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Experimental Study on NACA 2415 Airfoil with Rotating Cylinder at Leading Edge

*Nashidul Islam**, *Md. Mamun Islam*, *Mohammad Mashud*, Abdullah Al Faruk
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT
An aircraft's aerodynamic efficiency largely depends on lift and drag forces, stall angle at different stages of flight. The increase of lift and stall angle improve maneuverability and performance of any fixed wing aircraft. An experimental investigation has been conducted on a two dimensional NACA 2415 airfoil equipped with a rotating cylinder at leading edge. Rotating cylinder serve as active control device for boundary layer flow separation, thus increasing airfoil's lift and stall angle of attack. The effect of angle of attack, momentum injection ratio (ratio of cylinder linear motion to free stream air velocity) on the lift coefficient, drag coefficient and stall angle of attack are investigated in this study. The use of rotating cylinder at the leading edge of the airfoil increases the lift coefficient compared to the conventional NACA 2415 airfoil about 38.63% and stall angle increases to 16° from 12° at momentum injection ratio of 0.1173.

Keywords: NACA 2415, Coefficient of Lift, Momentum Injection Ratio, Rotating Cylinder, Stall Angle.

1. Introduction

Most common problem to solve of every aerodynamic research is to increase lift and decrease drag forces of the wing without decreasing stall angle of attack. Higher lift to drag ratio is useful in raising heavier payload and to improve maneuvering performance of fixed wing aircraft. If boundary layer separation over an airfoil is avoided this higher lift to drag ratio can be achieved [1].The classification of boundary layer control methods into active and passive categories is one of the most common schemes. Vortex generators, distributed roughness, streamlining, and uniform blowing and suction are among various devices that are employing for the passive flow control technique. On the other hand, some of the active flow control methods are heating wall, movement of surface elements, oscillatory blowing and suction, and synthetic jets[2].
Hassan and Sankar [3] investigate the effect of fore-body boundary-induced vorticities on the generation of laminar or turbulent boundary layers over modified NACA 0012, NACA 63-218 airfoil with leading edge rotating cylinder. They use an implicit finite difference procedure to solve the two-dimensional compressible full Reynolds-averaged Navier-Stokes equation. According to investigation for subcritical flow rotating cylinder create a wall jet like effect resulted in the decline or complete elimination of surface separated flow region. Thus increasing sectional lift force by using leading edge rotating cylinder.
Tennant [4] tested a symmetrical airfoil model with a trailing edge cylinder in a low speed wind tunnel. Here lift produced as a function of cylinder speed when cylinder speed is three times higher than free streamSpeed. And lift produced at 0º angle of attack is 1.20 when speed ratio is 3.
X. Du and T. Lee[5] investigated the leading edge rotating cylinder(LERC) as a boundary layer control device on NACA 0015 airfoil. Here effect of a LERC on the growth, development and separation of boundary layer along with wake structure development on the behind of symmetrical airfoil NACA 0015 airfoil had been demonstrated.
Ahmed Z. Al-Garni [6] experimentally studied a two dimensional NACA 0024 airfoil mounting a leading edge cylinder at leading edge. This experiment showed that lift coefficient of NACA 0024 airfoil increases from 0.85 to 1.63 and delay stall angle of attack by about 160%.
V. J. Modi[7] uses concept of moving surface boundary layer control applied to Joukowsky airfoil throughout an experimental study by flow visualization technique. Here maximum lift coefficient achieved as around 2.73 which is approximately three times of the original airfoil.

The focus of this paper is to provide an effective- active control method of the boundary layer. This was accomplished by replacing the normally static leading edge of NACA 2415 airfoil with an input controlled rotating cylinder. Sometimes this process is known as moving surface boundary layer control(MSBLC). This investigation explains the effect of angle of attack, α and momentum injection ratio, $r=U_c/U_\alpha$on the lift, drag and stall angle of NACA 2415 airfoil.

2. Experimental Setup

First NACA 2415 airfoil surface has been generated by using C++ programming language by applying basic airfoil surface equation. Then surface has been created using SolidWorks with appropriate dimension suitable for wind tunnel testing. A cylinder groove has been cut in front of the airfoil so that external cylinder can rotate within the groove. Details dimension is given in Fig.-1.Actual model of modified NACA 2415 airfoil has been created using wood and a 24V DC motor has been directly coupled with cylinder which is to be rotated. A holding mechanism for this rotating cylinder and airfoil on wind tunnel is created which is shown in fig 2 along with wind tunnel setup. For this experiment subsonic wind tunnel of 1m × 1m test section dimension has been used. Experiment was conducted at free stream velocity

*Corresponding Author Tel.: +88-01
E-mail addresses: i.nashidul72@gmail.com

25m/s and 30 m/s. And cylinder rotation has been used 4000 rpm. This gives momentum injection ratio, r=0.1173 for 25m/s free stream velocity and r=0.097 for 30 m/s free stream velocity. For determining static pressure on upper and lower surface of airfoil 27 pressure tube has been used distributed chord wise along a distance 10 mm. Reynolds number was 4.7×10^{5} based on airfoil chord. Aerodynamic forces have been measured by integration of static pressure over the surface of airfoil assuming skin friction drag is small compared to the pressure drag.

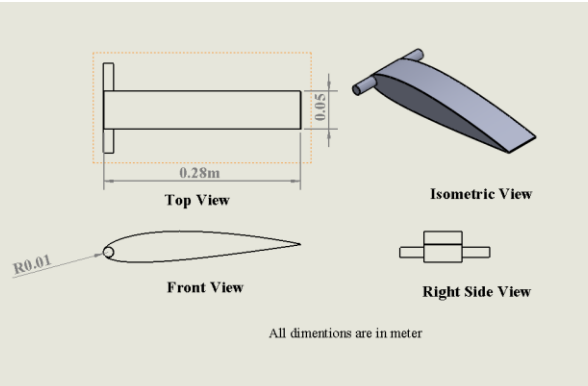

Fig.1 Dimensions of modified NACA 2415 airfoil

Fig.2 Airfoil mounted on wind tunnel.

3. Result & Discussion

Using static pressure over the airfoil, pressure coefficient at 0, 4, 8, 10, 12, 16, 20-degree angle of attack has been measured for both original NACA 2415 airfoil and with cylinder rotation at leading edge of modified NACA 2415 airfoil. From the experiment it is observed that actual NACA 2415 airfoil shows attached flow over it until 12° angle of attack. Thus stall angle, α_{stall} for NACA 2415 airfoil is 12° angle of attack. When cylinder rotation at the leading edge has been used, at 16° angle of attack flow becomes fully separated for both momentum injection ratio r=0.1173 and r=0.0973. Thus stall angle for both momentum injection ratio is $\alpha_{stall\ (with\ momentum\ injection)}$ =16°. This phenomenon is shown in Fig.-03 and Fig.-04 for NACA 2415 actual airfoil and both momentum injection case in terms of pressure coefficient, Cp.

For both Fig.-03 and Fig.-04 original NACA 2415 airfoil upper surface pressure coefficient is indicated by label “original airfoil upper” and lower surface pressure coefficient as label “original airfoil lower”.

Using same technique pressure coefficient at both upper and lower surface of modified NACA 2415 airfoil is indicated using label “r=0.1173 upper” and “r=0.097 lower” for momentum injection ratio 0.1173 and 0.097 respectively.

From Fig.-3 it is clear thatoriginal NACA 2415 airfoil shows flow separation at 0.35C position but when momentum injection was applied then flow didn’t separate in 12º AOA.

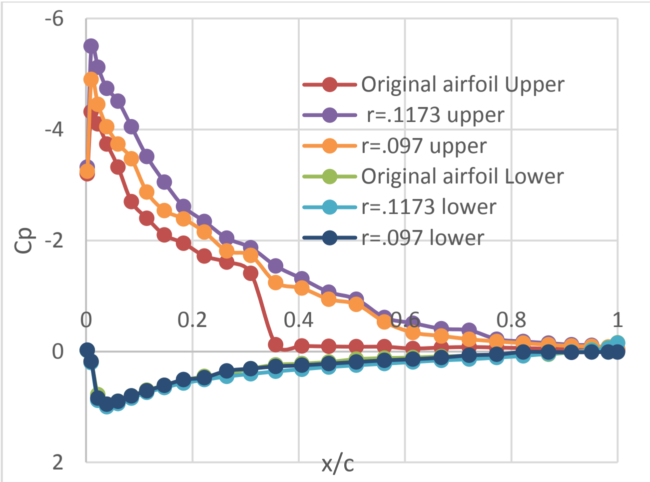

Fig.3 Effect of leading edge rotating cylinder on pressure coefficienr, $C_p$at 12º AOA.

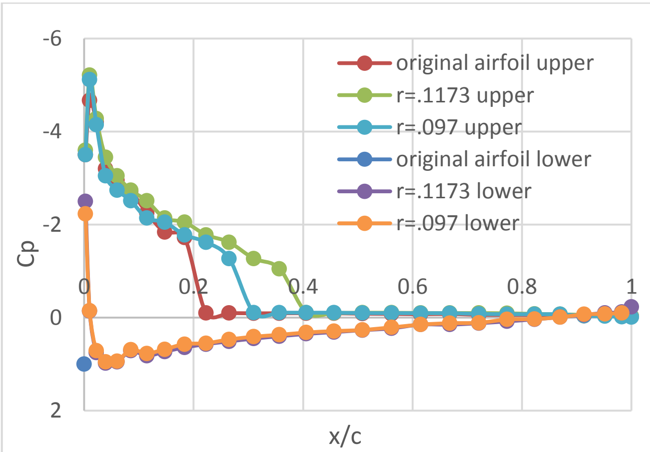

Fig. 4 Effect of leading edge rotating cylinder on pressure coefficient, $C_p$at 16º AOA

Fig.-4 shows separation phenomenon for all three cases without cylinder, with cylinder supplying momentum injection ratio r=0.1173 and r=0.097 at 16º AOA.

Flow separation occur 0.2C, 0.3C, 0.4C position from leading edge when using actual NACA 2415 airfoil, Momentum injection ratio r=0.097 and r=0.1173 respectively at 16º AOA.

Fig.-5 shows lift coefficient, C_l varied when cylinder rotation is used at momentum injection ratio r=0.1173 and r=0.093 and without leading edge rotating cylinder using label "r=0.1173", "r=0.097" and "original airfoil" respectively. It is clear that stall angle delayed from 12º for actual airfoil to 16º for modified airfoil when rotating cylinder is used in front of airfoil. Maximum lift coefficient increases about 38.63% for r=0.1173, 20.88% for r= 0.097 than the lift coefficient of actual NACA 2415 airfoil. This increased lift coefficient helps airplane to carry more payload and increases maneuverability greatly.

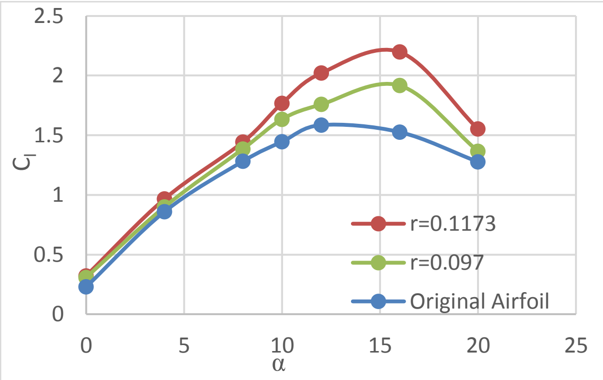

Fig. 5 Effect of rotating cylinder on lift coefficient, C_l

Lift coefficient increases with increased momentum injection rate. From Fig-5 it is evident that maximum lift coefficient at r=0.1173 is 2.2 and at r=0.097 maximum lift coefficient is 1.91 at 16° angle of attack for modified NACA 2415 airfoil. Maximum lift coefficient is 1.58 at 12° angle of attack for original NACA 2415 airfoil.

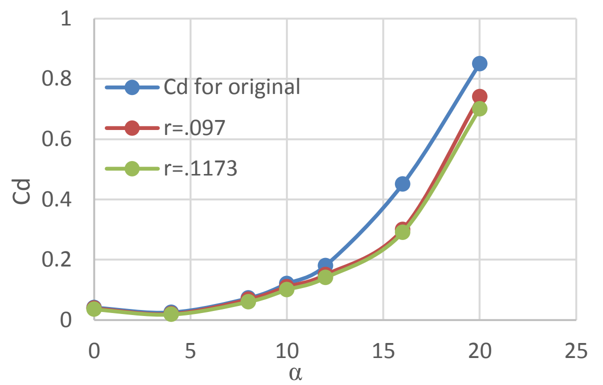

Fig. 6 Effect of rotating cylinder on drag coefficient C_d

It is clear that pressure drag decreases with the increase of momentum injection ratio.For actual NACA 2415 airfoil drag coefficient is C_d=0.85 at 20º AOA and when momentum injection ratio, r=0.1173 C_d is 0.7 at 20º AOA.

4. Conclusion

The wind tunnel test program shows that leading edge rotating cylinderwith airfoil is a successful device that produce more section lift than normal airfoil at the same angle of attack hence reducing the need for higher angle of attack to achieve more lift. With high momentum injection ratio in the leading edge lift coefficient increases and stall angle of attack delayed. The increase in lift coefficient and stall angle of attack for momentum injection ratio, r = 0.1173 is about 38.63% and 4° angle of attack respectively.This increase in the lift coefficient and stall angle of attack would make an airplane fitted with such an airfoil more maneuverable and improve its performance in terms of STOL. And C_d decreases slightly when using momentum injection. This also helpful in airplane economy.

NOMENCLATURE

C : Chord Length
C_l : Lift Coefficient
C_d : Drag coefficient
C_p : Pressure coefficient
r : Momentum injection ratio
α : Angle of attack

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