FLYING-MACHINE MEMORANDA.

By Lawrence Hargrave.

[With Eight Diagrams.]

[Read before the Royal Society, N.S.W., August 7, 1889.]

Since December 1887, several developments have taken place in the evolution of flying-machines which it is proposed to describe more or less lucidly in this paper; perhaps the writer over-estimates their value, but it is hoped that such as they are they will shew some of our members that in effect the drudgery is done and competition alone is desired to bring the matter to a practical issue. Great efforts have been made to get a reliable motor; a single cylinder vertical engine absorbed much time and labour, but want of skill in construction involved such an amount of unnecessary weight that if it is ever completed it will nearly all have to be re-made.

The centering difficulty gave birth to several curious mechanisms for pulling the crank off the centre, the best of them is shewn in Fig. 1, as it may be useful to engineers where a flywheel or two cylinders are inadmissible. In the position shewn both parts of the india-rubber spring are slack, when the ball-crank pin K gets to C it begins to store power through the cord A and continues to store it until K arrives at D; this stored power is given out between D and E pulling the main crank-pin L over the top centre. When the main crank-pin L gets to F it begins to store power through the cord B, and continues to store it until L arrives at G, this power is given out between G and H, and pulls L over the bottom centre. An air compressor, reducing valve, and Richard's indicator were also made, but need no special description here.

The next engine constructed had a variety of tackle for using petroleum spirit vapour as a motive power, the only result as yet being that manual skill in silver-soldering and light engine work was acquired. At this time what may be called a most valuable invention was made, namely the mechanical movement by which the wing can be made to describe rigidly the figure-of-eight observable in the motions of the wings of living organisms; a perspective view of the model is shewn in Fig. 2; the movement is applied to the three cylinder engine Fig. 3 and will be appreciated at its true worth by the makers of trochoided plane flying-machines.

As there seemed to be considerable difficulty in making intelligible the action of what the writer calls the trochoided-plane, it was thought that by devoting some attention to the evolution of
a screw-driven machine other workers might be brought into the field. Three varieties of models were made, namely, with double and single screws in the bow, and single screw in the stern: Fig. 4 shews the single screw in the stern, and it is the most practicable and serviceable form.

It was thought that the tendency of the body to revolve on the screw shaft in a contrary direction to the screw would cause an objectionable list and swerving of the machines, and that two screws revolving in opposite directions would be necessary; this tendency is not observed in the experiments when the screw is small in diameter compared with the width of the machine. The two-bladed screw of the model shewn in Fig. 4, is 28 inches in diameter, the blades are 9 inches long, 6 inches wide at the tips, and 3 inches wide at the inner ends, giving a total surface of 126 square inches; the pitch is 7 feet 4 inches.

The comparison between this machine and the trochoided-plane one stands thus:—

<table>
<thead>
<tr>
<th></th>
<th>Screw.</th>
<th>Trochoided Plane.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area in square inches</td>
<td>2090</td>
<td>2130</td>
</tr>
<tr>
<td>Square inches area per lb weight</td>
<td>1045</td>
<td>1019</td>
</tr>
<tr>
<td>Weight in lbs.</td>
<td>2·00</td>
<td>2·09</td>
</tr>
<tr>
<td>lbs weight per square inch...</td>
<td>00095</td>
<td>00100</td>
</tr>
<tr>
<td>Foot-lbs of power used</td>
<td>196</td>
<td>470</td>
</tr>
<tr>
<td>Horizontal distance flown in feet...</td>
<td>120</td>
<td>270</td>
</tr>
<tr>
<td>Distance in feet per ft.-lb of power</td>
<td>61</td>
<td>57</td>
</tr>
</tbody>
</table>

This is thought to show that as propellers the screw and the trochoided plane are about equally effective, and that if either has the advantage, competition will bring it to the surface; a feature of these machines is the trifling amount of thrust that moves a comparatively heavy body horizontally when supported by a large flat surface.

The two diagrams exhibited drawn by Fig. 5, and Fig. 4, shew a point of high thrust during the first second of time; it is called the still air diagram to distinguish it from the following part of the card which is the moving air diagram: it is undecided which represents the moving machine's thrust, most probably the still air diagram is nearest the truth. Fig. 6, does not shew the still air diagram, because the pencil was pressed too hard on the indicator drum.

After trying unsuccessfully to find out Brotherhood's arrangement of valve gear, a three-cylinder trunk engine Fig. 3, was designed and made; it works very smoothly and carries 120lbs of air pressure, combining lightness with accessibility, and simplicity of construction and adjustment in an eminent degree: the weight is 19½ ounces, and the drawing shews every detail. This engine was made in about 120 hours at a cost for material of 12 shillings and is not beyond the capabilities of the most ordinary mechanic.
The idea was conceived that a three cylinder screw engine could be made by turning the boss of the propeller into an engine, thus allowing the cylinders to revolve on the crank-shaft, the shaft and crank-pin being stationary and the thrust coming direct on the valve face. Of course the idea was put into execution with all speed, resulting in the production of the predecessor of Fig. 5, which weighed \( \frac{3}{4} \) of a pound, this worked so satisfactorily that after some kindred experiments were made Fig. 5 came into existence, weighing only 7\( \frac{1}{4} \) ounces, and taking the first five seconds of the diagram, (Fig. 6) we see that the revolutions are at the rate of 456 per minute, the receiver pressure falling from 150lbs to about 120lbs. The cylinders are \( \cdot88 \) inches diameter: the stroke is 1\( \cdot3 \) inches and the valve cuts off at \( \cdot75 \) of the stroke. The screw blades are set at an angle of 20° giving a pitch of 44\( \cdot4 \) inches, the diameter of the screw is 36\( \frac{1}{4} \) inches, and the area of each blade is 32\( \cdot7 \) square inches.

The diagram Fig. 6 shews the thrust time and revolutions of this engine to far surpass the india rubber driven screw as a motor. The diagram was taken on one of those combination instruments which assume such varied forms in the hands of experimentalists.

The air receivers for these motors are made of ordinary tinsmith's tinned iron plate, the thickness of plate in the receiver for Fig. 5 is \( \cdot013 \) inches, and it is found to have a breaking strength along the plate of 62,000lbs per square inch section of metal, so 3 inches was the diameter determined on, and \( \cdot18 \) cubic feet capacity; the weight is 29 ounces, and it has been pressed to 250 pounds per square inch without any sign of weakness. The longitudinal seams are \( \cdot06 \) inch lap soft solder joints which experiment proves to be more than 100% strength; the folded joint though easier made is obviously weaker.

The whirling machine was rigged up again to see the comparative effect of cutting the body plane of flying machines transversely and putting the pieces one above another like a venetian blind, and it is found that the paper surface of the body is best in one connected piece. This instrument now has a simple method of conveying the beats of a pendulum up the revolving post to the arm carrying the indicator drum; it has also a centrifugal speed indicator.

A number of experiments regarding the positions of the centres of gravity and effort were made so that the risk of damage to a valuable machine might be minimised. A cross-bow was made for discharging various forms of stick and paper models with adjustable weights, resulting in the production of Fig. 7 as being the form necessary for the screw engine and receiver, Fig. 5. No particular virtue is attached to the sloping back of the two sides of the body plane, and it is introduced here because the receiver being
only about 4 feet long brings the centre of gravity very far aft. It is found that if more than 25% of the area is in advance of the centre of gravity the models turn up and wreck ensues as a matter of course. One remarkable experiment repeatedly made, for which the writer cannot account is that Fig. 7, which is called F model, with an area of 216 square inches and weighing 2·5 ounces is propelled 18 feet by stretching the crossbow 12 inches; and another model called C, weighing 6·5 ounces and having an area of 756 square inches is propelled 20 feet by the same motive power, the speed of the latter being obviously slower; it looks as if large areas were more important than powerful engines where speed was of little consequence.

As regards the slope sideways of the halves of the body plane, it is found that so long as the centre of gravity is at all below the centre of effort there is no tendency to swerve, the turning up or down of the models is entirely due to the distance of the centre of gravity from the forward edge of the body plane.

On looking into the relative positions of the centres of gravity and effort of the three most successful machines yet made, it appears that the percentage of the areas in advance of the centres of gravity are:

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
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<tbody>
<tr>
<td>48 band L</td>
<td>19·3%</td>
</tr>
<tr>
<td>24 band H.J.K</td>
<td>20·0%</td>
</tr>
<tr>
<td>48 band single screw</td>
<td>23·3%</td>
</tr>
</tbody>
</table>

These positions were arrived at by experience gained by repeated wrecks when groping in comparative darkness.

We now come to what is thought by the writer to be the most deeply interesting point in all the experiments. It is observed that the successful flyers maintain a horizontal position during a horizontal flight, that is to say, that the body plane is practically level and not tilted up forward at anything approaching the angle, theory leads us to expect.

Taking observation L, a machine of 14·8 square feet area, weighing 2·09 lbs; i.e., the paper is loaded to 141 pounds per square foot, the speed being at the most 12 miles per hour. The sine of the angle of elevation of the machine should be equal to the pressure in pounds per square foot divided by 0·0023 times the square of the velocity in miles per hour, or to support a plane of 14·8 square feet area 2·09 pounds weight by wind moving at the rate of 12 miles per hour, we should have to incline it at an angle of 25°.

This is an angle sufficiently great to be unaccountable for except by assuming that the personal equation of the observer deceived him and that what he thought was level was really tilted at an angle of 25°. Therefore it becomes necessary to invent a theory that would account for the discrepancy, and the theory is that the
visible under surface of the stationary machine is not the under surface of the flying-machine as it carries along with it and rests on a cushion of air more or less wedge shaped: and that the angle of this air cushion is self-adjusting for varying speeds within some unascertained limits so long as the machine is balanced by having from 20 to 25 per cent. of the area in advance of the centre of gravity.

Fig. 7 is to shew what is supposed to be the state of the air on and in which the machine moves. AB represents the vertical longitudinal section of the body plane. The circles and arrows are sections of transverse horizontal vortices or air rollers originated by the friction of the paper surface on the undisturbed air; these gradually work towards the tail and come to rest again after the machine has passed. There may be one or many layers of these anticyclonic vortices, but one is sufficient for this explanation, and in the figure it is greatly exaggerated, the pressure is supposed to be highest at the centres of the vortices, and their diameters to increase as they pass aft.

You will observe that the breasts of the inequalities or waves adhering more or less closely to the paper and marked C, D, E, F &c., are steepest when the vortices are small and close together, and it is thought this is the reason the first quarter of the body plane supports half the weight, and that the projections of these declivities represent an approximation to what is in effect the curved bottom of the flying machine LMB.

Again, suppose the visible under surface to be more uneven, and that the air rollers pass very slowly towards the stern, they then become, as it were, part of the structure and the lower forward parts of their circumferences Z, Y, X &c. become the bearing surface of the machine. The upper surface must be affected in a similar way, though it is thought that the vortices would have low pressure centres and large diameters producing a less curved invisible top JKB to the machine. It will be readily seen that if the speed increases the vortices have less time to increase in diameter and therefore both top and bottom curves will be flatter.

Perhaps some of the members have hauled a punt over a flat sandy beach and have noticed that when there is a little water on the sand though not sufficient to float the punt, if the bow be raised and then dropped suddenly on the water and pulled forward before the water has time to squeeze out at the sides, a long distance may be traversed with very little labour. And why? Because the punt is on water rollers. This theory may be contrary to well known laws, but if we do not state our views how can we hope to be set right by those who can interpret the facts better.

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