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Aerodynamic Requirements of Avian flight

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Abstract

The essential aerodynamic requirements of avian flight are wing loading and ratio of wing mass to body mass of the flier, and frequency of wing beat and aspect ratio of flight surface (wing). Hence, these aerodynamic parameters are computed and critically evaluated in order to understand avian flight for 25 species of small, medium and large birds. The study suggests that low aspect ratio and high wing loading are advantageous for good maneuverability. The birds with high wing loading are associated with high speed flight.

Key words: *Frequency of wing beat, Wing loading, Aspect Ratio, Avian Flight*.

1. Introduction

Flight surface (wing) of a natural flier is the basic and the most important flight apparatus and as such it is not the same with respect to structure and design in different fliers. Natural fliers like insects, birds and bats have developed successful flight apparatus. The morpho-functional adaptations in relation to flight surfaces and associated structures differ. There are also differences in their phylogeny, anatomy and physiological adaptations of these fliers. But each group has to face the same aerodynamic problems associated with the flight.

Information regarding the aerodynamic principles involved in the flight of natural fliers is available, but the details of the functions of the flight surface of these animals are not completely understood. Considerable research on flight in insects [1-4] has been done and a few studies have been made on the flight of birds [5-9 and bats [10-12]. Puranik, et. al. [13] proposed that the wing beat frequency of any flier in the hovering state of flight could be determined from the knowledge of the rate of mass flow of air induced downward by the wing disc. This shows that the wing beat frequency is a function of the body mass, wing span and wing breadth. Hence any variation in these parameters produced by the wing mutilation should introduce corresponding variations in the wing beat rate of the flier. Adeel Ahmed [14] elucidated the importance of hovering flight by using analysis which assumes that the wings act as steady state airfoils. When a flier is in the state of hovering the system is said to be in a state of 'dynamical equilibrium' which is achieved by the flier by generating a reacting force to just overcome its own weight. During the course of normal hovering the results are convincingly the same for the majority of hovering fliers. He did extensive work on flight surface and aerodynamic parameters of natural fliers. Nasiha Saher Bano, et al [15] presented a comparative study on wing beat frequency of various species of birds. Frequency of wing beat of avian fliers was calculated using different theories and the data was compared and discussed. They suggested that Mass flow theory was superior to any other theory proposed for the computation of wing beat frequency. Nasiha Saher Bano, et al [16] reported data on induced power, inertial power and dynamical efficiency of 25 species of wide variety of birds, when they fly in the state of hovering. Also, presented body parameters such as body mass, length, span, effective breadth, area, moment of inertia and frequency of wing beat of birds. The study on flight of small, medium and large size birds revealed that induced power was directly proportional to mass or weight of the flier. Further, suggested that inertial power was not a function of any one parameter of flight surface (wing) of a flier. But it comprised wing dimensions, moment of inertia, stroke angle and frequency of wing beat. Finally, they concluded that dynamic efficiency (η) of flight surface (wing) of birds was a function of body parameters as such it could not be related to a single parameter and was independent of size (small, medium and large) of a flier.

The present study is an attempt to calculate certain aerodynamic parameters, which are basic aerodynamic requirement in understanding avian flight.

2. Materials and Methods

The birds selected for the present investigation are 25 species. They were purchased mostly from birds dealer, birds Chowk, Hyderabad. Some were collected from Pakhal lake and Bhadrakali tank, Warangal. After making measurements birds were set free to fly.

The body mass (M_f) of the birds was measured using common digital balance with an accuracy of 1 gm. The wing length (l), wing span (L_w) and wing area (A) were measured by stretching the wings properly and pinned to a drawing board. The contour of the wing was drawn on drawing sheet carefully along the wing margins. A meter scale was used to measure wing length and wing span, while Planimeter was employed to measure wing area.

The wing beat frequency of some birds were observed in nature. In the case of small birds with relatively high frequency, the wing beat frequency was measured under stroboscopic flash

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using electronic stroboscope. Knowing basic body parameters, aerodynamic parameters like aspect ratio, wing loading and wing mass and body mass ratio were computed.

3. Results and Discussion

Table 1 presents average values of aerodynamic parameters of 25 species of flying birds taking 5 birds of each species. The aerodynamic parameters selected for study are frequency of wing beat (ϋ), aspect ratio (AR), wing loading (WL) and $2M_w/M_f$. The relation between mass of the wing and mass of the flier is linear ie directly proportional (Fig. 1).

Table 1- Aerodynamic parameters of the fliers

S. No.	Flier	υ (Hz)	AR	WL (gm/cm^2)	$(2M_w)/M_f$
Passeriformes					
1	*Nactorinia asiatica*	10	5.8	0.13	0.18
2	*Estrilda amandava*	40	6.0	0.21	0.10
3	*Loncura malabarica*	45	5.2	0.19	0.11
4	*Loncure punculata*	40	5.9	0.22	0.07
5	*Loncura malacca*	30	5.5	0.29	0.08
6	*Passer domesticus*	17	5.8	0.24	0.08
7	*Dicrurus adsimilis*	5	5.5	0.13	0.25
8	*Turdoides striatus*	15	5.3	0.26	0.10
9	*Acridotherus tristis*	10	5.3	0.22	0.14
10	*Corvus splendens*	5	4.8	0.20	0.35
Psittaciformes					
11	*Melosittacus undulatus*	20	7.6	0.29	0.08
12	*Psittacula cathorpae*	8	7.6	0.24	0.11
13	*Psittacula krameri*	10	5.9	0.23	0.15
Pelecaniformes					
14	*Egeretta garzetta*	6	7.2	0.30	0.17
15	*Ardeola gravii*	10	6.4	0.31	0.18
16	*Bubulaus ibis*	6	7.3	0.25	0.26
Coraciformes					
17	*Merops orientalis*	8	5.1	0.09	0.28
18	*Upupa apops*	6	5.1	0.11	0.28
19	*Coracias indica*	5	6.3	0.18	0.22
Apodiformes					
20	*Apus affinus*	12	8.6	0.16	0.15
Galliformes					
21	*Peridicula astatica*	20	5.7	0.26	0.13
Strigiformes					
22	*Bubo bengalensis*	10	5.4	0.24	0.19
Falconiformes					
23	*Falco peregrinus*	8	5.7	0.247	0.17
Gruiformes					
24	*Grus grus*	9	4.2	0.27	0.17
Columbiformes					
25	*Columba livia*	11	5.2	0.31	0.13

M_f: Mass of the flier, ϋ: wingbeat frequency, Mw:Mass of single wing, AR: Aspect Ratio, WL: wing loading

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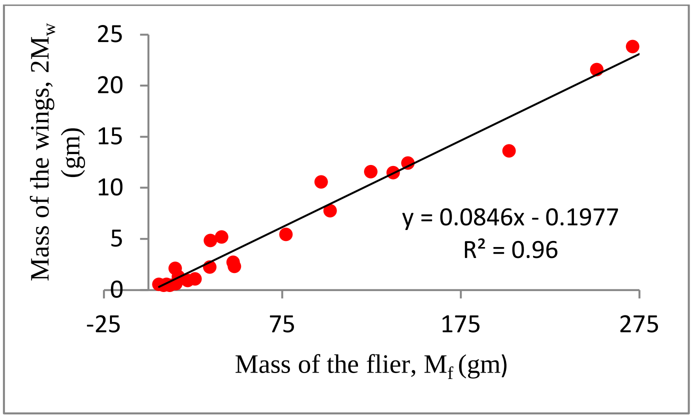

Fig.1. A plot between Mass of the wings and Mass of the flier

Aspect ratio, the ratio between the square of wing span to wing area, is a measure of manoeauvreability of the flier. It is well known that higher the aspect ratio higher the manoeuvreability of the flier. High aspect ratio represents long and narrow wings. Hence, wing experiences drag at the wing tip due to the vortices developed at the wing tip in turn induced drag can be minimised Thus, fliers with higher aspect ratio can have greater maneuverability.

Wing loading, body mass per unit wing area, is another parameter which describes the aerodynamic characteristics. The lower the wing loading the greater is lift. In birds, species with high wing loadings are associated with the high speed flight where those with low wing loadings have low speed flight (Vaughan, 1970).

The results of the study throws light on the characteristic differences in the design and function of the flight surface among the natural fliers (birds) and the aerodynamic parameters of these fliers correlate them to maneuverability of the flight adaptation.

Hovering is the type of flight where the flier just beats the wings but does not move forward i.e. forward speed is zero. In nature, it is practiced by medium-sized-fliers. During hovering the wing beat rapidly back and forth in a horizontal plane thereby producing maximum lift which is directed straight upwards and thus the wing beats tends to be maximum. In order to control the speed and power of flight, the flier is unable to vary this parameter except over a narrow range. Hovering humming birds are exceptions to this rule, where a large amount of variation is observed. Thus, wing beat frequency increases with decreasing body mass, provided geometrical similarities exist and vary unpredictably when geometrics of the flier are dissimilar.

Finally from the data of present investigation, it can be concluded that the fliers having high loading and low aspect ratio can fly at low velocities with low wing beats but at the cost of relatively high inertia. Further, fliers can possess relatively increased maneuverability.

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