*The following Correspondence appeared in the "Engineer," the result of a leading article of Dec. 29th, 1882, headed :—*

## "FLYING MACHINES."

Last week we noticed a curious little book by an author who has not thought good to make his name public. We have said of this book that it is a prose poem, and this we think may be held of a great deal that has been written concerning flying. In all ages man has desired to emulate the bird. Indeed, it would not be too much to say that for five thousand or six thousand years he has been trying to fit himself with wings which will carry him through the air. Persistent failure has attended every enterprise of this kind; and the hopes which have been formed that the constructive powers possessed by modern engineers would solve the problem have all been disappointed. We are probably no nearer to flying now than we were a thousand years ago; yet the questions unsolved are not without interest, and it may even serve a good purpose if we place before our readers a few truths which are constantly overlooked by labourers in this particular path of mechanical enterprise.

It is generally assumed that because birds can fly men ought to be able to fly. The operations effected by the bird are just as mechanical as those of the man who walks on dry land or swims in the sea. If only we could perceive precisely what it is a bird's wings do, then we could fly. Now, this seems to us to be a very specious and shallow argument. It is not probable that there is anything occult or mysterious about the action of a bird's wing. So far as the slower birds,

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such as the rook, are concerned, it is very easy to watch every movement of the wings, and we believe it is more than probable, not only that the wings of many model flying machines act just as do those of the rook or other birds; but that, as far as mere ascension is concerned, almost any species of wing action will serve. For example, we may cite the sixpenny toy called a "flying bat," which is nothing more than a very light screw propeller. This will rise nearly a hundred feet in the air if well made, flutter about for a while, and descend. The wing of a bird offers less resistance to the air when it ascends than it does when it descends; and furthermore it is quite probable that in all cases, and it is certain that in some cases, the down stroke is made far more rapidly than the up stroke, and produces thereby a stronger reaction. This seems to be the whole secret of wing action. When we come to deal with the elegances, as we may call them, of flight, we have to do with the idiosyncracy of the flyer. The rook may be said to resemble a heavy Dutch farmer, skating to and from market, in straight lines, while the swallow is like the most accomplished figure skater that it is possible to imagine; or, put in another way, we may compare varieties in styles of flying with varieties in gait. The hippopotamus, for example, can walk and even run—so can the deer. In both cases the processes, as a series of mechanical operations, are very similar; but from any other point of view they are quite different. We have no doubt that if men could once fly, we should soon have as many styles developed as there are men. If then, it may be urged, there is nothing mysterious about wing motion, and a simple up and down flapping wlll at least suffice to raise a bird in the air, why should not men fly? The answer is that they are not strong enough. If we consider birds as machines, we see in the first place that they are all comparatively small. There is no bird of flight which weighs as much as even a very light man; but there are many birds which are far stronger than men. The albatross, is, we believe, the largest—we do not mean the heaviest—bird of flight in existence. Its wings measure sometimes as much as 13ft. from tip to tip, but the total weight of the bird seldom, if ever, exceeds 28lb., or one-sixth that of a powerful man. But the albatross can keep its wings in motion for a whole day, while the strongest man would be exhausted if he had to keep beating the air with them for half-an-hour. There are many birds with limited or no powers of flying which weigh much more; but we shall not be far wrong if we say that the maximum weight of any natural flying machine, which can fly well, does not exceed, say, 30lb. Now this is a very important truth, because it goes to show that that is about the limit of weight beyond which the air cannot be utilised for bird flight. Nature does not make many mistakes; or, in other words, the conditions under which species are developed are such that everything goes as far as it can go in size and speed. If it cannot go further, that is because certain conditions interfere to prevent it. If it were possible, we should have birds much larger and heavier than the albatross, or the condor, or the eagle. We may rest certain that the roc of Eastern story is a mechanically impossible creature. The reason why huge birds do not exist is this: It is well known that the strength of every machine rapidly decreases as it increases in dimensions. Thus, for example, the crank-shaft and other parts of a model steam engine, if all made to scale, are immensely stronger than would be those of a similar engine made with the same proportions, and, say, twelve times the size. Let us apply this to the albatross, and suppose that its wing, instead of being some 6ft. long, was 12ft. long. All the bones being doubled in length would be doubled in weight; but they would also have to be at least doubled in strength, which represents another duplication; so that an albatross with a spread of wing of 26ft. instead of 13ft. must weigh, not 28lb., but four times as much, or 112lb. at the very least. Nor would the argumentation stop here, for the area of the wing would have to be altered. Merely to double its length would not suffice; its breadth must, *cæteris paribus*, also be doubled, and thus we have four times the area; but this would again double the strength or weight of the bones, and a very little calculation will suffice to show that a bird with a spread of wing of 28ft. could not weigh less than 2cwt., instead of 28lb. Next comes the question, is it impossible to get as much power in proportion out of 2cwt. as we can out of 28lb.?

A great deal has been written from time to time about the effect of the wind on inclined planes in keeping birds afloat in the air. Those who have a competent knowledge of the laws of dynamics are, however, aware that the inclined plane action cannot alone keep a bird from falling to the ground. The action is at best just that of the wind on a kite; and the equivalent of the string must be provided or the bird will be carried away, just as a kite is when the string breaks. Birds, when sailing, are either going with the wind or are using up momentum acquired by previous rapid motion. The work done by the bird will vary continually; but it is strictly analogous to that of a swimmer, who, carrying a load, has to keep himself afloat by his own exertions. There is no way out of this. Nothing is got from the air in the way of help, save when upward currents strike the flying bird; and that such currents exist, every engineer who has seen the decking of a bridge lifted in a gale well knows. Returning then to our albatross, the work it does is equivalent to continually lifting 28lb. The idea that the bird is buoyant in the air is a delusion. If it weighs dead 28lb., it will weigh living 28lb., and the variation in the displacement of the dead and living bird cannot represent more, at the most, than an ounce. In round numbers 13 cubic feet of air weighs 1lb. The albatross, therefore, represents no less than 13 × 28 = 364 cubic feet of air, while its entire displacement is probably at most 4 cubic feet. An increase in dimensions of one-fourth when alive as compared with the same bird dead, would represent about $\frac{1}{360}$ of its weight saved by extra buoyancy, which is nothing. The weight of the bird then may be regarded in exactly the same light as the weight on a brake driven by a portable engine. The brake wheel is always trying to lift it up. The power expended is measured by the distance passed over by any point in the rim of the brake wheel in one minute, multiplied by the weight and divided by 33,000 per horse-power. Now, if we could tell the distance passed over by the bird's wings at each stroke and the number of them, we should, knowing its weight, be able to estimate the power expended. We cannot do this in the case of the condor or albatross; but bearing in mind the small specific gravity of air, we shall not be very far wide of the mark if we say that an albatross probably possesses as much muscular energy as a man. The utmost load that a man working at a crane cradle can put forth for a day's work is 20lb., at a crank handle making about 3ft. per second; and nearly all the muscles of the body are engaged in this work. It will be seen that if even half this work is got out of the very much smaller muscles of the albatross, the energy of the muscles—on whatever it depends—must be very much greater than it is in a man. The pectoral muscles of the swallow weigh much more than all the other muscles in its body put together, and in all birds which fly well, it will be found that the muscles actuating the wings are relatively enormous in dimensions. But not only is this the case; the bird works at a higher pressure, if we may use the words, than any other animal. Its temperature is considerably above 98°, that of man, and the mammalia generally; and all the swift birds live on food capable of giving out much energy while concentrated as to dimensions. Thus the swallows, eagles, hawks, vultures, &c., are all carnivorous. Again, it will be found that the arrangements for aërating the blood in birds are extremely complete, and this is one reason no doubt for their high temperature. In other words, we have in the bird a machine burning concentrated fuel in a large grate at a tremendous rate, and developing a very large power in a small space. There is no engine in existence, certainly no steam engine and boiler combined, which, weight for weight, gives out anything like the mechanical power exhibited by, let us say, the albatross.

It is then simply for lack of muscular power that man can never fly. There is no combination of wings or arrangements of any kind which will compensate for this fact. Whether he can produce a machine to supplement his own want of force remains to be seen. Such a motor cannot, we think, be driven by steam. It is, however, not impossible that a machine might be made which would be caused to fly by means of a small electric motor run at a very high speed and worked by the aid of a couple of wires from the ground. This, however, would hardly be flying in the true sense of the word. That wings and suchlike things can be made we have no doubt; and experiments enough have been made to prove that, if power enough be available, flight can be achieved. When a machine can be made, each pound of which will develop as much energy as each pound of a bird, flying may be possible—not till then.

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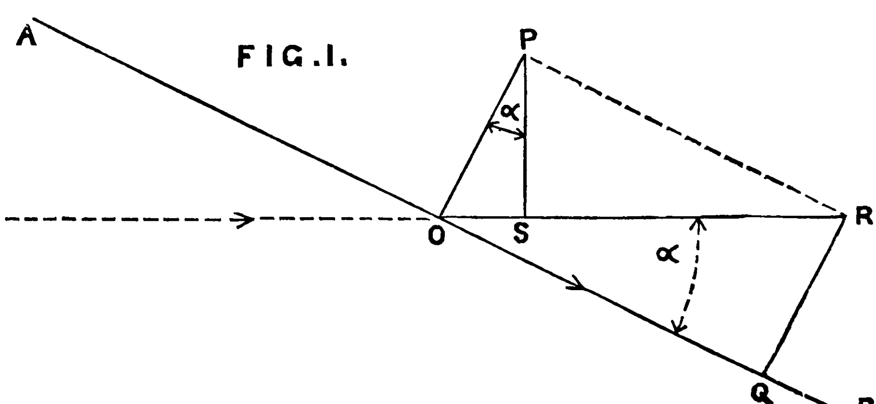
## FLYING MACHINES.

SIR,—The problem of artificial flight is from time to time discussed in scientific journals, and when much the same conclusions have usually been arrived at, the subject drops. These conclusions are:—(1) That man can never hope to fly by his own unaided muscular power. (2) That it is possible man may hereafter construct flying machinery by means of which he may be carried through the air, but that neither the suitable motor nor machinery have yet been contrived or even suggested.

The first of these conclusions is, for a certain reason mentioned in the first paragraph of your article last week, a tolerably safe one, and the second is safer still. With even a remote possibility of its being practicable, the subject is so important that I trust you will permit me to make a few remarks upon the statements and arguments employed in the article in question. The ground there taken is that the practicable limit to a natural flying machine has been reached by nature, and the arguments in support of this are of two kinds:—(1) That nature does not make many mistakes, or, in other words, the conditions under which species are developed are such that everything goes as far as it can go in size and speed, so that if larger natural flying machines had been possible there would have been larger birds than there are. (2) That for certain mechanical reasons, which are given, larger natural flying machines are not possible. With regard to the first, it seems only necessary to point out that it was well the early shipbuilders did not use this argument in connection with the nautilus, or perhaps the swan, or we might now be dependent upon our natatory powers for oceanic communication. The mode of arguing the second point appears to need more serious consideration. It is well known that the strength of every machine rapidly decreases as it increases in dimensions? To commence with, the example quoted, viz., the crank shaft of a model engine, and one of twelve times the size. Unless all books and practice of machine construction are wrong, their torsional strength will vary as the cubes of their diameters, and this, whether solid or hollow, that is, the larger one will be 1728 times as strong as the model. Their relative weights will vary as the square of their diameters and as their lengths, that is, the weight of the larger is also 1728 times that of the smaller. Thus they are of exactly the same proportional strength. If it be intended to state that in practice the model would be stronger, then this can only be due to abnormal conditions of material, &c., which cannot fairly be taken into consideration. But this is not the only part of the engine. Take, for instance, the approximate weight of cast iron pedestals (Unwin's "Machine Design"), $W = 1 \cdot 1d^3 + 18$lb.; so that as the strength varies as the cube of the diameter, the weight for the larger one may be a great deal less in proportion than for the model. Many other instances might be quoted to show that at any rate the statement is not true for "every machine." With a beam or girder a proportional increase in every dimension does result in weakness, but no engineer would think of distributing his material in the same way in a very large girder as he is obliged to do in a small one, for the increase of size enables a more economical section to be employed. Coming now to the example taken—viz., that of the albatross. It may be admitted at once that the weight must vary as the cube of the linear dimensions—that is, the weight of a similar bird with twice the length of wing would be eight times as great, or would be 2cwt. instead of 28lbs. It thus seems a pity that the matter is complicated by introducing the question of strength before the required power is dealt with, as upon this depends the strength of the wing required. It is stated that the strength must be at least doubled when the length only of the wing is doubled. Remembering that the resistance of the air varies as the square of the velocity, it might easily be shown that the strength should be at least eight times, instead of twice, as great. Passing to the question of power. The soaring of birds is a most important fact, of which no one who has taken the trouble to make observations has any doubt. Though it was lately the subject of a protracted discussion in the columns of a contemporary, no satisfactory explanation appears to have been given of it. Certainly it cannot be dismissed by a mere assertion, much less by a more than questionable analogy. Thus it cannot be admitted that the action of a swimmer even carrying a weight is "strictly analogous" to the work done by a bird. The density of water is 800 times that of air, so that the proportional efforts to sustain weight, and to overcome the resistance to motion, are greatly different in the two cases. Moreover the fluid friction is very different in air and water, and to admit the analogy as a strict one would be to cut away the only grounds on which soaring can be explained. Perhaps the following explanation may partly account for the soaring power of birds, which has been stated by competent witnesses to be exhibited only when a wind is blowing. Let A B be the plane of a bird's body, making an angle, and with the

FIG. I.

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horizon; let O be the centre of pressure, and O R be the effective horizontal action of the wind on A B. By resolution, effective normal force = O P = O R sin. $a$. Tangential force (ineffective) = O Q = O R cos. $a$. Resolving O P gives force tending to drive the bird back = O S = O R sin.$^2$ $a$; force tending to support the bird = P S = O R cos. $a$ sin. $a$ Thus the bird would only have to exert a force O R sin.$^2$ $a$ in order to remain stationary. As long as $a < 45$ deg. this force is less than its weight, and is smaller the smaller the angle $a$. Until this reasoning is shown to be erroneous it cannot be asserted that, "Nothing is got from the air in the way of help save when upward currents strike the flying bird," for in the assumed case the current of air is horizontal.

The next analogy seems scarcely open to argument. Is it really meant that the weight of a bird may be regarded in exactly the same light as the weight on a brake driven by a portable engine, and that the power exerted by the bird may be measured in the same way by taking the distance passed through by the wings? If so, it would have been well to have made a few calculations with, at any rate, approximate values in the case of the albatross. Doing this, it may be readily seen that the power thus given is from ½-horse power to 1-horse power. The values given in the article for the maximum power exerted by a strong man are equivalent to a little less than $\frac{1}{9}$-horse power. Thus the assumption which immediately follows, viz., that the power of an albatross may be taken as nearly that of a man, has not the slightest connection with the previous line of argument, being in fact quite at variance with it; neither does the allusion to the small spec. gravity of the air justify the assumption, which must therefore be taken for what it is worth. As to the correct mode of estimating the power of an albatross, this is certainly a difficult matter, and I fear I have already

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trespassed too much on your space to venture any further suggestions.

It is to be hoped that the brief concluding remarks of the article will not be taken as giving the results of the labours and investigations of the many able scientific men who have worked at the subject, or as being even the very briefest summary of all that modern improvements in small motors or machinery can suggest for the solution of one of the oldest and most interesting of problems.

H. S. HELE SHAW.

*University College, Bristol,*
*January 2nd.*

[Our correspondent will, we think, see on reflection that his strictures on what we have written are not justified by facts. In what we said concerning the strength of models, it is clear from the context that we referred really to weight for weight; and this, we think, Professor Hele Shaw sees quite plainly. We agree with him, as a matter of course, that the shaft 1in. in diameter would be as strong as the shaft 12in. in diameter, weight for weight; but he has overlooked the fact that the strains on the 12in. shaft would be immensely greater than the strains on the 1in. shaft; because the areas of the pistons would vary as the squares of their diameters—not as their diameters; and our statement is specially applicable, as our correspondent indirectly admits, to the framework of any structure—bird or machine—intended to fly through the air. Our argument must also be taken as applying to the whole model, not to individual members of it. We are a little surprised that Professor Hele Shaw should cite the nautilus—which has no bearing whatever on our argument. As well say that the tiny humming bird marked the limit of nature's progress in flying. Has Professor Hele Shaw forgotten the existence of the whale?

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That whales are not bigger than they are is not a result of a limitation of capacity for floatation in water, but of other and totally different conditions—such as facility for obtaining food, power of blood distribution on the part of the heart, and the possibility of obtaining muscular power enough to give the animal the necessary velocity of motion through the water. We come now to our correspondent's diagram, and the argument he has based on it, which involves a very curious error, no doubt due to a complete oversight. Professor Hele Shaw would be quite accurate if he could show that there was any current in the air relative to the inclined plane; but as a matter of fact, the inclined plane must, by the condition of things, be moving at precisely the same rate as the air, and for the plane no current exists. Thus, when a boat is floating down a stream, it has no steerage way, because there is no current as to the boat, though there may be a very sharp current as to the banks of the river. A kite will fall when the string is broken, just as though no wind existed, only it will not fall vertically down, but will describe a curved path of greater or less irregularity, in its descent. The wind acts on the inclined planes of ships' sails, and the sails of ice boats, just as Professor Hele Shaw has shown in his sketch, but only because the boat is held up to the wind either by the water or the ice. The occupants of the car of a balloon are in perfect calm, although the balloon may be flying before the wind at sixty miles an hour, nor would they be sensible of any current of air were it not that the force of the wind being variable, the inertia of the balloon will have to be overcome when a gust blows, or its momentum expended when the velocity of the breeze falls off. Therefore, what we have said is perfectly correct, and birds can only sail by virtue of momentum, or as Professor Shaw implies, by the direct forward propelling action of their wings, but in this

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case they gain no assistance whatever from the air, save in a sense that a locomotive may be said to be assisted by an inclined plane in climbing up a given vertical height. Whether an inclined plane is or is not used, the foot-pounds of work expended by the bird or the locomotive must remain unaltered. We have failed to catch our correspondent's meaning in the passage concerning the analogy between the weight on a friction dynamometer and the action of a hovering bird, and we can therefore only maintain that the analogy does exist. The resistance of the air to a wing is apparently a function of the weight of air displaced at each stroke, and its velocity. We shall be glad to hear an expression of opinion on this point from Professor Hele Shaw.—Ed. E.]

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## FLYING MACHINES.

Sir,—I will deal as briefly as possible with the points under discussion before proceeding to the further expression of opinion which you invite.

(1) With regard to the case of the two engines, one of which is twelve times as large as the other. The piston area of the larger one would, as you truly say, vary as the square of the diameter, and would therefore be 144 times that of the smaller; the length of the crank would be twelve times as great, and the resultant crank effort would therefore be 1728 times as before. But the strength of the shaft is also 1728 times as great, that is to say, in this particular respect, as well as in others, the proportionate strength of the large one is exactly equal to that of the smaller, and it is clear that the power and weight vary as the cube of the linear dimensions. As to the argument being taken as referring to the whole

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model, I beg to point out that I took the very part of the machine specially referred to in your article.

(2) I had not forgotten the existence of the whale, neither had I forgotten the purposes for which it is adapted, and, therefore, I purposely avoided citing as analogous to a ship an animal which spends so much of its time beneath the water. As a creature floating partly immersed upon its surface, the nautilus seems, however, to be strictly comparable with our rowing and sailing craft, and moreover the largest creature of the kind. Howbeit, let the case of the whale be taken and a few figures in connection with it. One of the largest whales ever caught measured 95ft. in length and weighed 249 tons. The Servia—not to take an extreme case—is 530ft. long and of 8,500 tons burden. It will be found that such a tonnage is amply sufficient to enable her to be propelled by muscular power—that is to carry a sufficient number of men to produce 10,500-horse power—if steam power were not forthcoming, and this directly meets the first argument in the article. Moreover, though it would be interesting to have a clear demonstration of the reasons why whales are not bigger than they are, such a demonstration would unfortunately, in the face of the above facts, quite upset the argument in question.

(3) By referring to my letter you will see that all the diagram is set forward to prove, and what it does prove, is that a bird may sustain its weight in the air by the exertion of a force much less than that weight. Thus the statement in your article which altogether denies this, except for upward currents, remains unproved. The matter is a most important one and not by any means self-evident. It is perfectly true that the current does not exist with reference to the quiescent plane. But it just as certainly does exist when the bird, which the plane represents, begins to exert

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force. The object of the diagram is to show that the small horizontal force O S counteracts the horizontal tendency of the wind to move the plane, that is the bird. At the same time the weight of the bird is sustained by the vertical force P S. The bird, therefore, remains absolutely at rest in space, the wind notwithstanding. I took care not to enter upon the debatable ground as to what action supplies this necessary force which, acting for hours, can scarcely be due to momentum. What the elementary facts you quote have to do with the argument it is rather hard to see. I trust I have been sufficiently explicit in refuting the charges of oversight, forgetfulness, and error which you think fit to make.

Coming now to the point on which you ask an opinion. The article unmistakably and clearly intimates that the weight on a brake is analogous to the weight of a bird, and the distance passed over by the rim of the brake-wheel to that moved through by the wings. As the formula is given, it is easy to insert approximate values. The weight of the bird is 30lb., the distance passed through by the centre of the wing, from 3ft. to 5ft. The number of strokes when rising or stopping suddenly is, according to observers, from three to four per second. These data give from ½-horse power to 1-horse power. This wing velocity is no doubt maintained only for short periods; still, if the formula and reasoning were correct, this incredible power would be exerted, though even for a short time. But, from accounts of those who have handled the albatross, there seems little warrant for assuming anything like the power of a man.

If the action of the wing could be assumed to be similar to that of a plane surface, the resistance might be found from any one of the formulas in use connecting the pressure and velocity of the wind. Although the wind action is not exactly thus, the resistance is at any rate, as you say, a

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function of the velocity, and that function probably the square. A little consideration would show that, this being the case, we should expect the wings of birds to decrease in size with the increase of the bird. This de Lucy has shown to be true, and from measurements of the ladybird, stag beetle, pigeon, and stork, Professor Thurston calculates that a man of the ordinary weight should be able to fly with wings having an area of 40 square feet. Villeneuve gives a length of 10ft. for a bat having the weight of a man. Hastings makes the surface from five to ten times $\frac{3}{2}\sqrt{W}$, the area being in square centimetres and the weight in grammes. These conclusions point to the absurdity of the dimensions allowed by some writers; as, for instance, Hartwig, who gives from 12,000 to 15,000 square feet, and also to the fact that the mode of reasoning adopted in your article to arrive at the spread of wing, and consequent weight of bone, differs at any rate from that of the most recent scientific workers.

H. S. HELE SHAW.

*University College, Bristol,*
*January 16th.*

[Professor Shaw still appears to us to be mistaken in his views, and in order to prevent this discussion taking too wide a range, we shall confine ourselves to one portion only of the subject, putting the rest on one side for the moment. Obviously the most important question raised is the work expended by a hovering bird. It is clear that if the bird merely extended its wings and gave them no motion it would fall to the ground, the velocity of fall being retarded by the resistance of the air. But in falling work must be done on the air which may be measured by the difference between the actual final velocity of the bird on touching the ground and the theoretical velocity. We may take the case of a bird swooping down to the ground from, let us say, the height of 99·37ft., when its final velocity, if it had fallen freely, would be 80ft. per second; but the bird may arrive at the surface of the ground with little or no velocity. Let us assume that the bird weighs 10lb. Then it is clear that in the arrest of its descent not less than 1000 foot-pounds of work have been done on the air in some way. If now we take the case of the same bird soaring, it is evident that to attain a height of 100ft. it must expend 1000 foot-pounds of energy at least, and this will be exerted on the air. But much more than this will be required. It is well known that the resistance of a liquid such as water to the thrust of an oar, paddle-wheel, or screw propeller is determined altogether by the weight of water sent astern and its velocity, and the broad rule has been laid down by Rankine that that propeller is best which sends astern the largest weight of water at the least velocity. Assuming that the same truth holds good of elastic fluids like air, we find that the bird's wing must act to a great disadvantage as compared to an oar moving through water, because it sends a small weight of the fluid downwards at a very high velocity. In other words, a very considerable amount of work is done in putting air as well as the bird in motion, and the utilisation of a current of air in causing the ascent of the bird will in no way affect the work to be done, save in the way that we have already pointed out, namely, that the time expended in attaining a given height will be greater in this case than if the bird climbed straight up, so to speak, at once. But no matter in what way a given height is reached, the work done by the bird cannot be less than that represented by its weight multiplied by the height. If Professor Shaw can prove that elastic fluids give reaction in a way differing from that of water, then the problem may assume a new aspect as regards wasted power. On this subject, however, we are not aware of the existence of any published information, for the subject has never been investigated, experiments with fans in cases hardly bearing on it. When our bird has attained a height of 100ft., if it intends to remain there without rising or falling sensibly it must exert muscular force, and what that force will be is the point to be decided. The condition of the bird is, however, precisely that of the break weight on a dynamometer; of which it is known that the power expended is equivalent to the weight in pounds multiplied by the angular velocity of the pulley in feet per minute and divided by 33,000. Professor Shaw seems not to have caught our meaning, and we can, perhaps, better convey it to him by saying that a strict parallel to the case of the bird would be supplied by a boat, which a rower, by the aid of oars, would attempt to keep stationary in still water while some one attempted to pull the boat astern by a tow line. In the case of the bird gravity takes the place of the pull on the tow line, and wings take the place of oars, and we now venture to submit the following problem for solution to our correspondent:—Let it be supposed that a Cambridge racing crew, pulling thirty strokes a minute, can impart a velocity of twelve miles an hour to their boat. Now let us suppose that a line is attached to the stem of the boat, one end of which line shall pass over a pulley, and that sufficient weight is hung on the line to impart a velocity of twelve miles an hour to the boat with her crew sitting in her but not rowing. Next let the boat be turned round and the line attached to her stern. If matters are suitably arranged the boat will then move astern at some velocity less than twelve miles an hour, depending on the shape of the boat. This difference may be neglected. Let the crew now proceed to pull as before at just such a speed as will keep the boat stationary. What proportion will the power then exerted by the crew bear to the power expended when the boat was not secured by a line? In the case of the bird the action of gravity is direct, instead of taking place through the medium of a pulley. If Professor Shaw should say that the work expended by the boat's crew will be the same in both cases. then we say that the work expended by the bird in hovering will probably be the same that it would expend in flying upwards at a velocity identical with that which it would have when, during falling with outstretched wings, the resistance of the air exactly balanced the action of gravity, and the rate of fall became constant.—Ed. E.]

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FLYING MACHINES.

Sir,—The discussion is now reduced to the question of the work done by a bird when hovering. You deal, however, with two points in your remarks—(1) the method of its measurement; (2) its actual measurement.

(1) The reason of my having hitherto failed to catch your meaning is now clear. You took, in conjunction with the weight of the bird, its wing velocity; but at the same time you meant to take the hypothetical velocity of the falling bird. The two things are entirely different. The illustration of the boat was perfectly unnecessary to make the matter clear. A simple statement would have sufficed. The work done is, then, rather more than the weight of the bird multiplied by the distance it would have passed through in any given time at the constant velocity attained sooner or later after falling from rest with outspread wings. If, however, you do take the wing velocity—as suggested in your article—then the force to be taken with it is not the weight

of the bird, but the force exerted at the centre of pressure of wing. Either way of treating the matter would be theoretically correct, but not practical—from want of complete data.

(2) But in applying the former method you arrive at a result which I quite fail to understand. You say that the work expended by the bird in hovering will probably be the same that it would expend in flying upwards at the above-mentioned constant velocity. Now the bird in falling from rest would have its velocity increased until the resistance of the air just equalled the pull of gravity, $w$. This is proved by the fact that to ensure the uniform motion of the falling weight in Atwood's machine the other weight must be equal to it. The reaction of the cord in this case supplies the resistance to the falling weight which the air does to the bird. In flying up at the constant velocity, there would be a resistance, not perhaps quite so great as in falling with spread wings, but still considerable. Let this be $w$ 1. But in hovering evidently only the pull of gravity, or $w$, acts on the bird. Thus you appear to say $w + w = w$ 1. There are here decidedly mistaken views on one side or the other.

In conclusion, I may point out that you do not allude to the question of soaring. All that you say refers to a bird hovering without motion—as a whole—relative to air or wind, either horizontally or vertically. To judge from hawks and other birds, this latter requires considerable effort. The whole weight must, we are quite agreed, be supported. Not so with soaring; this is effected when either the bird is in motion through the air or when the wind effects the same result with a minimum of effort. What action supplies the small force that, as shown by my diagram, is necessary, is not well understood. Probably it is an imperceptible wave action of the flexible wing, which Mr. Brearey has demon-

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strated, does take place, and which Dr. Pettigrew has fully discussed. Some explanation is needed of the graceful soaring of the albatross, which for hours together scarcely deigns to flap its wings, or the still more majestic flight of the gigantic condor in an atmosphere less than half as dense as that in which small birds hover with such apparent labour. Until this fact is otherwise explained most people will continue to think that the bird in soaring does derive assistance from the air, and will refuse to believe that it is only upward currents which aid to sustain its weight.

H. S. HELE SHAW.

*University College, Bristol,*
*January 23rd.*

[We fail to see that Professor Shaw's present letter has advanced matters in any way. Apparently he gives up the hovering question, and concedes he does not know how birds hover. We maintain, as we have done from the first, that all that birds do in the air they perform by violent muscular effort, for the display of which they are specially constructed. It will be time enough to discuss other matters, such as soaring, when we are assured that our correspondent has given up the hovering problem as insoluble. Let us discuss one thing at a time.—Ed. E.]

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FLYING MACHINES.

Sir,—My object in commencing the discussion on the above subject was to take exception to certain statements in your article, which appeared to have an important bearing on the problem of aërial navigation. The only point on which we still differ appears to be the question of the effort exerted by a bird in the air. Even in this matter we are at any rate agreed so far as the mode of measurement of work done, when the bird is relatively at rest to the air, and this is the only part of it on which I have expressed an opinion.

The solution of the problem of artificial flight will be, from the nature of the case, more difficult than that of artificial locomotion, either by land or sea, has been; but not a few writers and observers agree that its most hopeful feature is the assistance derived from the air by a suitably formed body in motion. This is how they account for the soaring of birds; this is how the apparently authentic but otherwise incredible instances of men who have, even for a small distance, managed to fly are accounted for; such, for instance, as Besnier in 1678, the Marquis de Bacqueville in 1742, Berblinger in 1811, and others. The imperfect state of aëro-dynamics renders any statement of the exact amount of this assistance impossible. Until more reliable data and experiments are forthcoming, the matter may well await further discussion.

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*January 30th.*

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