SOARING AND GLIDING FLIGHT OF THE BLACK VULTURE

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INTRODUCTION

In 1950 Raspet published an interesting paper giving the glide performance of the black vulture (*Coragyps atratus atratus*). The sinking speed of several birds of this species was measured by flying in formation with them in a light sailplane and estimating the relative rate of descent. Prior knowledge of the sinking speed of the sailplane then enabled the performance of the bird to be determined.

It was discovered that the bird had two distinct types of gliding flight, which were designated soaring and gliding. When soaring the bird circles in a rising current of air, usually a thermal, and remains aloft without flapping its wings; to do this a low sinking speed in still air is required. When gliding, on the other hand, the bird travels over ground possibly looking for food or possibly travelling from thermal to thermal. To do this a low rate of sink combined with a comparatively large airspeed is required, because it may be necessary to penetrate into the prevailing wind. It appears that the black vulture, in common with other land-soaring birds, satisfies these two requirements by altering the geometry of its wings. When soaring the primary tip feathers may be spread and the leading edge of the wing is bent forward slightly; when gliding the primaries are closed and bent backwards. Typical wing planforms are reproduced from Aymar (1935) in Fig. 1. Some good photographs of these birds can be seen in the works of Aymar (1935), Storer (1948) and Barlee (1953). When soaring with a wind crossing the thermal the birds appear to combine both types of flight; wings fully open on the downwind part of the circuit and slightly closed when completing the turn into wind. In this way the bird manages to remain within the thermal at zero or negative sinking speed.

The opening of the wing feathers clearly increases the span of the wing and thereby reduces the trailing vortex, or induced drag, but probably at the expense of increasing the profile drag slightly. The minimum sinking speed is proportional to $C_{D_0}^{\frac{1}{4}}/b^{\frac{3}{2}}$, where C_{D_0} is the profile drag coefficient and b is the wing span; thus it is apparent that an increase of b, even with a similar proportionate increase of C_{D_0}, is beneficial. For fast gliding, on the other hand, the vortex drag, which decreases with the square of the speed, becomes relatively less important than the profile drag, which increases with the square of the speed; then it is beneficial to reduce the area of the wing by reducing the wing span.

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The purpose of the present paper is to re-examine in more detail Raspet's measurements on the black vulture, to analyse the effect of opening the tip feathers and, in the light of this, to suggest the reason for the existence of slotted primary feathers on land-soaring birds.

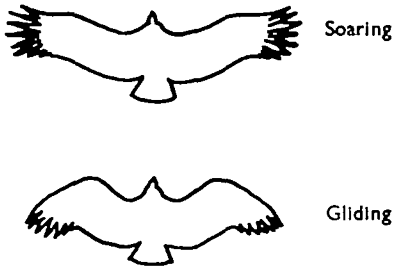

Fig. 1. Sketches of wings of black vulture.

RE-EXAMINATION OF RASPET'S MEASUREMENTS

Gliding flight. For this type of the flight the geometry of the wing planform is constant or nearly so. Thus, the rate of sink in still air, V_s, may be related to the equivalent air speed, V_e, by the usual performance equation

$$\frac{WV_s}{V_e\sqrt{\rho_0/\rho}} = C_{D_0}(\tfrac{1}{2}\rho_0 V_e^2)\,S + \frac{1}{\pi e b^2}\frac{W^2}{(\tfrac{1}{2}\rho_0 V_e^2)},$$

where W is the all-up weight,

ρ is the prevailing air density,

ρ_0 is the standard sea level density (1·23 kg./cu. m.),

S is the wing area,

b is the wing span,

e is the Oswald span efficiency factor.

Thus
$$V_s V_e = \frac{1}{2}\frac{\rho_0^{3/2}}{\rho^{1/2}}\frac{S}{W}C_{D_0}V_e^4 + \frac{2W}{\pi e b^2 \rho^{1/2}\rho_0^{1/2}}.$$

(Finding the minimum value of V_s from this expression and assuming S to be proportional to b, yields the formula for minimum rate of sink quoted in the introduction.)

Raspet's data for gliding flight are plotted as $V_s V_e$ against V_e^4 in Fig. 2 and the measurements are seen to lie accurately on a straight line. Assuming

$W = 2{\cdot}32$ kg.

$\rho = 1{\cdot}19$ kg./cu. m.—estimated to be prevailing at the time of flight.

$e = 90\%$—an estimated value for the gliding planform (Fig. 1),

the intercept of the line with the $V_s V_e$ axis yields $b = 1{\cdot}12$ m. which is about 20% less than the value in the soaring flight configuration ($b = 1{\cdot}44$ m.). Observation of the black vulture does indicate a change of wing span of this order (see Fig. 1).

Assuming that the wing area is also 20 % less than that of the soaring configuration, the slope of the line gives

$$C_{D_0} = 0{\cdot}0064,$$

and, with a ratio of wetted area to wing area of about 2·5, the drag coefficient based on wetted area is 0·0026. The range of Reynolds's number based on mean wing chord for the gliding flight is $2{\cdot}9 \times 10^5$–$4{\cdot}4 \times 10^5$ and the drag coefficient of a smooth flat plate moving parallel to its plane at these Reynolds numbers varies from 0·0025 to 0·0020 if the boundary layer flow is laminar, and from 0·0059 to 0·0053 if it is turbulent. Hence, as noted by Raspet, the bird achieves a drag only slightly in excess of the value for a flat plate with laminar flow.

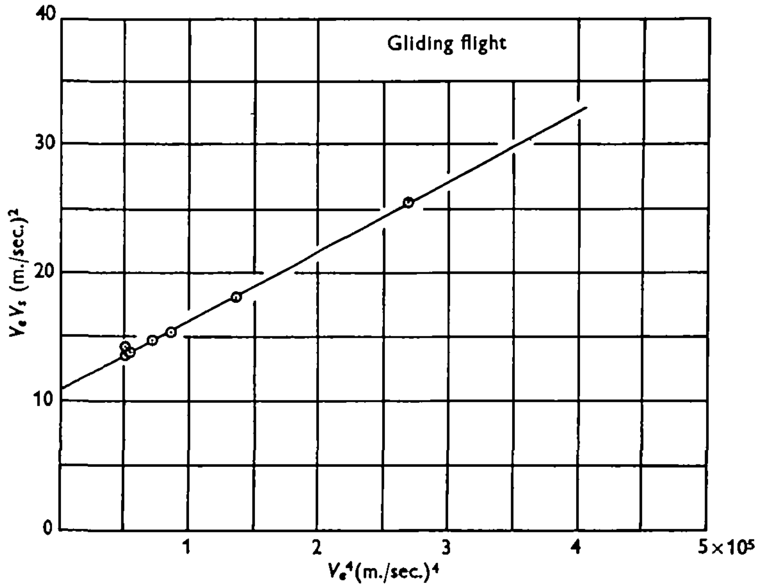

Fig. 2. Gliding flight of black vulture.

Soaring flight. The measurements for soaring flight are presented in the form $V_s V_e$ against V_e^4 in Fig. 3. This figure includes the gliding curve of Fig. 2 and also the curve obtained by assuming a 20 % increase of span and wing area, combined with a 20 % increase of drag coefficient. It is seen that the results at low air-speeds lie fairly well on the latter curve, that one point lies on the glide curve and that a second point is well above both curves. For this second point, the bird is travelling at low incidence with highly cambered wings, and thus the drag coefficient is increased due to separation of the airflow from the under surface. In addition the drag may also be increased by aerodynamic distortion of the primary feathers when in the soaring configuration. Thus, the drag coefficient may well be increased by a factor of something like 100 % and account for the increased rate of sink which was measured.

It is seen, therefore, that the results are consistent with plausible changes of wing geometry and drag coefficient with forward speed.

The results do not support the contention of Fisher (1946) and Raspet (1950) that, from the viewpoint of vortex drag, the effective aspect ratio of a wing with open tips is higher than the purely geometric value. This is investigated further in the

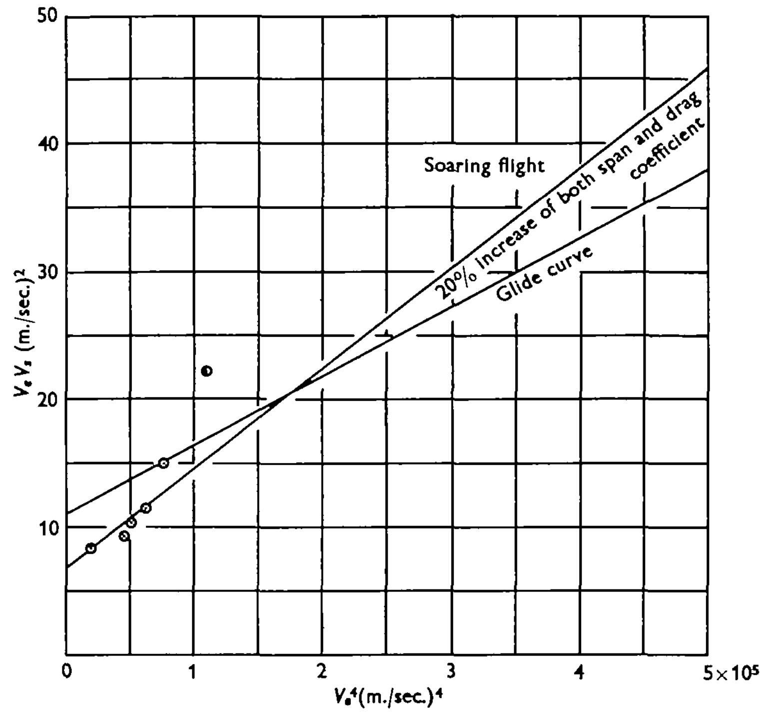

Fig. 3. Soaring flight of black vulture.

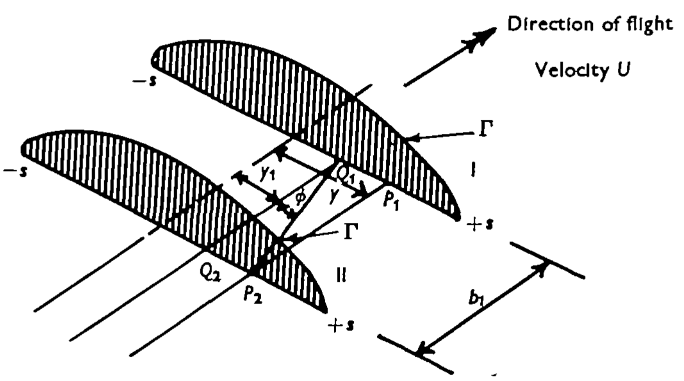

Fig. 4. Three-dimensional sketch of bound vortices in tandem.

appendix of the present paper where it is shown, within the framework of certain simplifying but, nevertheless, plausible assumptions, that the vortex drag of a series of equally loaded tandem wings is identical with that of the single wing obtained by closing the gaps. There appears to be no support therefore for the theory that the vortex drag is reduced by opening the primaries.

SUMMARY

1. The soaring and gliding performance of the black vulture has been analysed and the following conclusions are drawn.

2. The wing span of the bird is altered in flight so that it may perform two tasks efficiently. First, that it may soar in rising currents of air for which a low sinking speed and thus a large wing span are required. Secondly, that it may penetrate into wind without undue loss of height for which a reduced wing area is desirable. Adjustment of the wing geometry towards the optimum soaring configuration is achieved by bending forward and opening the primary tip feathers.

3. Since the airflow readily separates from the flat primary feathers at high angle of attack, these feathers, which are emarginated, are parted to form slots. The alula also presumably assists in delaying the flow separation over the primaries.

4. It is unlikely that the opening of the primaries reduces the vortex drag.

I am indebted to Dr August Raspet for giving me access to unpublished information and for commenting upon this paper.

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APPENDIX

The trailing vortex drag of tandem wings

Consider two wings I and II in tandem. Using conventional lifting line theory (see, for example, Glauert (1948)) the wings are each replaced by a bound, line, vortex.

In Fig. 4 the loading or, what is equivalent, the circulation is as shown. It is assumed to be the same on each wing.

In order to determine the drag of the tandem wings, the induced down-wash due to the bound vortices and the trailing vortices shed from them is examined.

On Wing I the induced downwash velocity at Q_1 due to the infinitesimal trailing vortex shed at P_1 is $\dfrac{-d\Gamma}{4\pi(y-y_1)}$.

The downwash at Q_1 due to the trailing vortex leaving the wing at P_2 on Wing II, is

$$\frac{-d\Gamma(1-\cos\phi)}{4\pi(y-y_1)}, \quad \text{where} \quad \phi = P_2\hat{Q}_1Q_2,$$

and due to the infinitesimal portion dy of bound vortex at P_2, is

$$\frac{-\Gamma dy\cos^3\phi}{4\pi b_1^2}$$

Thus, the total downwash at Q_1 is

$$w_1 = \int_{-s}^{+s} \frac{-d\Gamma}{4\pi(y-y_1)} - \int_{-s}^{+s} \frac{\Gamma \cos^3 \phi dy}{4\pi b_1^2} - \int_{-s}^{+s} \frac{(1-\cos\phi)\, d\Gamma}{4\pi(y-y_1)}.$$

Similarly, the total downwash at Q_2 is

$$w_2 = \int_{-s}^{+s} \frac{-d\Gamma}{4\pi(y-y_1)} + \int_{-s}^{+s} \frac{\Gamma \cos^3 \phi dy}{4\pi b_1^2} - \int_{-s}^{+s} \frac{(1+\cos\phi)\, d\Gamma}{4\pi(y-y_1)}.$$

Thus
$$w_1 + w_2 = -\int_{-s}^{+s} \frac{d\Gamma}{\pi(y-y_1)}.$$

The total trailing vortex drag of both wings

$$= \int_{-s}^{+s} \rho(w_1 + w_2)\, \Gamma dy,$$

where ρ is the air density

$$= \int_{-s}^{+s} \rho 2\Gamma \left[-\int_{-s}^{+s} \frac{2d\Gamma}{4\pi(y-y_1)} \right] dy_1.$$

This is identical with the vortex drag of a single wing with the same distribution of circulation and the same *total* lift. In other words splitting a wing to produce two tandem wings does not alter the vortex drag. Furthermore, the above result is clearly true for any number of equally spaced wings in tandem as long as the loading is distributed equally between them.