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AERONAUTICS OF BIRD FLIGHT

WITH FIFTEEN ILLUSTRATIONS

By STERLING BUNNELL

We are now in the dawn of the aerial age and as we are air-minded and our curiosity is kindled to learn the art of flying, perhaps by observing the birds, those skillful veterans of aviation, we may be shown the secrets of flight which Nature through the ages has evolved.

Ten years ago when I learned to fly and use the aerial ocean as a playground many of the mysteries of bird flight, which in boyhood days had thrilled me with awe and envy, began to clear and my early interest in ornithology turned toward an inquiry into how birds fly.

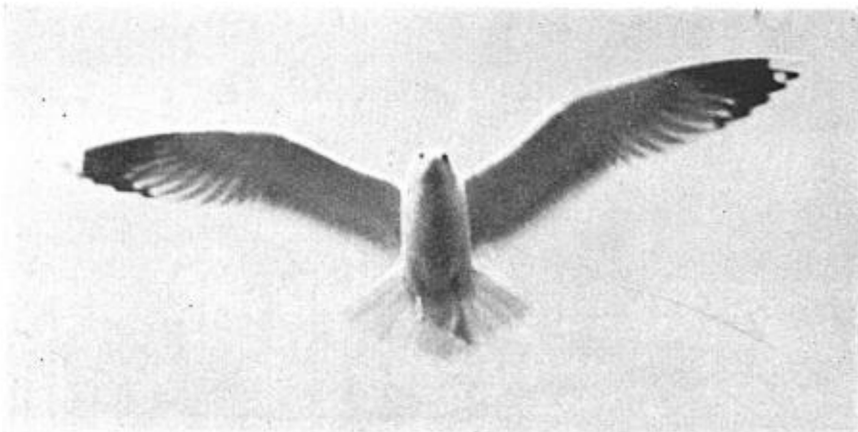

Fig. 94. THE BIRD CAN SHOW US HOW.

So familiar are we with the flight of birds that we have lapsed into the habit of thinking it beyond our comprehension and so have let it go at that. By thinking, however, in terms of aerodynamics derived from aviation the maneuvers of birds may be readily understood. Therefore, if we start with the simpler problem of learning to fly an airplane, the way in which birds fly will be unfolded to us. The airplane motor and propeller furnish the forward speed, and the uplift is provided by the wings acting on the rush of air caused by the speed of the plane. The wings are slightly tipped in a forward and backward direction so their under surfaces face slightly forward. This angle with the horizontal is called the incidence and, together with the wing area and speed, gives the plane the lift. In flight the support given by the air pressure is firm and ample, but should the plane slow down to stalling speed it will immediately fall. Should the motor stop, the pilot merely noses his plane downward until it glides down hill and so maintains the all-necessary speed which furnishes the air pressure that acts on the wings and supports the plane. Thus, if a plane is one mile high the pilot can safely glide ten miles to a landing field.

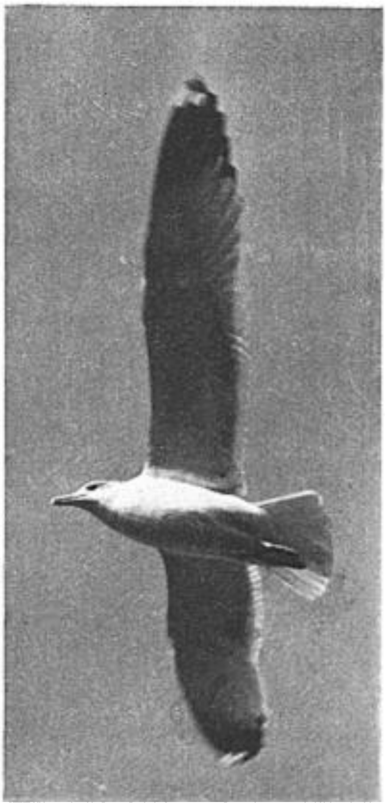

Fig. 95. THE SOARING BIRD IS REALLY GLIDING DOWNWARD IN AN UPDRAFT. THIS GULL WAS PHOTOGRAPHED ON THE WINDWARD SIDE OF A FERRYBOAT.

Mysteries of soaring flight. First let us solve that oft debated problem, "How does a bird fly without flapping its wings?" We have all stood on the upper deck of a ferry boat while a sea gull but an arm's length away remained beautifully poised on motionless wings keeping up with the boat even in the presence of a stiff side wind. There may be fifty of them at once, all with motionless wings and all keeping steadily abreast of the moving boat. Should one but glance out from the other side of the boat the mystery will be solved, for here all the gulls are flapping their wings. As the wind strikes the side of the boat it shoots up over it and down again on the other side. The motionless gulls are riding the updraft while the flapping gulls are working their passage in the downdraft. As a gull is light and has plenty of wing area, an efficient wing curve and low resistance, his gliding angle is very low compared with the one-to-ten of a plane. He does not require much of an updraft to allow him to remain level with the boat while he is really gliding downward in his relation to the air. With a very low gliding angle a bird in still air would descend quite slowly. If the speed of an updraft exceeds this speed of the bird's descent when gliding, it is apparent that when gliding in such an updraft the bird can execute maneuvers and can even ascend without ever flapping his wings.

Man uses this principle in his glider, which is a very light motorless plane with a low gliding angle. A range of mountains is selected against which the wind blows constantly, and by utilizing the updraft so produced, man has remained aloft in a glider as long as fifteen hours.

Once while on a hilly seacoast fronting to the north and with a north wind blowing, a long line of pelicans came along the coast in my direction, sailing very low and with motionless wings. On they came, undulating up and down with the rolling contours of the gullies and ridges, and to my surprise passed directly over my head although I was in plain sight. They had found an upshoot of air fringing along those hills and preferred, even in the face of danger, to travel without effort along this rather than to leave it and be required to flap their wings.

On a ridge of hills stretching along the Pacific Ocean I had often noticed an abundance of large hawks and marveled at this because here where the weather was too bleak for small animals to thrive the food of these birds was scarce. Finally it dawned on me that the hawks lived there because they were lazy. The constant stiff breeze from the ocean against the hills furnished them by its updraft effortless transportation throughout their domain.

Once on a still, cold, foggy morning while deer hunting in the mountains we came upon several dozen turkey buzzards in a cañon grouped on the branches of a tall dead tree. It was suggested that some hunter must have killed a doe, but this was not the correct explanation. The breast muscles of a buzzard are small and the wing area tremendous, so the effort in flapping such wings is fatiguing. As there was not a breath of wind to aid them that morning they preferred to roost. The wing muscles, which in fact constitute the breasts, are small in all soaring birds, so in the buzzard they are not sufficiently powerful to flap the wings for long. Later, a breeze sprang up and straightway the buzzards deserted their tree and scattered over the ridges where they were seen to be circling, but invariably on the windward sides of the ridges. Whenever one was seen to leave such a location of updraft he was observed to busily flap his long wings until he reached another upward current on the windward side of some ridge or peak, where again he could sail about in leisure. Putting this to practical use the direction of the wind may be told by observing on which side of the peak the buzzards sail.

Still later this same morning the fog lifted and the sun shone hot. By ten o'clock wavering atmospheric lines of heat bordered objects of the landscape and then it was that the turkey buzzards were seen to sail widely over the cañons irrespective of the upshoots of wind against the hills. Everywhere, in response to the sunshine, columns of heated air were rising and the air became soarable. These updrafts of heated air were amply sufficient in speed for the buzzard with his low gliding angle to sail about in them and even to gain in altitude. Such updrafts, due to heat, which are familiar enough to pilots, make one when flying over a heated valley bump in and out of one rising column after another, with the feeling of jolting along in a vehicle over a rough corduroy road.

Sea gulls invade the city of San Francisco as mendicants from the bay, seeking donations of food. Flocks of them on warm still days are often seen circling over certain spots in the city, where air is heated by reflection from pavement and walls of buildings and protected from winds. Here with motionless wings they sail round and round, flapping their wings only when sailing away from the location. Sensitive as they are to air currents they have found an updraft of heated air in which flying is but easy gliding, so there they collect. The updraft is shown by the smoke from the many chimneys, which ascends rapidly where the gulls are sailing and does not do so where the gulls are compelled to flap their wings.

The above examples illustrate that birds soar by means of updrafts, caused from either wind influenced by the shape of the terrain or from convection currents of heated air. There are, moreover, other principles involved in soaring flight, as we shall soon see.

Wings of airplanes and birds. Let us now consider what has been learned experimentally about the shape and action of wings of airplanes and see how the same principles have long been present in the wings of birds.

A wing with flat plane surfaces, as in the early airplanes, is poor in efficiency, for it sets up a great swirl of eddies and pull-backs, especially on its upper surface. The form found to give the greatest uplift and the least resistance is the shape of wing now generally adopted in airplanes, fairly thick with a blunt edge in front and a gradual taper to a thin trailing edge at the rear. It has a decided curve from

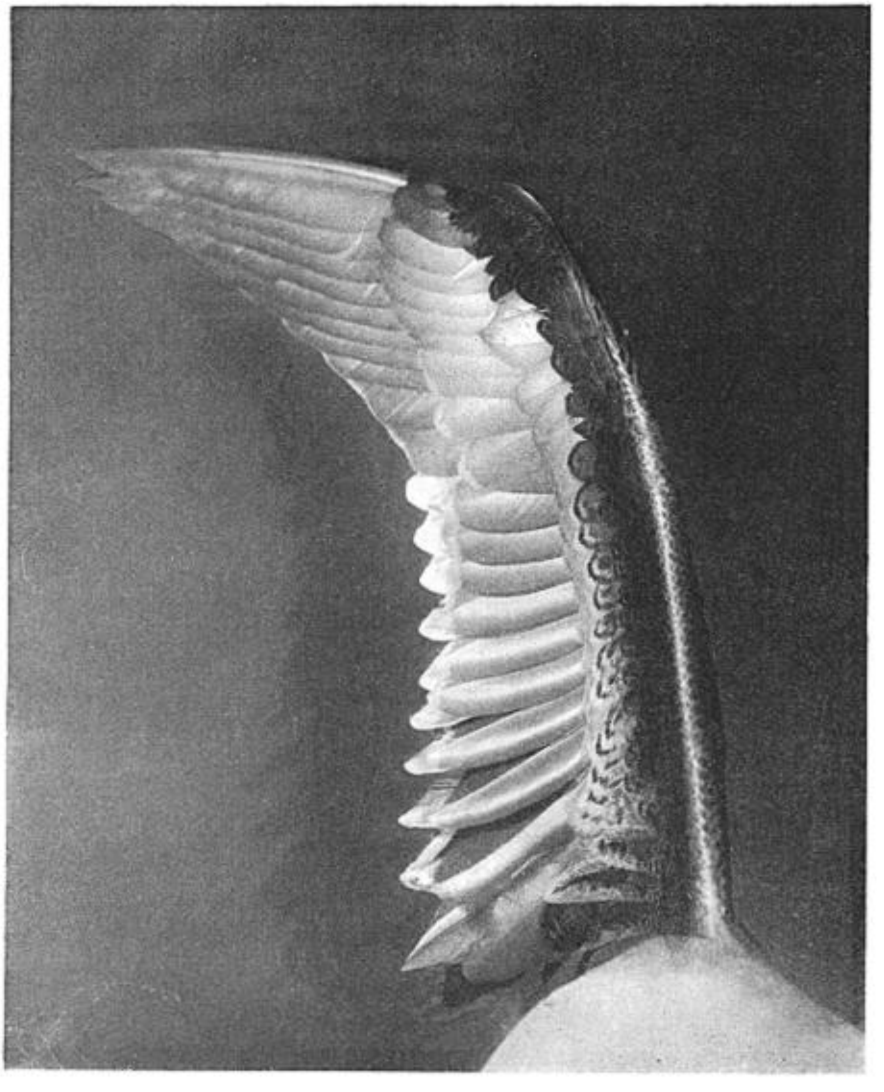

Fig. 96. NATURE'S WING CURVE. THE WING OF A DUCK CHECKS WELL WITH THE WING CURVES DEVELOPED BY MAN FOR MAXIMUM EFFICIENCY AT LOW SPEEDS SUCH AS THOSE OF BIRDS.

front to rear called the camber, with the convexity upward, so that the lower surface is straight or concave and the upper convex, and the greatest degree of curvature is in the forward third. The tips of the wings are tapered also to diminish resistance.

For the lower speeds, such as those of birds, a concave under surface gives greater lift. In high speed airplanes the under surface may be slightly convex.

Knowing how wonderful are the adaptations of Nature, it is not surprising to find in the shapes of the wings of birds these same characteristics that make for efficiency in the wings of airplanes. Birds' wings show the same thick front edge, formed by the thickness of the bones and muscles and short-cropped backward curving feathers. Projecting backward from this in a good curve or camber are the long wing feathers. Several rows of shingled feathers or wing coverts furnish the gradation in thickness from front towards the rear edge.

This pattern of wing is carried out even in the shape of the individual long wing feathers or primaries. The front vane of each of these feathers is narrow, so the thick shaft is located at the entering edge, and there is a good camber and a tapering tip. As in the wing of an airplane the bird's wing is also tapered at the tip and those with blunt wing tips, such as the turkey buzzard, have interdigitations which increase efficiency and cumulatively act as one tapered end.

The camber of a wing in addition to giving lessened resistance contributes in soaring birds to the uplift, as we shall soon see. A thin flat surface or plane held horizontally in the wind will have no tendency to move up or down. If, however, the surface be curved or cambered it will travel with a measurable force in the direction of its convexity. It is due to this principle that clothes on a line in a strong wind stretch out in a position higher than the line and that a flag bellies in undulating waves down its length.

In wind the moving body of air is held back in its lower levels by the irregularities of the terrain, so that its speed close to the land or sea is least and becomes greater as the altitude increases. The wind thus held back by the earth becomes rough and rolling on its course and is full of up and down components, which constitute the internal workings of the wind. The downthrusts of the wind are parried by the convex surface of the well cambered wing of the soaring bird, but the upthrusts are caught by the concave parachute-like under surface and add to the uplift. Also, as each long wing feather is valved against the next, the wing is impervious to the upward gusts of wind, but some of the downgusts may pass between the feathers. By virtue of the camber and this valvular action of the feathers in selecting only the upthrusts some birds so utilize the roughness of the wind as to gain from it a material uplift. Thus, soaring birds not only utilize upward currents of air from wind and heat, as already mentioned, but also profit by the internal workings of the wind, and this brings us to the flight of that king of all soaring birds—the wandering albatross.

Peerless flight of the albatross. Month after month this marvelous mariner sails the wide ocean for thousands of miles, resting only in the breeding season on certain islands, and on the ocean only when his indispensable ally, the wind, ceases to blow.

As mentioned above, there is a difference in the speed of the wind, low down where it lags on the water and higher where it is freer, and this is part of the secret of the albatross' marvelous flight. In addition the wind traveling undulatingly over endless parallel ridges of ocean swells that lie always at right angles to its course becomes rich in vertical components or so-called internal workings. Such air is well adapted to the selective action of birds' wings by virtue of their camber and to a lesser degree the valvular action of the wing feathers, so that the effects of the many little upthrusts are accumulated and furnish the bird considerable support while he swiftly glides.

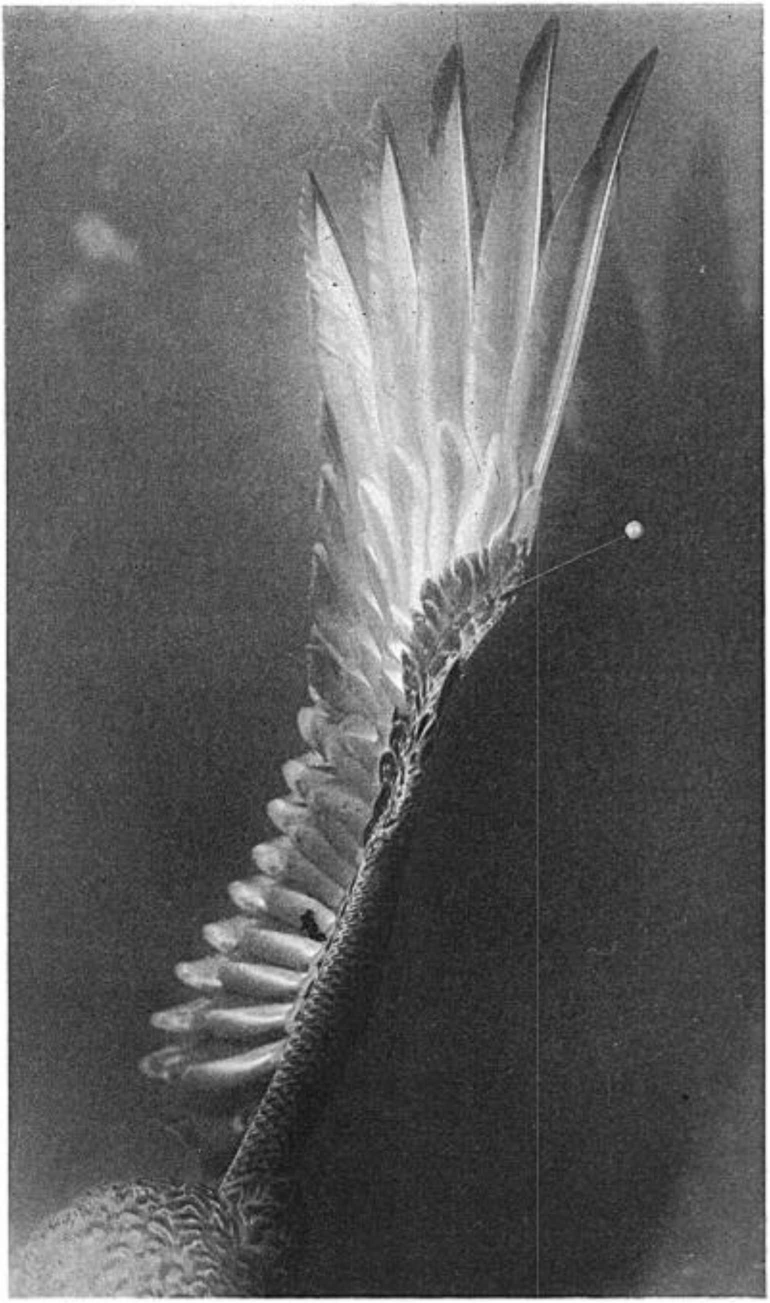

Fig. 97. Position assumed by the inside wing in making a turn. The tip acts as a resisting front to turn the bird about. The tortion of the wing takes place in the two joints beyond the wrist.

With these two wind factors in mind, let us watch the albatross in his ceaseless circling. Now he is high over the ocean facing into the wind against which he is traveling. The tip of one of his long narrow wings is seen to bend slightly upward, with the result that he makes a graceful banking turn and faces backward and with the wind. He is then high above the ocean where the wind has great speed and, as he sails downward with the fast wind, he gathers in his backward descent terrific speed. Now with this great speed to his credit he turns in a wide arc close to the waves until again facing against the wind and in the direction in which he is traveling. Being now in the slowly moving surface wind and also well provided with plenty of surplus speed he travels forward for a great distance so close to the water that he fairly skims the waves. His speed in this low layer of air sheltered from the resisting high wind lasts him until he reaches a position in advance of that at which he started. Then before his speed is exhausted he by a slight turning of his wrists zooms high in the air again and well in advance of his former point. He now repeats the same cycle and so keeps sailing ever in wide circles, gathering speed from the high winds and using it in his long advances in the shelter of the low winds. Thus, he utilizes this difference in the speed of the wind at high and low levels and also prolongs his long swift glide by advantageously using the internal workings of the wind.

Flight by flapping of wings. Let us now turn from soaring methods and consider the flight of the majority of birds, which is by a flapping of the wings.

It may be thought that birds can fly vertically upwards like helicopters, but few have sufficient strength for this. The hummingbird is an exception, as his pectoral or wing muscles, which constitute a bird's breast, are for his size so tremendous. He is like a scout airplane with an overly powerful motor. The pigeon, which also has a powerful breast, can ascend almost vertically for forty feet. So also can the mallard duck by a sudden upward rush, when he is flushed from the marsh, but the bird then flies off in a more gradual ascent, as such upward spurts cannot be continued. If a sparrow be placed in a smooth chimney a yard in diameter he will be unable to escape, as a vertical flight of more than about four yards renders him exhausted. When birds fly upwards, even for so short a distance as to a telephone wire, they ascend circling with a moderate slope, as if climbing on a road with a certain per cent of grade. Even the short flights in aviaries do not exceed forty degrees in steepness. It requires too much power; and we shall soon see that aside from the first flush, the flap of the wing is not to raise the bird but to give him forward speed, so that in ascending he is really gliding upwards at an easy angle.

Among the insects are many that are able to fly vertically upwards, but insects differ from birds in several essentials. Their specific gravity is less and the relative strength of their wing muscles is much greater; also, the rates of wing vibration far exceed those in birds, as evidenced by the high-pitched hum of the wings of many species.

When a bird flaps his wings the air thus set in motion is not forced downwards but backwards. If the flapping of the wings were to raise the bird upwards in the air, as is popularly believed, we would notice that its body would bob upward at each beat of the wing. But this is not the case, except in landing and taking off and in stationary fluttering. In flight the level of the body scarcely changes with the wing beats. For instance, how often have we seen a duck or a cormorant fly along so evenly, in spite of its powerful wing beats, that its body traveled in a straight line across the sky.

The breast muscles correspond to the motor and the beating of the wings to the whirling of the propeller in an airplane. They furnish the forward speed and not the uplift. The real support of the bird in the air while flapping its wings is furnished by the gliding action of the wings on the air, just as it is with a mono-

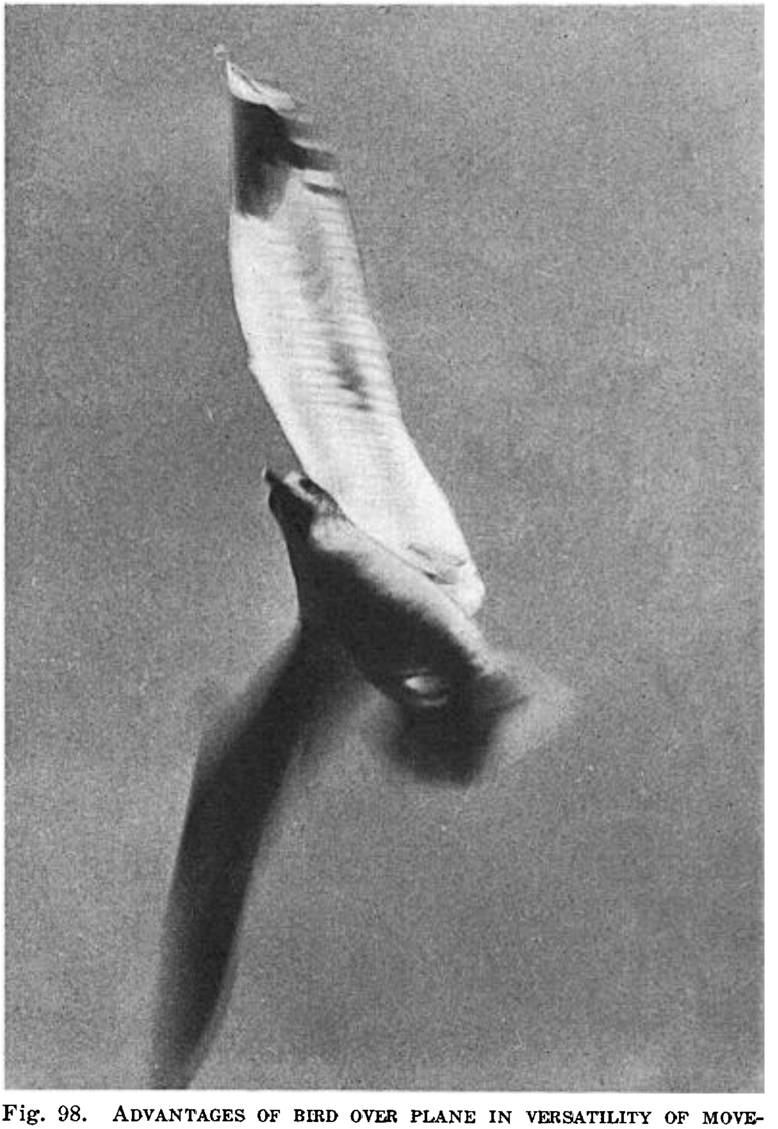

Fig. 98. ADVANTAGES OF BIRD OVER PLANE IN VERSATILITY OF MOVEMENTS OF THE WINGS.

plane. The wings act in this gliding function continuously throughout the wing beat irrespective of whether in a downward position or raised in a sharp dihedral angle.

The action of the wings in furnishing forward speed is like that of two fans directed backward. As the front edge of the wing is stiff and the wing feathers are elastic, a sort of sculling action is given to the air. This sculling action is intensified in some rapid flyers, such as doves or falcons, by having the long tips of the wings directed backward. As the air is fanned or sculled backwards the bird gains his forward speed and with this obtains his support on the air, just as does the monoplane, as explained at the beginning of this article. The flapping bird is really gliding while forcing himself forwards by his sculling. Most birds with long wings, as easily seen in the gull, flap their wings principally in their outer thirds for propulsion, while the inner two-thirds of the wings are fairly steady for gliding action or support, like the wings of an airplane.

We have seen how a large breast indicates powerful wing beats, as in the hummer, quail, pigeon, duck and water ouzel; but where are the large muscles that raise the wings? There is scarcely any meat on the back of a duck. So long as a bird has forward speed he does not have to raise his wings. His wings are set at an angle of incidence, so he need but relax his breast muscles and they will fly back from the pressure of air on their under-surfaces.

Fig. 99. TAKE-OFF FROM THE GROUND WITH A JUMP AND THEN A FLAP. WINGS ARE ABOUT TO FLAP.

Take-offs and landings. Most birds are able to make far better take-offs and landings than can airplanes. The latter in taking off must dash along the ground until sufficient speed is gained for the wings to furnish support, and in order to continue gaining in speed they must in rising maintain a low angle of ascent. Birds also must gain flying speed before they are well launched in flight. This they accomplish in various ways. When on an elevated perch or rock an initial dive readily furnishes the speed, consequently trees and cliffs are the natural roosting places of birds. Sea birds in taking off from their rookeries in high cliffs fly precipitously downwards for hundreds of feet to gain great speed. They level off just above the water and shoot far out over the ocean. Take-offs from the level ground, however, require more effort. Some gain sufficient speed at once by an initial jump and a burst of extra powerful propulsive wing beats, but others must with great effort add some helicopter vertical action to their initial wing beats before accelerating to the necessary speed for easy flight. A few birds have take-offs like those of airplanes, such as the mud-hen, which must run over the surface of the water spattering and fluttering until finally it exceeds its stalling speed and gains the air. Even the albatross has difficulty in launching into his real home, the air. If he is on the deck of a ship the gunwale is a sufficient barrier to hopelessly prevent his escape; and strangely enough the unnatural motion of a ship, so different from his own graceful curves, makes him seasick. To take-off from his nesting ground, such as the flat surface of Laysan Island, he must first

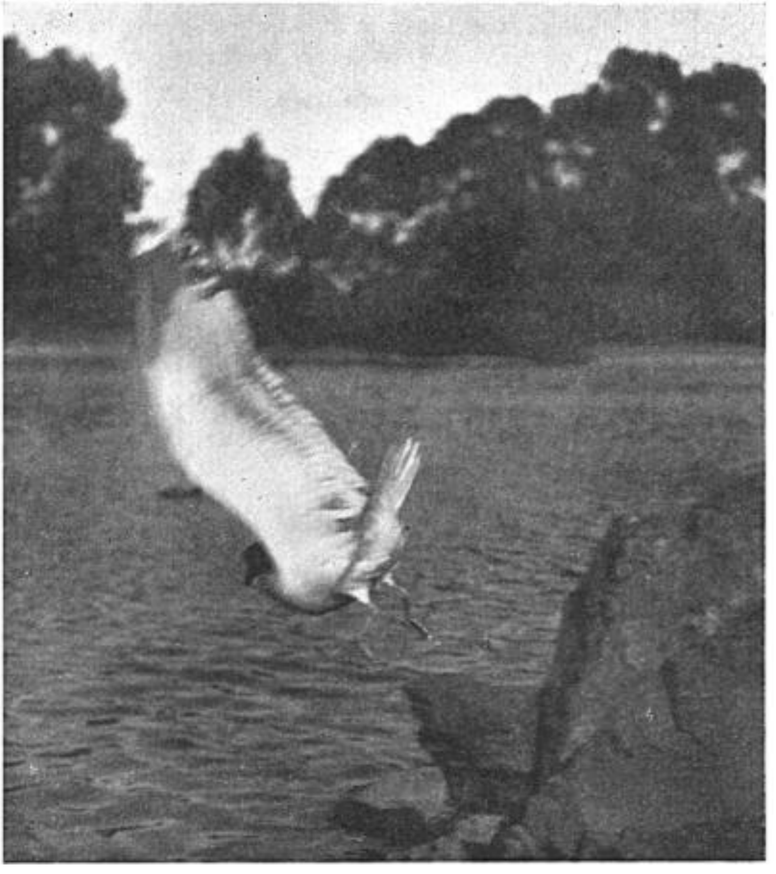

Fig. 100. TAKING OFF BY DIVING FROM AN ELEVATED POSITION ON A ROCK.

run along the ground a great distance. So also in rising off the sea he runs along the surface of the water. If, however, the take-off is in the face of a strong wind it is much easier for him to rise. The necessary speed to be gained is with reference, of course, to the air and not the land, as it is immaterial whether the speed is that of the moving bird or of the wind. This speed relation between bird and wind applies also to airplanes and wind. In some of the transoceanic flights the pilots waited several days for the proper wind for taking off in their heavily laden airplanes. In a strong wind an airplane can rise after a very short run and so also can an albatross in a gale take right off from the crest of a wave.

Like airplanes all birds land and take off into the wind. The speed of the wind is then added to their own speed, but if the landing or take-off is made with the wind the speed of the wind is subtracted from that of the bird or airplane and there is not sufficient left for support in the air. Even the little sparrows in the grass when the wind is blowing take off and land into the wind, turning at the same time if their course is in another direction. Many kinds of sea birds can be readily caught when on the ground by running toward them down the wind, as they must then face the intruder in their take-off. The nesting rookeries of hordes of sea birds of soaring flight, such as boobies, frigate birds and pelicans, are placed on a slope or exposed flat where the force of the wind or the updraft will facilitate their landings and take-offs and also aid the young in their debut into the air. On one such slope on San Benedicto Island I remember seeing at each gust of wind the young frigate birds spread their long wings, reveling in the feel of the wind and even ascending in the stronger gusts a foot or two in the air and settling back again. Eventually, one after another sailed out into that moving medium of air which was to become their home.

Fig. 101. GULL DESCENDING PARACHUTE-LIKE, WITH WINGS UPWARD IN DIHEDRAL ANGLE FOR STABILITY.

It is interesting to watch birds when landing, as they do it much in the manner of airplanes. An airplane glides down evenly, approaching the ground closer and closer as it loses flying speed until finally just as the stalling speed is reached it is practically on the ground, along which a short run follows as friction absorbs the inertia. Watch, for instance, a blackbird alighting on a lawn and see how he prolongs his glide until, when but a few inches above the grass, his flying speed is spent and with one flutter he gently alights. Other birds, as pigeons, flutter down parachute-like for several feet with wings in a sharp upward or dihedral angle for better stability and with tail broadly spread to check the drop.

Just as the airplane can swoop up a slope and land without a run, so does a bird swoop up to a perch in a tree and land perfectly balanced. If flying downwards to a perch beneath him, however, he checks his speed with a little flutter and accurately lands on the twig. At close range in an aviary the method of checking speed and gracefully landing on a perch may be beautifully seen. Just as the perch is reached both wings and the tail are widely spread in a broad resisting front. The bird stops and lands so accurately on the perch as to excite the envy and admiration of any aviator. Clumsier relatives like the mud-hens check the speed of their glide by plumping breast-on into the water with a loud splash and plowing along the surface until halted.

Maneuverings in flight. We have now to consider how the bird changes his direction in flight and maneuvers so expertly in any direction. Again by starting with the airplane, which in this day all of us should know how to fly, we can better understand the controls of a bird.

As an airplane flies in three dimensions it has in its tail both a vertical rudder and two horizontal flippers and so can turn sideways, upwards and downwards. In turning in the horizontal, banking is necessary as in a race-track to prevent skidding, and this control of rotation on the airplane's longitudinal axis is by the flippers at the rear edges of the wings, called ailerons. Thus, to make a turn to the right one starts with rudder to the right, left aileron down and right aileron up. Then when in a vertical bank the tail flipper is elevated and the turn is completed. The controls which, of course, must throughout the maneuver be nicely

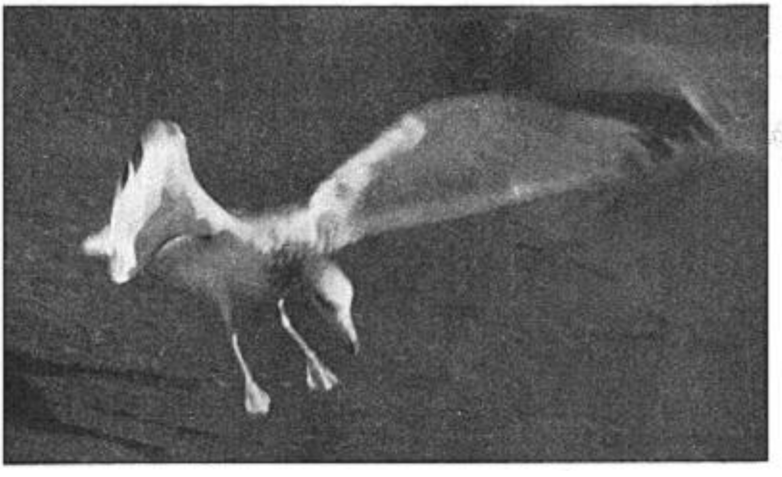

Fig. 102. A LANDING AT STALLING SPEED.

synchronized are neutralized as soon as their effect has been accomplished and even reversed in recovering from the turn. Birds, however, are devoid of rudder and though some have a tail for a flipper its upward force is lacking and in many the tail is but rudimentary. Its principal functions are that of the horizontal stabilizer of an airplane, to furnish additional supporting surface in flight and to act as a brake. In the latter function the body of the bird is tipped up so the outspread wings and tail present a broad front that at once stops the bird. The guiding is done by the wings and these have many motions which are lacking in the airplane. They may be raised or lowered, pointed forward or backward, and by rotating on their long axes may change their angle of incidence at will.

If a soaring bird wishes to incline downward, he directs his wings slightly backwards. This places his wings or lift behind his center of gravity, which is normally opposite the wings, and being thus nose-heavy, he aims downward. Similarly, to direct his flight upward he places his wings forwards. This shifts the lift to in front of the center of gravity, thus making him tail-heavy and he aims upwards. By slightly increasing the angle of incidence in the wings when they are either forward or backward their lift in this position will be accentuated, thus accelerating the maneuver.

To make a turn the outside wing is rotated at its tip or as a whole so as to increase the angle of incidence and, therefore, to increase the lift on that side, just as the aileron acts in an airplane. The incidence is also decreased in the inside wing, thus robbing it of lift, and the bird assumes the banked position. Simultaneously the wings are pointed forward to give tail-heaviness and this acting by centrifugal force directs the bird around the turn.

Birds use another factor in turning, much as the oarsman holds one oar to turn his boat about. The wing has the ability, by a motion at the two joints beyond the wrist, to rotate its tip until its under surface faces directly forwards (fig. 97), just as we can with outstretched arms and hands, held palm downward, direct

Fig. 103. GULL TURNING. WHILE BANKED THE WINGS, OR LIFT, ARE PLACED FORWARD OF THE CENTER OF GRAVITY AND THE BIRD BY CENTRIFUGAL FORCE NOSES BACKWARD AROUND THE TURN.

the under surfaces of our fingers forwards while the wrists scarcely turn. Even the individual four or five last wing feathers rotate toward a vertical plane, as does also the wing tip as a whole, so a resisting front is presented to drag that wing back and turn the bird.

Birds making a sharp turn on a glide are seen suddenly to drop the inside wing and rotate the down-pointed outer half so that it faces directly forward as a brake, thus pirouetting the bird around.

Flapping birds execute maneuvers similarly to gliding birds, but in addition accentuate the lift of the wing or wings where necessary by extra powerful wing beats when in the above angulated or rotated positions.

All birds bank well in turns. A familiar example is seen in the flash of white of the under surface as a flock of sandpipers wheels away.

Should one desire to study the principles of bird flight, as in a slow moving picture, he need but visit an aquarium and watch the fishes. Their many devices for motive power and for guidance by fins are fascinating to watch, as they make banking turns and go through all the maneuvers of birds, and with the same principles, but in their denser and, therefore, slower medium, water.

The part of the bird's wing that controls the finer degrees of incidence is beyond its forward angulation, which corresponds to our wrist. . The aileron-like movement of the tip is especially noticeable in the long wings of soaring birds. The bird's shoulder-joint has much the same action as our own, with the exception that it bends farther backwards. The backward or rather upward angle which the two wings form with each other is in aviation called the dihedral angle and in airplanes

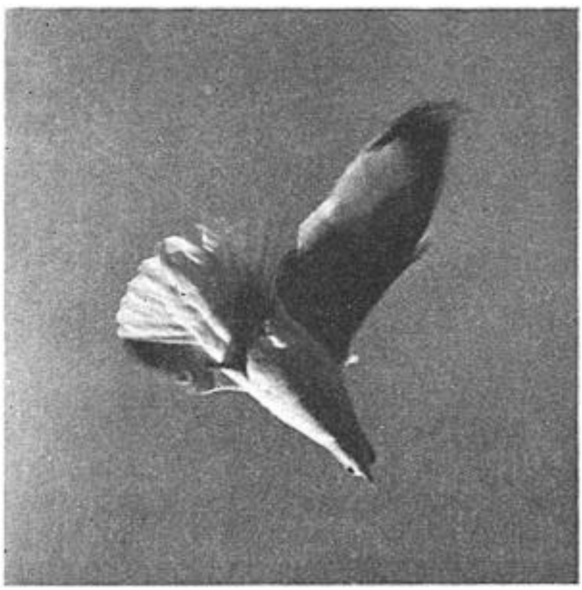

Fig. 104. NOSING DOWN. WINGS, OR LIFT, ARE PLACED BEHIND CENTER OF GRAVITY.

it is found to add much to lateral stability. If an airplane built with some dihedral angle leans to one side, the lower wing will thus present a greater lifting surface in the horizontal than will the upper wing and so will automatically right the plane. Birds when in need of better balance when the air is rough increase the dihedral angle of their wings, either in their wings as a whole, as in the pigeon, or only in the inner halves of their wings, as often in the gull. The dihedral angle is also used by birds while landing, just as they are slowing to the stalling speed and are losing their hold on the air.

Long wings held in a dihedral angle frequently show a sharp downward bend at the wrist-joint, especially when the air is turbulent. Thus, the dihedral angle of the inner half of the wing gives lateral stability and the outer halves of the wings are best placed to take advantage of the current of air which the inner halves of the wings deflect outwards. The movements of the wing are more versatile in the outer half from the wrist outwards, and thus further increase the lateral stability

Fig. 105. CHECKING SPEED BY INCREASING THE ANGLE OF INCIDENCE OF WINGS.

Fig. 106. FLUTTERING GULL MAINTAINING ALTITUDE BY FANNING AIR DOWNWARD, WITH PLANE OF WINGS ALMOST VERTICAL.

furnished by the dihedral angle of the inner half. Birds when fluttering or hovering without forward speed place their wings in a strong dihedral angle and well forward of their center of gravity, so the body hangs in a somewhat upright position. The incidence of the wings is greatly increased and especially so beyond the wrist-joint, so the flapping fans the air directly downwards, thus maintaining the lift without forward speed.

Various adaptations of different birds. Birds that do much flying from

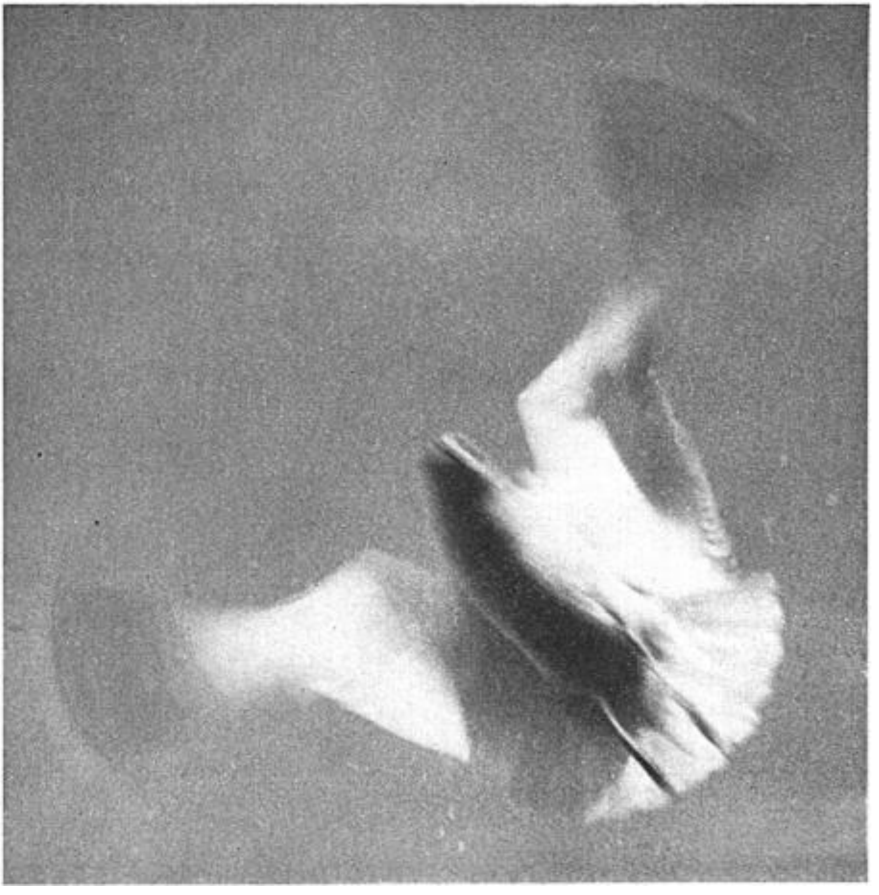

Fig. 107. STATIONARY GULL FLUTTERING, WITH MOST OF MOTION AT WRISTS OR FORWARD ANGLES OF WINGS.

perch to perch usually have a long tail to give them a purchase on the air and so steady them. Birds like herons, may derive some stability from their long legs, as does the tight rope walker from his balancing pole. If the legs of these waders are long, the neck must be long also, so as to reach to the ground, and the tail must be short to keep out of the wet, but in flight the wings alone steer the bird and the rest of the design is not so important.

Like racing airplanes, very swiftly flying birds present a minimum surface of resistance by having small wings, and have a powerful motor in the form of a large breast. With such small wing surface the speed of vibration must be great, so that a whirring sound is produced, as in the quail or duck. The more rapid the vibration, the higher is the musical pitch, until the record is reached in the hummingbird, which actually hums. Birds with these proportions are also the swiftest gliders and in fact have so much weight of motor for the small wing surface that their stalling speed is high. Should they attempt to glide slowly they would drop.

Other birds, such as hawks, when wishing to glide steeply with terrific speed diminish their resistance by half closing their wings. When an airplane is in such a dive the pilots say the wires sing "Nearer my God to Thee". Falcons, eagles, nighthawks and tropic birds in diving with this harrowing swiftness produce with their wings a shriek similar to that of the airplane.

Fig. 108. DIHEDRAL ANGLE OF INNER HALVES OF WINGS FOR LATERAL STABILITY.

In gliders the long and very narrow wing has been adopted as having less resistance, as it causes fewer eddies and pull-backs than does the broader wing. This explains the long narrow wings, like the blades of the boomerang, of such swift sailing birds as the shearwater, albatross and the swift.

The flight of some birds, such as petrels, swallows, nighthawks, flycatchers, snipe and woodcock, is quite erratic, darting jerkily this way and that like a bat or a butterfly. The breast muscles in these birds are very strong and have long leverage, so that each wing beat shoots the bird along, and the beats of each wing are more or less alternately forceful. Such birds are most skillful stunt flyers and many catch insects on the wing. "Wing-overs", "Immelman turns" and most of the stunts of the aviator may well be seen in the flight of the swallow.

Many finches, shrikes and woodpeckers fly undulatingly in a series of swoops. This manner of flying is from flapping the wings intermittently in the intervals between the crests of their line of flight and resting between each of the spurts.

Water birds with labored flight, such as grebes, loons, murres and auklets, are usually seen flying close to the surface of the water. This is taking advantage of the firmer support furnished by the air which the water blocks as it is displaced downwards by the incidence of the wings.

Some birds including penguins, murres and water ouzels are able to fly under the water. Penguins bank and turn most gracefully under water, flying about with their short thick wings much as other birds do in the air. The shape and size of their wings are perfectly adapted for flying in water and so must be short and thick like the propeller blades of a boat, as compared with the long slender blades of the propeller of an airplane.

On moonlight nights on the ocean I have seen the shearwaters and albatrosses still flying as in the daytime, so it is probable that when the ocean is rough they fly continuously. This necessitates a special sort of wing muscle, like the muscle of the heart which works constantly without rest from birth until death. Muscle adapted for continuous action like hearts or breasts of birds that spend much of their time on the wing is of dark meat. For instance, the tail muscle of a rattlesnake whose function is to vibrate the rattles for long periods, is dark, while the meat throughout the rest of his length is white. Also, birds that run more than they fly, like quail, chickens and turkeys, have dark meat in the leg muscles and white meat in the breast.

The speed of birds is not great; small birds fly about 30 miles an hour and gulls about 25 miles an hour. When an airplane at 90 miles an hour is flying along with a flock of ducks, the ducks appear to the pilot to be flying backwards. If, however, they are gliding downwards or flying with the wind their ground speed may exceed 100 miles an hour.

Colonel Munson who paced ducks with an airplane claims that canvasbacks fly 72 miles per hour, sprig 65, mallard 55, and swans 45.

As seen from an airplane birds are creatures of the earth's surface and seldom stray far above it. They seem to be part of the evolutionary biochemical reaction between the surfaces of three media—land, water and air; in fact, animal life and plant life are seldom found far from the juncture planes of these three media. Hawks and buzzards are sometimes seen at 1500 feet above the earth, and migrating birds have been seen at great altitudes, but they have been at such times crossing mountain ranges and so have not been far above land.

Colonel R. Meinertzhagen after interrogating six hundred English aviators concluded that most birds migrate at altitudes under 3000 feet, with the majority well under this altitude, and that they usually fly below the clouds, so as to keep landmarks in sight. In only thirty-six instances were birds seen over 5000 feet and in only seven recorded cases were they seen between 8500 and 15000 feet.

Flying is laborious at high altitudes where the air is thin. The familiar Jenny airplane reached its maximum height at about 5000 feet and many modern planes cannot exceed an altitude of 10,000 or 12,000 feet. Therefore, most of the birds that soar, with such few exceptions as the condor of the Andes, which has the greatest wing area of any bird, are found at lower altitudes. An example of the poor flight of birds in high altitudes is seen in the method of quail hunting in the Andes at 15000 feet, where a crowd of people and dogs run after the quail which averages but three flights and then is so exhausted that it can be picked up.

Now that we have indulged in thinking of this most delightful means of locomotion are we over-stepping in philosophizing that the happy creatures are the agile ones and those that fly, while the sordid creatures are the slothful ground folk and those that burrow?

In the line of a little propaganda for aviation: Have you ever thought when thrilled with the music of the bird chorus at daybreak that it is an expression of their joy as they are about to fly?

San Francisco, California, June 4, 1930.