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Performance of Aerodynamic Characteristics on Different Shapes of NACA Aerofoil

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Abstract

The selection of basic lifting surfaces of aircraft, aerowing, is one of the very vital issues on the basis of lift, drag and performance. The designing of the Aerofoil with desired aerodynamic characteristics is not so easy till date. From the beginning enormous number of scientists and engineers toiled hard in this field to develop proper shape and design of aerofoil. Here a little effort has been taken to study the performance of varying designs of aerofoil with the help of low velocity wind tunnel at CCET, Bhilai. In this work, an experimental investigation and an enhancement in the performance of an aerofoil of different shape have been considered for study. The study has been conducted at Mach number 0.71 and Reynolds number 2.11 × 10^5 as well as altering the shape of three different aerofoil. All the aerofoils have been tested for a wide range of angle of attack from 0 degree to 20 degree at a step of 2 degree interval and result shows that symmetrical aerofoil produces 100 percent more lift compared to flat aerofoil, performance of symmetrical aerofoil increases 240 percent compared to cambered aerofoil. Symmetrical aerofoil is the best amongst cambered and flat aerofoil at lower angle of attack but at higher angle of attack i.e. after 8^0 angle of attack cambered aerofoil shows better performance.

Index Terms: *Aerofoil, Lift, Drag, Critical angle, Lift to drag ratio, Reynolds number.*

1. Introduction

The observation on birds flying altered into technology in 1903 when Wright Brothers gave their new invention and thereafter continuous endeavors in this field. Researchers and scientist put in their enormous effort with progress to a great extent but still, there are many more findings to be done to get freedom in the air. Continuous attempts have been made to enhance the performance of lift, speed and aerodynamic efficiency of an aircraft by reducing drag. Aircraft wings are the lifting surfaces with the chosen aerofoil sections (M. N. Haque et al. 2015). From the commercial passenger carrier to supersonic fighter used in defence services, everywhere there has been an exponential growth in the aviation industry. However, still there is vast scope for further improvements. Here is a study that makes one such attempt. At present, different kinds of surface modifications are being studied to improve the maneuverability of the aircraft. Vortex generators are the most frequently used modifications to an aircraft surface (A. Shariq, A. Hussain, and M. A. Ansari 2018) . Transition from laminar to turbulent flow due to the positioning of dimples at the surface strongly influences the flow separation and the skin friction, thus affecting the airfoil aerodynamic characteristics (P. C. S. Kapsalis et al. 2016). Vortex generators create turbulence by creating vortices which delays the boundary layer separation resulting in decrease of pressure drag and also increase in the angle of stall. A stall, as a threat to safe flight, is a condition in aero-dynamics and aviation industries where the angle of attack increases beyond a certain value such that the airflow starts to separate and the lift begins to decrease drastically (P. C. S. Kapsalis et al. 2017). It helps to reduce the pressure drag at high angle of attack and also increases the overall lift and aerodynamic efficiency of the aircraft.

Airplane wing performance is often tainted by flow separation which mainly depends on the proper design and effective modifications (M. N. Haque et al. 2015) . Furthermore, non-aerodynamic constraints are often in conflict with aerodynamic restrictions, and flow control is required to overcome such problems. The surface modifications which are being considered in the given study are layer/layers of dimples of hexagonal shapes and the position of dimple layers in reference to chord. Flow remains attached with the surface at lower angle of attack. As soon as the angle of attack increases, the flow separation begins from the particular regime of aerofoil surface to the trailing edge of the aerofoil. The separated regions on the top of the aerofoil increase in size with the angle of attack and hinder the wing's ability to create lift. At the critical angle of attack, separated flow is so dominant that, further increase in angle of attack produces less lift, efficiency and vastly more drag (M. S. Genc et al. 2012). In order to verify the effect of series of dimples, result of hollow and solid dimples and relative position of dimple series with respect to the chord have been made in this study. Through this experimental study, we aim at making aircrafts more maneuverable by defining the layer/layers of dimples with their respective position over the airfoil surface. Also we are looking for improving performance by more Cl/Cd ratio i.e. increasing aerodynamic efficiency.

Aerodynamic efficiency is one of the key parameters that determines the weight and cost of an airplane. Roughly speaking, an aircraft's range is directly proportional to its aerodynamic efficiency without any increase in fuel usage. Improved aerodynamics is critical to both commercial and military aircraft. For commercial aircraft, improved aerodynamics reduces operating costs. It also significantly contributes to the national security by improving efficiency and performance of military aircraft. The results justify the increase in the overall lift and aerodynamic efficiency, reduction in drag at higher angle of attack of the airfoil.

1.1 Experimental Set up

Experiments as per defined scheme were conducted at the 7.4 m long low speed wind tunnel located in the Fluid Mechanics Laboratory of Christian College of Engineering and Technology, Bhilai.

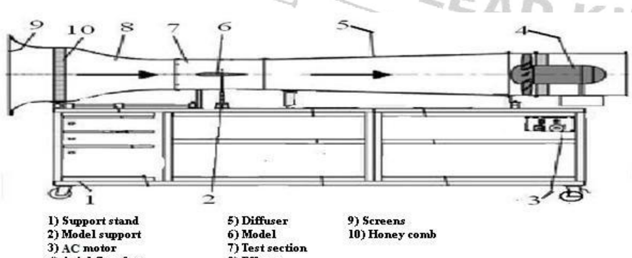

Fig.1. 1, Schematic diagram of the experimental setup.

The body of the wind tunnel is made of wood with honeycomb structure, further reinforced by wooden strips to maintain the strength of the tunnel. The body of the tunnel is divided into three major sections i.e. Inlet section called as Effuser, centre part called Test section and outlet section as Diffuser. Effuser is 3.8 m long which is gradually convergent towards the center section and made of wooden strip of honey comb structure. Face of the effuser is made of very close mesh rectangular structure that facilitated laminar air flow at the entry of the section. Test sections is at 4 m downstream of tunnel entrance as shown in fig.1.1 and 1.2.

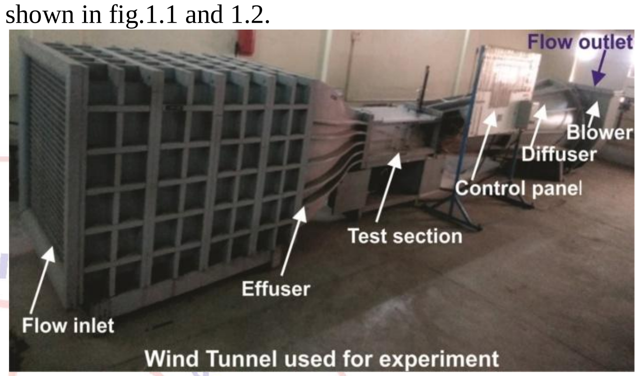

Fig.1.2 Wind tunnel used for the experiment at Christian college of Engineering and Technology, Bhilai. Different section of the tunnel as marked over the tunnel.

Three sides thick Perspex made rectangular test section of 0.3×0.3×0.9 m3 as shown in fig.1.2 were used in placing the models and provided clear visibility while tests were conducted. A small Perspex side window and total top thick Perspex cover can be opened whenever requirement arises; otherwise both the panels remained closed during an experimental run.

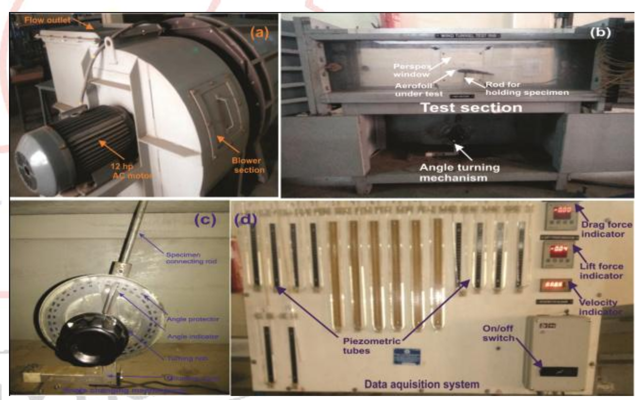

Fig.1.3 (a) A photographic view of front part of Blower coupled with motor, (b) photographic view of Test section with aerofoil and connecting rod holding the model under test.,(c) Angle turning mechanism used for adjusting angle of attack , (d) Data acquisition system.

A Connecting rod that is attached with a special mechanism at the bottom of test section arranged for holding the model under test is shown in fig. 1.3. An angle protector set with angle turning mechanism monitored the defined angle of attack whenever test had been carried out. Continuous divergent, 3.4 m long wooden honeycomb end section is the diffuser. At the end of the diffuser, blower is attached to create the flow of air within the tunnel. A photographic view of different section of tunnel is shown in Fig. 1.3 (a) and (b). A bend Pitot tube is positioned at that section to observe the velocity of the flow while experiments were conducted. A specially designed hot air gas indicator was also used to record the velocity of flow.

A long data acquisition control panel was placed on the stand where fifteen Piezometer tubes are mounted to record the pressure if required, at the different section of aerofoil under test as shown in fig.1.3 (d).here Three separate digital indicators were used to record Drag force, Lift force and velocity for every change of circumstances in the experiments. An on/off switch mounted over the panel to start and stop the blower as and when requirement arises in the period of experiment is shown in fig. 1.3 (d).In the past days, when human being was yet residing in the part of creation, the main method for velocity was his legs. Subsequently, we have established faster and more plentiful methods for voyaging, most recent comprising the air conveyance. Since, its innovation planes have been adopting more fame as it is the quickest method of conveyance accessible. It has additionally picked up fame as a war machine since World War II. This prominence of air transport has prompted numerous innovations and exploration to grow quicker and more conservative planes. This work is an attempt to adjudicate how we can deduce most extreme execution from an aerofoil segment. An aerofoil is a cross section of wing of the aircraft. Its fundamental occupation is to give lift to a plane amid departure keeping in mind of trajectory. Yet, it has a component of resultant force called pressure –form drag which restricts the movement of the plane. The measure of coefficient of lift and its force required by an aircraft relies on upon configuration and assembly of various parts to the concerned aircraft. Heavier one accommodate more lift while lighter oblige less compared to heavier ones. Accordingly, contingent on the utilization of plane, aerofoil area is resolved. Lift however exert additional prediction to the uplift raising speed of the aircraft, which in turns depends on upon the plane with respect to flat speed. Hence, the coefficient of lift and coefficient of pressure is the deciding factor to ascertain how the lift responds as per the velocity and various parameters.

Fig.1.4 Shows the three different types of aerofoil has taken for experimental purposes, (a) Camberd, (b) Flat and (c) Symmetric aerofoil.

1.2 Mathematical model

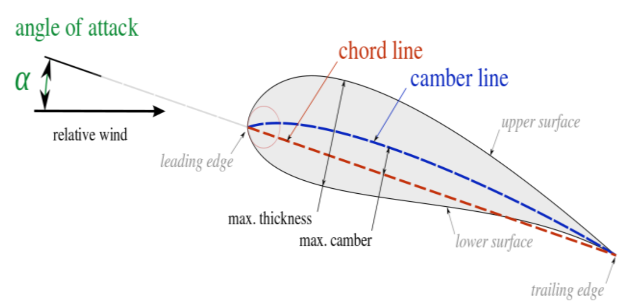

Fig.1. 2.1 Airfoil Section

$L = \frac{1}{2} C_l \rho A V^2$

$D = \frac{1}{2} C_d \rho A V^2$

The Reynolds number is defined as $R_e = \frac{\rho L u}{\mu} = \frac{\rho L}{\nu}$ where:

- ρ is the density of the fluid (**SI units**: kg/m^3)
- u is the velocity of the fluid with respect to the object (m/s)
- L is a characteristic linear dimension (m)
- μ is the **dynamic** viscosity of the fluid (Pascal or N·s/m^2 or kg/m·s)

$M = \frac{U}{C}$

M is the Mach number

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u is velocity of the moving aircraft and
c is the speed of sound at the given altitude

2. Result and discussion

The three different types of aerofoil of equal thickness and projected surface area has been chosen for tested in low velocity wind tunnel kept in Strength of Material in CCET, Bhilai. The test has been conducted by preparing each model with defined specific wood and finished properly as shown in the figure. In certain cases it is painted with red paints and proper smoothness is achieved. Three different models placed in the test section as per installing instruction laid down by the supplier.

Three sets of data were taken by placing three different aerofoils from data acquisition system of wind tunnel at different angle of attack. Angle of attack varies from zero degree to twenty degree at the step of two degree. The experiment was conducted at flow velocity of V= 42±3 m/s. The value of C_D , C_L , and C_L /C_D all are recorded from the data acquisition system from the wind tunnel. The value of co-efficient was recorded when the wind tunnel reaches its equilibrium speed and most cases the time of each experiment was for 3±0.2 sec. Similar practices was continued just after changing the angle of attack. Calibrated Pitot tube was used for measuring the flow velocities within the tunnel. Coefficient of lift and coefficient of drag and performance (C_L /C_D) verses angle of attack as shown below.

In figure 2.1 (a) & (d) describes that the coefficient of lift (C_l) of flat and cambered aerofoil significantly differs from symmetrical aerofoil. In fig.2.1, (a) cambered aerofoil produces highest value of C_l is 5.29 at 17^0 where as the symmetrical aerofoil produces value of C_l is 6.02 at 13^0 angle of attract, it also prominently observed that stall occurred at symmetrical aerofoil is quite early as compared to cambered aerofoil. At 13^0 angle of of attack the % increase of of C_l value for symmetrical aerofoil is 14.8 compare to cambered aerofoil. And in (d) highest value of C_l is 3.02 at 18^0, it also prominently observed that stall occurred at symmetrical aerofoil is quite early as compared to flat aerofoil. And value of lift coefficient increases by near about 100% in symmetrical aerofoil as compared to flat aerofoil. The critical angle for flat aerofoil is recorded as 17^0 in place of thirteen degree for symmetrical aerofoil. Fig.2.1 (b) & (e) plot show that the value of drag coefficient (Cd) for both cambered and flat aerofoil compared with symmetrical one. The value of Cd is comparatively lower in symmetrical aerofoil at lower angle of attack up to 8^0 thereafter the value of Cd for symmetrical aerofoil increases sharply. Both camber and flat aero foil produces lesser value of Cd at higher angle of attack. Stall occurred for cambered aerofoil at 18^0 and flat aerofoil at 17^0 successively. Similarly the performance (C_l/C_d) of cambered and flat aerofoil that is plotted in fig.2.1 (c) & f depicted that the value of (C_l/C_d) for symmetrical aerofoil is 240% higher than flat and 206 % higher than cambered aerofoil approximately up to 8 to 9 degree angle of attack but the performance of camber aerofoil after 12^0 and flat aerofoil after 13^0 supersede over the symmetrical aerofoil.

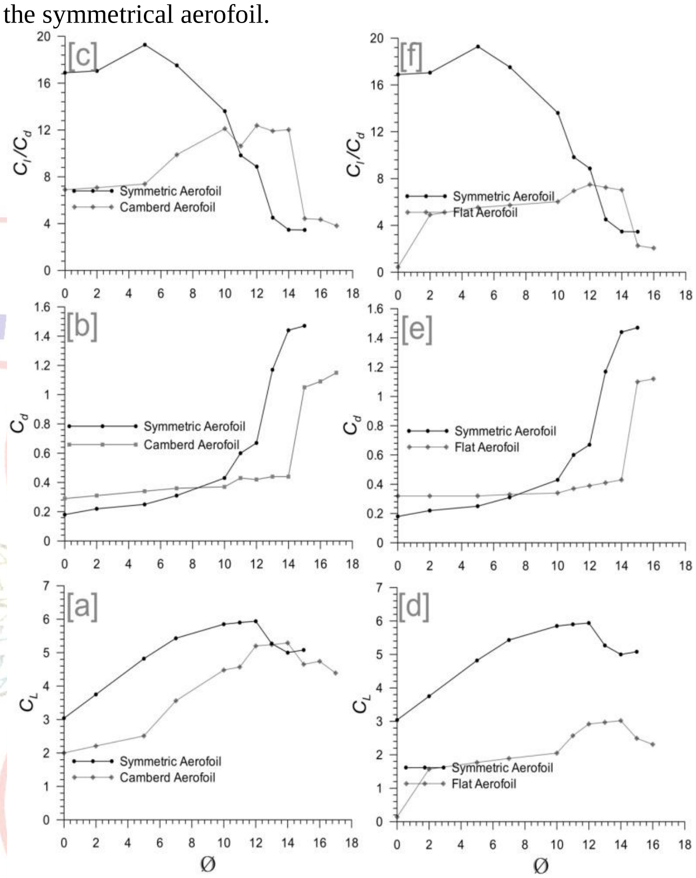

Fig: 2.1 The plot (a) & (d) shows that coefficient of lift with angle of attack (Ø) ,(b) & (e) coefficient of drag with (Ø) and (c) & f with performance of aerofoil with (Ø).

In fig.2.2 (a),(b) and (c) plots describes the comparison of lift coefficient C_l, Value of Drag coefficient C_d and the performance C_l/C_d of all three different aerofoil. The plot (a) clearly explain that symmetrical aerofoil generate highest value of C_l till to 13^0 angle of attack but above that cambered aerofoil proves better performance amongst all three different shape of aertofoil. It also illustrate that the critical angle for camber aerofoil is significantly high than other two types aerofoil with similar thickness and surface area. In 2.2 (b) The value of Cd is quite similar in flat and cambered aerofoil compare to symmetrical aerofoil but in symmetrical aerofoil shows very distinct difference than other two types aerofoil. The value of coefficient of drag for symmetrical foil was appreciably low but as soon as it crosses 8^0 then that value of Cd certainly rises up and overshoots the value of other two types of aerofoil. Fig 2.2(c) it also illustrates that performance (C_l/C_d) of symmetrical aerofoil is drastically high at 6^0 angle of attack and the values 240% higher than

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cambered and 315% higher than flat aerofoil. As critical sharply decreases up to 12^0 and after 12^0 the the value of C_l/Cd in flat aerofoil reaches to 12.2. The result shows that at higher critical angle the flat aerofoil is the best for selection.

increases the value of C_l/C_d of symmetrical aerofoil

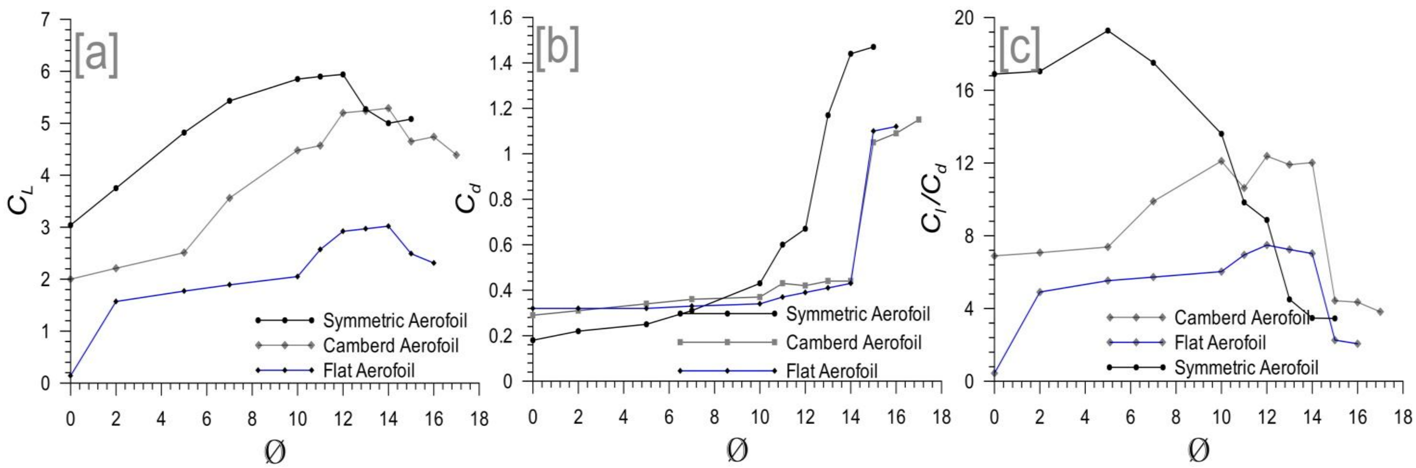

Fig: 2.2 The comparison plots illustrate (a) coefficient of lift with angle of attack (Ø) ,(b) coefficient of drag with (Ø) and (c) performance of aerofoil with (Ø) of three different shape of aerofoil.

3. Conclusion

Total of 32 experiments has been conducted in three different shapes of aerofoils to study the performance of the varied aerofoil shape keeping same thickness and projected surface area. There are 12 experiments have been conducted keeping a wide range of angle of attack from 0 degree to 20 degree at a step of 2 degree interval. Based on the performance it is viewed that Symmetrical aerofoil is quit best than cambered and flat aerofoil at lower angle of attack but the flat aerofoil shows prominent performance at higher critical angles. The stall angle is also extended for flat as well as cambered aerofoil but in symmetrical aerofoil stall occurred early that is closed to 13^0angle of attack.

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