sunset that the Robin and the Mockingbird sing, the coefficients being .91±.02 and .81±.04, respectively. It seems highly probable that light intensity is the main cause of the song ending but that other factors cause it to vary somewhat, causing the song to end earlier than usual on some days and later on others.

Literature Cited

Dorno, C., 1924. Reizphysiologische studien über den Gesang der Vögel im Hochgebirge. Pflüger's Archiv für die gesamte Physiologie, 204: 642-651.

Haecker, V., 1916. Reizphysiologisches über Vögelzug und Frühgesang. Biologisches Centralblatt., 36: 403-431.

———— 1924. Reizphysiologisches über den Abendgesang der Vögel. Pflüger's Archiv für die gesamte Physiologie, 204: 718-725.

Schwan, Albrecht, 1920. Vogelgesang und Wetter. Pflüger's Archiv für gesamte Physiologie, 180: 341-347.

Shaver, Jesse M., and Gladys Walker, 1930. A Preliminary Study of the Effects of Temperature on the Time of Ending of the Evening Song of the Mockingbird. Auk, 47: 385-396.

Walker, Emily Barry, 1928. The Relation of Light to the Awakening Song of Birds. An unpublished master's thesis, George Peabody College for Teachers.

Walker, Gladys, 1929. The Relation of Temperature, Relative Humidity, and Wind Velocity to the Evening Song of Birds. An unpublished master's thesis, George Peabody College for Teachers.

George Peabody College for Teachers,
Nashville, Tennessee.

THE SOARING OF RAPTORIAL BIRDS*

BY R. H. PALMER

Perhaps the most spectacular of the many accomplishments of birds is that strange modification of their flight called soaring. An old red-tail, floating high in the air, moving in more or less irregular circles, banking in the sharp turns or against sudden gusts until he is a mere speck against the sky, "oozing around," as Riley says, and with scarcely a beat of the wing, does not fail to register on the mind of even a casual observer. A buzzard appearing as a mere dot in the distance and slowly moving towards a decaying carcass, bent on the

*This paper was transmitted to the present Editor in 1925 by his predecessor; the delay in publication has been due to the misplacement of the figures.—Editor.

twofold mission of banqueteer and scavenger with the same ease is an object of wonderment even to the more thoughtful observer. A Sparrow Hawk, poised immovably in the air, scanning the field below for a mousy diet seems to be a living, concrete instance of one valid exception to the law of gravitation. How do they do it? is a question often asked and many more times wondered.

It is the purpose of this paper to record a few observations and to suggest what is hoped may be a possible explanation, or at least to throw some light on this common though none the less rather curious and interesting phenomenon. It is not the intention to have included in any deductions or inferences any but the raptorial birds as this is the only order on which any observations, more or less extended, have been made.

I have very often noted that hawks and buzzards seemed more energetic, and used their wings in the commonly accepted manner, in the early morning or in cloudy weather or when there was little or no wind; stated conversely, they resorted to soaring only *when the sun was shining* or *when the wind was blowing;* and that the Sparrow Hawk never hovered without beating its wings *except in a wind.* I have further noticed that they are much more prone to soaring in hilly or mountainous country than where the topography is uniform, as in the broad Mississippi Valley. The connection, I take it, is this: the physical phenomenona I have mentioned cause currents in the air that these birds take advantage of. Let me explain. The sun shining on the earth heats the ground which in turn heats the overlying air. This expands and rises or sets up convection currents. The large many domed cloud banks with the horizontal bases resembling aggregates of giant milk-weed down floating in the air, cumulus clouds, are formed by just these currents so the meteorologists say. If one takes the time to watch the evolving round masses that are continually unfolding or blossoming out in a cumulus cloud, he is seeing the process actually in operation. What is taking place is this: the currents of warm air rise and are cooled to the point where the water vapor condenses and a cloud results. Above this they are visible and the unfolding is seen. Obviously these can be formed only while the sun is shining. Now a hawk or buzzard can by means of his rudder-like tail poise over the most advantageous points of this potential cloud and by circling keep over these points. At the same time, by circling, he moves up a spiral incline. If he remained over one fixed point, it would require a rather strong, though not unusual, current to overcome the

pull of gravity and carry him upward or to prevent his falling.* What really takes place, as will be explained later, is that he is gliding *down* an incline. It is possible that the spiral motion of the rising air may in some manner bear a casual relation to the circling direction taken by the bird.

The wind and topography factors need a word of explanation. Air moving against a rise of land follows along the topography and up the hill or mountain side causing by its upward movement a bulge or arch in the layers of air above the crest of the hill or ridge. This roughly parallels the ground below. It is on this bulge that the Sparrow Hawk is able to poise with absolutely no movement of his wings, balancing himself by steady, sure movements of his broad fan-like tail. Where there is a ridge as along a range of hills or along a well defined bank bordering the floodplain of a fair sized river it is no uncommon sight to see red-tails and buzzards soaring along, apparently for the pure sport afforded, or to see a Sparrow Hawk hovering.

A few examples may serve to make my point clear. Several years ago in southeastern Idaho I was up in the hills and observed an eagle floating in broad irregular circles a thousand feet or so in the air. It was a bright sunny day and he was taking full advantage of it all. Apparently he had nothing else particularly in view for he was in sight something better than an hour. Idaho weather is like the time-tables of the railroad—subject to change without notice. Several small and then larger and larger clouds rapidly hove in sight so that much less than a half of an hour the sun appeared between the cloud masses very much less than half of the time. Along with this sudden change the eagle began to manipulate his wings and shortly *flew* off (not by soaring) and disappeared.

Another day I was walking along the crest of a rather steep ridge broadside of which a thirty-mile, steady wind was blowing. A flock of nine buzzards were sailing up and down along the crest a hundred feet or so in the air "without an apparent movement of their wings," as I wrote in my notebook; and further, "a little Sparrow Hawk was

*The efficacy of these rising currents to carry a bird upward might be questioned. It needs but to be called to mind that hail is caused by drops of water being carried upward where they receive a coating of snow. Hailstones often bean evidence of having been carried upward and dropped at least three successive times. Personal communications from aviators record the fact that when these currents are encountered the planes are shot upward by their force. In a recent parachute drop from an airplane at an elevation of 6,000 feet in Seattle, it was observed that the parachute was carried upward several hundred feet by these rising currents.

hunting in his usual way hovering over likely places. Several times he remained absolutely stationary in the air facing the wind without a movement of his wings, his little tail moving up and down in a steadying motion." On another day in the same locality I saw a hawk remain absolutely stationary in the air except for the slight steadying motion of his tail for forty seconds by actual measurement.

In the summer of 1920 I had a fine opportunity to observe the flying and soaring of buzzards. For a month or so I was camped in a small canon in the Simi Hills down in southern California. A half mile or so down the canon was a large hog ranch into which cholera was making costly inroads. This, of course, called in Nature's scavengers in great numbers. It was no uncommon sight to see 150 of these spectral fellows variously distributed in the air, on posts, in trees, or gorging themselves on this filthy diet. Light morning fogs were the usual thing and as long as these were on these birds never soared without *losing elevation.* However, when there was a wind they would soar around in true buzzard form. As soon as the sun appeared over the hills and dispelled the fog the same change in their system of aerial navigation followed.

The question may arise as to how soaring birds progress through the air. The answer is this. They simply coast down hill *with reference to the medium they are in* and this medium rising keeps them at the same elevation above the earth. For example, if a cardboard is allowed to fall its course is not straight down but rather zigzag due to the resistance of the air. If this zigzag course is prevented by proper balancing so that one end is somewhat lower than the other it will sail down an incline. Now if there is an upward current of air sufficiently strong to keep the cardboard at a given elevation it will move forward in a horizontal line. The accompanying figures illustrate the principles of physics involved. Let W-P (Fig. 1) represent a cross-section of the cardboard in question and x the angle it makes with the horizontal or, in the case of the soaring of the bird, the wing pitch, a-g the resistance of the air or its upward push and a-b the force of gravity. Now if there were no pitch to the cardboard or wings, i. e., if W-P were horizontal the resistance of the air would act in a direction exactly opposite to the pull of gravity and the cardboard or bird would fall in a given time a distance that would be the resultant of these two forces, say to the point g′. But the pitch of the cardboard or the wing pitch of the bird (and this is exactly analogous of the trim of a sail) alters these simple conditions.

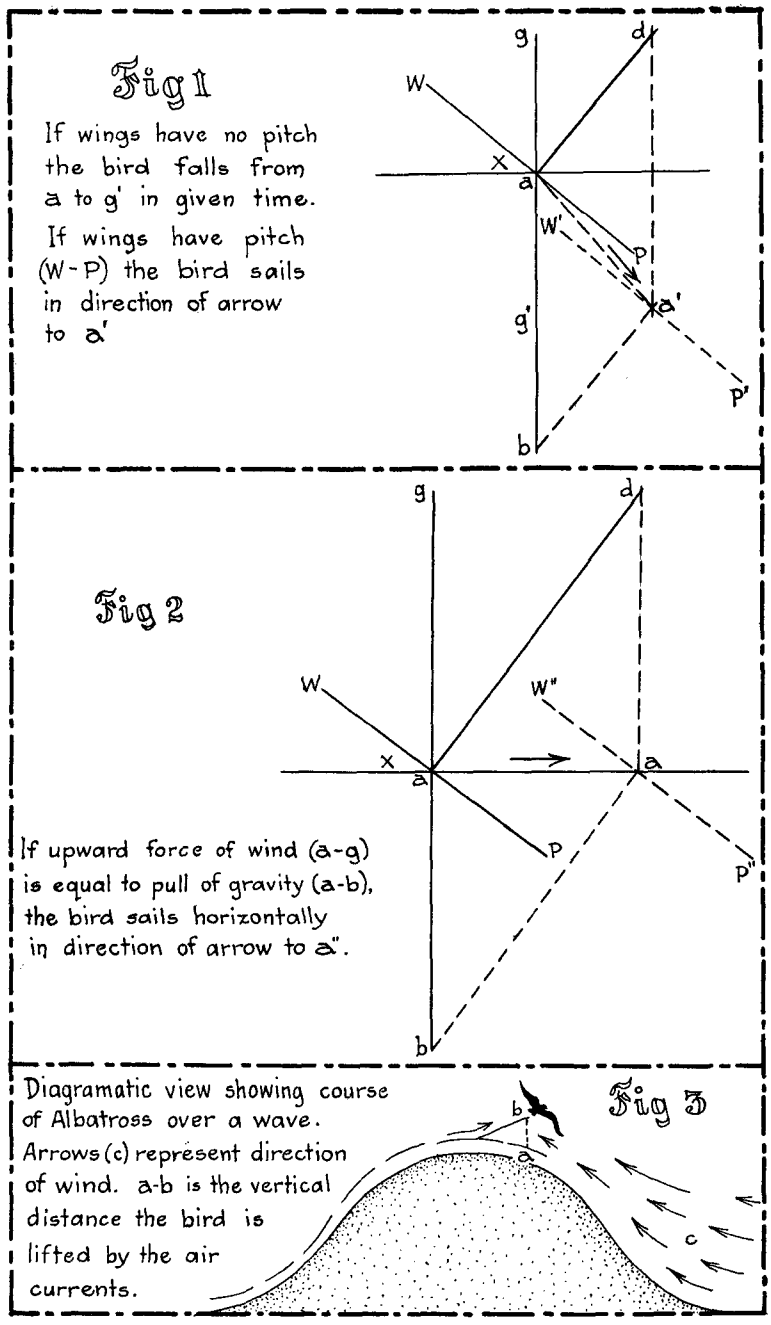

FIG. 6. Diagrams for the article on soaring flight.

The wing pitch resolves the resistance of the air into two components: one acting parallel to the wing (a-w) and hence having no effect and one acting at right angles to the surface (a-d). We now have the two forces acting on the bird; a-d due to air resistance, and a-b the gravity pull. The resultant a-a′ leaves at bird at a′.

In the third case, illustrated in Fig. 2, there is an *upward current* of air a-g acting against the bird equal to the force of gravity a-b (and in the case of soaring the wing pitch is exactly adjusted to this end). We now have the two components a-d and a-b with the resultant a-a″, i. e., the resultant is the only force effective to move the bird with the result that it moves in a horizontal direction to the position a″.

A moment's reflection will show that any increase or decrease in the force of the upward current can be met by changing the pitch of the wing so that the only effect, within ordinary limits, will be an increase or a decrease in the horizontal velocity of the bird.

As stated, this discussion refers to raptores only. However, I cannot refrain from mentioning some observations made on the Black-footed Albatross (*Diomedia nigripes*), or the goony, as he is known to the sailors. In September, 1920, I had an opportunity to keep several of these birds under observation off and on for several days. These long, narrow-winged fellows are past masters in the art of soaring. They usually keep within less than a foot of the water and there is seldom a movement except to veer sideways or up or down to avoid a passing wave or swell. They have no difficulty whatever in following a steamer by resorting to soaring only. So close do they hug the water that they occasionally cut its surface with the tips of their pinions. However, it was noticeable that *they rose a considerable distance in the air as the crest of a wave passed under them*, i. e., the wind, moving faster than the wave, *moved upward* as it passed up to and over the crest; and as the bird appeared over the crest it likewise was carried upward a few inches. This allowed him enough elevation to cupply velocity sufficient, while going down into the trough to carry him to the crest of the succeeding wave. The slight acceleration to his rising course a-b (Fig. 3) was very often noticeable. In other words the goony, on a very small scale, was doing exactly what the nine buzzards were doing on a much larger scale, with the difference that the crest was continually changing. This latter, however, introduces no new factors. I regret to add that during the entire time the albatrosses were under observation there was a high wind and a heavy sea; so there was no opportunity to secure any data on their flying when there was no possible assistance from this source.

Gulls following a boat soar in certain difinite areas with respect to the boat. It seems probable that some of the air eddies, that are caused by the boat's motion through the air and the accompanying wind together with the heated air that escapes from the engine room and funnels and streams *backward* and *upward*, may result in small areas where there are upward currents that are sufficiently strong and persistent to support birds for a longer or shorter distance.

UNIVERSITY OF WASHINGTON,
SEATTLE, WASHINGTON.

QUARTERING FLIGHT IN MIGRATION

BY E. C. HOFFMAN

By quartering flight is meant flight not directly against the wind, but rather at a substantial angle with the wind, perhaps fifteen to forty degrees. That such flight exists in nature is shown by the observations of Lynds Jones (1) on Hummingbirds flying from Pelee Island to Middle Bass Island in Lake Erie. It is also shown by William Beebes' notes on the Albatross (2). A. H. Clark (3) mentions the direction of the migration of the Golden Plover as being not in a direct line to the destination but across prevailing southwesterly winds along the northern part of their journey. However this last observation may be due to the fact that many birds tend to begin their migration during a period of high barometer (4). The direction of the winds in such an area of high air pressure being clockwise the migration routes in the area covered by the average northeasterly moving "high" would tend toward the eastward in the fall and toward the westward in the spring (5), (6). One of the most complete accounts of the flight of flying fishes is that by Holland (7) who states that the flight is at an angle with the wind.

Somewhat analogous is the tacking of a sailboat advancing against the wind by using the force of the same wind acting against the resistance of the boat to the water. See Headley (10), page 8. Perhaps in the case of the bird the resistance is furnished by pulsating air currents. Pulsating air currents are discussed by Wolfgang Klemperer (8), who in a letter to the writer dated December 20, 1929, mentions the Knoller-Betz theory of pulsating air currents. (9), (11), (12). Variations in wind velocity are also discussed by Otto Lilienthal (13); by Huffaker (14); by Hankin (15) who mentions "a form of air motion that blows a feather to leeward at one speed and blows the