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¹Alex Matsyura, ²Kazimierz Jankowski, ¹Maryna Matsyura**BIRDS' FLIGHT ENERGY PREDICTIONS AND APPLICATION
TO RADAR-TRACKING STUDY**¹*Bogdan Chmelnitkiy Melitopol State Pedagogical University,
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In offered research, we propose to observe diurnal soaring birds to check, whether there the positions of birds in formations are such, that the wing tip interval and depth meet the predictions of aerodynamic theory for achievement of maximal conservation of energy or predictions of the hypothesis of communication. We also can estimate, whether adverse conditions of a wind influence the ability of birds to support formation. We can assume that windy conditions during flight might make precision flight more difficult by inducing both unpredictable bird and vortex positions. To this, we need to found change in wing-tip spacing variation with increasing wind speed, suggesting or rejecting that in high winds bird skeins maintained similar variation to that on calm days. The interrelation between variation of mean depth and wind speed should prove this hypothesis. Little is known about the importance of depth, but in high winds the vortex is likely to break up more rapidly and its location become unpredictable the further back a bird flies; therefore, a shift towards skeins with more regular depths at high wind speeds may compensate for the unpredictability of the vortex locations. Any significant relationship between the standard deviation of wing-tip spacing and wind speed suggests that wind has a major effect on optimal positioning.

Results of proposed study will be used also as the auxiliary tool in radar research of bird migration, namely in research of flight features of soaring birds. It is extremely important to determine all pertinent characteristics of flock for model species, namely flocking birds.

Key words: birds, flock, radar, flight

Distinction of pressure between top and the basis of bird wing that provides lift cannot be maintained outside of the wing tips, since then there is no surface to separate two areas of pressure. Hence, high-pressure air under a wing flows around the tip and inside across a dorsal surface of a wing. This last stream forms a sheet of turbulent air from leading edge into the wake of a bird (Higdon and Corrsin, 1978). This flat vortex forms the sheet that curls into two concentrated tubular vortices, derived from each wing tip (Higdon and Corrsin, 1978; Rayner, 1979; Hummel, 1983).

With reduction of wing tip interval, the induced power required for formation flight also decreases, because the following bird flies in progressive stronger upwash from the canopy vortices of its neighbor. Outside of a critical negative wing tip interval, however, the following bird starts to fly in central downwash and tests increase in expenses, or negative economy. Hence, there is an optimum wing tip



interval (WTS_{opt}) that maximizes the reduction in the needs of induced power. This theory is received for fixed wings, but can be applied to flapping flight.

Horizontal distance between the tubular centers of vortex (dv) behind the fixed wing:

$$dv = (p/4)b \quad (1)$$

Where b is wingspan (Higdon and Corrsin, 1978; Hummel, 1983; Hainsworth, 1987, 1988). However, in stricter model, Hummel and Beukenberg (1989) receive center-to-center distance of vortex as $0.89b$, rather than $(p/4)b (=0.78b)$. Since 0.89 is less than 1.0 and areas of upwash hinged of the centers vortex, an optimum wingtip interval, which maximizes induced power savings (WTS_{opt}), there will be a negative value:

$$WTS_{opt} = 0.5b \quad (2)$$

The negative wing tip interval can only be achieved, by overlapping wing tips, which is achieved in V formation. In theory, at optimum wing tip interval (WTS_{opt}), flight of formation can demand only 50-60 % of the induced power of flight solo (Lissaman and Shollenberger, 1970; Hainsworth, 1987). In addition to wing tip interval, birds can influence on their savings by changing distance they fly behind birds ahead. The vortex sheet behind a fixed wing in steady flight is curtailed to be formed two concentrated vortices within the limits of two lengths of a chord (the maximal wing width) (Rayner, 1979). On progressively increased distances outside of point where tubular vortices all over again is formed, their rotary vorticity is reduced (this distance is perpendicular to wing tip interval and refer to depth) and, as vortices are less concentrated before rolled point, they will provide smaller assistance. In theories, effect of depth is non-significant after that point (Hummel, 1978). However, practically, the exact site of vortex will change because of wind and thus predictability of position will decrease. Therefore, the point rollup represents an optimum interval for depth. However, the break-up and reduction of vortex forces with depth are badly understood (Badgerow and Hainsworth, 1981; Hainsworth, 1987, 1988; Badgerow, 1988). If depth of birds relative to the birds in forward increases, the energy saving hypothesis assumes that there should not be parallel increase in interval of wing tip. A prediction of an optimum arrangement to maximize savings of energy can to be in comparison with an alternative hypothesis, that the interval in V is for orientation and communication (Gould and Heppner, 1974; Williams *and others.* 1976). This last hypothesis predicts, that the wing tip interval and depth should be positive correlated to support a constant angle between the birds. It can provide an effective method for communication of flight way and speed between birds (Badgerow, 1988).

MATERIALS AND METHODS

Bird flocks could be photographed from directly below with the established tripod-mounted camera. The spirit level should be used to guarantee, that the camera always specified vertically. It will allow the analysis of photos for wing tip intervals and depth without correction for perspective distortion. The height between birds therefore could not be measured, but due to Hummel and

Beukenberg (1989), the height does not greatly affect the optimum wing tip interval. Fast shutter speed of 1/125 s and fast black-and-white film should be used for clearness of the image. The installed camera should be capable to move between positions along the width of flight way. There is big degree variability between lines of flight within the limits of flight path though in general the birds fly to and from northwest of the roosts.

To measure wing tip intervals and depth from photos, the standard measure of scale should be accepted from a sample of dead birds / museum specimens / the literary data. Bill-to-tail length is the measure to scale the photos. The bill-to-tail length potentially can change because of stretching and contraction in the neck during flight. Two measurements could be accepted from each interesting bird: one with its neck expanded but relaxed, and another with its) neck stretched to the maximal length. Average of these two values will be used for each individual bird and as a measure to estimate scale in the photographic analysis. Wingspan (b) also can be measured in the same sample of birds, distributing their wings by side completely. Span is used to predict an optimum wing tip interval (WTS_{opt}) and to calculate the observed wing tip interval from photos. The wing tip interval and depth could be evaluated directly from photos, measuring them on photos and estimating them as functions of standard bill-to-tail length for that photo.

Wing-tip spacing can be measured by drawing a line back from a bird's body center along the direction of travel and measuring the distance between the line and the following bird's body center perpendicular to the direction of travel. This figure will be converted to wing-tip spacing by subtracting the mean wingspan from the sample of etalon birds. Depth could be measured as the distance between adjacent body centers parallel to the direction of travel. The body center is defined as midway between the bill and tail and midway along the wingspan.

We can use the estimated span from the sample of dead birds to calculate the optimal wing-tip spacing (WTS_{opt}) using equation 2. Using Hummel and Beukenberg's (1989) model, we will be able to estimate the vortex filaments behind a bird apart. Therefore, the optimum wing-tip spacing (WTS_{opt}) will be predicted. Given the mean wing chord of the dead birds, we can also estimate the optimal depth to maximize energy savings. To maximize energy savings, we thus will predict that birds should fly at some concrete depth.

The wing-tip spacings are to be measured across skeins. The distribution of observed wing-tip spacings pooled across all skeins will be compared with the predicted wing-tip spacing (WTS_{opt}) maximizing energy savings. The mean wing-tip spacing could be determined. The wing-tip spacing index, R , is:

$$R = b_{EFF}/(b_{ACT} + WTS) \quad (3)$$

(Badgerow and Hainsworth, 1981), where b_{EFF} is the effective wingspan ($b_{ACT} - 2 WTS_{opt}$), b_{ACT} is the actual wingspan and WTS is the wing-tip spacing. $R=1$ when wing-tip spacing is optimal.



As induced drag is reduced, energy savings increase by a factor of $1/e$, where e is a measure of energy savings available through formation flight. Percentage energy savings can be derived from this relationship and can be plotted against R , with the maximum saving when $R=1$ (Lissaman and Shollenberger, 1970; Badgerow and Hainsworth, 1981). The individual depths must be measured across skeins. Theoretically, the lead birds could obtain an advantage from a bound vortex about the wings of their two trailing birds, but presumably, this would only be useful when depth is small. However, there could be difference between depth for the lead birds in each skein and the depths of the other birds. There must be a significant relationship between the wing-tip spacing and depth. The prediction from the communication hypothesis that there should be a positive relationship between wing-tip spacing and depth could therefore be supported.

RESULTS

Wing-tip spacing

The birds must save some energy by formation flying. The distribution of savings either side of the optimal wing-tip spacing is asymmetrical and quite sharply peaked around the optimum (Hummel and Bock, 1981; Hummel and Beukenberg, 1989), losses being experienced when wing-tip overlap is greater than half a wingspan (Hainsworth, 1987). Because of this asymmetry, it has been predicted that the optimal location to fly, if there is error involved in maintaining spacing, would be in the direction of increased wing-tip spacing, particularly if errors in maintaining spacing ability are large (Badgerow and Hainsworth, 1981). In this way, the birds would minimize the risk of experiencing energy losses. The variation in wing-tip spacings supports the suggestion that birds find difficulty maintaining their positions and thus a less risky strategy of flying, on average, outboard of the optimal location might be favored.

The extent to which savings occurred in total costs for flight depends on flight speed and thus on the sum of power to provide induced power and power to overcome the profile and parasite drag (Rayner, 1979; Hainsworth, 1987; Pennycuick, 1989). Using the Pennycuick model, we can calculate for bird with definite weight the predicted induced power, a profile power, and a parasite power when flying at its minimum power velocity (Pennycuick, 1989). Savings in formation flight are for induced power only, so at high speeds the total saving is proportionately less. We estimate at the observed mean wing-tip spacing whether the birds fly at their maximum range speed, from which we can estimate their total saving might amount in relation to their total predicted flight costs.

Depth

The reduction in strength of vortices behind animals is poorly understood. The intensity of the vortex strength decline behind birds and its break-up are complex processes that are poorly understood for fixed wings and not at all for flapping wings (Higdon and Corrsin, 1978). Intuitively, the optimum distance for depth

might be predicted to be where the vortex filaments form: two wing chords behind the bird in front. The modal observed depth may reflect a distance where the vortex is still strong enough to bestow an induced power saving, but not so close that there is any risk of collision or erroneous movement into the zone where tubular vortices have not yet formed.

Relationship between wing-tip spacing and depth

The prediction of the communication hypothesis, namely that wing-tip spacing and depth should be positively related to provide information on position could be supported. Although the adjustment is not precise, there may be some trend for birds at larger depths to be found at wider wing-tip spacings. Gould and Heppner (1974) interpreted large negative wing-tip spacing as support for the orientation/communication hypothesis; however, this interpretation was rejected by Badgerow and Hainsworth (1981). Williams *et al.* (1976) used radar to measure the length and angle of Canada goose formations and found a significant negative relationship between V length and V angle. They suggested that formation flight was probably not the result of a single energetic factor but might have social components as well. The presence of inexperienced birds could have placed a premium on orientation/communication (Badgerow, 1988). This may also be a factor for the model bird species in this study, as it will take place in the autumn, some after they will arrive from their breeding grounds.

Effects of wind

We can assume that windy conditions during flight might make precision flight more difficult by inducing both unpredictable bird and vortex positions (see Hainsworth, 1987). To this, we need to found change in wing-tip spacing variation with increasing wind speed, suggesting or rejecting that in high winds bird skeins maintained similar variation to that on calm days. The interrelation between variation of mean depth and wind speed should prove this hypothesis. Little is known about the importance of depth, but in high winds the vortex is likely to break up more rapidly and its location become unpredictable the further back a bird flies; therefore, a shift towards skeins with more regular depths at high wind speeds may compensate for the unpredictability of the vortex locations. Any significant relationship between the standard deviation of wing-tip spacing and wind speed suggests that wind has a major effect on optimal positioning.

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