MR. WALLACE has well said that the question, How a bird's wing moves in flight, "is a very important question." In these days, when scientific attention is being directed to the problem of aërial navigation, it is especially important. I have the less hesitation, therefore, in troubling you with some further remarks in reply to the strictures of this very accurate observer.

At the outset I must deny that I assumed either that a bird's wing is inflexible or that it is a plane. Of its flexibility I had no cause for speaking at all; but so far from regarding it as a plane, I expressly objected to Dr. Pettigrew so representing it in his supposed refutation of the orthodox view. The point in dispute is entirely concerning the down stroke; against Mr. Wallace's account of the up stroke I make no objection.

First, what may we infer *à priori* concerning the down stroke? (1) Its efficiency is independent of the velocity of the bird: this is simply a consequence of the second law of motion. We have to suppose a bird fixed in still air, and to ascertain the effect which ensues on a downward blow of the wing. The subsequent forward velocity of the bird, so far as that depends on the down stroke, is but a consequence or an accumulation of these effects. It is thus only needful to analyse the single effect itself. To this end the shape and varying flexibility of the wing must be noted. Along the exterior margin we have a rigid area, comparable to the blade of an oar, and formed for the most part of bone, in the *top side* of which the rigid tubes of the primary and secondary feathers are inserted. On the under side of this, which we may term the oar part of the wing, there is thus a considerable concavity, the direction of which when the wing is extended is decidedly backward. The area towards the middle line of the wing is flat and horizontal, approximately so at all events, when the bird is freely suspended in the air. Of the posterior, the larger, half of the wing it is true, as Dr. Pettigrew says, that the aspect is forward, more especially in heavy birds with broad and rounded wings. The flexible extremities of the feathers readily turn upwards like vanes in the manner so well shown in Fig. 80 of Dr. Pettigrew's work. We may thus roughly distinguish four areas, beginning from the front: (*a*) the oar area; (*b*) the plane or flapping area; (*c*) the kite area; (*d*) the vane area. (2) Now we may inquire what will be the effect of each when the wing is struck downward. The reaction from the oar area will be (*a*) a force directed upwards and forwards; that from the plane area (*b*) a force directed upwards simply. Against the kite area will impinge the air sent backwards and rebounding from the blow of the oar area; the effect of this (*c*) is all that corresponds to what Dr. Pettigrew calls the kite action of the wing. Lastly, the same air in escaping through the feathers, and especially in raising the tips in the vane area, will produce the forward motion (*d*) to which Mr. Wallace refers, besides contributing something (*e*) to support the bird's weight. The horizontal component of (*a*) together with (*d*) will carry the bird forward. The slighter horizontal component of (*c*)—slighter because proceeding only from the rebounding air and from a yielding surface—will tend to hinder the forward motion: hence the absence, more or less complete, of this area in quick fliers. The forces (*b*), greater part of (*c*), and (*e*) will sustain the bird against gravity.

Neither Dr. Pettigrew, nor apparently Mr. Wallace, distinguishes the motion consequent on a surface striking against the air from that of a surface gliding through it. If I incline a sheet of paper to the horizon and let it slip from my hand it will descend with a similar incline towards the ground; but if, having stiffened it, I strike it against the air at the same inclination it will tend to rise in a direction at right angles to that inclination. The *blow*

directed downwards and backwards must give an impetus upwards and forwards; the *still surface* so directed will glide downwards and forwards. I do not deny that if the down stroke of the bird's wing be directed backwards, *beyond a certain angle*, the resultant motion will be, as Mr. Wallace says, "obliquely downwards." But why? Because all the sustaining forces above enumerated are so seriously diminished—the horizontal and forward forces, with the exception of (*d*), being increased—that, to use Mr. Wallace's words, "the surplus vertical reaction of the down stroke over the up stroke is no longer able to overcome gravity," which converts the bird's wings for the nonce into kites as it comes sailing downwards, making but an occasional strike, now that the horizontal effect of the wings is so great, to increase the obliquity of its descent.

But within the limits of this angle, whatever they be, the effect of a downward and backward blow must, on mechanical grounds, be in general such as I have said. For clearness' sake it may not be superfluous to note an ambiguity in the expressions "downwards and backwards," "downwards and forwards;" they may apply either to the direction of the surface of the wing or to the direction of the anterior margin. I maintain only that the direction of the surface—in some wings, merely that of the anterior portion of the surface—is downwards and backwards. The anterior margin, by the contraction of the great pectoral muscle, is drawn downwards and forwards, in which, by the way, there is the further advantage that less air will escape from under the wing in front.

But, secondly, what can we *observe* as to the down stroke? (1) A fact, pointed out to me by an anatomical friend—that the great pectoral muscle which depresses the wing is inserted into a crest situated on the upper and forward side of the head of the humerus, so as to tilt the under surface of the wing slightly upwards, *i.e.* give it a backward direction. (2) If the flight of rooks, or still better of pigeons, be watched from a window towards sunset, the position of the shadows on the under side of the wings will be found pretty conclusive as to their direction. (3) The forward inclination of the wings of a bird about to alight, which shows that the motion of the wings in such a position retards flight. (4) The action of heavy land or water birds, that have to attain some momentum by the use of both feet and wings before they can rise; here surely a forward blow against the air is manifestly absurd. (5) "The highly-inclined position of a hovering bird," noticed by Mr. Wallace, and not of the bird only, but of his wings.

Mr. Wallace's closing remark is both true and sound:—"A bird's wing is a highly complex apparatus, subject to a variety of flexures and motions in every feather." Still it is possible, even probable, that all this variety is referrible to a few simple principles. It is with these alone that I have ventured to concern myself.

JAMES WARD

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