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DISCUSSION ON THE VARIOUS PAPERS ON SOARING FLIGHT

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About six years ago I discontinued temporarily a course of study on the flight of birds and the laws relating thereto, after having pursued it for a number of years in a rather isolated place. From my investigations and experiments I have been able to draw some conclusions which agree well with some presented in papers read at the conference concerning the soaring of birds and the nature of wing surfaces.

After many experiments with kites, I became convinced that the laws of incidence and reflection, as ordinarily applied to planes, did not apply in the case of a fluid medium impinging on a plane surface, particularly when striking it obliquely; and I commenced in series of investigations to discover what are the movements of fluid particles when approaching plane surfaces, and the consequent actions and reactions.

For this purpose I pursued three sets of experiments.

In the first, the movements of the wind when striking a plane were studied; in the second, the movements of a gentle draft against a small plant; and in the third. the movements of water, when striking a plane, in a slow current.

In the first experiments very light down was scattered in a breeze moving from 5 to 10 miles an hour. When free from disturbances it traveled in straight lines, but when an obstruction was placed in its path it changed its direction and movements in various ways, according to the nature or position of the obstruction or the velocity of movement.

Perfectly plane surfaces were used, the largest being 8 ft. high and 4 ft. wide, standing perpendicularly on the ground, and so arranged that it cou1d be adjusted at various angles to the direction of the wind. When it was so placed as to cut the wind edgewise, there was no appreciable disturbance of the floating particles of down, but on giving it an angle, ever so slight, the particles approaching it changed their direction of motion, tending to strike the surface less obliquely.

This tendency manifested itself near the front edge when the angle was very small, but as the angle was increased the particles changed their direction at greater distances in advance of the plane. For angles between 5° and 20°, the deflection was noticeable at distances varying from two to six times the width of the surface (meaning by width the distance from the front to the rear edge). The deflection, very slight at first, became more marked as the plane was approached; and in gentle velocities, the particles striking the forward part of the surface, traveled in lines nearly normal to it. In some instances the particles, striking the plane a short distance back from the front edge, would turn, then advance against the wind and make their escape around this edge.

A particular examination of the particles in the stratum of air adjacent to the surface, especially those near the forward edge showed that they moved at a great variety of angles, nearly normal to the surface at the front and parallel with it at the rear. The air passing immediately around the edges whirled in eddies on the rear surface, and the main current continued for a short time to travel in lines parallel to the surface of the plane, this movement being a counterpart of that in ad advance of the plane. These two counter movements formed the first of a series of waves, which continued sometimes 200 yds. distant, large at first, but gradually decreasing in size, and then disappearing entirely. The waving air, filled with particles of down, presented a peculiar spectacle, suggestive of the squirming of an immense serpent or the waving of very long flag.

The second set of experiments was performed thus: small metallic planes-the largest 4 in. square-were placed in a draft regulated at will, and a beam of light, from a heliostat, used to light up the floating dust particles, which in the darkness revealed their slightest movements. As these approached the plane the changes already mentioned were noticed, though more marked in some respects. For instance, when the plane varied about 5° from the direction of the current, some of the particles, having passed the front edge and "reaching the surface about one-quarter the distance between the front and rear edges, would turn and, slowly advancing toward the front edge, pass around it, their velocity increasing from the time they turned till they escaped.

In the third set of experiments metallic plane surfaces were placed at various angles in currents of water, and the movements were observed by means of dust scattered on the surface, and of a fiber of silk attached to a slender wire and used as a flag.

The dust revealed the general motions, while the flag served the purpose of examining more carefully the direction of motion in any particular portion. The same phenomena shown by air currents were noticed in these experiments, the great difference in the elasticity of the two media having no appreciable effect in the general results.

In the experiments with water, the pressures at different points were manifested by elevations of the surface. The water in contact with the front surface of the plane was elevated, and that in the rear depressed. An examination of the elevation on the surface of the plane showed that the point of maximum height moved from the center toward the forward edge as the plane was placed more obliquely to the current. A study of these changes seemed to indicate-

First, that the location of maximum height was coincident with or not far removed from the location of maximum normal pressure, and, second. that the element of pressure, perpendicular to the direction of the current, is greatest at the front edge, decreasing rapidly from this point in passing to the rear edge.

It is probable that the differences of level on the surface of water find their parallel in compressions and rarefactions of air, in striking a plane. My attempts to investigate this point were unsuccessful for want of adequate apparatus. In hopes of experimentally determining the general resultant of the forces and movements of fluid particles when meeting a plane obliquely, and hence the surface best suited for receiving them, I studied the effect of planes with a re-entrant angle in streams of water. These were formed of a short and a long plane fastened a right angle thus____. In this arrangement the point of the short side represented the front edge of an imaginary plane in the line of the hypotenuse.

The water meeting this contrivance traveled in a perceptible curve between the front and rear edges, its movements being made visible by floating scum. These experiments, though instructive, contained elements of error which rendered some of the results doubtful. In some further investigations light fabrics were fastened by one edge to a wire stretched horizontally, the opposite edge being sometimes loaded to give weight and stability. When placed in a wind, these were thrown into curved surfaces, the rear edge sometimes rising higher than the front The highest point of curvature being nearly always higher than the front and in advance of the center of the surface.

While these effects were a demonstration of the change or direction given to a fluid current by the disturbing influences of an inclined plane, they were of little value in giving the desired information. This, however, was afterward obtained by an examination of birds' wings, and a study of the actions and reactions of fluid particles, meeting planes under various conditions.

In the examination of the wings of hawks, buzzards, eagles, sea gulls, pelicans, wild geese, and other birds, I found the under surface of the wing from the front to the rear edge a true parabola, varying in its curvature, both according to the relation between the weight of the bird and its wing surface, and the proportion of length and breadth of the wing. A comparison between these various models suggests that the curvature is also affected by the tilt given the wings from the base to the tip.

The parabolic curvature a few inches from the base of the wing seems most perfect. At this point the front edge is the vertex of the parabola.

In comparing the distance between the front and rear edges -the chord-with the focal length of the parabolic curve, the following order seems to exist. The length of the chord is to the focal length as the weight of the bird is to the wing surface; this relation being affected by the proportion between the length and breadth and the tilt of the wings. I do not give this as an exact proportion, but simply as an indication of the relations. In the pelican's wing the chord is five or six times the focal length of the curve; in the gull's it is three or four times, while in hawks and buzzards it is two or three times. The difference between the focal length and the chord de- creases in passing from the base to the tip of the wing - i.e., the curves become more open; and from the center to the tip the front edge gradually varies from the principal vertex of the (parabolic) curve.

Final1y, the curves of the various sections seem to run in constantly diverging lines, the rear portions inclining toward the tip of the wing. As a result of these several variations, the curvature between the tip, rear edge, and the base, front edge, is much greater than that between the tip, front edge, and the base, rear edge. In some experiments with dried wings these special phenomenon were noticed.

If a wing was placed suddenly in a wind so that the front and rear edges were in line with the direction of the wind, there was no sensible pressure on the under surface; but if the wing was first placed obliquely to the wind, the under surface facing it and slowly turned till the edges were in the position first mentioned, the air continued for some minutes to press on the under surface. Also when this position was reached, the down on the under surface, from the front edge back to nearly one-eighth the width of the wing, continued to be ruffled, indicating a movement of air from this point toward the front edge.

The first two phenomena suggest that when a plane is set obliquely to a current, a structure is given to the fluid movements, which continues to exist after the edges have been placed in a line with the current. This may be the explanation of the continual tipping of birds' wings in soaring. From these experiments and observations it appears, first; that a plane deflecting a fluid current produces a wave, it being on the crest, the particles approaching it ascending to the surface, and those leaving descending from it; second, that the surface best suited for receiving and utilizing tile movements and forces is one having a gradually increasing curvature from the rear to the front edge; and, third, that the curvature of this is dependent on the relation of weight to the surface and the length of the surface to its breadth.