 1891, 1892, "Progress in Flying Machines," by Chanute.
 - "Le Vol des Oiseaux," by M. Marey.
 - "L'Aéronaute."
 - "Revue de l'Aéronautique."
 - "Scientific American," and Supplement.
 - "La Navigation Aérienne," by Tissaudier.
 - "L'Histoire des Ballons," by Tissaudier.
 - "The 'Century Magazine,'" 1891.
 - "Experiments in Aerodynamics," by Langley.
 - "Fores' Sporting Magazine," 1890, 1891.
 - "L'Empire de l'Air."
 - "Revue Scientifique," &c., &c.
 - "Proceedings of the Aeronautical Society of Great Britain."
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MR. GEORGE PHILLIPS, R.E.: With your kind approval I should like to make some remarks upon this most important subject of Aerial Navigation. I agree with the lecturer that in this country aeronauts, or, more properly speaking, people who profess to have discovered *the* way of navigating the air, are looked upon as a species of harmless lunatic. The reason that this is the case will be apparent when I explain that with a few notable exceptions all these people are only theorists, and in this more than in any other science there seems to be no limit to the wild schemes proposed by them. To give instances of the humbler inventors, I may mention that one ingenious gentleman, arguing that air does not give much hold to

a screw, proposed that a small tank containing water should be suspended under the balloon, and the screw made to revolve in it. Another ingenious inventor at the Aeronautical Congress in Paris proposed a system of propulsion, in which a long lever with a weight at the end was raised by clockwork; when it arrived at the horizontal position it was suddenly released and fell vertically. He hoped that the successive jerks thus given would propel a balloon. More discredit, however, is brought on the subject by those who have scientific theoretical knowledge, without having the least idea of the practical difficulties which render their schemes unworkable. The lecturer would appear to have drawn too much on books and newspaper articles for the subject of this important lecture; and I am sorry to see that good, bad, and indifferent inventors have been placed side by side in such a way that it may lead to quite an erroneous impression as to the feasibility of aerial navigation. It is not right as it seems to me to compare true scientists like Giffard, Dupuy de Lôme, the brothers Tissaudier, Renard, and Krebs, with the schemes of Campbell and Mayer. The lecturer's own scheme for a navigable balloon with its curves formed by a trochoid of revolution is open to the practical difficulty that the extremities from their shape would be extremely difficult if not quite impossible to keep rigid. The means at our disposal for this are the interior air balloon as employed in France, and also the bar compressor of General Hutchinson, which latter, as far as I know, has never been practically tried. Easy entrance curves are not required for balloons or machines working in air, for air is a fluid having elasticity which water has not, and the resistance to forward motion is greatly dependent upon dealing effectually with skin friction. It may be interesting to note that a scientific Commission assembled by the French Government in 1888 to report upon the capabilities of navigable balloons arrived at the conclusion that, owing to the difficulty of keeping the envelope taut, and also on account of skin friction, navigable balloons could not be made to go at a speed exceeding 30 miles an hour. A steam engine has been proposed by the lecturer as being the best means of propelling balloons. The experiments carried out in France by those who are the greatest authorities on the subject, the Chalais-Meudon people, show that in the first instance they tried an electric motor (with which the experiments with "La France" were carried out), worked by primary batteries.¹ They then tried a petroleum motor which they shortly had to abandon. This has now been succeeded by another electric motor, but whether it is worked by primary or secondary batteries, I do not know; but the result obtained has been that 10 kilowatts is the total weight per H.P., which allows of working for ten consecutive hours. The reason why a steam engine will not do, is the fact that the condensation of the water presents practical difficulties which are almost insurmountable. In 1887 Mr. Yon, the eminent aeronautical engineer in Paris, was entrusted by the Russian Government with the construction of a navigable balloon. This balloon, 66 metres in length, was to be driven by a petroleum engine of 50 H.P., and it was estimated that it would obtain a speed of 25 miles per hour. Everything went well except the condenser, and after trying every possible device, they failed to get it to work. Without a condenser, they lost 750 lbs. per hour simply through their water, which destroyed in great measure the equilibrium of the balloon.² Of course I have not lost sight of Mr. Maxim's steam generator, which appears to be a very light and good motor, but then Mr. Maxim has to allow for fuel about 9 lbs. per H.P. per hour; which for ten hours makes 90 lbs. weight of fuel, and this does not compare favourably with the French electric motor. Respecting the experiments which have been carried out with machines heavier than air, there is no doubt that Mr. Hargraves, Mr. Maxim, and Professor Langley have carried out experiments which will prove of great value to us; but strange machines, like those of M. Ader, we only know of by newspaper reports, and we have no proof that they ever did go up. All

¹ These batteries, five to six times more powerful than bichromate batteries, have as poles platinized silver and zinc; the liquid consists of equal parts of hydrochloric acid and chromic acid.

² After this failure with the condenser, the Russian Government claimed the balloon as it was and took it to Russia. What they have since done with it is unknown.

we require for aerial navigation is a light and powerful motor; that the French apparently have got, and if we could have it, there is no doubt that a reasonable sized navigable balloon could be made which would go up to 30 miles an hour. The great objection against navigable balloons has been their cumbersomeness. The machine of the future undoubtedly will be some form of a machine heavier than air. Experiments are being made, but whether they will succeed or not, we do not know. I hope Mr. Maxim will be successful, but there is no doubt he will have practical difficulties in the descent which may be excessively dangerous. A successful aerial machine heavier than air will require to be able to take its own weight from rest, and to come down vertically and gently.

Mr. J. STRINGFELLOW: I have very little to add to what Captain Fullerton has said, because he has treated this subject in a most masterly way. There are one or two minor points necessary to add to what is stated. One being that, between the latter end of the last century and the commencement of the present one, there were great efforts made towards aerial navigation. Of course, they had not the advantage of coal-gas; they had to work with hydrogen; but if we were to take the diagrams before us and to compare them with the diagrams of designs drawn out up to the year 1820, we should then find the whole of them already set out, and the mathematical calculations and researches made, connected with them. However, neither in what has formerly been designed or proposed, nor in any of the designs and proposals submitted to us by the lecturer, is there contained the essential requirements for practical aerial navigation. I believe there is no one who has gone into this matter so deeply as I have, and, as an engineer and a practical man, I claim to have solved the question of aerial locomotion. I am not prepared to say anything about it publicly, because I am waiting the opportunity to demonstrate to the world that an Englishman can master practical aerial locomotion the same as we have mastered land and water locomotion. I may say that having worked the whole of it through as to its principles, and without reference to any text-books, I find the principles underlying flight are the simplest mechanical laws that it is possible to conceive. Wing-power is the simplest form of non-resisting propeller for a given expenditure of energy. With regard to the wing-motion, the power derived from it is not so much the blow on the air, or the force exerted for lifting purposes, as it is that of a sinuous cleavage power. The fish in the water and the snake in the grass move by a similar law. Mr. Hiram Maxim, one of our best mechanical engineers, seeks to obtain combined levitation (that is, rising from the ground) and propulsion by a machine, or by mechanical force alone. It is self-evident that we cannot trust to such a means as that for practical aerial navigation, although of course it is perfectly practicable to so obtain rising and propelling power. But if we should adopt such a machine as could rise in the air, it being simply a machine, if any part of the mechanism went wrong, or the motive power were to stop, all control would be lost, and it must come down crash; the same as a bird will if it is winged or loses its power of motion. It is imperative to have supporting or buoyant power as well as mechanical flight or propulsion. The simplest form of mechanical propeller is the wing, but the great difficulty in the adaptation of wings to aerial navigation has been the enormous leverage supposed to be required. For example, presuming a practical machine or aerial vessel was constructed, it would have to be something like 160 to 200 feet long; the wings for that dimension necessarily being an enormous length would require an enormous leverage to work them; but, in following it through, I found there was an easy way to get over that, and yet to retain practical efficiency. The other thing was with regard to guiding power. Amongst the 100 or so designs exhibited at the Aerial Exhibition held at the Alexandra Palace a few years ago, there was not one system or design that indicated the true method of guidance, that is, the method by which birds guide their flight. It took me six years to find out how the birds flew—that is the correct principles of bird flight, and it took me four years more to find out how they guided themselves. For aerial navigation there is required: 1st, displacement; 2nd, motive power; and 3rd, guidance; and we have to assimilate these and bird flight to mechanical principles for a practical result. I built a machine entirely on those principles, an elongated balloon-shaped body for displacement, and worked it both with and without gas, and which, in motion and guidance, answered perfectly.

The CHAIRMAN: We would rather have a discussion on the paper than a vague account of what has been done in other places.

Mr. STRINGFELLOW: I will conclude by intimating that I shall be happy to place myself at the disposal of any of the Royal Engineers, to go into the matter with them privately.¹

Mr. BADEN-POWELL (Scots Guards): I perhaps might be allowed to say a word or two on the lecture, which has been very interesting and very exhaustive. There is nothing very much to add, but I should like to make one or two suggestions. First, I see a picture of the screw of "La France." This screw is placed in front, and I understand that this was an ordinary shaped screw to draw the balloon, or rather the car, along. The lecturer has not referred to another balloon which was designed and, I believe, built and actually tried by a gentleman named Gower, who lectured in this Institution some years ago.² He placed a "flat screw" (if such a term can be applicable) in front of the horizontal axis of the balloon itself. This screw worked in such a way as to drive away air and so form a vacuum in front of the envelope, and so, as it were, suck the balloon along. This seems to me rather a good idea theoretically, because there is always a difficulty about the stiffness of a balloon, and if a vacuum is created just in front of it this stiffness is not then so necessary. I should also suggest that a framework inside the balloon seems a necessary thing. In propelling a gas bag along through the air it is always liable to be more or less flabby unless it is in some way pressed outwards. I should suggest a framework somewhat similar to that of an umbrella, which, I think, could be made very light. It is merely a matter of calculating what weight it would have to be; but some such light framework would keep the balloon stiff, and then it could be propelled with much greater ease than is the case with a flabby bag. Theorists very often assume that a balloon is an air-tight bag blown out quite tight, but I know in practice that this is by no means the case. There is always a certain amount of leakage, and temperature affects the gas so much that you would nearly always find that if the balloon was quite tight to start with a certain amount of gas would soon escape or contract from the coldness of the air, and this, it seems to me, would necessitate some stiffening. Of course, if the balloon had a framework inside it, it would have to have something like a small balloon inside connected with the outer air so as to allow for expansion and contraction. Temperature affects the lifting power of a balloon so greatly that I think it an absolute necessity to have some mode of making a balloon rise and fall without wasting gas or having to carry heavy ballast. I could give a practical instance. I remember being in a balloon when we were up at a height of 3,000 or 4,000 feet in sunshine. A cloud came over the sun, and the balloon, owing to the contraction of the gas, went straight down and landed us on the ground, and did not seem inclined to go up again, so without letting out any gas, a balloon can fall in that way, and have no lifting power when on the ground. That just shows how, in practice, you discover facts which you would hardly think were applicable in theory. Then, again, the lecturer divided the subject into two distinct portions: one as to navigating a vessel lighter than the air; and the second part dealing with apparatus heavier than the air. I do not see myself why these two should not be to some extent combined (as has been suggested several times before). Having an apparatus made, we will say, like an aeroplane, as generally designed, but having two skins: the interior might be blown out with gas, and in that way you might have a sort of flat-shaped balloon which would have a certain amount of lifting power, and in this way the apparatus may be greatly lightened. I do not say I should look upon that as really a practical apparatus for the future navigation of the air, but it seems to me something might be done in that way with an experimental machine. Of course, the subject is a very difficult one to deal with, because inventors are jealous, and foreign nations, who are designing these balloons for military purposes, naturally keep their inventions very secret, so that the only accounts we get of all these are

¹ Mr. S. wishes it to be noted that he addressed himself more to the abstract question of accomplishing successful aerial navigation than to criticizing the paper read by Captain Fullerton.

² See Journal, No. 131, vol. xxix, 1885.

from the newspapers, and we know how often newspaper accounts are very inaccurate and misleading. It seems a pity in some way we cannot get at greater details, but, of course, we cannot expect it. If countries are at work in rivalry you cannot expect them to tell each other what they are doing. With regard to an aeroplane, what we want is to start the machine at a very rapid pace, and once it is going along in the air I should have thought it would not have required that speed to be kept up by mechanical propulsion. If we look at an albatross soaring in the air we know it somehow starts—we won't go into how it starts, because very few people have seen one start; but once well under way it has a certain amount of speed on it, and it goes along somehow managing to sustain itself in the air. If we have a machine which could be started by some very powerful engine, such, for instance, as compressed air, or some explosive so as to start it at a great rate, then I expect we should require a very much less amount of engine to merely propel it gently along after once it has got the start. However, it is, of course, very difficult to say how such theories will work in practice. It is a matter for more experiment, and I only hope we shall get more experiment.

Captain S. GORDON MCDAXIN: After so much has been said, and very much to the purpose, on the subject of flight, I trust you will excuse the very few observations I shall attempt to make upon the subject. It does not appear to me (although perhaps my powers of apprehension may not have been sufficient to understand) how far the lecturer has intended to represent a flight of birds dealing with a succession of columns of air. In Diagram 15, where you may take the columns of figures as representing successive columns of air and flight of birds passing along, I think we could understand how when they came in succession over each column of air they would have to overcome the inertia of that column; whereas any screw device acting in a stationary manner pulls down the column of air, so that it is always grinding or churning, as it were, one column instead of passing in succession from column to column, and overcoming in succession the inertia of these several columns of air. It seems to me to be very much like the difference between grains of sand falling upon a lecture table and grains of sand passing through a tube 10 to 30 feet in length, when the effect is very different. The whole column of air above it is set in motion: the grains of sand coming down would, under these circumstances, perforate a slab of glass an inch in thickness, and even a slab of granite the same thickness. I do not think this principle has been recognized in dealing with flight, as it might have been by many who have touched upon the subject. The great difference between screw action and the action of wings of birds in flight is, that in flight the bird is encountering a succession of columns, and having to overcome their inertia glides along them, instead of simply acting in one place, as does a screw propulsion.

The CHAIRMAN (General Dawson-Scott): I feel myself rather an impostor in sitting in the chair on this occasion, because I have devoted no great attention to flying machines, or to dirigible balloons; but I happen to be Commandant of the School of Military Engineering, and in that position I am Captain Fullerton's Commanding Officer, so when he asked me to take the chair I felt great pleasure in doing so, more especially because his lecture is on a subject of great interest. We hear of German balloons on the Russian frontier sailing about, and apparently being under perfect control, and I suppose what the Germans can do we ought to be able to do. I have seen a good deal of military ballooning, and one of the gentlemen who has spoken upon the present occasion has been employed under me, and I know him to be a very good practical balloonist, as also we know Mr. Baden-Powell to be. They know the difficulties that have to be encountered, and have pointed some of them out. The diagrams before us seem very complicated. They show what has been done, and indicate what very large balloons or flying machines we must expect to have to deal with for either aviation or ballooning on a large scale. I am sorry the lecturer did not give Fig. 8 the same scale as Fig. 6. The latter, he told us, was 40 feet long, a balloon propelled through the air, and not an entire success, by one man. Fig. 8, which was proposed to be the war balloon of the future, is 240 feet long and 30 feet in diameter. That would be a troublesome thing either to make or to guide, or to manage in any way. I will allow the lecturer to contradict me afterwards, but I rather think that we are mistaken in

supposing that the war balloon of the future must of necessity be such a big machine. I do not think Mr. Maxim, who has been referred to as making some flying machines at the present time, and who we all know to be a very ingenious man, contemplates having such a large balloon, capable of carrying great weight, as is there portrayed. In fact, a gentleman remarked to me to-day that in some paper that Mr. Maxim had written at the end of last year he said he thought the war balloon of the future would be simply used, as the captive balloon is now, as a means of observation, in which case it would only have to take up one or two men to reconnoitre the enemy's troops and forces, and I think that the idea of dropping half a ton of dynamite on to an enemy's ship, or into an enemy's town, though it looks very formidable here, is rather outside of practical politics as far as we have got at present. I think the lecturer himself does not quite believe in it. I feel sure that if any of us really thought that any action of ours could upset our naval defensive system, or make the "silver streak" for practical purposes disappear, we should refuse to have anything to do with it. With these few remarks I will ask the lecturer to reply to the observations that have been made.

Captain FULLERTON: I have not much to say in reply. With regard to the shape of the proposed war balloon, it is difficult to show it properly; there should be more of a dip here, and it should be more of the shape called by naval architects "fair shaped." I think this form gives the least resistance to forward motion, a very important matter. The size of the balloon of course depends upon how much weight you want to take up. For reconnoitring balloons, perhaps two or three men are as many as are wanted, but you can hardly take less. Our spherical balloons, without any engines or machinery, require a 10,000 cubic feet capacity for three men, and of course if you have machinery, &c., the lifting capacity must be increased. The reason why I choose Myers' aerial bicycle is, that this is a class of machine which can be easily made anywhere. It could not go very fast, but some 9 miles an hour might be got out of it without much difficulty. As regards the feasibility of dropping or firing shells downwards from a balloon, there does not seem to be much difficulty in the matter. No doubt it would be very pleasant for us if arrangements of this sort were not likely to be invented; but if other people are going to invent them, and use them against us (as they specially say they will), surely the best plan is to try and get ready to defeat their efforts.

THE CHAIRMAN: It only remains for me to ask you to join me in giving a vote of thanks to Captain Fullerton for his lecture.

NOTES.

1. *Chalais-Meudon Experiments.*—The Chalais-Meudon people do not seem to have touched the subject of aeroplanes. The experiments of Professor Langley were most carefully carried out, the newest and best forms of recording instruments having been used, and they most certainly cannot be considered to be of "secondary importance," as Mr. Phillips suggests. I may point out here that in a comparatively new science like "aerial navigation" it is of the very greatest importance to look at the subject from different points of view, and, in doing this, books and newspapers are of the very greatest assistance.

2. *Shape of Balloon Bodies.*—I do not agree with the idea that "easy entrance curves are not required for machines working in the air." A "fair shape" is essential. It is impossible to drive any but "fair shaped" bodies through the air at a high rate of speed. As regards skin friction I agree with Mr. Maxim, who expressly states in his published account, as a result of his experiments, that there is very little or no skin friction. Mr. Langley's experiments apparently give the same result.

3. *Motors.*—Eventually an electric motor may be found to be the best, but Commandant Renaud stated, in "L'Aéronautique" (1899), that electricity was a failure, and would not be used in future. As regards steam, see note on Condensers.

4. *Condensers.*—I am not aware how the Chalais-Meudon people tried their condensers; but one would imagine that condensers moving through the air would

work rather better than those stationary on the ground. If the air is allowed to play freely upon the tubes, or surfaces, the condensing power must be largely increased. Most probably, in the case quoted by Mr. Phillips, this was not done.

Mr. Maxim puts his condenser in the aeroplane, and he states that it is very efficient.

5. *Coal and Water*.—2 lbs. per I.H.P. per hour is the usual amount allowed for the ordinary class of engine. Nobody, however, supposes that Mr. Maxim's is an ordinary engine. His own published statement shows about 1,000 lbs. of coal and water allowed for (I understand) a ten hour trip. If 9 lbs., as above, was allowed, the coal and water alone would weigh some 27,000 lbs., or nearly twice as much as the total weight of his machine, engines, baggage, &c.!!!

6. *Temperature as affecting Balloons*.—Of course there is always a certain amount of flabbiness about a balloon, but the ordinary rules of physics explain how the temperature affects the gas in it. I should imagine the case quoted by Mr. Baden-Powell was due to the fact that, owing to the sunshine, the gas expanded and some had to be let out of the balloon to prevent it straining the envelope. When the clouds came out the gas contracted, and there was not sufficient left at the lower temperature to keep the weight up in the air.

7. *Gower's Balloon*.—I cannot explain the principle used by Gower. It depends entirely upon the theory of the screw propeller; but at present this theory is more or less in the clouds. I think the general tendency of a screw worked in this manner would be to cause a great strain on the balloon.

8. *Combination of Ballooning and Aviation*.—There is, of course, no reason why the two systems should not be combined. I divided the subject simply because I think it is easier to understand it when its branches are considered separately.

9. *Flight of Birds*.—Fig. 15 is not intended to show a "flight" of birds, but the different positions of the gull's wings at intervals of $\frac{1}{10}$ sec.

10. *Use in War*.—Mr. Maxim says: "When the first flying machine succeeds, its first great use will be for military purposes. . . . It will at once become an engine of war, not only to reconnoitre the enemy's positions, as has been attempted with the so-called dirigible balloons, but also for carrying and dropping into the enemy's lines and country large bombs charged with high explosives."

J. D. F.