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A Review on Bio-inspired Airfoil: Inspiration from Nature

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Abstract: ***With the advancement of modern technology, researchers have been working hugely on the aerodynamics with a view to improving and enhancing the performance of the existing airfoils. Several numerical as well as experimental investigations have been performed in this regard. A breakthrough in the field of aerodynamics is the modification of airfoils getting inspired from nature. This paper reviews the works on such airfoils. Researchers have tested several parameters to find out their effects on the overall performance of the airfoils. Modifications on the geometry of the airfoil have been investigated. Different Reynolds numbers have been used to analyze their effect on aerodynamic performance of the corresponding airfoil. The inspiration for such airfoils has originated from the low flight insects like butterfly, dragonfly etc. The places where conventional air vehicles can't reach, Micro Air Vehicles (MAV) can play an important role especially in military use for security purpose and so on.***

Keywords: Corrugated airfoil, Lift, Drag, Reynolds number, Aerodynamic performance, Angle of attack

1. Introduction

The development of miniature flying vehicles i.e. Micro Air Vehicles (MAVs) has paved the way for the continuous improvement of airfoils which are constructed on the basis of wings present in insects like dragonflies. For the lower Reynolds number, this type of airfoil carries extra significance. Moreover, the insect wings are usually characterized by corrugated airfoils. Hence, several modifications have been made in corrugated airfoils for their implementation in MAVs. Both experimental as well as computational works have been carried out by the researchers several times. Different aerodynamic parameters like chord, camber, angle of attack, Reynolds number, corrugation angles, corrugation position etc. have been changed to bring out the best performance from the airfoil. The effect of these parameters on lift, drag, pressure profile, flow separation has been studied elaborately in multiple research works. The computational works agree with the existing experimental works and it is not obscure that the corrugated airfoils provide better performance than the conventional airfoils.

2. Previous Works

Murphy and Hu [1] did a splendid experimental research on the bio-inspired corrugated airfoil. Based on this work, many further investigations have been carried out. He compared the performance of corrugated airfoil with a streamlined airfoil as well as a flat plate. The chord Reynolds numbers used in this experiments were in the range of 58000-125000. Aerodynamic lift along with drag was measured on the tested airfoils. Moreover, they incorporated a digital particle image velocimetry (PIV) in order to measure flowfield and quantify the vortex behavior and turbulent flow structures around the airfoils. Their findings from the experiments show that, corrugated airfoil provides better aerodynamic lift than the flat plate and streamlined airfoil. Also, the corrugated airfoil prevents large scale flow separation compared to the other two types.

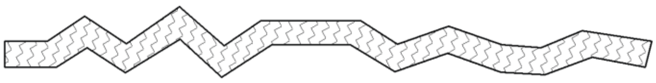

Figure 1: A Corrugated Airfoil [1]

Khan et al. [2] performed some computational research on such bio-inspired corrugated airfoils. They used CATIA for modeling the wings and then performed simulation on Ansys-FLUENT. In this research work, the authors used different corrugation angles to observe the performance of the airfoil. Flow separation occurs at the valleys of the corrugation. It is observed that the separated flows reattach at the rear end of the wing. In this analysis, they created three types of airfoils. One is triangular wavy airfoil and another two are modified wing (MW-I and MW-I) based on variable pitch length. They compared the performance of corrugated airfoils with flat plate and NACA 0015 airfoils. The aerodynamic performance of the MW-I is better than MW-II and NACA 0015 airfoils that means the lift to drag ratio (L/D) is larger in case of MW-I. In this investigation, Reynolds number used was in the range of 15000-38000.

Ho and New [3] performed an unsteady numerical investigation on two different bio-inspired corrugated airfoils at Reynolds number 14000. The aerodynamic performance and the flow characteristics of those two corrugated airfoils were compared with NACA 0010 airfoil. The aerodynamic performance of an airfoil can be suggested as good if the airfoil creates more lift compared to the generated drag. From the analysis of this investigation, it was found that corrugated airfoils produce more lift than the conventional smooth NACA 0010 airfoil. But at the same time, corrugated airfoils create some extra drag as penalty. The corrugated airfoils were generated based on corrugation size namely CorrugatedA (with small corrugations) and CorrugatedB (with large corrugations). Flow separation regions of these airfoils have been represented for various angles of attack e.g. 0º, 10º and 20º. Since the lift coefficient is better in case of the corrugated airfoils, the pressure variation plays very important role here. In case of smooth NACA 0010 airfoil, the pressure profiles are almost same for the upper surface and lower surface of the airfoil. This phenomenon eventually results in the zero lift force. On the contrary, there profiles exhibit variation on the lower and upper surface. Hence, the lift is no zero in this case. Up to angle of attack 20º, the corrugated airfoils show less flow separation with respect to the smooth NACA 0010 airfoil.

With simplified dragonfly airfoil, **Levy et al. [4]** investigated the aerodynamic performance at Reynolds number lower than 8000. Since many insects fly at Reynolds number lower than 20000, this work is a significant piece of work. It can be hypothesized that dragonfly flies without wing flapping at higher Reynolds number. Hence, this consideration can be incorporated at the design of airfoils for MAVs. In this study, the authors used low-speed wind and water tunnels for conducting experiments on corrugated airfoils in order to validate the numerical results. They also compared the performance of the corrugated airfoil with a traditional low Reynolds number airfoil: Eppler-E61. The corrugated airfoils provide superior results. In this research work, the angle of attack was varied between 0º to 10º. Since this study is focused on lower Reynolds number flight, the value of Reynolds number was always kept between 2000-8000.

Levy and Seifert, 2009 [5] studied different parameters of dragonfly airfoil at Reynolds number of 6000. The several parameters include the number of corrugations present in the airfoil model. The effect of two corrugations has been studied. Also, the effect after the removal of one corrugation has been investigated. Thus the researchers studied how the position of the corrugation influences the airfoil performance. The corrugation height effect has also been studied. The position of the corrugations with respect to the chord length also influences the airfoil performance and this has also been investigated. The region between the corrugations is known as valley and the effect of valley depth has been observed too. The first corrugation position also affects the performance of airfoil. In this regard, two airfoil geometries were taken. The cavity between the second corrugation and rear arc also affect the overall performance. The rear arc curvature effect has also been analyzed in this study. In the first half of the airfoil chord length, there is no significant effect of the arc curvature. The authors also examined the effect of the trailing edge slope on the aerodynamic performance of the airfoil.

Vargas et al. [6] also performed a computational research to investigate the aerodynamic performance of a dragonfly wing section in gliding flight. In this study, NACA 0008 airfoil was used for the purpose of validation with an angle of attack 4º. The Reynolds number was in the range of 2000-6000. Pleated airfoil, profiled airfoil and flat plate were used as airfoil geometry in this research. Aerodynamic coefficients like lift, drag were measured at 5000 and 10000 Reynolds number with 0º angle of attack. In this study, gliding ratio is the main point of interest. This gliding ratio is defined as the ratio of lift to drag. The performance of the wing section was compared with several conventional airfoils obtained from literature as well as the NACA 0008 airfoil.

Mondal et al. [7] performed some numerical investigation to find out the aerodynamic performance of bio-inspired corrugated airfoil at low Reynold numbers. These simulations were conducted at chord Reynolds number 80000. The authors analyzed the flow field around the corrugated airfoil by using structured grid and Finite Volume Method (FVM) which is based on Navier Stokes Equation. For better understanding, the researchers made all the flow parameters non-dimensional. From their analysis, they found that the coefficient of drag as well as the coefficient of lift remains unsteady for a significant time. Actually the oscillation doesn't diminish completely. Rather it gets confined to a certain range after a certain period. The oscillations are not periodic in this case. The authors investigated the flow field around the corrugated airfoil and the coefficient of pressure contours at several angles of attack like 0°, 4°, 8°, 12°, 16° and 20°. The authors of this research adopted the corrugated airfoil geometry from **Murphy and Hu [1].** The obtained result of this work is similar with the previous works of this corrugated airfoil i.e. corrugated airfoils provide higher aerodynamic performance by generating greater lift with moderate drag.

Meng and Sun [8] also used Computational Fluid Dynamics technique to observe the effect of wing corrugation at gliding flight at low Reynolds number. Although many investigations show that the corrugated airfoils provide better aerodynamic performance and increases lift force to a large extent compared to drag force, this study revealed something different. In this research work, the authors used very low Reynolds number (Re=200-2400). This investigation reveals that the presence of corrugations result in reduced lift force and brings a little change in frag force. In this study, the authors showed that about 16% lift force is reduced at 15°-25° angles of attack. Even the %lift reduction is more in case of smaller angle of attack because of lower lift force.

3. Conclusion

The nature never stops surprising us. The concept of the incorporation of corrugation in the airfoil comes from little insects around us. The wings of such insects are very thin and light. Also, the wings are corrugated in shapes. The interest of the engineers and researchers are increasingly growing about this topic. Numerous experimental as well as computational works have been carried out to find out whether or not the aerodynamic performance increases with the incorporation of corrugation in the airfoil geometry. Most of the studies find that the aerodynamic performance i.e. gliding ratio increases for the corrugated airfoil. Variation of performance is also observed with the variation of Reynolds number. At very low Reynolds number, the corrugated airfoil provides low lift. More research can be carried out. The Reynolds number range can be changed and corrugation shape can also be modified to find out a more suitable bio-inspired airfoil for Micro Air Vehicles (MAVs).

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