CONVECTION AND SOARING OVER THE OPEN SEA[1]

By

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The transfer of momentum between the winds and the sea surface is a fundamental problem of oceanography. In the theoretical treatment of drift currents at sea and of the movements in the turbulent layer of air just above, no consideration seems to have been given to the possibility of a varying pattern of flow under unstable conditions. Recently Langmuir (1938) made measurements of "helical vortices set up by wind" in the surface waters of a lake. Lines of Sargassum weed, which are commonly seen on the central North Atlantic, were mentioned as an indication that similar vortices occur in the ocean. The observations of soaring flight presented below suggest that in unstable air at sea there are definite patterns which vary with the velocity and the stability of the wind.

There is some evidence that the force exerted by the wind on the sea surface cannot be expressed by a single continuous function of wind velocity and other factors, so that the critical values of these factors are also of interest to oceanographers. The soaring gulls seem to provide some clues as to the critical wind speeds at which there are marked changes in the form of convective motion, and thus in the transfer of momentum between the two mediums.

In a recent article on herring gull soaring (Woodcock, 1940), it was pointed out that the flight tactics of the birds vary with the wind and with the relative air and water temperatures. It was also suggested that the variations in flight routine of sea birds might be used to study some of the characteristic air motions over the water. In the present paper further data concerning gull soaring are presented.

The observations used here were made while on board the research vessel "Atlantis." They are confined to a sea area 30 to 600 miles off the east coast of the United States, between the latitudes 16° N. and 45° N. When cumulus clouds were forming, the layer of air in which the soaring was done extended upward from approximately 45 meters above the sea surface ("Atlantis" mainmast height) to the cloud base. Soaring altitudes greater than 620 meters have been measured with a range finder.

All of the air and water temperatures were measured with one

[1] Contribution No. 260 of the Woods Hole Oceanographic Institution.

thermometer; an ordinary laboratory thermometer graduated in whole degrees centigrade. Special care was exercised in making the air temperature measurements, in order to be sure that the thermometer was held to windward of the ship and adequately sheltered from the direct rays of the sun. The heights above the water of the air temperature measurements ranged from 3 to 7 meters. A dip bucket was used to obtain water for surface temperature measurements. Wind

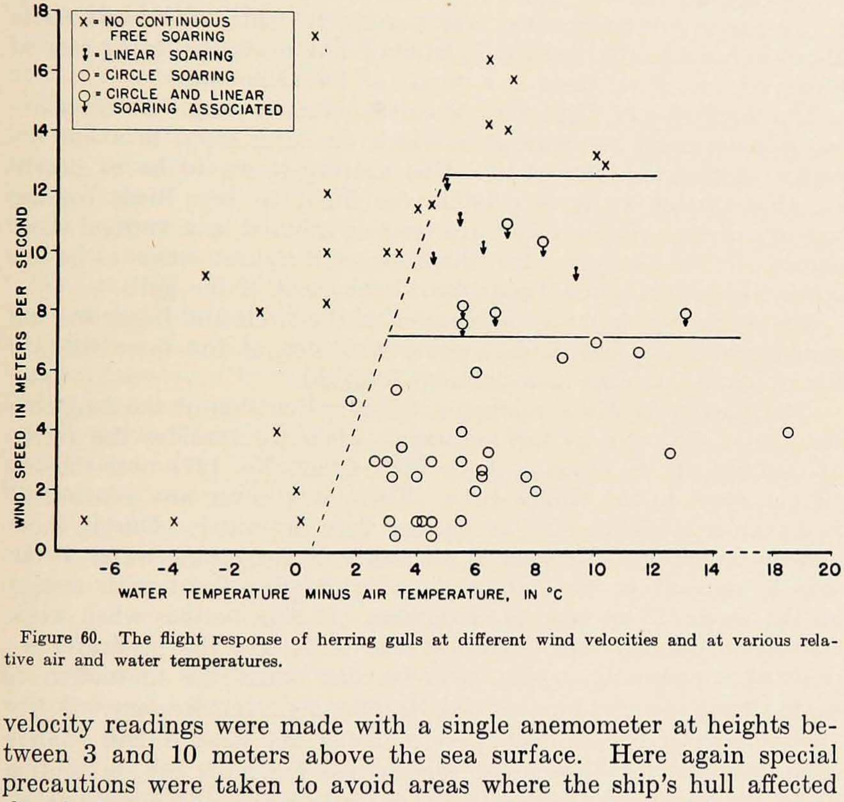

Figure 60. The flight response of herring gulls at different wind velocities and at various relative air and water temperatures.

velocity readings were made with a single anemometer at heights between 3 and 10 meters above the sea surface. Here again special precautions were taken to avoid areas where the ship's hull affected the air flow. (Correction for annemometer error has not been made, so the wind velocities are not absolute values.)

On Figure 60 the observations are plotted, with wind speed as ordinate and the temperature difference between the air and water as abscissa. Each observation represents a period of from 2 to 8 hours, with an average of about 6 hours. This does not mean that the birds were watched continuously for 6 hours, but that at any time during that period birds might have been seen performing the flight routine which the symbol represents. The symbols on the graph differentiate three types of flight response.

One type is the absence of continuous, free soaring. *Continuous* soaring is here defined as soaring which extends over a sufficient length of time to show that the bird is not merely soaring by losing altitude. The term *free* indicates soaring which occurs independently of surface obstructions.

The second type of flight response is here called circle soaring. *Circle-soaring* is continuous, free soaring in which the birds circle about in horizontally restricted, chimney-like up-drafts, being carried along downwind (if there is a wind) at the same time.

The third type of flight may be called linear soaring. *Linear soaring* is continuous free soaring in which the birds move in a line directly against the wind flow. This soaring seems to be as nearly two-dimensional as it is possible for flight to be. Birds soaring linearly in the same up-draft are seen distributed in a vertical sheet parallel to the air flow. The thickness of the sheet seems to be not much wider than a few times the wing spread of the gulls.

The marks which are a combination of the circle and linear soaring symbols indicate that circle soaring was seen at the same time as linear soaring, though in a different location.

The scarcity of observations on the negative side of the temperature scale (Fig. 60) is not surprising when we consider the rarity of stability (U. S. Dept. of Agri. 1938, Chart No. 127) over the sea off our coast in the winter time. There was never any continuous free soaring when the air was warmer than the water. During these periods the birds spend most of their time sitting on the water, if the ship is stopped, or they alternate wing-flapping flight with resting on the water, if the ship is in motion. During periods when weak convection obtains, one often sees the birds test the up-drafts repeatedly, apparently trying to determine when the up-motion is again strong enough to make wing-flapping flight unnecessary. A few observations of frigate bird soaring among the West Indian Islands seem to show that these most efficient soaring birds use, in routine flight, convection up-drafts which apparently occur with much smaller temperature differences between the air and the water.

It will be noticed that 13 meters per second wind-speed marks the upper limit for herring gull soaring, and also that there is no linear soaring below 7 meters per second. There seems to be some very marked change in the form which the convective motion usually assumes at these two points.

Experimental work by Phillips and Walker (1932) with unstable fluids has demonstrated that convection patterns are formed. These patterns vary; polygons being formed in horizontally motionless (without shear) fluids, with longitudinal and finally "strip-like cells" appearing as shear was introduced by horizontal flow. In unstable oil a further increase in shear caused the whole convection pattern to break down. In liquids it was found that the up-motion in the cells occurred in the centers, and the down-motion at the edges. In unstable air this was reversed, the up-motion being at the edges of the cells. In the strip-like cells formed in air, the up-moving current at the cell boundaries occurred in a sheet-like band extending up and down the direction of flow.

The change in the soaring tactics of the gulls at about 7 meters per second wind-speed, the sheet-like character of the up-drafts occurring between 7 and 13 meters per second wind-speed, and the total break-down of soaring conditions at about 13 meters per second wind speed, suggests that there is a similarity between the convection movements in the lower air and the experimental findings in unstable fluids.

Walker (1931, p. 413), in another paper in which he discusses Mal's work on forms of stratified clouds, says, "Mal's work has, I consider, transformed the interpretation of broken-up cloud layers as due to vertical instability from a plausible suggestion to an established fact; he has produced rectangular patterns and has shown that the types of cloud produced under different rates of shear resemble those formed in the laboratory." Perhaps convection patterns are also produced in the lower air, as the gulls seem to indicate.

Anticipating objections that these birds may be using some other known or unknown means of soaring, it should be brought out that there are three generally accepted (Horton-Smith, 1938, p. 98) requisites for soaring flight. If a bird is soaring, one of three things is happening: first, the air in which he soars may be rising; second, the bird may be descending; and third, the bird may be utilizing differences of horizontal velocity in the air. Here we want to show that we are dealing with the first condition.

In all of the observations here used the soaring gulls ascended many hundreds of meters into the air and stayed up for long periods of time. This quickly eliminates the second condition.

Concerning the third condition, i.e., horizontal differences of velocity in the air, Lord Rayleigh (1901, pp. 464 and 465) has said that while using "dynamical soaring" in strata of different relative velocities a bird must, upon entering one stratum, turn around until his direction is so reversed as to be with the wind of that stratum and contrary to the wind of the other stratum. But, in my observations of circle soaring the birds turn both clockwise and counterclockwise in the same area at the same time. Soaring on differences in horizontal velocity depends upon the increase of wind with height (Idrac, 1925), and it is doubtful if this flight is possible far above the surface of the sea (Rayleigh, 1901, p. 465). But circle soaring depends upon temperature differences, and occurs hundreds of meters above the sea. Thus we see that there are several reasons why circle soaring cannot be dynamical soaring.

In linear soaring the birds do not circle, but move in an apparently straight line, and to high altitudes. This completes the elimination of numbers two and three of the required conditions for soaring flight, and leaves us with the first, i.e., up-moving air.

On January 5, 1939, at the approximate location of latitude 40° north and longitude 71° west, the "Atlantis" was in a favorable position for a measurement of an interesting down-wind tilt of an up-draft at a time when thirty or forty gulls had entered it successively. The birds were so well distributed that a rough measurement of an angle of tilt could be made with the ship's wire-angle indicator. An angle of 30° from the vertical was found. At this time the wind velocity was 6 meters per second, the water temperature 10° C., and the air temperature 3.9° C. The tops of the rising air columns appeared to be at cloud level, for occasionally birds were seen to pass through or behind wisps of cloud. During these rare occasions when many birds enter an up-draft consecutively, a sufficient portion of its extent is demarked to show that the air column has continuity, and is not just a rising bubble of unstable air. In light winds these rising columns of air closely approach the vertical. As the wind increases, they become tilted in the direction in which the air is moving.

Collecting data by noting flight variations has been a long slow process, involving hours of watching the birds go through their flight cycles and awaiting the chance coincidences of weather and nearby gulls to fill in gaps on the graph. However, if an observer could control the movements of his ship so as to remain in a region of violent meteorological change, he should be able to collect further data concerning the convection flow very quickly. Murphy (1936, see pp. 38–108) has shown the correlation between the distribution of sea birds and the great current systems of the sea and air. Soaring sea birds are also useful indicators of detailed small-scale air movements.

The occurrence of instability in the surface air over the oceans is wide-spread. In view of the possible importance of convection cells in affecting air and water movements, oceanographers should find it useful to make a more thorough study of the convection patterns delineated by the gulls and other sea birds.

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