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Assessment of a Bio-Inspired Artificial Wing for Micro Aerial Vehicle Based on Structural Bio-Mimetics

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Abstract

This paper presents the structural design assessment of a bio-inspired artificial wing for flapping wing micro air vehicle based on pigeon bird. Bio-inspired ornithopters are unable to implement themselves in surveillance environment due to lack of basic bio-mimetics during conceptual and design phase.The idea of this research is to bridge this gap through assessment of structural parameters including weight, moment of inertia and feather placement leading to development of an artificial wing using actual feathers of pigeon bird and glass fiber-epoxy composite. The camber and wing structure is assessed through the fabrication of mold which is further utilized to define the shape of artificial wing. Future work includes the performance assessment of the developed wing for lift and thrust generation in an actual prototype of flapping type micro air vehicle.

*Keywords:*Artificial Wing; Ornithopters; Bio-mimetics; Wing Structure; Micro Air Vehicle

1. Introduction

In present scenario of complex ISR environment, there is an ever growing need to develop a futuristic flapping wing MAV [1] inspired by natural bio-mimetic parameters. This new trend in MAV community is to take inspiration from flying insects or birds to achieve efficient flight capabilities. Biological systems are not only interesting to

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MAV engineers for their use of unsteady aerodynamics with flapping wings, but also inspiring engineers for other aspects such as distributed sensing and acting, structural capabilities, acoustic parameters and visual characteristics.

Bio-inspired warfare systems currently lack basic biomimetic characteristics based on wing flapping and its parameters. The design and development of artificial wings based on bio-inspiration from bird flight is a field of active and demanding research to enhance the flight and surveillance capabilities of Flapping Wing Micro Air Vehicles. Structural bio-mimetics can enhance the performance parameters like lift and thrust generation and also mimics the strength and mass distribution of bird wing.

b

Fig. 1. (a) pigeon bird; (b) flapping wing micro air vehicle.

Pigeon birds constitute the bird clade Columbidae which include about 310 species. Feral pigeons (Columba livia domestica), also called city doves or street pigeons are commonly seen in India as in Fig. 1(a). The present research includes structural assessment of bird wing based onmean chord, aspect ratio, disc area and moment of inertia.

Micro air vehicles (MAV) are class of unmanned air vehicles having a size restriction of 300 mm. Flapping wing micro air vehicles are a class of MAV with flapping of wing as the main source of lift and thrust generation. As shown in Fig. 1(b), these vehicles present various civilian and military applications in the field of surveillance and reconnaissance with a video camera and sensors equipped on it.

The specific objectives of this research include the assessment of various structural parameter of a pigeon. The various Bio-Mimetic Parameters to be considered for complete assessment includes visual, acoustic, structural Biomimetics and performance Based Biomimetics.

Nomenclature

S_{wing}	Wing Area
B	Wing Span
C_m	Mean Chord
R_a	Aspect Ratio
S_d	Disc Area
I	Moment of Inertia
m_i	mass of i_{th} strip
d_i	distance b/w centre of strip i and shoulder joint
w	width of each strip
n	number of strip
r_1	mass of i_{th} strip
m_w	wing mass

2. Structural Biomimetics

Bird wing constitutes the most important morphological variable for flight performance and structure. The structural parameters are needed to be assessed for biomimetic preparation of artificial wing. Wing span, the distance from one wing tip to the other, decides the flight characteristics of birds. Beside this, wing areas have major contribution in flight performance calculations.

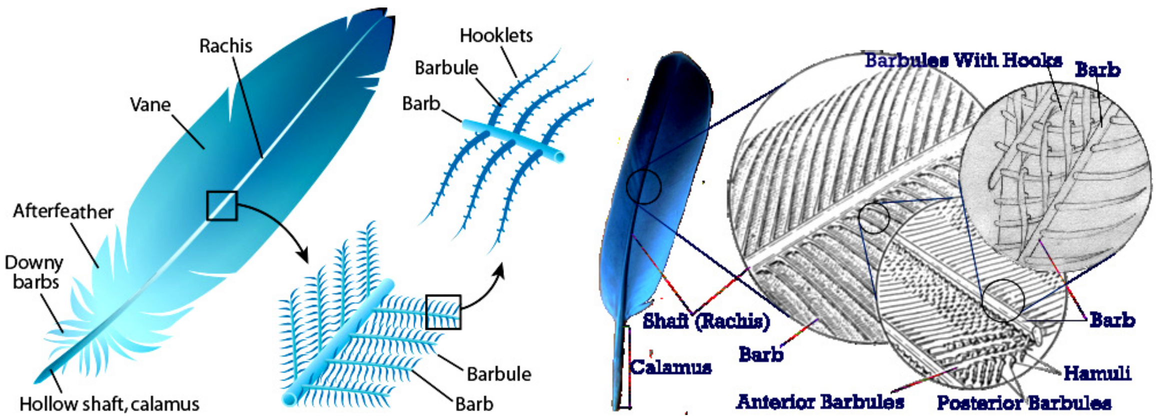

Fig. 2. morphology of pigeon bird feather

The pigeon uses its wings to fly, move forward and maneuver [2]. The trailing edge of the vane, central quill with a web of filamentous material extending from two opposite sides, is broader and more flexible than the leading edge as shown in Fig. 2. Forward thrust is produced as the wing beats down and the vane twists with the trailing edge going up and forcing air backwards to produce forward thrust. The shape, color, texture, and size of feathers vary with species, and with position on the body, each feather has one or more of the parts of a typical body feather. The central shaft of the feather is rachis and the calamus at its base inserts into the skin of the bird. Feathers are highly differentiated for insulation, flight, protection and visual display. The various parameters being considered in this research are Mean Chord, Aspect Ratio, Disc Area and Moment of Inertia [2].

2.1. Mean Chord

Chord, in Fig. 3, is the distance from leading edge of wing to the trailing edge, measured along the direction of air flow. Since the chord is non-uniform across the wingspan, mean chord (C_m) is required to be calculated. Generally, the maximum root chord is where the wing joins on to the body, and taper to a smaller tip chord. The mean chord, calculated through Eq. 1 , is the ratio of the wing area (S_{wing}) to the wing span (B).

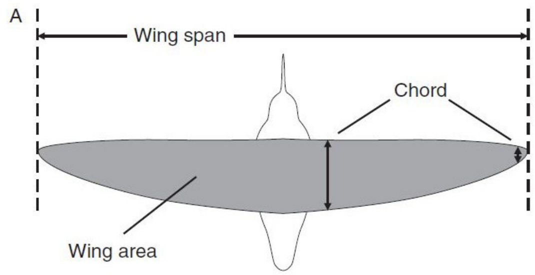

Fig. 3. chord and wing span of bird wing

$$C_m = \frac{S_{wing}}{B} \quad (1)$$

Original Pigeon wing of a dead bird is used for assessment and calculations. Leading edge is tilted at various angles across the transverse axis of bird as in Fig. 4. The outlines were traced on graph paper for measurement of wing area and span. The area was measured using Digital Planimeter and the wingspan was measured. The mean chord is calculated using the data at angles of 0, 18, 36, 54 and 72 degree.

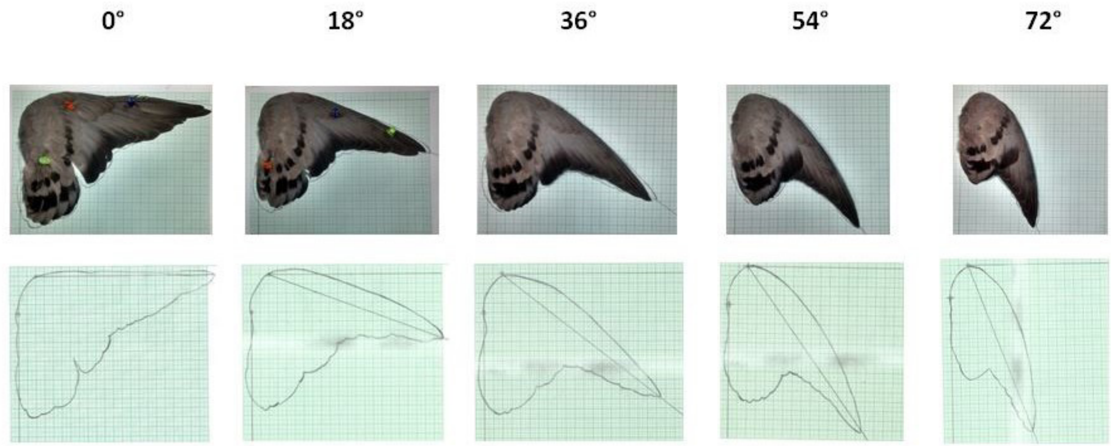

Fig. 4. leading edge variation and area measurement

2.2. Aspect Ratio

Aspect ratio is defined as the ratio of wing span to the mean chord, which expresses the shape of the wing. More conveniently, it is defined as the ratio of square of the wing span (B^2) to wing area (S_{wing}) as in Eq. 2. Since the wing area and span of birds varies with age and species, aspect ratio is assumed to be constant for species. Thus wing shape is assumed to be same for a common aspect ratio, but size may be different.

$$R_a = \frac{B^2}{S_{wing}} \quad (2)$$

Similarly as for mean chord, the aspect ratio was calculated using the data and above equation for various angles of leading edge. This assessment will help in biomimetic design of artificial wings on the basis of shape.

2.3. Disc Area

Disc Areais defined as the area of a circle whose diameter is equal to the wing span. As the leading edge angle varies, the wing span varies, thus causing the variation in disc area. As the wing area variation causes variation in lift forces, the assessment provides thrust parameters for wings. Eq. 3 defines the disc area calculation which is assessed for various angles.

$$S_d = \frac{\pi B^2}{4} \quad (3)$$

2.4. Moment of Inertia

Moment of Inertia of bird wing is related to the agility and manoeuvrability [3]. To measure the wing's moment of inertia, a tracing of the wing is first marked into chord wise strips as each strip contributes to mass. The assessment is done using wing strip analysis for different angles of leading vertex. The wing was cut into 10 strips of equal width perpendicular to the wing axis where each strip was carefully cut with a scalpel and measured using electronic weight balance. The equation for calculating is shown in Eq. 4.

$$I = \sum_{i=1}^{n} m_i d_i^{\,2} + \frac{m_i w^2}{12} \quad (4)$$

Each wing strip was considered to be a bar, with a homogeneous mass distribution along its width rather than a point mass at the center of the strip.Thollesson and Norberg [4] ignored the second term in Eq. 4as it shows a negligible effect.

3. Data Assessment and Calculations

The above mentioned wing parameters were recorded and calculations were done for structural assessment of the pigeon bird wing. Initially, as shown in Table 1, the mean chord, aspect ratio and disc area are calculated to analyse the effect of leading edge angle variation. The calculations are done using the wing area and span measurements.

Table 1. An example of a table.

Sl. No.	Angle (degree)	Mean Chord (C_m) (in cm)	Aspect Ratio (R_a)	Disc Area(S_d) (in cm^2)
1.	0°	9.74	4.866	1764.601
2.	18°	7.63	5.872	1576.325
3.	36°	7.89	4.968	1206.874
4.	54°	9.93	2.701	564.104
5.	72°	13.65	1.392	283.528

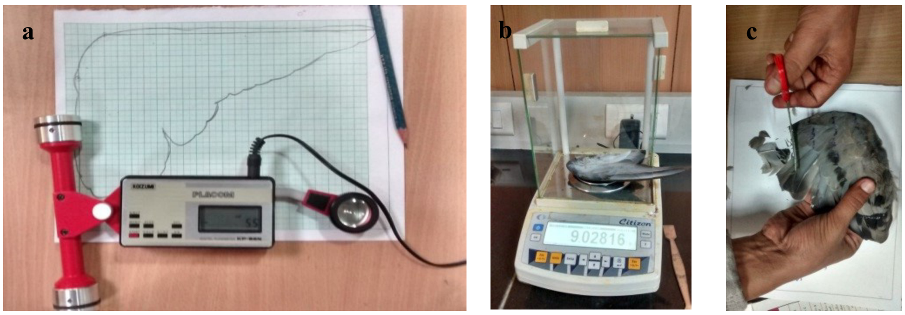

Fig. 5. (a) area measure with Planimeter; (b) digital weight measure; (c) wing strip cutting

The Fig. 5 above shows the measurement of area using Planimeter, weight measurement and strips cuts. The moment of inertia is calculated using Eq. 4, by measurement of strip mass (m_i) with d_i as the distance b/w the center of strip i and the shoulder joint. The calculations were done for each strip and then summation for all strips were done for analyzing the total moment of inertia as in Table 2.

Table 2. moment of inertia calculations of pigeon wing

Strip Number (i)	Strip Mass in grams (m_i)	Distance in cm (d_i)	$m_i \times d_i^2$ (g cm²)
1	0.0192	1.15	0.025
2	0.032	3.45	0.38
3	0.1103	4.75	0.52
4	0.1423	8.05	9.22
5	0.1943	10.35	20.81
6	0.2822	12.65	45.16
7	0.5396	14.95	120.60
8	0.8671	17.25	258.01
9	0.973	19.55	371.88
10	4.4943	21.85	2145.05
Summation	7.6543 grams	25.15 cm	2971.66 g cm²

4. Assessment Results

The leading edge angular variation is assessed for mean chord variation and aspect ratio variation and graph is plotted for comparison as shown in Fig. 6(a). The mean chord increases with increase in angular variation while the aspect ratio decreases. Also, the disc area, as shown in Fig. 6(b), decreases with angle.

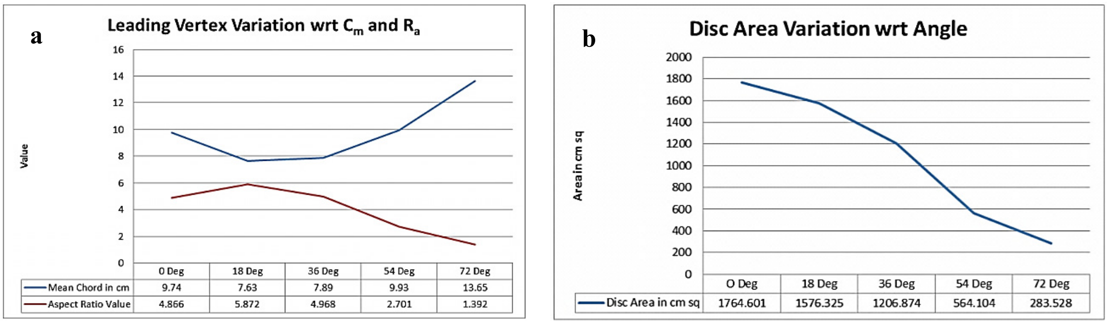

Fig. 6. (a) plot for mean chord and aspect ratio; (b) plot for disc area variation.

For the assessment of moment of inertia, initially the variation of strip mass and strip distance is plotted with respect to the strip number, starting from the end edge of wing, as shown in Fig. 7(a). The mass of the strips first increases uniformly till 8th strip and then there is a sudden increase till last strip. The distance variation is taken as uniform, thus the graph shows almost linear increment.

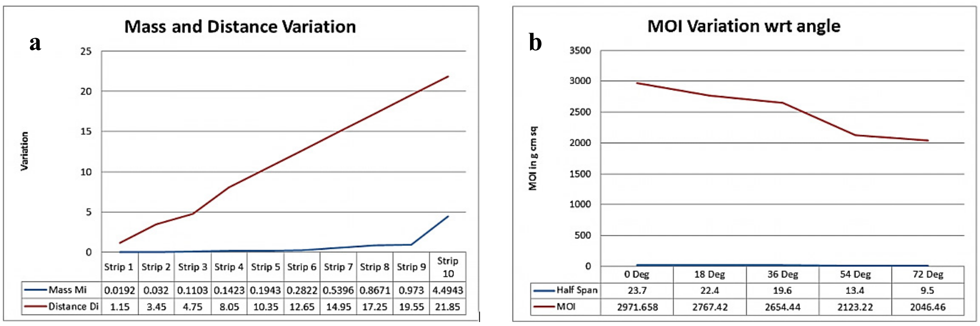

Fig. 7. (a) mass and distance variation across strips; (b) MOI variation for different angles.

The moment of inertia variation was plotted for five different wings at different angles as shown in Fig. 7(b). Since different wings are used every time, the variation in moment of inertia is decreasing very smoothly. Also the half span of the wing is plotted which shows an almost uniform decrease.

The assessed structural parameters analyzed in this research are further utilized for development of artificial wing structure for flapping wing micro air vehicles. The naturally fallen wing feathers of pigeon birds are utilized for the same in a prepared mold of Plaster of Paris as shown in Fig. 8(a). The developed mold was made with an imprint of the natural wing camber which is utilized to provide shape to artificial wing structure. A complex composite structure, as shown in Fig. 8(b), consisting of natural feather, glass fibers and epoxy matrix is prepared to mimic the discussed structural parameters.

Fig. 8. (a) developed mold using natural pigeon wing; (b) artificial wing preparation using feathers.

5. Conclusions

The presented research provided the assessment of various parameters of structural biomimetics with reference to a pigeon bird wing. The mean chord variation, which is increasing gradually with angular variation of leading edge, suggests a method to variate average lift force for differential manoeuvrability of flapping wing systems. The analysis recommends the distribution of chord across the span for artificial wing. The aspect ratio decrease with respect to angular variation which describes the variation of wing shape, causing variation in moment generation. The thrust force generation is a parameter of disc area, which decreases with decrease in angular variation of leading edge. The strip analysis is done for mass distribution, suggesting the concentration of weight at shoulder joint. The most important parameter, moment of inertia which relates the mass with shape and size of wing, is assessed through strip analysis and further utilized for artificial wing generation with same values. The assessed parameters through original wings are further utilized for artificial wing generation, thus providing a concept of using the fallen feather based composite wing for flapping type micro air vehicles. This research provided a platform for future research in high flight performance natural wing development for unmanned aerial vehicles having low weight and enhanced structural characteristics.

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