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Performance Analysis of Fluted Wing Surfaces for Low Altitude Air Vehicles

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ABSTRACT

Low altitude air vehicles are becoming fascinating day by day which can be used for military and civil purposes. These vehicles are mostly used for reconnaissance, surveillance, search and rescue, disaster management and recreational purposes. The most common low altitude air vehicles are of the flapping and rotary wing configuration.

This study is intended to understand the effect of low Reynolds number (Re) flows related to fluted wing for possible application in Low altitude air vehicles. Three wings' profiles i.e. Corrugated A, Corrugated B and Flat Plate were fabricated to undertake the experimental work in a subsonic wind tunnel. Aerodynamic forces like lift, drag and moments were measured by using strain gauge balance. The measurements of moments were done in all the three axes (longitudinal, lateral and vertical axes) to find static stability of all three tested wings. The tuft and smoke flow visualization were employed on all the three types of wings to understand the flow behaviour like wing stall, flow reversal and spanwise flow. Probe measured boundary layer velocities at three different semispan locations (30%, 60% and 90% of the semispan) at a fixed chord length of 70% from leading edge (0.7 c) with range of angles of attack (AOA) and Re.

The CFD simulation of corrugated A wing with six Re ranging from 11000 to 22000 and AOA ranging from -40 to +80 in interval of 40 were done by using ANSYS Fluent software to find lift, drag, velocity contours, pressure contours and to get the location and fluid flow behaviour of Leading Edge Vortices (LEVs). CFD results showed the existence of LEVs in the valleys of Corrugated A profile and better aerodynamic characteristics such as enhanced lift and reduced drag in comparison to Flat Plate and Corrugated B profiles.

Keywords— AOA, Re, CFD, SCB, BET, UAV.

I. INTRODUCTION

After millions of years of evolution, Nature has ensured optimum aerodynamic conditions for natural flyers to face all adverse environmental conditions. Out of these natural flyers, the insects such as the dragonflies (*Sympetrum flaveolum*) are found to be unique in their aerodynamic performances like maneuverability, gliding, climbing and diving ability making these insects to replicate future creation of Low altitude air vehicles. Dragonfly makes use of its wings to fly and can also stay aloft for long duration. Dragonfly can glide without expending much of its own energy and so overhead for a longer time. Thus, the gliding feature of dragonfly wing is a one of the desired aerodynamic performance which could be incorporated into present Low altitude air vehicles in terms of power saving capabilities.

The present study aims to analyse two different types of corrugated wings named as Corrugated A, which has the similar corrugated section and other is Corrugated B, which is modification of corrugated A with a hump after 40% of chord length from leading edge. This hump is made aft of the wing as separation occurs close to the trailing edge. These two corrugated wing sections were compared with a baseline Flat Plate having similar chord length, span and aspect ratio. Experimental tests carried out by usinglow subsonic open wind tunnel by taking Re and the AOA as variables.

II. LITERATURE REVIEW

A. Introduction

A substantial amount of information is available about the natural flight of birds and insects; but most of the available information is related to biological aspects. Although engineers have now started contributing to understanding aerodynamics of natural flight of birds and insects, inadequate amount of information is available for low speed flight. From an aeronautical point of view very little information is available regarding methods of flapping system of birds and insects which falls in low speed and low Re regimes. Further, sufficient documented research work is not available, which can provide the accurate prediction about efficiency of flapping wing flight mechanism. From aerodynamics viewpoint, this flapping wing flight has not been well understood as there is lack of knowledge related to unsteady flow at low Re regimes. This lack of knowledge in unsteady aerodynamics provides a framework to understand forces governing the motion of flapping flight.

B. Background

Unmanned air vehicles (UAVs) have been the focus of aeronautical researches and engineers since the last two decades. This focus was promoted by the need of such air vehicles which are capable to execute communication, surveillance, search & rescue and detection of nuclear, biological and chemical materials during disaster conditions (Mueller and de Laurier, 2003). Further research work on smaller than UAVs, which can be portable, called Micro Air Vehicles, become even more challenging than the previous one to fly in dull, dirty and dangerous environment (McMichael et al. 1997). The low altitude air vehicles should be able to fly in low altitude, have long flight duration with small wing and low weight. the low altitude air vehicles need to meet demanding capabilities much better than the existing fixed wing or rotor wing aircrafts, such capabilities are takeoff, loiter, hover, climb, cruise, maneuver, landing and gust resistance.

C. Unsteady lift theories

Conventional aerodynamics by using quasi-steady state conditions was found to be inadequate as it couldn’t explain about lift forces generated by natural fliers. The lift force is directly similar to wing surface area and relative flow velocity. These parameters of natural fliers (insects) could not produce lift more than the weight of insects, which is the primary condition for flying any object (Vogel, 1967; Dinni and Maughner, 1994; Lentink and Gerritsms, 2003). This leads to develop some unsteady lift theories, which are able to explain the generation of lift in flapping wing fliers. So the researchers mainly focused on unsteady theories of flapping wing for lift generation. Some of the essential theories, related to this thesis are described in subsequent sections.

III. EXPERIMENTAL METHODS

A Wind Tunnel (WT) is experimental equipment for producing consistent wind flow of known rate in a channel where air flow behaviour can be examined. The WT is also useful for fluid mechanics and aerodynamic experimental analysis. This equipment can also be used for evaluating and testing of automobiles / wing / aircraft/ missiles to gain their aerodynamic efficiency/ characteristics and flow behaviour surrounding it.

Fabrication of the wind tunnel is done by using teakwood in main frames and water proof plywood as covering materials. The tunnel diffuser angle is made less than 9^0 so that the flow separation is avoided in the diffuser. The wind tunnel speed can be varied from 3 to 45 m/s. An inclined tube manometer is fixed on the tunnel. The two limbs of the manometer are connected to the static pressure holes one in the settling chamber just before the contraction and the other to that at the beginning of test section.

A. Performance of Wind Tunnel

Wind speed in a wind tunnel is measured and calculated by using Bernoulli's lawgiven in Equation.

$p0 - p = ½ \rho V^2$

Here p0 is static pressure in settling chamber, p is static pressure in test section, ρ is density of air, V is velocity of air. (p0-p) measured and is given by ρwgh, where ρw is the density of liquid used in the manometer (Methyl alcohol) 'g' is acceleration due to gravity and 'h' is the vertical length of liquid column sustaining the pressure. Density of air at Hyderabad, India is taken as 1.2 kg/m^3 and the density of alcohol is 0.8 kg/m^3. If 'h' is measured in millimeters of alcohol column, the velocity is given by Equation .

$V= 3.68 \text{ (h in mm)}^{1/2}$

If the measured liquid column length on the inclined manometer is h_m and initial value of liquid column is h_i then

$h = (h_m - h_i)/2$ because the manometer is inclined to 30^0 to the horizontal.

B. Specimen preperation

When a body moves in a fluid, the body develops aerodynamic forces and moments. These are the basic important aerodynamic characteristics in order to analyze the bodies for their aerodynamic behavior. These are calculated in wind tunnel on scaled model to predict the aerodynamic properties in real proto type machine by extrapolating to the prototype. These forces and moments are measured appropriately by suitable strain gauge balances which are intended to go well with definite given stipulation. These stipulations usually depend on the maximum and minimum loads which can be measured, maximum and minimum size of the model and also size and test section of the wind tunnels etc.

The balance system was designed for the above specifications and can be fixed easily in 600 x 600 mm test section. The model is mounted on the stem that protrudes in to the test section and has simple mechanism for pitching and yawing of the model. The stem is fixed on a metric plate which transfers the loads on to six strain elements. The outputs of the strain gauges are amplified by amplifiers, which are low noise and highly stable. The outputs from these amplifiers are measured by using microcontrollers. The programs installed on PC can down load the values written on the flash card and convert this in millivolts (mV) output from the system to actual loads i.e. lift, pitching moment, rolling moment, side force, yawing moment and drag. The maximum values which can be measured are mentioned above. The picture of Six Component Balance EBAL-00106 used is shown in Figure below.

C. Six Component Balance

The SCB consists of following three major parts.

1) **Balance mechanism:** This mechanism made of load transfer device to strain gauged system along with pitching and yawing measuring lever system. This system also consist of a calibration attachments system used to calibrate the balance.
2) **Strain gauge instrumentation amplifiers:** There are six strain gauge amplifier for every six strain gauged elements. Used to amplify the signal generated by strain gauges.
3) **Microcontroller capacity mechanism:** This mechanism is used to measure the different forces and moments based on microcontroller system. This is used to measure output from the concerned strain gauges which is used for measuring outputs from the different strain gauges. The obtained value is amplified and communicated to computer and to store the measured values.

Details of RPM, velocity and Reynolds number

RPM	'h' mm	'V' m/s	Reynolds Number (Re)
100	0.5	2.53	1.9x10^{4}
200	2.5	5.66	4.4x10^{4}
300	5.5	8.39	6.6x10^{4}
400	10	11.32	8.9x10^{4}
500	15	13.86	1.09x10^{5}
600	22.5	16.98	1.3x10^{5}
700	31	19.93	1.5x10^{5}
800	41	22.92	1.8x10^{5}
900	53	26.06	2.05x10^{5}
1000	66	29.08	2.2x10^{5}
1100	80.5	32.12	2.5x10^{5}
1200	96.5	35.16	2.7x10^{5}
1300	114	38.22	3.0x10^{5}

Fabrication of Corrugated A Wing.

Fabrication of Corrugated B Wing.

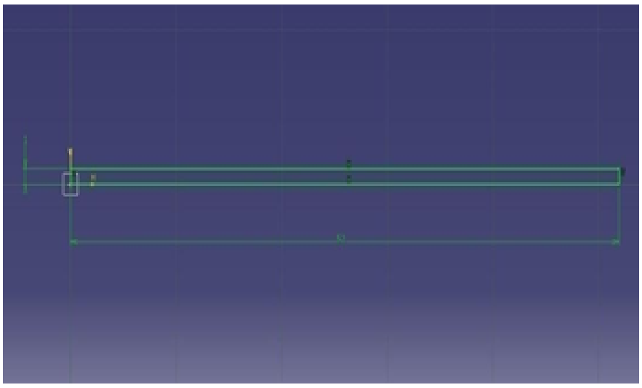
IV. NUMERICAL ANALYSIS

This study uses two different types of computational methods. First one is Two-Dimensional Panel Method, which is simple and fast need limited computational facility. The mathematical formulations are given. The own codes are made in MATLAB second one is Computational Fluid Dynamics (CFD) method, in this commercial ANSYS Fluent Software is used. This needs more advanced computational facility, time, and money. This is one of the proven methods.

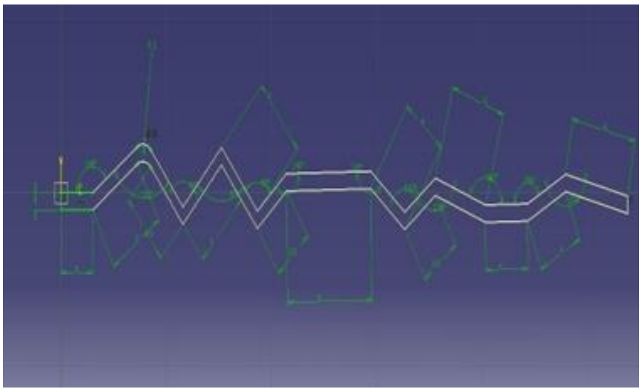
A source is a point at which the fluid appears in the field at uniform rate while a sink is point in which the fluid disappears at uniform rate in m^3/s. Each source or sink has specific strength denoted by circulation; Γ. The point source or sink is distributed uniformly in all directions of the flow field and obey the continuity equation and irrotational motion everywhere except at the point itself, Houghton and Carpenter (2003).

A. Airfoil geometry

A computational CFD study under taken to assess the panel method for its suitability in low Re flows which can be useful for MAVs flight range. Flat plate and a corrugated A model of wing were modeled by using ANSYS software with suitable co- ordinates to test their performance in gliding flight. The chord length for both the profiles was taken as 52 mm. Figure show the flat plate and Figure shows the corrugated profile.



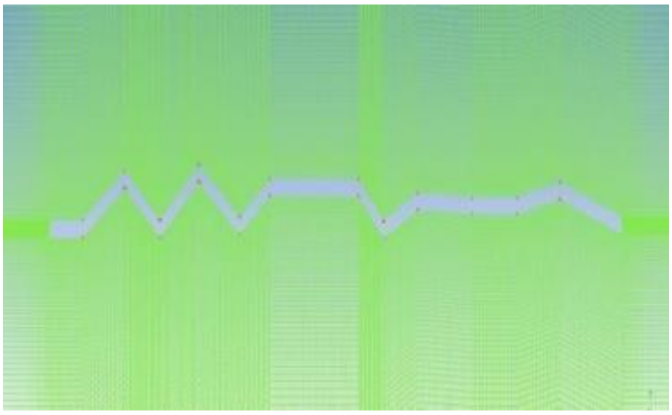
Geometry of the Flat Plate.



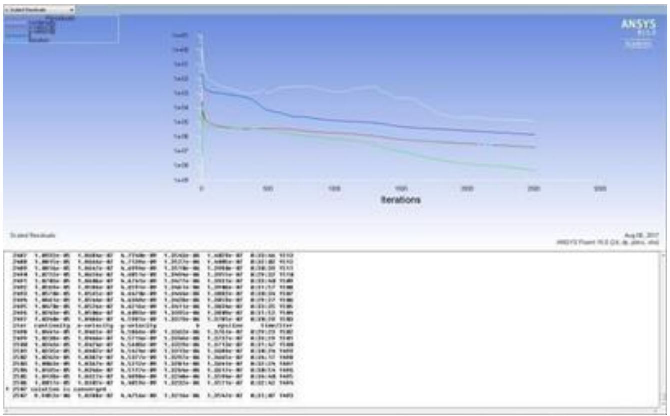
Geometry of Corrugated A profile Tamai et al. (2007).

B. Computational grid and boundary conditions

Computational grid was considered for simulations is depicted. The free stream velocity, and static pressure are prescribed at the inlet. The distance between the top and bottom boundaries is taken as 600 mm which is the width of wind tunnel where the physical models are tested. ICEMCFD is used for meshing the grid. Blocking technique is used for generating a structured grid.



Grid on corrugated A airfoil.



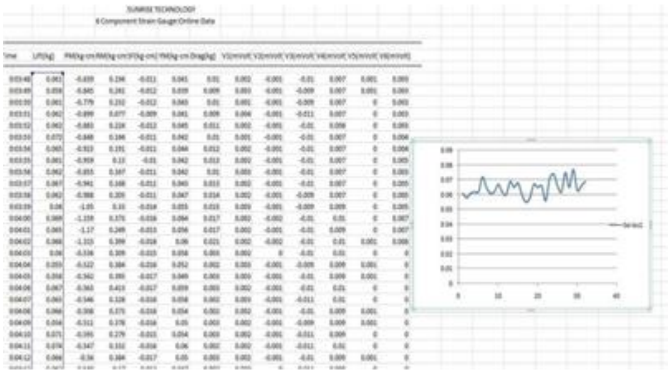
Mesh convergence

V. RESULTS AND DISCUSSION

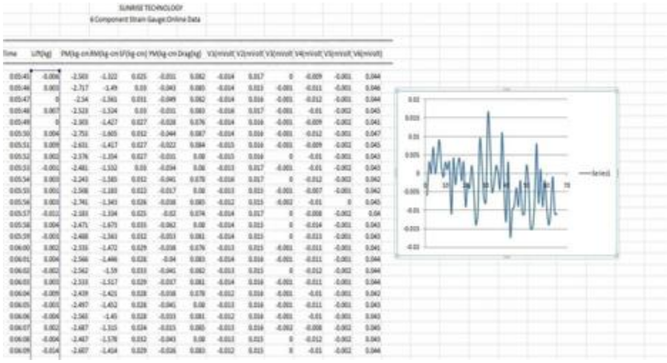
The aerodynamic forces like lift (L) and drag (D) were measured by a Six Component Balance (SCB) model WBAL-00106, which was fitted underneath the test section of Wind Tunnel. Wind Tunnel speed was regulated and controlled by AC Motor Controller. The motor RPM (Rev/minute) is calibrated to find the wind tunnel free stream velocity and converted to Reynolds number as per Equation 4.31. Three types of wings i.e. Flat Plate, Corrugated A and Corrugated B were fabricated and mounted on the top of the stem of the SCB. This stem is inter-connected to the different strain gauges fitted inside the Balance. These strain gauges convert forces and moments into electrical signals and give output in voltage, which are amplified by digital amplifier. These voltage signals are converted to forces and moments and displayed on the screen directly. This SCB is able to measure three forces like Lift, Drag and side force and three moments like pitching, rolling and yawing. The accuracy of this SCB is 0.1 N for all forces and 0.1Nm for all moments. The possible errors in lift force and moments are 2% and in drag force 3% as claimed by manufacturer. The experimental results obtained are analyzed.

The stabilization study of SCB was done by running the wind tunnel for long time and observing the SCB values to get reading within the range. The stabilization studies were done at -4^0, 0^0, 4^0, and 8^0 AOA.

It took minimum 10 minutes to 30 minutes for the value to get stabilized. The stabilization was done for wind off mode and wind on mode of SCB. The wind off mode gives the initial wing loading without the effects of fluid flow.



Six-component balance stabilization study at -4^0 AOA at wind off mode.



Six-component balance stabilization study at -4^0 AOA at wind on mode.

The CFD results of CL/CD ratio of Corrugated A profile were compared for three different Reynolds numbers i.e. 11000 and 22000 with experimental results.

Results showed that CL/CD at Re 11000 is found highest at all tested AOA and lowest at Re 50000 in both experimental and CFD results. It was also observed that computational results of all the tested Reynolds numbers are very closed with experimental results up to 4 degree AOA. Deviation in results of CFD with experiments is less than 5% from -4^0 to $+4^0$ AOA. At 8 degree AOA, the deviation in computational results with experimental results is significant and found that for Re 11000it is 25%, for 50000 it is 21% and for 72000 it is 10%. When the AOA increased 8^0 AOA, CFD results over predicted because it is not able to capture unsteadiness.

The coefficient of lift for corrugated B profile was found higher compared to other two profiles i.e. Flat Plate and Corrugated A. The drag coefficient for corrugated A found to be comparatively lesser than Flat Plate and Corrugated B wing and hence the performance (CL/CD), was found highest for corrugated A profile followed by Corrugated B profile and Flat Plate. Flow visualization by tuft revealed that flow separation and flow reversal first occurred near the wing root (30% of semispan) at lower AOA (6^0) and low Reynolds number on Flat Plate only. On Corrugated A wing flow separation and reversal observed at 10^0 AOA with expanded span locations from 30% in Flat Plate to 70% in Corrugated A wing. A delay in stall angle of 4^0 is observed due to corrugation on wing, which is 40% more delay angle than the Flat Plate. It was also found that as AOA increased to 12^0, more span area is affected by flow separation and reversal. Total breakdown of laminar flow observed at this AOA and Re. The flow near the wingtip (15% from the tip) was not found reversed at any tested AOA and Re in both types of tested wings. Flow parameters like pressure and velocity found varying in different spanwise locations.

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