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Comparative Aerodynamic Study of Effect of ALULA on Two Birds Pigeon & Parrot Wings

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Abstract— The goal of this research project was to test the aerodynamic parameters like lift, drag, L\D ratio and also the pressure distribution on two authentic birds' wings i.e. pigeon and parrot .The main purpose of using two different birds' wings is to study the effectiveness of wing span and area, in their flight. This analysis was made using digital subsonic wind tunnel. Consequently it is necessary for us to study about aircraft flight with an emphasis on bird flight. As per the given theoretical results the lift and drag varied for both the birds. Though both the birds have the same ability to flap, for generating lift, the aerodynamic parameters varied because they had different velocities, and where adjusted at different angles of attack. The study of bird wing also gives the concept of alula which plays the major role and helps the bird to fly. It is a sensory anti-stalling structure and its activity depends on its shape and air pressure. In the present analysis the airflow over the bird's wings of pigeon and parrot with alula locked and unlocked was tested. On comparing it was found that the lift for the parrot's wing is greater than that of the pigeon, with the alula open and closed. The pressure distribution varied for both the birds considerably with varying angle of attack having its alula unlock. The results are found to be good so as to benefit the mankind in perceptive of the bird flight and advances in aircraft technology.

I. Introduction

Aerodynamics is defined as the science which deals with the study of motion of air around the flier and subsequent motion of the body through air [1]. The concept comparative analysis of pigeon and parrot wing with the effect of alula gives the complete knowledge of flight performance of biological fliers. In an airplane the aerodynamic forces are developed by the propeller (thrust) and the fixed wings (lift). The biological; fliers basically posses movable and flexible wings and these wings are responsible for the generation of all aerodynamic forces such as vertical lift, forward thrust and induced drag in contrast to an airplane. The study of bird wing also gives the concept of alula which plays the major role and helps the bird to fly. The biological wing of the bird has a complex structure and up and down movements integrated with all other subsystems required for flight [2&3]. In the present analysis we have tested the airflow over the bird's wings of pigeon and parrot with alula and without alula. The flight parameters of both birds are to be calculated. The basic flight parameters are body mass, wing length, wing span, wing area, and effective breadth of the wing, wing loading, aspect ratio, velocity, angle of attack. [4] The main intension for choosing these birds is, because pigeons have well developed sternum, thick plumage and long pointed wings. They are most powerful fliers used by human agency. Pigeons and doves are stout-bodied birds with short necks, and have short slender bills with a fleshy care. The wings are large and have low wing loadings; pigeons have strong wing muscles (wing muscles comprise 31–44% of their body weight) and are amongst the strongest fliers of all birds fig (1). They are also highly maneuverable in flight. Rose-ringed parakeets (parrot) measure on average 40 cm (16 in) in length including the tail feathers. Their average single wing length is about 15–17.5 cm (5.9–6.9 in) as in fig (2). The tail accounts for a large portion of their total length. Characteristic features of parrots include a strong, curved bill, an upright stance, strong legs, and clawed zygodactyls feet. Parrots have rounded head, strong wings and short neck. Legs have two toes in front and two in the rear which help in firm grip. Pointed hooked strong beak is adapted for eating hard seeds and fruits. It has been reported that the parrot beak has a maximum pressure per square inch for cracking hard nuts. They have an adaptation for fast high-level medium frequency flight. They are also known for round about landing which reduces their high velocity before landing. They have highly colored plumage [5].

Fig.(1) Pigeon wing structure

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Fig. (2) Parrot wing structure

II. Background

The aerodynamic forces are lift and drag, these forces rise due to two causes, the force due to pressure on the surface and the force due to viscosity or shear [11 &12]. Lift can be defined as a force component perpendicular to the free stream velocity, and drag is the force component parallel to the free stream velocity. As the angle of attack increases, lift increases i.e. lift and angle of attack are proportional to each other, where drag is inversely proportional to lift, refer fig (3). Generally we do not calculate lift and drag directly we calculate it by the lift and drag coefficient CL and CD.

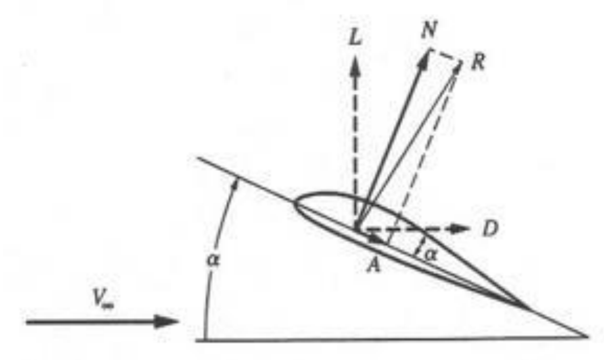

Fig (3) Aerofoil Inclination.

Another important unsteady aerodynamic effect which we are interested in is stall. A stall is a condition in aerodynamics and aviation where in the angle of attack increases beyond a certain point such that the lift begins to decrease. The angle at which this occurs is called the critical angle of attack. This critical angle is dependent upon the profile of the wing, its plan form, its aspect ratio, and other factors, but is typically in the range of 8 to 20 degrees relative to the incoming wind for most subsonic airfoils. As angle of attack increases, the separated regions on the top of the wing increase in size and hinder the wing's ability to create lift. At the critical angle of attack, separated flow is so dominant that further increases in angle of attack produce less lift and vastly more drag. From the fig (4) below we can clearly understand the flow separation at different angles of attack.

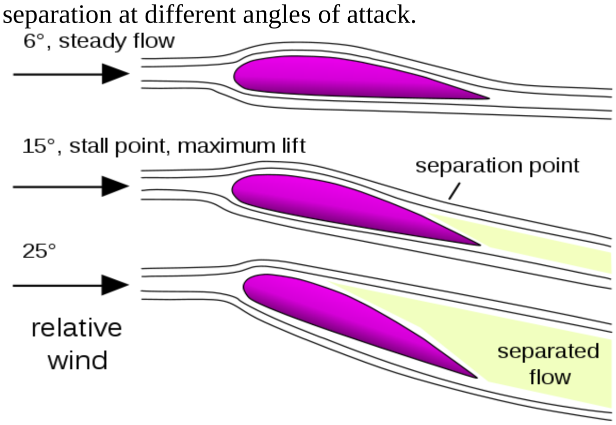

Fig (4) Source: Google images

Since birds are highly visible and common animals, humans have had a relationship with them since the dawn of man. Sometimes, these relationships are mutualistic, other times; they may be commensal. Birds have helped humans and benefited them in many ways, apart from helping they have been a source of motivation. They have always given new ideas to develop the aviation industry and make it grow. Birds are able to fly because of a variety of specialized adaptations. They have high metabolisms to supply their body with energy. They have lightweight bones. They have feathers, some of which are "flight feathers" that are long, strong, and able to produce lift and act as control surfaces. They also have a bone called the furcula, more commonly known as the "wishbone," in their chest, which is very important for being able to produce strength. The mechanics of flight are not unlike an airplane; the factors of lift, weight, thrust, and drag all interact to allow for controlled flight. By flapping their wings, birds create thrust and lift. They are able to steer by changing the shape and orientation of their wings and tail. They change the shape of their wing between the upstroke and down stroke as they flap to minimize drag on the upstroke and maximize the thrust generated downward on the down stroke, providing both lift and thrust. When all the feathers in a bird's wings are set in a certain way, so that the air cannot flow through them, the wing takes up a special shape which makes the air flow much faster over the top surface of the wing than it flows below the under-surface of the wing when the bird is gliding through the air. The difference in air-speed between the top and bottom surfaces of the wings gives the wings a "lift" force which can easily counteract the force of gravity. Hence the bird flies.

The bird's wings play a vital role in their flight. The wings are made of feathers, which keep them light and help produce lift for their flight. Flight feathers are the large feathers of the wing and tail. Flight feathers of the wing are collectively known as the regimes, and are separated into three groups. The primaries attach to the metacarpal (wrist) and phalangeal (finger) bones at the far end of the wing and are responsible for forward thrust. There are usually 10 primaries and they are numbered from the inside out. The secondary's attach to the ulna, a bone in the middle of the wing, and are necessary to supply "lift." They are also used in courtship displays. There are usually 10-14 secondary's and they are numbered from the outside in fig (5). The bases of the flight feathers are covered with smaller contour feathers called **coverts**. There are several layers of coverts on the wing. The alula, or bastard wing, is a small projection on the anterior edge of the wing of modern (and some ancient) birds. The alula is the freely moving first digit, a bird's "thumb," and is typically covered with three to five small feathers, with the exact number depending on the species. When flying at slow speeds or landing, the bird moves its alula slightly upwards and forward, this creates a small slat on the wing's leading edge [8]. This functions in the same way as the slats on the wing of an aircraft, allowing the wing to achieve a higher than normal angle of attack and thus lift without resulting in a stall. During stretching of the wing down toward the ground, the alula is abducted from the wing and can be clearly viewed.

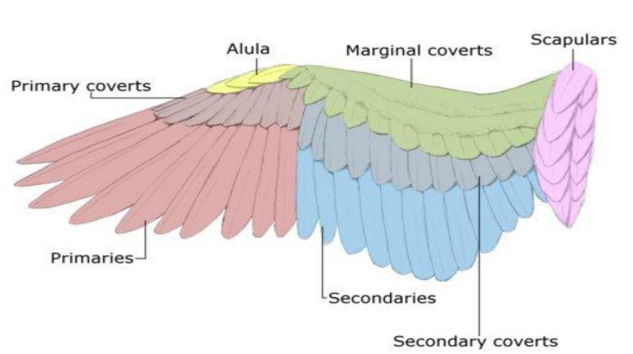

Fig (5) source: http://www.pigeonracingpigeon.com

A flying bird in nature is capable of variety of flight maneuvers such as active, hovering, flapping, bouncing, soaring, gliding, migration. The flight path is inclined downwards at a relatively constant speed below the horizontal line in the direction of gravity. Gliding in still air is known as "slope current" flight. During gliding the air is assumed to be stationary. Generally gliding can be observed in birds that have large wings. In active flight birds fly faster by flapping their wings continuously. Hovering birds will be at a steady place and flap their wings continuously as in fig (6). It is a kind of power on flight. The rate of change of momentum supports bird's weight and the forward velocity of the flier is zero. Soaring flight enables a bird to remain airborne by making use of wind currents without beating the wings as in fig (7). The energy is extracted by air moments and is converted as kinetic and potential energy. During soaring the wind velocity is neither horizontal nor uniform. By soaring some birds cover hundreds of kilometer during annual migration. Soaring are of two type's static and dynamic soaring [6]. Static is when birds use the energy of changing horizontal wind speed. In dynamic soaring birds use the vertical movements of the atmosphere. Flapping enables the bird to fly faster [7]. Birds gain more energy by continuously flapping their wings to maintain stability as shown in fig (8)

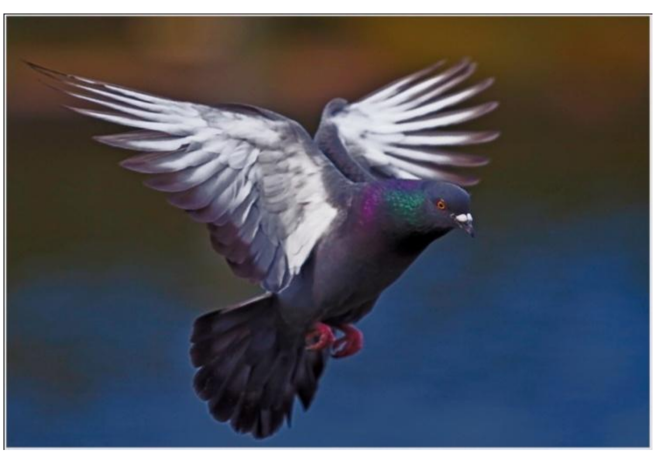

Figure : Pigeon hovering

Pigeon soaring

Parrots flapping

Fig (8) Parrots Flapping

Migration is found in efficient fliers which fly between Arctic and Antarctic continents (18000km/hr in each way). Migration occurs twice during the flight from breeding grounds to the winter quarters and then a return, refer fig (9). Migration is marked by its annual seasonality [13].

Migration of bird:

Fig (9) Migration of birds

III. EXPERIMENTAL ANALYSIS

After the extensive book research the next step was for us to learn how to use the wind tunnel, and begin the testing. The measurements of lift and drag are taken from the digital system which is attached to the wind tunnel as in fig (10). For the testing of birds wings the wind tunnel used was digital which gives lift, drag and also the pressure distribution. For testing our prototype we need to check the proper working of wind tunnel. Airfoil is placed in the test section of the wind tunnel and is supported downwards by strut and clamps. Then the strut is fixed to three component balance and tightened with the two screw design where one screw attached to it and the other screw tightened around it to secure a given angle of attack. A compass is fixed in the front phase of the test section to measure the angle of attack. When the wind tunnel is "on" the airfoil moves upward and backward and the digital system attached to this airfoil will take its movements.

Fig (10) Subsonic Wind Tunnel

As from the title of the paper we know that, we are comparing the wings of the pigeon and parrot. To find the aerodynamic parameters for these wings we need to place the wing in the wind tunnel. We need to make arrangements to clamp the wing in the wind tunnel, since the wing is very light and also flexible it is difficult to fix it in the wind tunnel. To make the wing stiff we need to stitch the wing with a cloth underneath the wing, which is smooth, such that all the feathers are close to each other, without any gaps between them, or else it may cause vertex formation .To make the wing further stiff, place an "I" shape strip of aluminium, of thickness and length as per requirement of the wing. To fix this wing to the wind tunnel we need to make "L" shape clamps, as shown in fig (11 &12).

Screws and clamps:

Fig.(11) – Bolts, Nuts and Clamps

Fig (12) "I" shape strips and clamps

First and foremost we will consider the pigeons' wing, the length of the "I" shape strip is 8cm. The horizontal columns are 4cm in length and 2cm in breadth, the beam is 4cm long and 1.2cm wide. Holes are to be drilled with a drill bit of M5 so that we are able to fit screws and nuts of M4 through the holes, to fix the wing and "I" strips as shown in fig (14). The AutoCAD illustration of the strips is shown if fig (13). Now that we have made our wing stiff we need to fix it to the strut to do that we need to create clamp that are in "L" shape . To prepare the clamps we need to take aluminium strips of 2 cm long and bend it with the help of a mallet at its center or at the half of the strip to get an "L" shape. Drill holes as was drilled for the "I" strips. Hence by using these strips, clamps and screws we can fix the wing in the wind tunnel refer fig (15 &16).

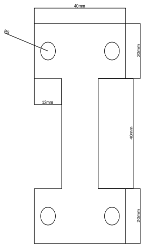

Fig (13) I-section

Fig (14) "I" strips and clamps for the pigeons' wing:

The steps is to "on" the motor of the wind tunnel and adjust its velocity to that of the pigeons', the velocity we considered is 13.4m/s. Initially place the wing at zero angle of attack and note down the values of lift and drag, similarly at the same velocity change the angle of attack and note down the values of lift and drag. Now using the values of lift and drag calculate coefficient of lift and drag by the following: $CL=2L/(density*V^2*S)$ & $CD=2D/(density*V^2*S)$ [9]. After calculating the lift and drag coefficient of the wing with alula locked. Now unlock the alula and continue the same procedure. We notice that when the alula is opened the stall is delayed.

Pigeon fixed to the strut:

Fig (15) Pigeon wings fixed in Struts

Fig (16) Pigeons' wing in the wind tunnel

Our next steps is to find out the pressure distribution for that we need to make holes at the thickest part of the wing, at the minimum thickness and also at the normal thickness. Note these holes should be in a straight line. The holes should be as big as the pipe diameter such that the pipe could be inserted through it. A precaution that we require to take is that the pipes should be inserted equal to the surface. Now position the wing in the wind tunnel as shown in fig (17). These pipes are connected to the respective manometers'. Before we "on" the motor of the wind tunnel take the initial readings from the manometer, after switching on the motor wait till the fluctuations are settled and note down the readings for different angles of attack refer fig (18). Calculate the Cp by using the formula:

$$Cp = (P - P\infty)/q$$

Fig (17) wings attached with struts

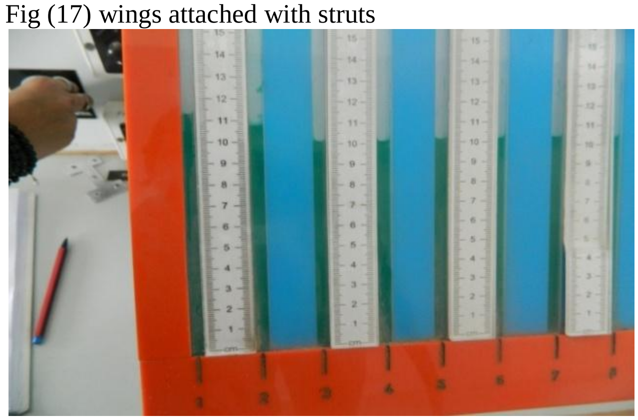

Fig (18) Varying pressure distribution

Now as we have found the lift, drag and pressure distribution for the pigeon's wing, in same way we need to find it for the parrot. The dimensions for the strips will change as the length of the "I" strip is 8cm, the width is 4cm. The beam is 4cm long and 2cm wide, whereas the column is 4cm as in fig (19).The size for the "L" clamps remain the same. The AutoCAD illustration is as in fig (20). As has been the procedure for the pigeons' wing, repeat the same thing for the parrots' with alula closed and open. The pressure distribution is also done in the same manner. Refer fig (21 to 25).

Fig (19) "I" strip for the parrot, clamp, and screws

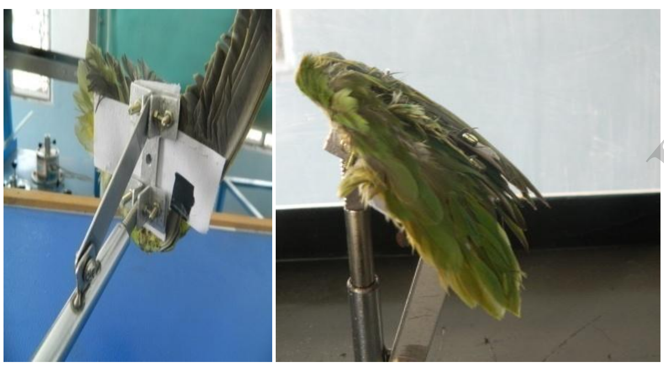

Fig (21) Parrots' wing fixed to the strut

Fig (22) Wing in the wind tunnels' test section

Fig (23) Readings from the digital system:

As from the formulas given above to find the coefficients of lift, drag and pressure we require some parameters like velocity, reference area, density, atmospheric pressure. Other than this some other parameters which we need to find out are aspect ratio, effective breadth, mass, chord length, wing span.

Since the maximum velocity of the pigeon is 50km/hr, the wind tunnel velocity is adjusted to 13.5m/s. In case of parrot since its maximum velocity is 70km/hr, which when converted to m/s is19.4m/s, the wind tunnel velocity is adjusted to 18.6m/s. Consequently the velocities for the birds are obtained. The density of air at room temperature i.e. at 25^0C is 1.1839 kg/m^3. The atmospheric pressure is 101000 at the room where the experiment was conducted.

Fig (24) Pressure distribution test

Reference area of the wing is calculated by using graph; since the shape of the wing is irregular it is better to find the area through graph method, as shown in the fig (25). The steps involved in this method are as follows: place the wing over the graph, draw the outline of the wing on the graph, count all the fully covered boxes and note them down ,then count the more than half covered boxes, and half covered boxes ,and less than half covered boxes. After counting those all note them down .Total all of them and the area is found in cm^2. Repeat the same procedure for the other wings with alula closed and open. Area of the pigeons' wing with alula locked is 0.01835m^2, and with alula open is 0.1891m^2as shown in fig (23). Area of the parrots' wing with alula locked is 0.088m^2, with alula unlocked is 0.094m^2.

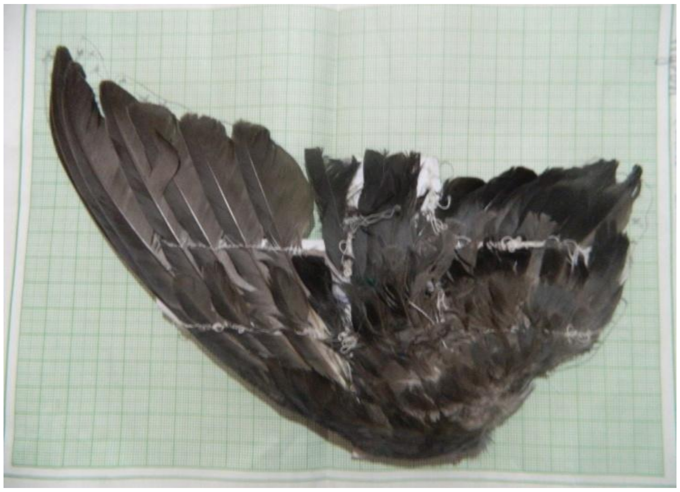

Fig (25) pigeon on the graph

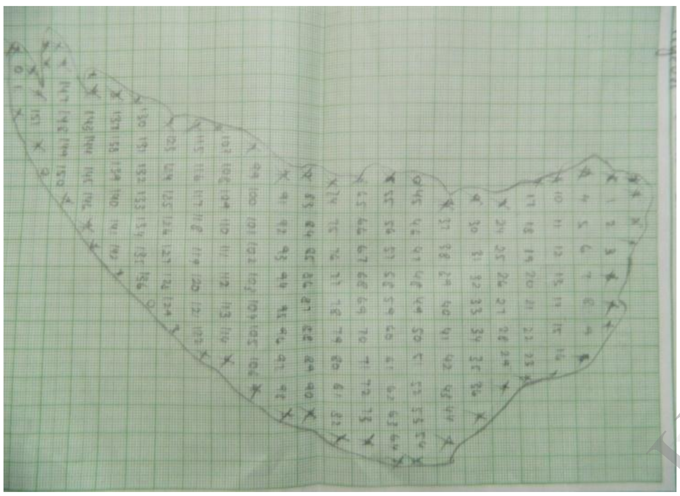

Fig (26) Area of the bird wing

The next parameter is the aspect ratio (A.R) is defined as the square of the wing span divided by the area A of the wing plan form which given L^2/A where L is the wing span, and "A" is the area. The aspect ratio varies when the alula is open and closed, since aspect ratio is inversely proportional to area. The (AR) for the pigeons wing is 2.797 when the alula is open, and when the alula is closed it is 2.89, for the parrots wing it is 2.22 with alula closed, and 2.08 with alula open it is .The wing span of the pigeon is 22, and parrot is 14.

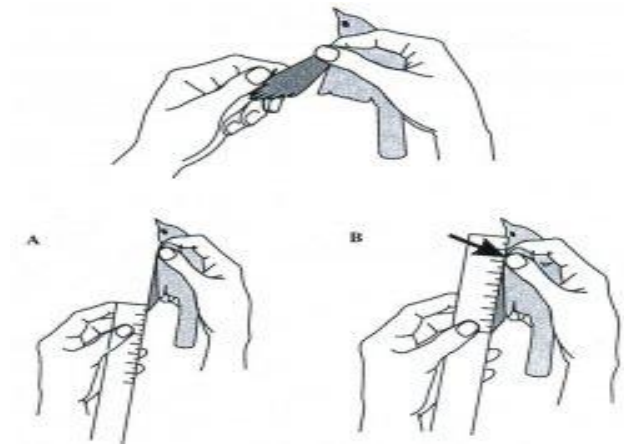

Fig (27) measuring the wing

The effective breadth is B_{eff} =A/2l, where A is the flight surface area and l is the length. The effective breadth of the birds' wing varies with the reference area since it is directly proportional to area. The B_{eff} of pigeon with alula open is 4.1108cm, and with alula locked is 3.9891cm.For the parrot the B_{eff} is 3.14cm and with alula unlocked is 3.35cm.

The mass of the pigeons' wing is obtained as 15grams, and for the parrot it is 5 gram.

The tables given below specify the values for both the wings. Note: V-velocity, S-reference area, S_{open}-reference area with alula open AOA-angle of attack, den-density. The values in table1 are the all-purpose values for pigeon wing. "open" refers to alula open.

Pigeon wing				
Inputs			Formula	
V	13.5	m/s	CL	$2L/den*V^2*S$
Density	1.1839	kg/m^3	CD	$2D/den*V^2*S$
S	0.0184	m^2		
S_{open}	0.0189	m^2		

TABLE 1

WITH ALULA CLOSED

AOA	0	5	10	15
L	0.19	0.45	0.18	0.01
D	0.22	0.36	0.42	0.52
CL	0.095977	0.227313	0.090925	0.005051395
CD	0.111131	0.18185	0.212159	0.262672564

Table 2: Values with alula closed

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WITH ALULA OPEN

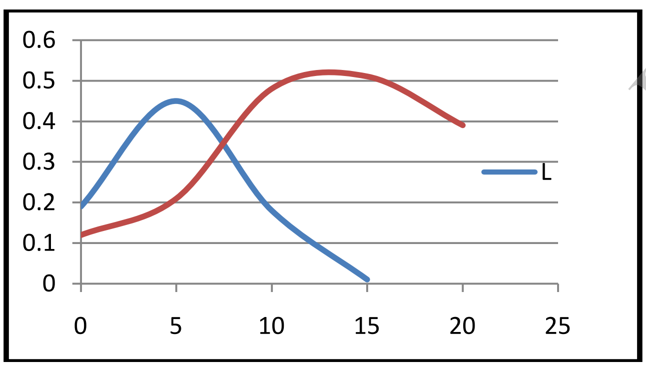
AOA	0	5	10	15	20
L	0.06	0.21	0.48	0.51	0.39
D	0.05	0.1	0.25	0.29	0.4
CL	0.029411	0.102938	0.235287	0.249991	0.1911
CD	0.024509	0.050514	0.122545	0.142152	0.19607

Table 3: Values with Alula open

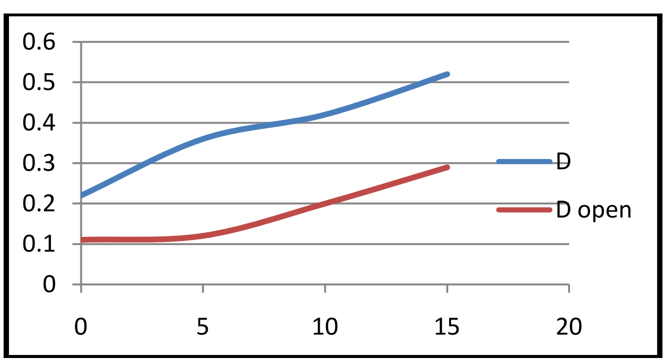
Pressure distribution

AOA	PORT NUMBERS		
	Max	mid	Min
0	12.8	12.1	12.5
5	12.9	11.5	12.2
10	12.9	11.7	12.2
15	12.9	11.9	12.2

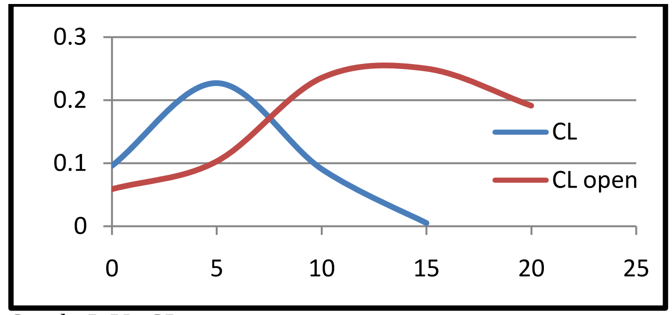
Table 4: Pressure distribution at different port numbers



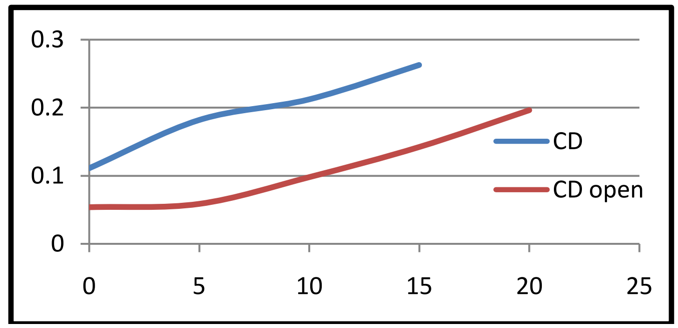
Graph: L Vs L open



Graph: D Vs D open



Graph: L Vs CL open



Graph: CD Vs CD open

Pressure distribution

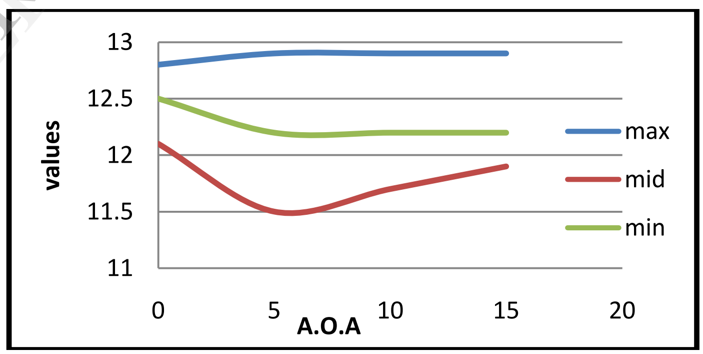


TABLE 5

Parrot wing				
Inputs			Formula	
V	18.6	m/s	CL	2L/den*v^2*s
Density	1.184	kg/m^3	CD	2D/den*v^2*s
S	88	mm^2		
	0.088	m^2		

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Table 6

AOA	0	5	10	15
L	0.19	0.66	0.3	0.14
D	0.35	0.42	0.43	0.46
CL	0.011	0.037	0.017	0.008
CD	0.019	0.023	0.024	0.026

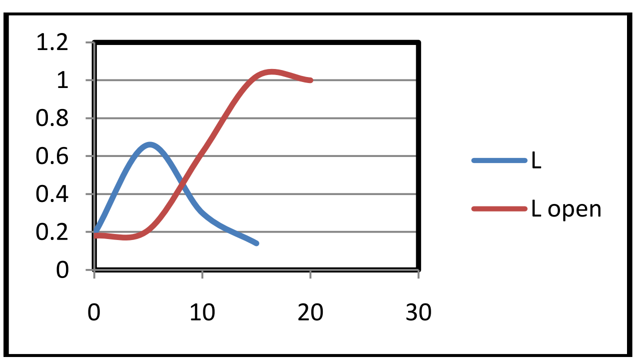
Table 7

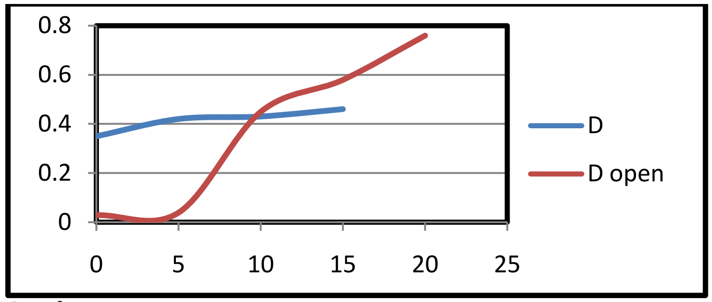
AOA	0	5	10	15	20
L	0.18	0.21	0.62	1.02	1
D	0.03	0.04	0.45	0.58	0.76
CL	0.009	0.011	0.032	0.053	0.05
CD	0.002	0.002	0.023	0.03	0.04

Pr. Distribution

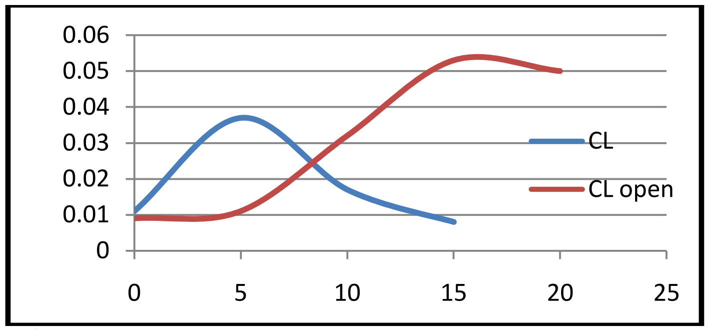
AOA	PORT NUMBERS		
	max	Mid	Min
0	12.3	12.4	-
5	14.1	13.4	-
10	14.2	13.6	-
15	14.8	13.8	-
20	14.8	14.1	-

Graph : L Vs L open

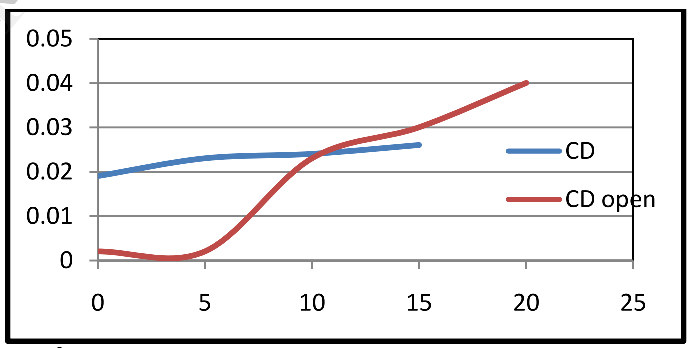




Graph: D Vs D open

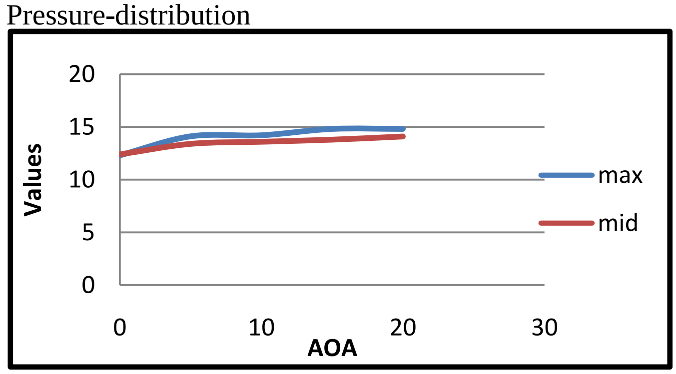


Graph: CL Vs CL open



Graph: CD Vs CD open

Pressure-distribution



We have seen the pressure distribution over both the wings and the graph plotted between the values (i.e. pressure variation at different ports), but the graph plotted between angle of attack (A.O.A) and coefficients of pressure (Cp) are given below:

Pigeon			
A.O.A	Cp(max)	Cp(mid)	Cp(min)
0	-936.106	-936.113	-936.109
5	-936.105	-936.118	-936.112
10	-936.105	-936.116	-936.112
15	-936.105	-936.115	-936.112

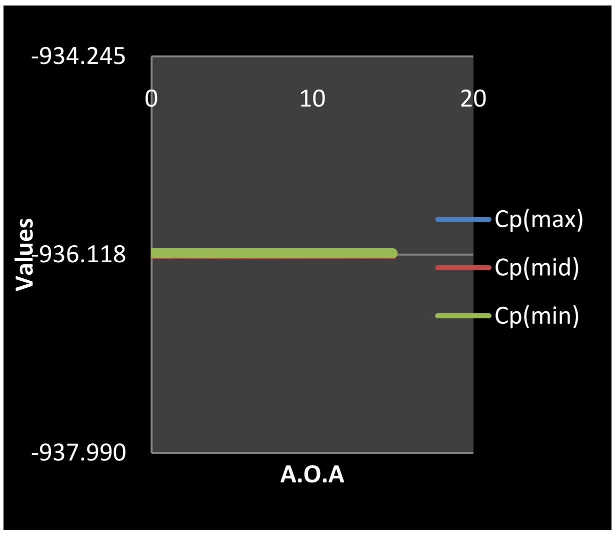
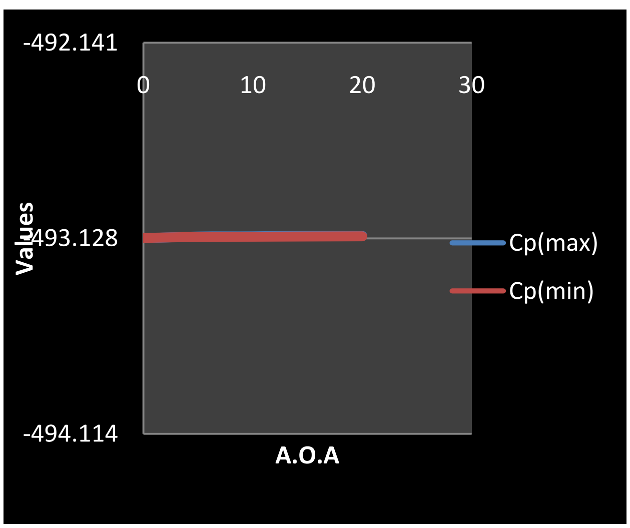


Fig. Cp Variation



IV CONCLUSION

From the above tables and graphs we can conclude that the stall is delayed up to certain angle of attack when the alula is open, rather, when it is closed. Another consideration is that the alula usually comes out at high angle of attack i.e. when the bird is landing or flying at slow speeds. The lift produced for the pigeons' wing is lesser than that of the parrots'. As we know from the given formulas that the coefficients of lift and drag are inversely proportional to reference area and since the reference area of the pigeon is larger compared to that of the parrot hence the lift is more for the parrot than the pigeon. From the pressure distribution graphs and values, it can be observed that pressure is minimum at the center of the wing at 5^0 angle of attack for pigeon. In case of parrot it is minimum at the center of the wing at 0^0 angle of attack. While finding the coefficient of pressure, as there is very slight variation in the values at different points, therefore the graphs are coinciding. The drag increased due to the experimental setup.

Parrot		
A.O.A	Cp(max)	Cp(mid)
0	-493.128	-493.127
5	-493.119	-493.122
10	-493.118	-493.121
15	-493.115	-493.120
20	-493.1158	-493.119

V FUTURE WORK

In future we will carry out the test on different bird's wings, and also increase the angle of attack to check for variations in result. The main aim of the present study is to throw light on the following aspects of future research. Structure analysis can be carried out like tensile, compressive and buckling test for the wing. Biological flight study and helps in improving the aerodynamic design and flight parameters of aircrafts or missiles. Use of light flapping and flexible wing models (varying wing area) need lot of careful research and application in aeronautic history. It is possible to design a light airplane with human sensory control to have a speed of 200 km/hr. This advantage may lead to higher take off acceleration (thrust or weight). Takeoff lower weight of biological fliers is the basic advantage to be considered in aeronautic history.CFD can also be carried to know enhanced flow properties.

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