BIOPHYSICS OF BIRD FLIGHT

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Introduction

There is no doubt that modern mechanical flight owes its inspiration to the observations of birds in flight by early philosophers and scientists as well as by interested laymen. The earliest living flying machine is dated about 150 million years ago. This was the pterodactyl of geologic times. In contrast, man-made flying machines are only 57 years old. You can see from this contrast of eras that we may look to new knowledge of flight from a study of this age-old concept of bird flight.

In Greek mythology, the story of Daedalus and Icarus is well known. Daedalus designed and built, supposedly, two flying machines, covered with feathers, using a structure of wax to support them. This was really a mythical imitation of bird flight. There was no application of real knowledge of the mechanism of bird flight, merely an imitation, in form, but not in function. But, of course, not having this knowledge, we, even today, cannot duplicate bird flight in the sense of a straight imitation in a scale such that a man could fly as a bird does on his own muscular power.

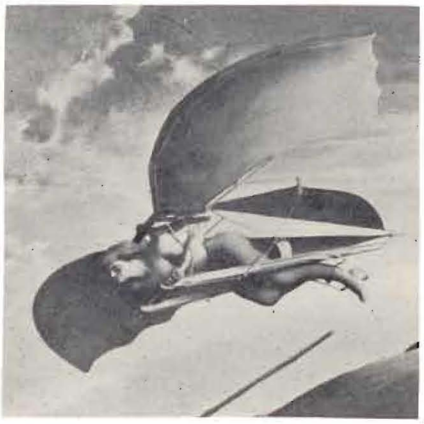
The first known flying machine constructed following bird flight concepts was that work so well known of da Vinci's. About 1505, da Vinci test flew this machine, using a test pilot, as is common practice today. The results are recorded in da Vinci's notebooks by the fact that after this test flight, there was no more mention of flying. There is rumor that the test pilot broke his leg. The test pilot, in this case, was one of da Vinci's household servants. (Figure 1).

It was Lilienthal (ref. 1) who also imitated bird flight, even to the point of using such small stabilizing tail surfaces that his machine was only marginally stable, but we must remember that it was also Lilienthal, who by this bird imitation, proved Newton, Kirchhoff, and Helmoholtz, to be wrong in their concept that lift is generated by a downward deflection of the air, simply as a reflection phenomena, disregarding entirely the suction on the upper surface. For his failure to understand that birds possess automatic stability due to instinctive reflexes, in addition to that inherent in their geometry, Lilienthal paid with his life.

The realm of bird flight can be clearly divided into two aspects: That on motionless wings, soaring, and that on flapping wings, which is really the working part of flight. This aspect is used in take-off and in climbing to altitude, even by soaring birds. It is used as a principal mode of flight by the non-soaring birds. The soaring phase of flight or the flight on motionless wings was divided by Lord Rayleigh in 1883 (ref. 2) into three separate categories:

1. Flight in which the path is not horizontal, in other words, gliding.
2. Flight in an air mass which has a vertical component, that is, static soaring.
3. Flight in an air mass which is not uniform in velocity. The latter is in the strict sense, dynamic soaring. Evidently, a good undertaking of the first phase, the motionless wing phase, would contribute much to an understanding of the biophysics of bird flight. The second aspect, much more complicated, flapping flight, has been theoretically studied, but very little experimental work has been done to support the various theories. It is the purpose of this paper to take up in detail the aerodynamics of a bird's wing, in particular, that of motionless wing flight.

Fig. 1. Leonardo daVinci's flying machine, painted by Robert Riggs, courtesy of IBM. Note that daVinci, knowing human anatomy as he did, at least tried to harness the powerful thigh muscles, whereas many other experimenters used only arm muscles.



When we consider the various tools available to us to study flight in general, we are apt to resort to the one which has been so useful in helping man to fly, namely, the windtunnel. It was a windtunnel which helped the Wright Brothers to arrive at proper airfoil sections, and the windtunnel is still today used for subsonic, transonic, supersonic and hypersonic flow studies. It will be interesting, therefore, to look at some results from windtunnel work on the measurements of bird aerodynamics and compare this to some data obtained in flight. From this, we can determine the validity of the windtunnel in bird flight work. In figure 2, we show a velocity polar of a laughing gull computed from data measured in the windtunnel, and that measured in flight. The velocity polar is clearly seen to consist merely of a plot of sinking speed, which is really a measure of the energy loss in flight, versus the forward velocity of flight. This is truly not a polar, but the terminology is that which is used in aviation. It should be mentioned that the laughing gull measured in the windtunnel (ref. 3) was not actually a feathered bird, but rather a clay model sculptured by an artist. The tunnel, however, possessed a rather low turbulence, an environment quite representative of that which one might find in the atmosphere. On comparing the sinking speed obtained from the windtunnel measurements, one sees that the sinking speed of the clay model is a little more than double that of the actual bird measured in flight at the speed of 30 mph. The flight measurement consisted of a very simple comparison of the flight of the gull relative to that of a sailplane while soaring on a ridge on Long Island. The pilot in the sailplane was able to adjust his speed to exactly follow the bird, and at this particular forward speed, the bird and the sailplane flew back and forth on a ridge for about two hours, neither outclimbing the other, nor losing altitude with respect to the other. This is proof that their sinking speeds at this forward speed were identical. It is just this concept of comparison flying, which will be discussed in some measurements of the black buzzard which was devel-