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Analysis of Lift and Drag Characteristics of Aerofoil made from Locally Available Materials at Low Reynolds Number

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ABSTRACT: This study determined the lift and drag characteristics of some selected aerofoils favoured by many wind turbine manufacturers at low Reynolds number. National Advisory Committee for Aeronautics Aerofoil. NACA 4415, 2412 and 0015 aerofoil were cast using thermo-set materials (fibre glass and polyester resin),Aluminium and Plastic. Wind tunnel experiments were performed to obtain the lift and drag forces. The size of the cast aerofoil is such that it can be mounted in the test section of the wind tunnel. Using the wind speeds of 3.0 m/s to 7.0 m/s at intervals of 1 m/s, the lift and drag forces were measured at different angles of attack. The Reynolds number, Coefficients of Lift, and Coefficients of drag and the ratio of lift-to- drag corresponding to each wind speed were obtained using the wind tunnel data management system and presented on tables 2, 3, 4 and figures 4, 5, 6.The three aerofoils test data exhibit the same trend; however, NACA 4415 aerofoil test data claims better performance with the wind tunnel test data due to its good shape, maximum camber use of composites materials based on its good mechanical property, light weight, ability to mounded into various shapes, and which produces the highest lift value of (14.4240) at 16.2000 degree angle of attack, and produces the second highest amount of lift- to- drag ratioof (11.6960) at 19.1 degree angle of attack and also produces the lowest drag value of (0.0480) at 6.9000 degree angle of attack. The obtained data can be applied to the design of rotor blades, operation of aircraft at low speed and the design of micro air vehicles, compressor blades, wind turbine blades, and inboard sections of helicopter rotors. It will also assist in the research into wakes of low flying crafts and wind turbines operating in low wind speed regimes prevalent in most parts of the world.

Keywords: Aerofoil, Lift coefficients, Drag coefficients, Lift- to- Drag ratio, Low Reynolds Number, Wind Tunnel Test.

Abbreviations

A Cross Sectional Area of Test Section [mm^2]
AIAAAmerican Institute of Aeronautics and Astronautics
AoA Angle of Attack [degree]
c Chord Length [mm]
C_d Drag Coefficient, Corrected for Analytical Method
C_l Lift Coefficient, Corrected for Analytical Method
D Drag (N)
h Vertical Distance Between the Floor of the Wind Tunnel and the Pitot Static Tube (mm)
L lift (N)
LCD Liquid Crystal Display
K Calibration Factor
M Mach number
NACA National Advisory Committee for Aeronautics
PIV Particle Image Velocimetry
Re Reynolds Number
S Plan area (mm^2)
V Flow Speed

Greek Symbol
α Angle of Attack [degree]
ρ Density of Fluid

I. INTRODUCTION

The wings may be considered as the most important component of an aircraft, the primary function of the wing is to generate lift. The aerofoil section is the second most important wing parameter; after wing plane area. The aerofoil section is responsible for the generation of the optimum pressure distribution on the top and bottom surfaces of the wing such that the required lift is created with the lowest basic knowledge of aerodynamics and basic of aerofoils. [1]

An aerofoil is the cross sectional shape of a wing or blade (of a propeller, rotor or turbine) or sail. An aerofoil shaped body moved through a fluid and produce aerodynamic forces. The component of this force perpendicular to the direction of motion is called lift. The component of this force parallel to the direction of motion is called drag [2]. The Reynolds number relates the density, viscosity, speed and size of typical flow in a dimensionless equation which is involve in many fluid dynamics problems. This dimensionless numbers appear in many cases related to the fact that flow can be seen as either laminar or turbulent [3].The aerodynamic forces of an aerofoil is primarilary the results of its shape, size and angle of attack. NACA Aerofoils are created and developed by National Advisory Committee for Aeronautics. Camber aerofoil is the asymmetry between the two acting surface of a wing and it can generate lift at zero or even negative angle of attack while Un-camber is the symmetrical between thetwo acting surface of a wing. Aerofoil shape body moved through fluid and produce aerodynamic forces. The forces of the wing examine the pressures above and below the wing, which can be related to velocity changes. An increase in the speed of a fluid occurs simultaneously with decrease in pressure with a high velocity above the upper surface of the wing than below [4].The aerodynamic forces and moments on a body are due to two basic sources:

a. Pressure distribution over the body surface.
b. Shear stress distribution over the body surface.

The pressure p, acts normal to the surface and the shear stress τ, acts tangential to the surface [4]. The performance of aerofoils at low Reynolds numbers has been of interest in connection with a wide range of applications, including the operation of aircraft at low speeds and the design of micro air vehicles, compressor blades, wind turbines, and inboard sections of helicopter, vertical stabilizers, submarine fins, rotary and some fixed wings [5]. However, difference in chord Reynolds number of micro – scale aircraft may be used for micro air vehicles [6].

In the design and research of commercially viable rotor blades for wind turbines and flying crafts, it is imperative that an accurate assessment is made of the aerodynamic characteristics of the aerofoils employed in making the blades. The findings of the study will not only simplify the difficult problem in obtaining data of aerofoils operating at ultra-low Reynolds number, but will also facilitate research into the design of wings, rotor, blades and wake analysis, the study will improved the performance of NACA aerofoil using thermoset material and assist to reduce the fuel consumption of airplane.

In this papercomparative analysis have been done on NACA 4415, 2412 and 0015 aerofoils at low Reynolds number. The goal of this paper is to find out that, which aerofoil is the most suitable to be used in low speed airplane on the basis of their lift coefficient, drag coefficient, ratio of lift-to- drag coefficient under a specified Reynolds number and the value of angle of attack varies from -5 to 20.5 degree with an increment of 2 degree.

II. MATERIALS AND METHODS

The materials used for the study include; Card board paper, Metal sheet (18 gauge), Polyester resin (Type R10- 03), Fibre glass, Car body filler, Sand paper, Hardener and Masking tape.

Themethods used to cast the aerofoils are by graphical or geometrical method which is addressed earlier by Karman- Trefftz von mises who gave theoretical approach. In this construction it slightly modified from the Karman- Trefftz aerofoil.Experimental method using wind tunnel machine was used to determine the lift and drag coefficients and the following methods are utilized to achieve the objective of the study [7].

a. Java Software

The java software was used to provide the coordinates and shape of the selected aerofoil. In order to draw the grid of the NACA aerofoil, data points are required. These data points can be obtained from an online java applet called javaFoil. The applet being used to find the data points of the required aerofoil. JavaFoil was used (as shown below in Figure 1. Figure 2 and Figure 3).

b. Aerofoil Model And Geometry

The aerofoil model and geometry were used from literature reviewed to have the exactly measurement of the aerofoil chord, span, maximum camber, position of the maximum camber and thickness. Table 1 shows the specifications of aerofoil used were NACA 4415, 2412 and 0015 which falls under the NACA Four-Digit Series, where the first digit specifies the maximum camber (m) as percentage of the chord (aerofoil length), the secondIndicates the position of the maximum camber (p) in tenths of chord, and the last two numbers provide the maximum thickness (t) of the

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aerofoil as percentage of chord, the chord length and span of the aerofoil are 100mm and 150mm respectively [5].

Table 1: Specifications of the Cast Aerofoil [8]

NACA Aerofoil Number	**0015**	**2412**	**4415**
Chord (c)	100mm	100mm	100mm
Length	150mm	150mm	150mm
Maximum camber	0	2%	4%
Position of maximum camber on chord	0	0.4mm	0.4mm
Maximum thickness	15%	12	15

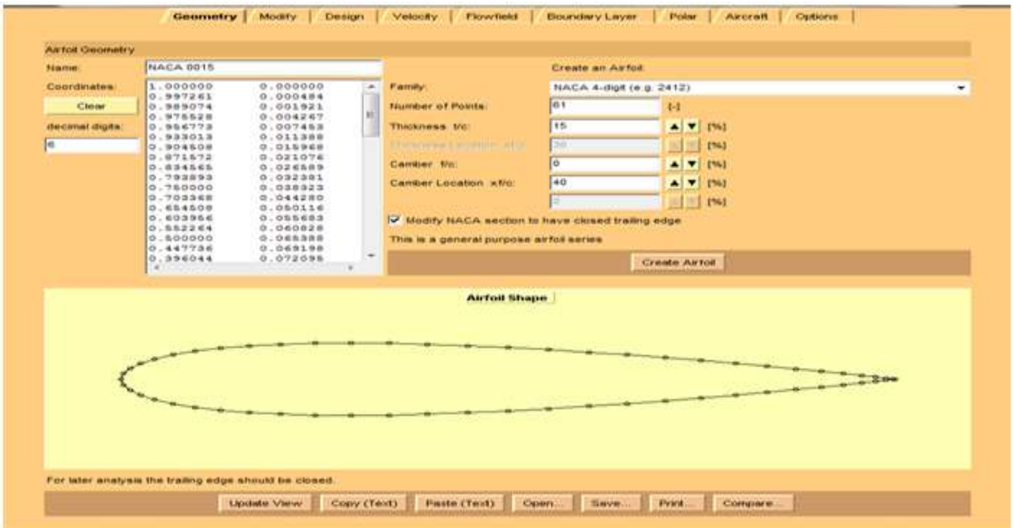

Figure1: NACA 0015 Aerofoil Geometry and Shape Using JavaFoil[9]

The NACA 0015 aerofoil is a symmetric aerofoil has a maximum camber of 0% at 40% of the chord length and a maximum thickness of 15%, the chord length of 100mm and a span of 150mm. By inputting these values into the applet, the correct aerofoil was obtained. The data points obtained were copied into a text file and were used to generate the cast aerofoil.The coordinates used for the shape of the aerofoil are shown in Appendix B1.

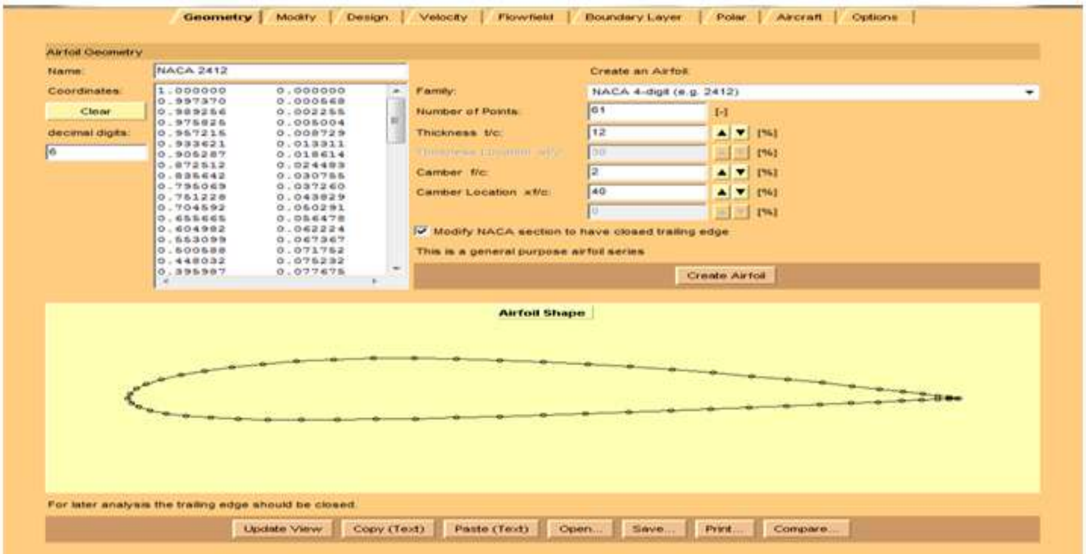

Figure 2:NACA 2412 Aerofoil Geometry and Shape Using JavaFoil[9].

The NACA 2412 is an asymmetrical aerofoil has a maximum camber of 2% at 40% of the chord length and a maximum thickness of 12%, the chord length of 100mm and a span of 150mm. By inputting these values into the applet, the correct aerofoil was obtained. The data points obtained were copied into a text file and were used to generate the cast aerofoil.The coordinates used for the shape of the aerofoil are shown in Appendix B2.

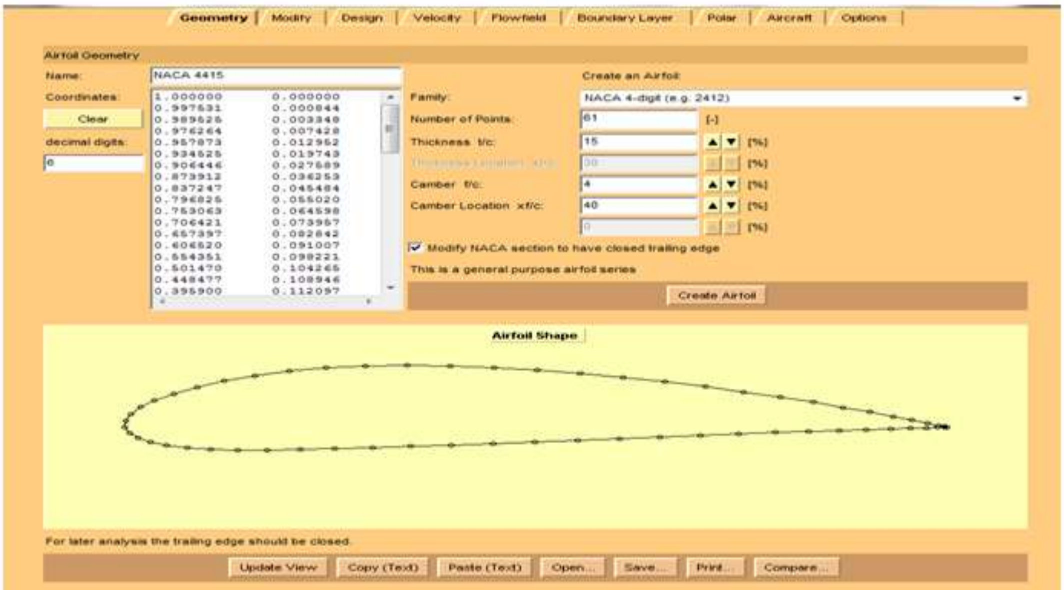

Figure 3: NACA 4415 Aerofoil Geometry, and Shape Using JavaFoil[9].

The NACA 4415 is an asymmetricalaerofoil has a maximum camber of 4% at 40% of the chord length and a maximum thickness of 15%, the chord length of 100mm and a span of 150mm. By inputting these values into the applet, the correct aerofoil was obtained. The data points obtained were copied into a text file and were used to generate the cast aerofoil.The coordinates used for the shape of the aerofoil are shown in Appendix B3.

c. The Production Process of Selected Aerofoil

The production process was as follows;

i. Metal sheet were use for pattern mould using the specification obtained from geometry and

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aerofoil model using welding and fabrication process.

ii. A fibre glass female mould was then taken from the original replica. The mould was in two halves. Durawax was applied to the mould to ensure that the item produced did not stick to the mould. This mould can be used a number of times

iii. The two halves were then filled with chopped fibre glass mat mixed with resin. Hardener and cobalt (accelerator that speed the hardening process) were added to the resin to start the curing process, once it is added it must be worked quickly as the resin will solidify quickly.

iv. The two halves filled with the mix were then matched together and held firmly for some few minutes. After the material being solidified, the mould was carefully removed.

v. The airfoils produced were then filled with good quality body filler for imperfection and sanded to get a smooth finish. The produced NACA 4415, 2412 and 0015 aerofoil are shown in appendix A1, A2 and A3 respectively (See Appendix A).

d. Experimental Set up Procedure

The experiment was conducted at the Department of Mechanical Engineering, Fluid Mechanics Laboratory, Bayero University Kano, Nigeria. NACA 0015, NACA 2412, NACA 4415 aerofoils were used for experiment to determine their aerodynamic lift, drag forces and lift and drag coefficients.

Plate 1. The Wind Tunnel at Bayero University Kano, Nigeria.

The wind tunnel was also equipped with stand-alone/computer interface HMI (Human Machine Interface) unit with LCD (Liquid Crystal Display) LCD with graphic display with key pad and HMI were used for data acquisition and the following procedure:

a) The wind tunnel was calibrated on installation and the k factor =0.1

b) Before starting the wind tunnel, the zeroing of the Digital Micro-manometer and zeroing of the three balance outputs (lift, drag and pitching moment) were performed.

c) For each model of NACA 0015, NACA 2412 and NACA 4415 aerofoils the following were measured and inputted in the wind data management system:

i. Aerofoil span 150mm

ii. Aerofoil chord 100mm

d) The barometric pressure was recorded at approximately 1atm and inputted in the wind data management system

e) The tunnel was turned onthe speed was adjusted to the desired value (3m/s to 7m/s at intervals of 1m/s).

For each configuration, the data were taken via the wind data system management at angles of attack from -5° to +20.5° at 2° increments and various Reynolds number. The FM02 Wind Tunnel utilizes a floor mount three components balance with single strut system which has facility for changing the angle of attack. The angle of attack can be changed by turning the rotary table under the balance. The load cell system gives the direct reading of lift, drag and pitching moments, in N and Nm. The room thermometers, room barometer as well as the tunnel inclined manometer were utilized during the experiment and

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the result obtain from the experiment are presented on tables 2, 3, 4 and figures 4, 5, 6.

III. RESULTS AND DISCUSSION

The experimental result presented here includes the coefficients of lift, coefficient of drag, lift- to- drag ratio and Reynolds number. The results obtained from the wind tunnel experiment are presented in tables 2, 3 and 4 respectively. The results were further presented graphically in figure 4, 5, 6 and discussed.

Table 2: Coefficients of Lift at Different Reynolds Number

Angle of Attack	**$C_l$atRe=6,019 NACA 4415**	**C_l at Re=10,612 NACA 2412**	**C_l at Re=8,424 NACA 0015**
-5.0000	1.2940	1.3420	1.5780
-3.2000	0.7550	1.4060	1.5990
-1.4000	0.2290	0.9040	2.4900
0.2000	1.4160	1.1160	1.5670
2.0000	0.8330	1.1810	1.2431
3.6000	1.2690	1.0900	0.8820
5.3000	1.6690	1.2520	0.7620
6.9000	0.0240	1.2520	1.3940
8.6000	1.9860	1.1460	1.4990
10.1000	1.6760	0.7470	1.0170
11.7000	2.9620	0.2580	1.5760
13.2000	1.8090	2.1480	1.4980
14.7000	2.4560	0.1790	1.5970
16.2000	14.424	1.2770	2.2750
17.7000	0.0000	4.0420	2.2040
19.1000	1.3100	0.3330	2.3900
20.5000	0.2270	1.5330	3.0950

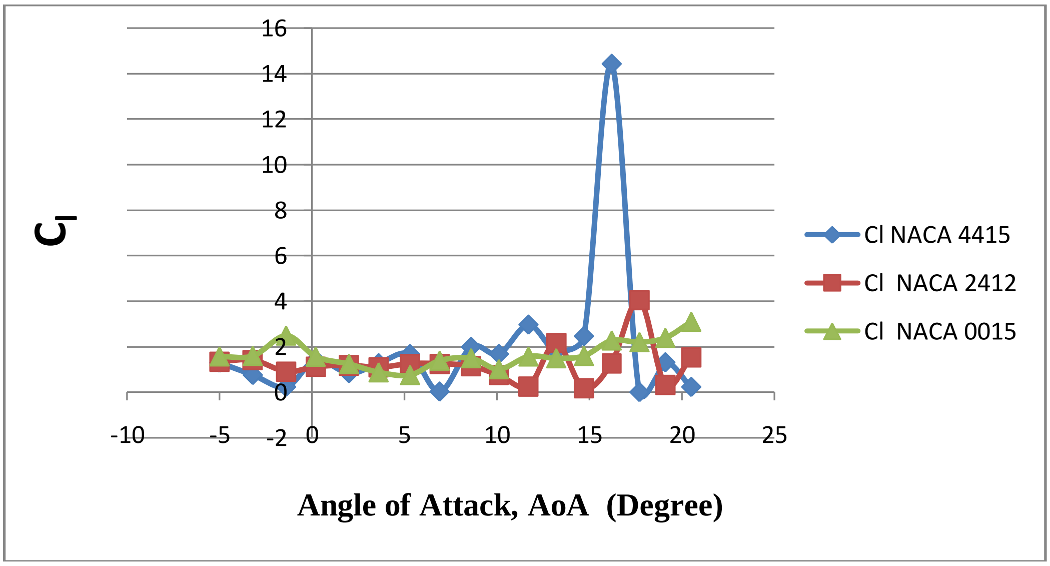

Figure 4: Graph of Coefficientsof Lift, AgainstAngle of Attack for NACA 4415, 2412 and 0015 Aerofoil at Re=6,019, Re=10,612 and Re=8,424 Using Wind Tunnel Experiment

A. Lift Coefficient

Lift is a mechanical aerodynamic force that is generated by a solid object passing through a fluid and this force opposes the weight of flying object and holds it in the air. It is a vector quantity and it acts through the centre of pressure of the flying object and fluid, around that flowing object. It takes no difference whether the object is passing through the fluid or the fluid is flowing over an object [10]

Lift is generally measured as non dimensional coefficient, Coefficient of lift (C_l).

$$C_l = \frac{L}{\left(\frac{1}{2}\right)\rho V^2 A} \qquad (1)$$

Where, L is the lift force, ρ is the density of fluid, Vis the flow speed and A is the relative plan area.

Here, coefficient of lift is generated over the three aerofoils at different angle of attack to perform a comparative analysis of these aerofoils on the basis of their predicted lift coefficients at angle of attack from -5 to -20.5 degree.

Table 2 and Figure 4 represent the variation of lift coefficients at different angle of attack and Reynolds number for these aerofoils.

As shown in table 4, for NACA 4415 aerofoil the value of coefficient of lift keep increasing from angle of attack 10.1000 to 16.2000 degree and coefficient of lift 1.6760 to 14.424 at Re= 6,019 and for NACA 2412 the value of coefficient of lift keep increasing from angle of attack 14.7000 to 17.7000 degree with coefficient of lift 0.1790 to 4.0420 at Re=10,612 while NACA 0015 the value of coefficient of lift keep increasing from angle of attack 13.2000 to 16.2000 degree with coefficient of lift 1.4980 to 2.2750 at Re=8,424.

Figure 4, for NACA 4415 aerofoil at Re=6,019 shows the highest lift coefficient 14.4240 at 16.2000 degree angle of attack meaning stalling angle and NACA 2412 aerofoil at Re=10,612 produces the second highest amount of coefficient lift 4.0420 at 17.7 degree angle of attack while NACA 0015 aerofoil produces the lowest amount of coefficient of lift 2.2750 at 16.2000 degree angle of attack. However, NACA 4415 aerofoil is more accurate and desirable factor that produces the highest amount of lift coefficients.

Table 3: Coefficients of Drag at Different Reynolds Number

Angle of Attack	**C_d atRe=6,019 NACA 4415**	**Cd at Re=10,612 NACA 2412**	**C_d at Re=8,424 NACA 0015**
-5.0000	0.8550	1.2580	0.5680
-3.2000	1.9440	0.2850	0.5580
-1.4000	1.1450	1.1060	2.4150
0.2000	0.2760	6.5490	0.9650
2.0000	0.3570	0.4540	0.5341
3.6000	0.5570	0.5490	1.0180
5.3000	0.3970	0.6060	1.1780
6.9000	0.0480	0.6060	1.7520
8.6000	3.4590	0.5290	1.6880
10.1000	2.9680	0.8350	3.2560
11.7000	0.7360	0.1250	1.4980
13.2000	1.1980	0.0590	1.6030
14.7000	1.9100	0.2300	2.0530
16.2000	2.1690	0.5330	2.4490
17.7000	0.7420	0.8970	2.2290
19.1000	0.1120	0.0450	2.3640
20.5000	0.1260	0.7360	3.0430

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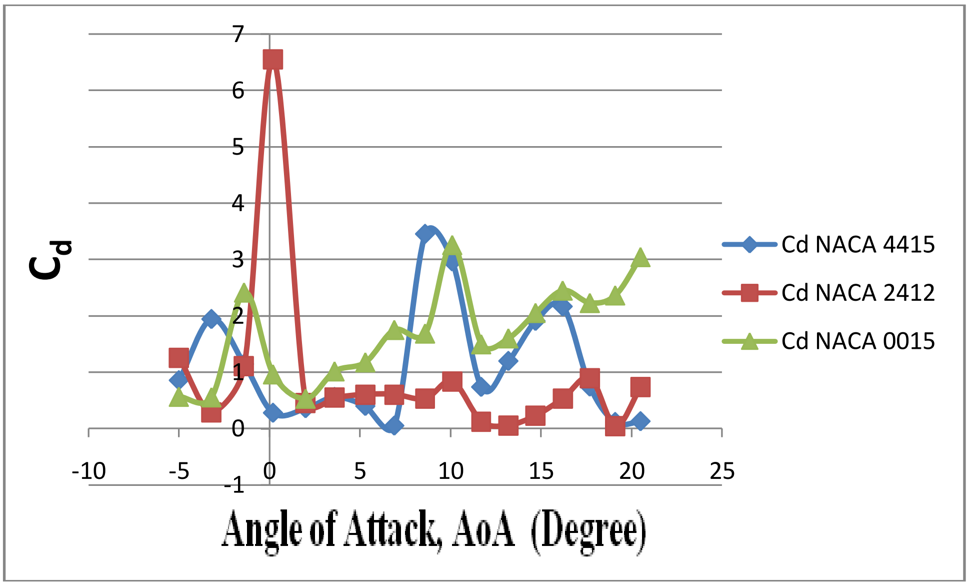

Figure 5: Graph of Coefficientsof Drag, AgainstAngle of Attack for NACA 4415, 2412 and 0015 Aerofoil at Re=6,019, Re=10,612 and Re=8,424 Using Wind Tunnel Experiment

B. Drag Coefficient

The lowest value of drag is the most desirable factor for any aerofoil. The drag force acts in the opposite direction of the moving object in a medium of a fluid. It not only opposes the motion of an object in a medium of fluid but also reduces its lift. The drag depends on the density of the fluid velocity of flowing or an object compressibility and viscosity of flowing fluid or a fluid around a moving object and the size and shape of the object [10]

The coefficient of Drag is a dimensionless quantity, used to evaluate resistance of a moving object in a fluid

$$C_d = \frac{D}{(\frac{1}{2})\rho V^2 S} \qquad (2)$$

Where, D is the Drag force, ρ is the density of fluid, V is the flow speed and S is the reference area.

Table 3 and Figure 5 represent the variation of drag coefficients at different angle of attack and Reynolds number for these aerofoils.

As shown in table 3, for NACA 4415 aerofoil the value of coefficient of drag keep increasing from angle of attack 3.6000 to 6.9000 degree and decreasing the coefficient of drag from 0.5570 to 0.0480 at Re= 6,019 and for NACA 2412 the value of coefficient of drag keep increasing from angle of attack 2.0000 to 19.1000 degree with coefficient of drag decreases from 0.4540 to 0.0590 at Re=10,612 whereas NACA 0015 the value of coefficient of drag keep increasing from angle of attack -1.4000 to 2.0000 degree with coefficient of drag decreasing from 2.4150 to 0.5341 at Re=8,424.However, NACA 4415 aerofoil is more accurate and desirable factor that produces the lowest amount of drag coefficients.

Table 4: Lift-to-Drag Ratio of NACA Aerofoils at Different Reynolds Number

Angle of Attack	**C_l/C_d atRe=6,019 NACA 4415**	**C_l/C_d at Re=10,612 NACA 2412**	**C_l/C_d at Re=8,424 NACA 0015**
-5.0000	1.5130	1.0670	2.7780
-3.2000	0.3880	4.9330	2.8660
-1.4000	0.2000	0.8170	1.0310
0.2000	5.1300	0.1700	1.6240
2.0000	2.3330	2.6010	2.7011
3.6000	2.2780	1.9850	0.8660

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5.3000	4.2040	2.0660	0.6470
6.9000	0.5000	2.0660	0.7960
8.6000	0.5740	2.1660	0.8880
10.1000	0.5650	0.8950	0.3120
11.7000	4.0240	2.0640	1.0520
13.2000	1.5100	36.4070	0.9340
14.7000	1.2860	0.7780	0.7780
16.2000	6.6500	2.3960	0.9290
17.7000	0.0000	4.5060	0.9890
19.1000	11.6960	7.4000	1.0110
20.5000	1.8020	2.0830	1.0170

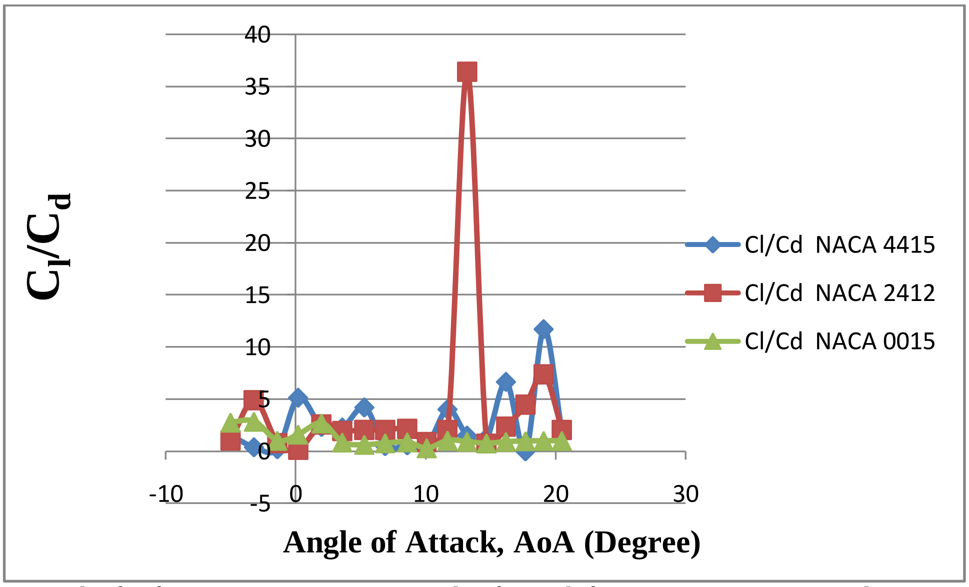

Figure 6: Graph of Lift-to-DragRatio against Angle of Attack for NACA 4415, 2412 and 0015 Aerofoil at Re=6,019, Re=10,612 and Re=8,424 Using Wind Tunnel Experiment

C. Lift- to- Drag Ratio

The higher value of this ratio is the most desirable factor for any aerofoil and also the maximum efficiency of an aerofoil. The value of lift-to-drag ratio can be increased either by increasing the value of lift coefficient or by decreasing the value of drag coefficient.

It can be seen from the table 4, that the value of lift-to-drag ratio for NACA 4415 aerofoil increases from 11.7000 to 19.1000 degree angle of attack with 4.0240 to 11.6900 lift-to- drag ratio and NACA 2412 aerofoil increases from 10.1000 to 13.2000 degree angle of attack with lift-to-drag ratio of 0.8950 to 36.4070 while NACA 0015 aerofoil increases from -3.2000 to 2.0000 degree angle of attack with decreases in lift-to- drag ratio of 2.8660 to 2.7011.

It can also be observed that NACA 2412 aerofoil produces the highest lift- to-drag ratio and NACA 4415 aerofoil produces the second highest amount of lift-to- drag ratio while NACA 0015 aerofoil produces the lowest amount of lift-to- drag ratio. However, NACA 2412 is more accurate and desirable factor for the design of airplane wings, which produces the highest amount of lift- to- drag ratio.

IV. CONCLUSION

An experimental study was conducted to investigate the aerodynamic characteristics in a wind tunnel with particle image velocimetry (PIV) between the Reynolds number Re=6,019 – 14,920.

The experiments were successfully carried out on the NACA 0015, 2412 and 4415 aerofoil's and were cast using thermoset materials due to it good mechanical property. However, aluminium and plastic aerofoils have not yielded positive result in the production process due to higher thickness and temperature.

The lift and drag forces of these aerofoils were obtained using the wind tunnel experiment. The three aerofoil test data exhibit the same trend; however, NACA 4415 aerofoil at Re=6,019 in figure 4 and table 2,for the wind tunnel test data claims better performance which produces the highest lift value of (14.4240) at 16.2000 degree angle of attack,meaning stalling angle, andproduces the second highest amount of lift-to- drag ratioand also produces the lowest drag value of (0.0480) at 6.9000 degreeangle of attack, and NACA 2412 aerofoil produces moderate result that had the highest value of lift- to- drag ratio of (36.4070) at 13.2000degree angle of attack and produces the second highest amount of lift coefficients value of (4.0420) at 17.7000 degree angle of attack.The performance of low Reynolds number aerofoil was primarily depending on maximum camber [11].Therefore, NACA 4415 aerofoil isthe best selected aerofoil performance that has ahigher maximum camber of (4). From the analysis, it can be concluded that NACA 4415, 2412 aerofoil which belong to camber/asymmetry aerofoil are factors to be considered while selecting the best aerofoil.

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APPENDIX A

Aerofoil Coordinates for the NACA 0015, 2412 and 4415

AppendixA1**:**Aerofoil Coordinate for NACA 0015

x	Y	x	Y
1.00000000	0.00000000	0.12842800	-0.06354200
0.99726100	0.00048400	0.16543500	-0.06836700
0.98907400	0.00192100	0.20610700	-0.07181800
0.97552800	0.00426700	0.25000000	-0.07387200
0.95677300	0.00745300	0.29663200	-0.07455100
0.93301300	0.01138800	0.34549200	-0.07392400
0.90450800	0.01596800	0.39604400	-0.07209500
0.87157200	0.02107600	0.44773600	-0.06919800
0.83456500	0.02658900	0.50000000	-0.06538800
0.79389300	0.03238100	0.55226400	-0.06082800
0.75000000	0.03832300	0.60395600	-0.05568300
0.70336800	0.04428000	0.65450800	-0.05011600
0.65450800	0.05011600	0.70336800	-0.04428000
0.60395600	0.05568300	0.75000000	-0.03832300
0.55226400	0.06082800	0.79389300	-0.03238100
0.50000000	0.06538800	0.83456500	-0.02658900
0.44773600	0.06919800	0.87157200	-0.02107600
0.39604400	0.07209500	0.90450800	-0.01596800
0.34549200	0.07392400	0.93301300	-0.01138800
0.29663200	0.07455100	0.95677300	-0.00745300
0.25000000	0.07387200	0.97552800	-0.00426700
0.20610700	0.07181800	0.98907400	-0.00192100
0.16543500	0.06836700	0.99726100	-0.00048400
0.12842800	0.06354200	1.00000000	0.00000000
0.09549200	0.05741100		
0.06698700	0.05007600		
0.04322700	0.04166800		
0.02447200	0.03232800		
0.01092600	0.02219500		
0.00273900	0.01138900		
0.00000000	0.00000000		
0.00273900	-0.01138900		
0.01092600	-0.02219500		
0.02447200	-0.03232800		
0.04322700	-0.04166800		
0.06698700	-0.05007600		
0.09549200	-0.05741100		

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AppendixA2:Aerofoil Coordinate for NACA 2412

x	Y	x	y
1.00000000	0.00000000	0.13188200	-0.03993200
0.99737000	0.00056800	0.16864900	-0.04147400
0.98925600	0.00225500	0.20890200	-0.04208300
0.97582500	0.00500400	0.25222600	-0.04186600
0.95721500	0.00872900	0.29818200	-0.04095600
0.93362100	0.01331100	0.34630300	-0.03950500
0.90528700	0.01861400	0.39610200	-0.03767900
0.87251200	0.02448300	0.44743900	-0.03548600
0.83564200	0.03075500	0.49941200	-0.03286500
0.79506900	0.03726000	0.55142900	-0.02994600
0.75122800	0.04382900	0.60292900	-0.02684900
0.70459200	0.05029100	0.65335200	-0.02367800
0.65566500	0.05647800	0.70214500	-0.02052000
0.60498200	0.06222400	0.74877200	-0.01744300
0.55309900	0.06736700	0.79271600	-0.01450200
0.50058800	0.07175200	0.83348900	-0.01174000
0.44803200	0.07523200	0.87063300	-0.00919400
0.39598700	0.07767500	0.90373000	-0.00689700
0.34468000	0.07876400	0.93240500	-0.00488000
0.29508100	0.07828800	0.95633000	-0.00317400
0.24777400	0.07624700	0.97523200	-0.00180900
0.20331300	0.07269200	0.98889200	-0.00081200
0.16222100	0.06772700	0.99715200	-0.00020400
0.12497300	0.06150300	1.00000000	0.00000000
0.09199600	0.05421000		
0.06365700	0.04606500		
0.04026100	0.03729500		
0.02205100	0.02812500		
0.00920600	0.01875200		
0.00183800	0.00934100		
0.00000000	0.00000000		
0.00364000	-0.00879200		
0.01264700	-0.01659300		
0.02689200	-0.02337400		
0.04619400	-0.02911000		
0.07031800	-0.03378100		
0.09898700	-0.03738200		

AppendixA3**:**Aerofoil Coordinate for NACA 4415

x	y	X	y
1.00020800	0.00156100	0.13700500	-0.04160300
0.99753100	0.00240100	0.17342900	-0.04191600
0.98952500	0.00489300	0.21306900	-0.04120500
0.97626400	0.00895300	0.25555400	-0.03968300

0.95787300	0.01444800	0.30050400	-0.03759000
0.93452500	0.02120200	0.34752000	-0.03518400
0.90644600	0.02900400	0.39618800	-0.03272300
0.87391200	0.03761800	0.44699400	-0.03015300
0.83724700	0.04679100	0.49853000	-0.02727000
0.79682500	0.05626400	0.55017800	-0.02423800
0.75306300	0.06577400	0.60139200	-0.02119800
0.70642100	0.07506000	0.65162000	-0.01826200
0.65739700	0.08386800	0.70031500	-0.01551100
0.60652000	0.09195400	0.74693700	-0.01299600
0.55435100	0.09908600	0.79096000	-0.01074200
0.50147000	0.10504800	0.83188300	-0.00875700
0.44847700	0.10964600	0.86923300	-0.00703500
0.39590000	0.11271500	0.90257100	-0.00556600
0.34346300	0.11369800	0.93150000	-0.00433600
0.29276000	0.11224700	0.95567300	-0.00333600
0.24444600	0.10843300	0.97479200	-0.00256000
0.19914600	0.10240700	0.98862200	-0.00200500
0.15744100	0.09440500	0.99699100	-0.00167200
0.11985100	0.08472700	0.99979200	-0.00156100
0.08682700	0.07372400		
0.05874500	0.06177600		
0.03589800	0.04926600		
0.01849900	0.03655500		
0.00668500	0.02395900		
0.00051900	0.01172100		
0.00000000	0.00000000		
0.00495900	-0.01062900		
0.01516800	-0.01964800		
0.03044500	-0.02706600		
0.05055700	-0.03290900		
0.07522900	-0.03722400		
0.10415600	-0.04008700		

APPENDIX B
Cast Aerofoils for the NACA 0015, 2412 and 4415
Appendix B1:NACA 0015 Aerofoil

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Appendix B2: NACA 2412 Aerofoil

Appendix B3: NACA 4415 Aerofoil