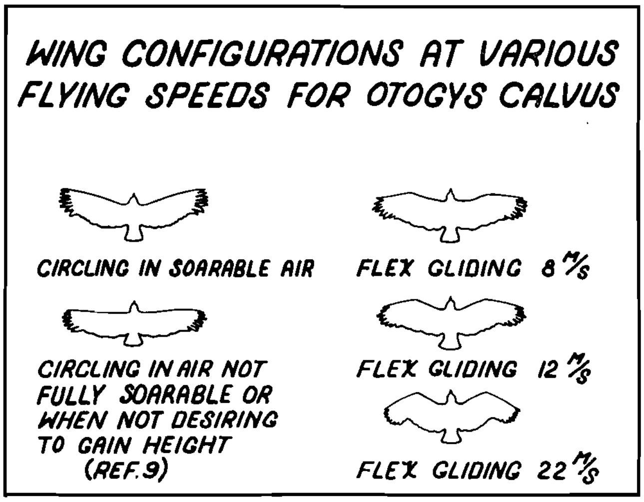

Figure 11.

bution necessary for trimming the sailplane at high angles of attack.

The question is then, "How does the bird accomplish this trimming without suffering the resultant induced drag rise?" Figure 11, taken from Hankin (ref. 9) shows the plan form of a buzzard (*Otogyps Calvus*) in various flight modes. At low speeds, the wings are swept forward. In other words, the center of pressure of the wing is moved forward of the center of gravity of the bird. As a result, an upward pitching moment is developed which counterbalances the nose down pitching moment of the highly cambered wing.

Whether the trimming by means of forward and backward sweep results in a stable configuration in pitch cannot be determined without a knowledge of the camber and angle of attack distribution of the bird's wing. However, the bird is capable of correcting for instability by means of intuitive sensing and associated reflexes.

The process of trimming to different speeds is clearly seen from figure 11. At very high speeds, the tips are swept back by bending the elbow of the wing. This tends to move the center of pressure of the wing farther back thus applying a nose down pitching moment and trimming for higher speeds.

The foregoing explanation of the control of a bird in pitch is admittedly sketchy. It would, however, be entirely possible to carry out experiments on the control and stability of a bird which had been trained to fly in a tunnel capable of being inclined with the horizon so as to force the bird to fly at different glide ratios and speeds. By adding weight to the bird ahead of, or behind his center of gravity, it would be possible to introduce pitching moments for which the bird would have to compensate with sweep of the wings.

So far, we have discussed only the aerodynamics of the bird in gliding flight and the bird's stability. Now, we will consider the process of gaining energy from the atmosphere, namely, soaring. Static soaring is accomplished by flying in an upward moving air mass having a higher vertical velocity than the bird's minimum sinking speed. By staying within the confines of such upcurrents, the bird will gain altitude.

One common source of upcurrents is that due to orographic lifting as the wind passes over a ridge. Birds are capable of soaring on declevities of very small dimensions. However, they also soar on mountain sides, the best example being the soaring of hawks on Hawk Mountain in Pennsylvania.

With a sailplane fitted with a sensitive instrument measuring the rate of climb, a pilot is able to duplicate the bird's feat of soaring on a ridge. In fact, many times a sailplane pilot merely needs to follow the bird in order to find the best lift.

Just how the bird measures the vertical velocity, and just how he determines which way to turn in order to stay in the upcurrent are questions which we cannot presently answer.

Another source of energy for soaring is that provided by thermal upcurrents. These exist both in hilly and in flat country. A very thorough exposition of the nature of birds soaring on thermal upcurrents is given by Huffaker (ref. 10). Not only did Huffaker in 1897 clearly describe the bird's thermal soaring, but he also indicated that there is good reason to believe that birds have some means for detecting thermal upcurrents at a distance, for they often head directly for a given area and began circling. They inevitably gain altitude.

Some years ago, the author speculated that the bird must measure in some way the temperature gradient in the horizontal plane and from this gradient is able to determine the direction toward the warm upcurrent core. An attempt to do this in a sailplane merely proved that we know too little about the nature of thermal upcurrents to be able to devise instruments for prospecting for the thermal upcurrents (ref. 11).

Another form of upcurrent, still a thermal upcurrent, but over water instead of land, was beautifully studied by Woodcock (ref. 12), using herring gulls as his indicators of the nature of the upcurrent. In figure 12, is shown a plot taken from Woodcock's paper which delineates the type of thermal upcurrent, a columnar or cylindrical vortex with axis horizontal. This research is a clear case of careful observation and analysis which should be applied to more of the problems of bird flight which have been mentioned previously.

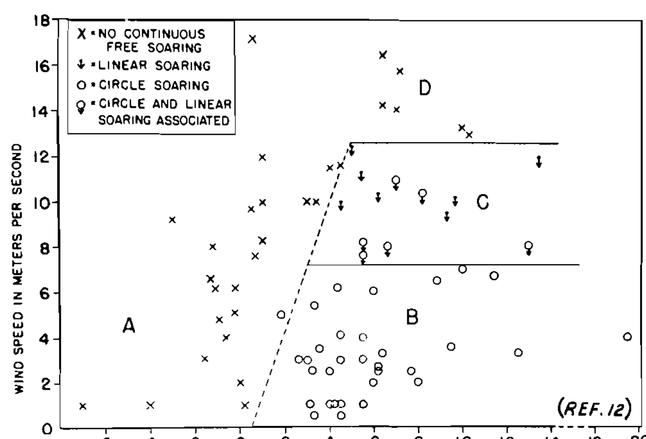

Fig. 12. Modes of soaring of herring gulls based on temperature increment and wind speed.