Performance measurements of a soaring bird

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THE history of aviation is intimately connected with the bird flight studies of early researchers. The mythical flights of Icarus and Daedaleus on wings fashioned of wax and feathers represent our earliest recorded thinking about human flight. The flight of Daedaleus from Crete to Sicily even today represents a record-breaking motorless flight had it been an actuality. The influence of da Vinci's studies of bird flight is apparent in his design. It is a prone-piloted ornithopter with scallopped monoplane wing surfaces. As the knowledge of flight accumulated there was an increased effort on the part of those striving to fly to understand natural flight. In the nineteenth century men such as Lilienthal, Marey, Langley and Huffaker made important contributions to the understanding of the elements of natural flight. At the beginning of the present century two students of natural flight, Hankin and Idrac, were able to continue their studies of flight despite the disrupting influence of the aeroplane.

Early efforts in bird flight research were confined to a close observation of the birds. A more refined approach was that of Marey who developed a time lapse camera which could be called the first movie camera. With this camera he was able to make models of the bird in a complete cycle of a wing flap. Langley also used a photographic technique with a stereoscopic pair of cameras. His studies as well as those of his associate Huffaker were confined to the soaring flight.

There is no doubt that an understanding of soaring flight should precede attempts at understanding the more complicated flapping flight. Soaring enthusiasts might have profited considerably in their development of the art and science of soaring flight had they maintained a closer liaison with the bird flight students. As an example of a possible contribution of this sort one merely needs to read Huffaker's [1] paper written in 1897 in which he describes fully and accurately the method of thermal soaring as used by the turkey buzzards (Cathartes aura) around Washington, D. C. It was not until 1930 that thermal soaring was first practiced by man. Another example is that of dynamic soaring, the basis for which was propounded by Lord Rayleigh when he stated that soaring flight required either a wind which is not horizontal or which is not uniform in velocity. The utilization of the latter is, of course, dynamic soaring which has not yet been accomplished in a controlled experiment by man. It is hoped in this paper to show how bird flight research on soaring birds can lead to an understanding of dynamic soaring.

The present study began in 1945 with an experiment in which a bird was trained by Mr. George F. Carter to carry a miniature barograph and recording anemometer. It was hoped to measure the performance of

1) *Huffaker*, E. C., On Soaring Flight, Smithsonian Report 1897.

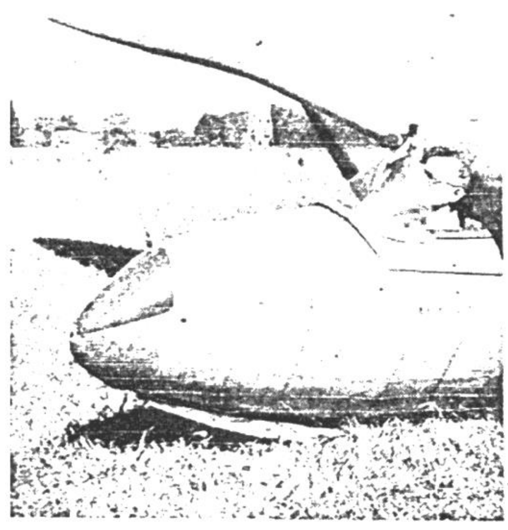
the bird as it glided between upcurrents. The method would have been subjected to errors due to the lack of knowledge on the strength of the downdrafts between the upcurrents. Unfortunately no data was obtained by this method for the bird died prematurely of an intestinal stoppage. Mr. Carter later offered to train a buzzard to fly in a wind tunnel. By this technique the errors due to downdrafts would not be included in the performance measurements. It would also permit a detailed study of the wing tip slots such as land soaring birds possess.

In 1946 the author accidentally flew with some sea gulls on a ridge. It occurred to him that the performance of the birds could be obtained by a comparison with the sailplane's performance. The results shown in this paper were the result of a continuation of the first flight with the sea gulls.

For bird flight performance measurements one requires a very slow speed sailplane of good or exceptional maneuverability. Unfortunately the trend in modern sailplane design is headed toward fast sailplanes. In Fig. 1 is shown a photograph of the sailplane used in the current studies. It is an English built Kirby Kite. Its performance curve or calibration curve as it is used in this work is shown in Fig. 2. Examination of the photograph Fig. 1 shows the radio antenna mounted in the nose of the fuselage. Installed on the wind shield is a Leica camera with a telephoto lens and a special optical viewfinder which permits determining the range of the bird.

Conditions ideal for collecting bird data are merely those ideal for thermal soaring. The crew for such measurements consists of three people, a pilot and two ground assistants. They go to the airport when thermal conditions are good, and tow the sailplane to 300 meters with an automobile. The pilot begins soaring while the ground observers scan the sky for birds. As soon as one is spotted soaring within reach of the sailplane the pilot is directed by radio to the bird. When the sailplanist sees the bird he begins reporting the airspeed and relative altitude of the bird with respect to the sailplane. The pilot attempts to adjust his rate of turn and turn radius to agree with that of the bird. Also during this soaring phase the pilot reports the shape of the bird's wing. The buzzards normally have their wing tip slots open when soaring (gaining altitude). After the bird and sailplane have gained sufficient altitude for the bird's immediate purpose the bird will strike out on a cross-country jaunt taking a fairly definite heading. It closes its tipslots and cruises at speeds up to 30 meters per second. During this cross-country flight the sailplane pilot may follow as closely as five meters behind and below the bird. He is thus able to see the bird's control motions, and to anticipate maneuvers and to photograph the wing configuration at close range. During this phase of flight the bird is usually not aware of the sailplane. However if the pilot speaks too loudly into his radio microphone or if the controls on the sailplane make a noise the bird immediately notices the sailplane and attempts an evasive maneuver. During this tracking the pilot sends to the ground observers the airspeed, relative altitude of the bird above or below the horizon and the wing configuration at closely spaced time intervals. This data is recorded on the ground as a

Fig. 1



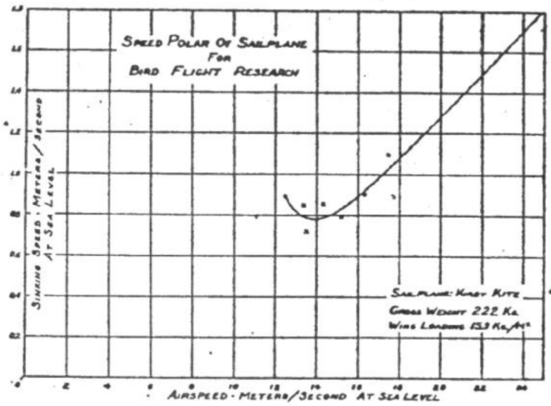


Fig. 2

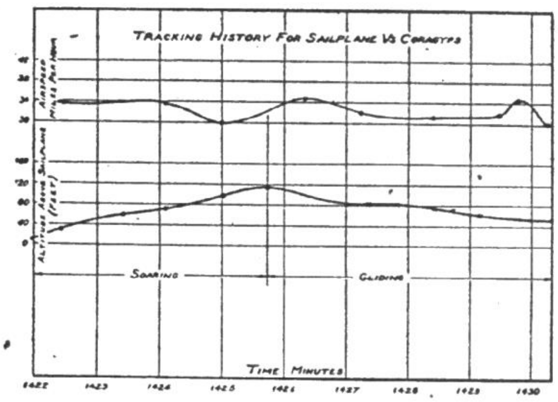


Fig. 3

function of time and is later recorded as a tracking curve, Fig. 3. From portions of this curve where the bird is in constant speed flight for at least one minute the slope of the relative altitude curve is taken as the difference in sinking speed between the bird and sailplane.

The sailplane's sinking speed is known from the calibration curve, Fig. 2, and thus the bird's sinking speed can be obtained since the difference is known. A series of such trackings will yield a speed polar for the bird in gliding flight. Similarly the data taken during the soaring phase may be plotted and the speed polar in soaring flight so obtained. It should be mentioned that in the soaring phase, circling flight, no corrections have been made for the increased sinking speed of the sailplane or bird due to centrifugal loading. The angles of bank used by both the sailplane and bird were usually less than 30°. Another assumption made in these measurements is that the bird and sailplane are influenced equally by vertical air motions in the atmosphere. Whether this is a valid assumption will be resolved by an independent experiment in which a captured bird will be taken up in a two-place sailplane at dawn when the air is stable. The bird will be released from the two-place sailplane while in slow flight so as not to disturb the bird. The measuring sailplane towed up at the same time will be ready to track the released bird and to make measurements in the still air. Whether the bird will cooperate in this experiment or simply dive to the lower warmer surface is yet to be determined.

On many occasions birds come to join the sailplane in a particularly good thermal. This makes it easy for

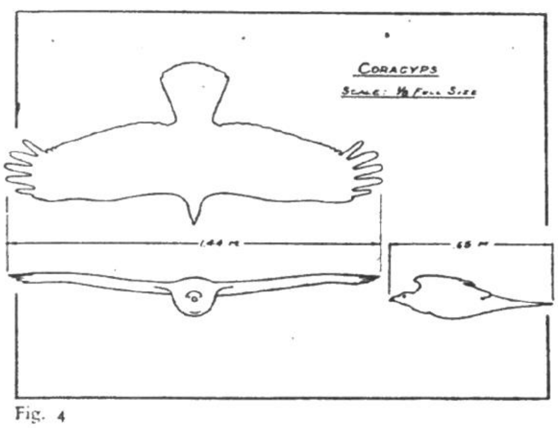


Fig. 4

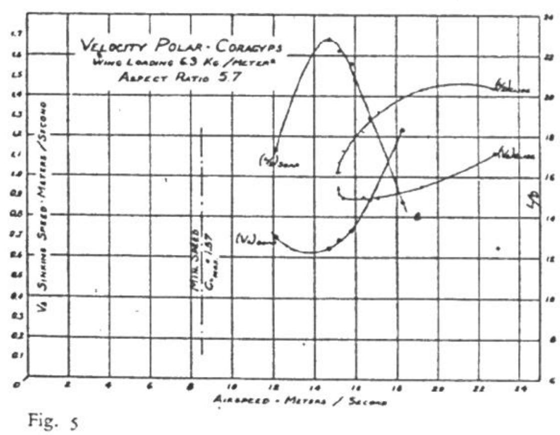


Fig. 5

the pilot to select a bird for measurement. It is evident from this behavior that the birds are not disturbed by the sailplane and that the results obtained approximate quite closely those in natural flight. The advantage of the silent flight of the sailplane is apparent in such research as this.

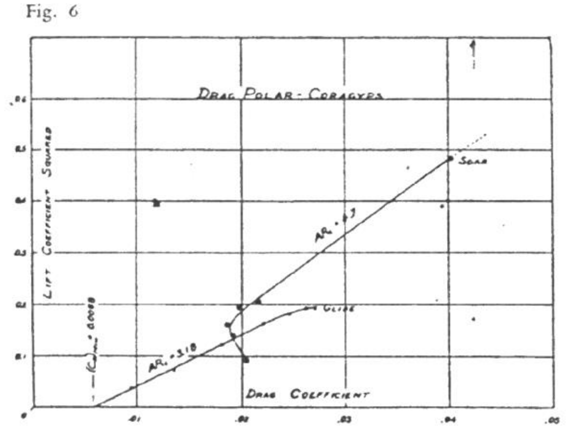
Following the usual sailplane practice there is shown in Fig. 4 the three-view or general arrangement of the aircraft under consideration in this paper. The bird is commonly called a black buzzard or scientifically Coragyps atratus. It is an excellent soarer though not as good as the turkey buzzard (Cathartes aura). However, the Coragyps happened to be quite plentiful in the autumn skies during the time the research was made. Fortunately the Coragyps is also 30% heavier in wing loading than the Cathartes. It is therefore easier to track with the sailplane used for this research. Since the sailplane had a wing loading nearly 2.5 times that of Coragyps, it had a distinct advantage in maneuverability over the sailplane. Because of this any evasive actions of the bird were completely successful.

In Fig. 5 are shown the measurements obtained by means of the sailplane tracking a number of different black buzzards. There may have been variations between one bird and the next but in these results the data are treated as a statistical average representation of the bird's aerodynamics. The wing loading and aspect ratio shown are also averages obtained by numerous ornithologists. The captured bird technique may be an improvement in this respect since the specimen (flight test article) can be weighed at take off and also measured for its geometry. Inspection of Fig. 5 shows that there are two distinct speed polars for the bird's two phases, soaring and gliding. The vertical velocity curve for the soaring phase appears quite similar to that of conventional sailplanes. However, the gliding phase curve has a much flatter polar. This is particularly evident if one views the gliding ratio curves. In sailplane terminology the bird would be said to possess a good speed range when gliding.

There are a number of other points which merit emphasis, the very low minimum sinking speed of the bird in soaring flight and the very low speed at which it can fly. If one computes the power required for the bird to sustain level flight at a speed of 13.8 meters per second one finds the phenomenally low value of 0.019 horsepower for a bird weighing 2.3 kilograms. This value corresponds to a power loading of 122 kilograms per horsepower. The lowest soaring speed, 8.5 meters per second, was determined by timing the bird around a complete circle and measuring the diameter of the circle in terms of the known wing span of the bird. The lift coefficient at this speed is 1.57, a relatively large value considering the Reynold's number at which this lift occurs, namely 140,000.

If the same data shown in Fig. 5 are plotted in terms of the non-dimensional coefficients of lift and drag there results the socalled drag polar Fig. 6. In this polar the lift coefficient is plotted as the square so that the drag polar, normally a parabola, is linearized. The reason for the bird's closing its tip feathers for gliding flight is immediately apparent from this plot. It does this to reduce his drag. With slots open it could not attain a lower drag coefficient than 0.019 but with the slots closed it can reach a minimum of 0.0058 in drag coefficient. It is also clear that the closing of the tip slots reduces the effective aspect ratio. At high speeds (low lift coefficients) the bird already has a very low induced drag and strives rather to reduce its parasite drag. Actual measurements of the induced drag and consequently the effective aspect ratio can best be done at lift coefficients much higher than those measured here. There is still left to be investigated the region from $0.7 < C_L < 1.57$. On the drag polar Fig. 6 this represents a region three times more ex-

Fig. 6



tensive than that shown. For this purpose a specially designed low speed sailplane is required, one which can soar at 8.5 meters per second and having a wing loading of not over 7.0 kilograms per square meter. This low wing loading would also insure good maneuverability provided the controls were properly designed for low speed operation.

With such a research sailplane it will be possible to accurately investigate the flight of birds near their stalling lift coefficient. Some preliminary results obtained by extrapolation indicate that the Cathartes can utilize its wing tips as diffusors so as to attain an effective aspect ratio greater than this geometric. This means, in essence, that this bird may be controlling the flow beyond its wing tips or that it is extracting some energy from the wing tip vortex. The delineation of this effect awaits the very low speed measurements. The very fact that the Coragyps is able even at comparatively low lift coefficients to control its effective aspect ratio is evidence that there should be expected even larger effects at the high coefficients. The very low minimum drag coefficient 0.0058 becomes all the more interesting when one compares this with that obtained by some of the cleanest modern aircraft. The lowest measured drag coefficient which has been published is that of the Lippisch designed ME 163 which was 0.010. To explain the paradoxically low drag of the Coragyps the drag coefficient based on total wetted area was computed and found to be 0.0020. The Reynolds number of the highest measured speed of this bird is 440,000. At this Reynolds number the drag coefficient of a flat plate in laminar flow is 0.0021. Comparing this value with that of the Coragyps leads one to conclude that the bird must be able to control the flow over its body and wing so that it is laminar over its entire surface. How it does this can only be suspected. Victor Lougheed claimed that bird's feathers possess an asymmetrical porosity according to the direction of flow. He stated that a measurement shows the ratio of porosities to be 10 : 1. If this is true then we must suspect the birds of having priority on suction through a porous surface as a boundary layer control means.

This paper is intended to show how powerful a research tool the sailplane becomes when applied to bird flight studies. The results reported while precise as measurements to $\pm$ 5% may not be truly representative of the static aerodynamics of the bird. It may after all be extracting energy from the atmospheric turbulence. If it is found by measurements in still air that a good portion of the energy for the bird's flight comes from this source then it will have been established that dynamic soaring is really practiced by birds and that man must learn from them the mechanism.

From these measurements on the Coragyps it was shown that this bird is able to fly with an extremely small expenditure of energy. Its power loading at minimum power required was found to be 122 kilograms per horsepower. It has been found by biophysicists that 45 kilograms of animal muscle is able to deliver one horsepower for several hours. These two values represent the power required and the power available. If man could devise a flying machine utilizing the fine aerodynamic principles of a bird yet weighing together with the powerplant (man) not over 122 kilograms and if 45 kilograms of muscle could be brought to work, then the dream of da Vinci would become a reality. The energy balance is established by these measurements: when the mechanism is better understood then and only then will man fly.

It is the author's good fortune to have the encouraging support in this work of Dr Harold Flinsch, director of the Engineering Research Station. To the very skillful bird tracking by Richard H. Johnson the author attributes the precision of these measurements. The author owes a debt of gratitude to him and to Fred Obarr who might have been soaring had he not volunteered his help on the ground.