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An Aerodynamic Comparative Analysis of Airfoils for Low-Speed Aircrafts

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***Abstract* - This paper presents investigation on airfoil S1223, S819, S8037 and S1223 RTL at low speeds to find out the most suitable airfoil design to be used in the low speed aircrafts. The method used for analysis of airfoils is Computational Fluid Dynamics (CFD). The numerical simulation of low speed and high-lift airfoil has been done using ANSYS-FLUENT (version 16.2) to obtain drag coefficient, lift coefficient, coefficient of moment and Lift-to-Drag ratio over the airfoils for the comparative analysis of airfoils. The S1223 RTL airfoil has been chosen as the most suitable design for the specified boundary conditions and the Mach number from 0.10 to 0.30.**

Key words: CFD, Lift, Drag, Pitching, Lift-to-Drag ratio.

I. INTRODUCTION

An aircraft acted upon by four aerodynamic forces; Thrust, Drag, Lift and Weight. Aircrafts are able to fly due to aerodynamic force produced when a fluid passes over the airfoil. An Airfoil is defined as the cross section of a body that is placed in an airstream in order to produce an aerodynamic force in the most efficient manner possible[1]. If the pressure below the wing is higher than the pressure above the wing, there is a net force upwards and this upward force generates lift.

There are two types of airfoils; symmetric and non-symmetric. The symmetrical airfoil has identical upper and lower surfaces and the mean camber line and the chord line are same in this airfoil. The Non-Symmetric airfoil has different upper and lower surfaces, the surface above the chord line has greater curvature than the surface below the chord line. The non-symmetrical airfoil can produce useful lift at zero angle of attack, that is why non-symmetrical airfoil has been used for the analysis in this paper.

In this paper comparative analysis has been done on S1223, S819, S8037 and S1223 RTL airfoils at low- mach number. The goal of this paper is to find out that, which airfoil is the most suitable to be used in a low-speed aircraft on the basis of their Lift-to-Drag ratio, Lift coefficient, Drag coefficient and Moment coefficient under the specified boundary conditions and the value of mach number varies from 0.10 to 0.30 with an increment of 0.5.

II. LITERATURE SURVEY

S. Kandwal et al [1] (Sept.-2012), performs the study of two-dimensional NACA 4412 airfoil using ANSYS-FLUENT for aerodynamic forces on an airfoil. The flow is considered as in-viscid and steady with the inlet temperature 288.18 K and Mach number 0.15. After obtaining different parameters from analysis of NACA4412 at specified boundary conditions, A comparison is done between results obtained from CFD simulation in ANSYS and results obtained from an experiment done in the wind tunnel. The comparative result shows that, the result from experiment and from CFD simulation showing close agreement between these two methods. So, the CFD simulation using ANSYS-FLUENT can be used as an relative alternative to experimental method in determining drag and lift.

Jasminder Singh et al [2] (June- 2015), Analysis is done on NACA 4412 and Seling 1223 airfoils using Computational Fluid Dynamics. The working conditions are; Inlet velocity of working fluid is 2.5 m/sec, laminar model and 1e-03 residual. The Angle of Attack (AOA) varied from 0^0 to 15^0 with an increment of 50 but, the area of airfoil, velocity and density of air were kept constant over various angle of attack. They compared lift and drag coefficients for these two airfoils and suggested that, NACA 4412 is suitable for use in Sports Plane, whereas, S1223 is suitable for Heavy lift Cargo Plane due to its high lift.

Mark D. Maughmer et al [3] (June- 2001) , They designed PSU94-097 airfoil to use on winglets of high performance Sailplanes. For the best performance of the winglet it must be capable to operate in a wide range of Reynold number. That's why, the analysis of this airfoil has been done on reynold numbers from $2.4x10^5$ to $1.0x10^6$ at different angle of attacks. For the validation of design of PSU94-097 airfoil, it was tested in the Penn State University Low-Speed, Low-Turbulence wind tunnel with the rectangular test section having filleted corners and then the results from the wind tunnel testing compared with the highly regarded two-dimensional airfoil codes, PROFILE Code and XFOIL. In all respect this airfoil satisfies all the requirements for the design.

M.M.M. Talukder et al [4] (January- 2016), They did analysis on S819 and S821 airfoil using Computational Fluid Dynamics method with the wind speed of 3m/sec, 4m/sec and 5m/sec and the angle of attack varied from -4^0 to 16^0 with an increment of 4^0 for a wind turbine blade profile. The results generated from CFD method by using ANSYS-FLUENT software were verified experimentally by testing the wooden model of airfoils in an open circuit suction type wind tunnel with a test section of 380 x 355 x 330 mm. They found that, sliding ratio plays a key role in defining the effectiveness and usability of wind turbine blade profile. The optimum angle of attack should be between 0^0 to 2^0 to get the maximum value of sliding ratio.

Rong Ma et al [5], Worked to optimize the design of S1223 airfoil for a high efficiency propeller of low dynamic vehicle in near space. To make a low-speed, high-lift airfoil they used direct search optimization algorithm EXTREM and airfoil flow field solver XFOIL. They generated two profiles of airfoil S1223_OPT1 and S1223_OPT2on the basis of S1223 airfoils profile and compared the results obtained after analysis of these three airfoils; S1223, S1223_OPT1 and S1223_OPT2 at M=0.1 at various angle of attack. They found that, S1223_OPT2 meets all the optimization design requirements among these three airfoils.

Mazharul Islam et al [6] (April- 2012), Performed comparative analysis of S8037, SG6040, S1210 and NACA0015 for fixed-pitch straight-bladed vertical axis wind turbine. For the analysis, the velocities of flowing fluid are 5 m/sec, 10 m/sec and 15 m/sec. During the analysis they found that, NACA0015 produces lowest amount of torque. At the end of their comparative analysis they found S8037 as the best airfoil for the applied boundary conditions among all other candidates, both in terms of starting torque and maximum $(C_p)_{net}$.

Tarun B Patel et al [7] (April- 2015), Performed analysis of Lift and Drag forces of NACA airfoils using PYTHON (x,y) 2.7.9.0 programming.. For a wind turbine blade NACA0012, NACA4412 and NACA6412 Airfoil profile is considered for analysis and with the variation in angle of attack and velocity the comparative analysis has been dome on these three airfoils. They concluded that, Maximum lift forces obtained for the NACA4412 airfoil comparative to all other airfoils under specified boundary conditions.

MD. Safayet Hossain et al [8] (October- 2014), They did comparative analysis of NACA 6409 and NACA 4412. The pressure distributions as well as lift-to- drag ratio of these two airfoils were compared with laminar flow velocity of 1 m/sec. After the comparative analysis, it was found that, NACA 4412 aerofoil is more efficient than NACA 6409 aerofoil.

III. METHODOOGY

A. Geometry Modeling and Meshing

The ANSYS-Fluent (version- 16.2) was used to analyze the flow analysis of flowing fluid over the airfoils. Imported co-ordinates of airfoil in Workbench to generate a two dimensional geometry of airfoil and also generated a two-dimensional region around the geometry of airfoil as a flow region for flowing fluid and it is assumed that fluid flow in z-direction is negligible. Structured mesh has been generated over the airfoil for better results. In meshing, element size is 7e-005 meter and airfoil model discretized into 27957 nodes and 27600 elements.

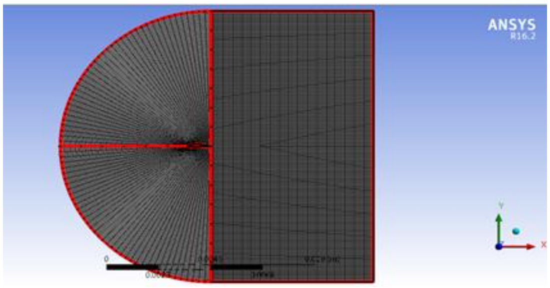

Fig. 1: Mesh Model

B. Boundary Conditions

All the boundary conditions are applied with an option of Double Precision for all the airfoils in 2-D dimension. Spalart-Allamas (1 equation) flow equation has been chosen for the analysis of flowing fluid. The flowing fluid is considered as Air- Ideal gas and the flow of the flowing fluid is steady.

For the analysis of airfoils on above mentioned boundary conditions, The Mach Numbers M= 0.10, M= 0.15, M= 0.20, M= 0.25 and M= 0.30 are applied on each of the airfoil for their comparative analysis for various flow conditions as mentioned in the Table-1

Table 1: Boundary Conditions for Airfoil Analysis

Inlet Boundary Conditions	
Inlet Type	Pressure-far Field
Temperature	288.17 K
Wall Boundary Conditions	
Wall Motion	Stationary Wall
Shear Condition	No Slip
Outlet Boundary Conditions	
Outlet Type	Pressure-Outlet
Gauge Pressure	0 Pa
Solution Method	
Scheme	Simple
Gradient	Green-Gause Cell Based
Initialization Method	Hybrid Initialization
Properties of Flowing Fluid	
Fluid	Air- Ideal Gas
Specific Heat	1.006.43 J/kg-k
Viscosity	1.7894e-05 kg/m-s

IV. RESULT AND DISCUSSION

A. Lift-to-Drag Ratio

The higher value of this ratio is the most desirable factor for any aircraft design. The value of drag-to-lift ratio can be increased either by increasing the value of lift coefficient or by decreasing the value of drag coefficient but in case of an aircraft design the lift directly depends on the weight of an aircraft and the drag depends upon the aerodynamic design of aircraft and its wings.

Table 2: Lift to Drag Ratio of airfoils at different Mach number

Mach Number	C_l/C_d at S1223	C_l/C_d at S819	C_l/C_d at S8037	C_l/C_d at S1223 RTL
0.10	0.5020	0.1632	0.1252	0.8215
0.15	0.5989	0.1745	0.1737	0.9239
0.20	0.7801	0.1697	0.2122	1.0911
0.25	0.9323	0.1803	0.2608	1.3437
0.30	1.0485	0.2254	0.3005	1.4143

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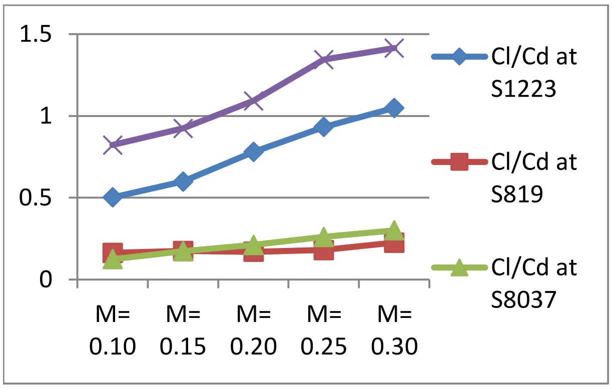


Fig. 2: Lift-to-Drag ratio verses Mach Number

It can be seen from the table 2, that the value of lift to drag ratio for all the airfoils increases from mach number 0.10 to 0.30 except S819 airfoil. From the table 2 and figure 2, It can also be observed that, At the mach number of 0.10 the lift to drag ratio for S8037 is lesser than that of S819 but as the value of mach number increases, the value of lift to drag ratio of S8037 gets higher than that of S819 as the value of mach number crosses mach number 0.15.

At all the mach number the highest value of lift to drag ratio is shown by S1223 RTL and the S1223 came on the second place in order to show the highest value of lift to drag ratio.

B. Drag Coefficient

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 fluid or an object, compressibility and viscosity of flowing fluid or a fluid around a moving object and the size and shape of the object.

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

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

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: Coefficient of Drag at different Mach Number

M	C_d at S1223	C_d at S819	C_d at S8037	C_d at S1223 RTL
0.10	1.3081e-03	9.8369e-04	8.0983e-04	8.9127e-04
0.15	1.1230e-03	9.0849e-04	6.9873e-04	8.0573e-04
0.20	9.0151e-04	7.6648e-04	6.2320e-04	7.0369e-04
0.25	7.6365e-04	6.4104e-04	5.0989e-04	5.6043e-04
0.30	6.9307e-04	5.3447e-04	4.5262e-04	5.3113e-04

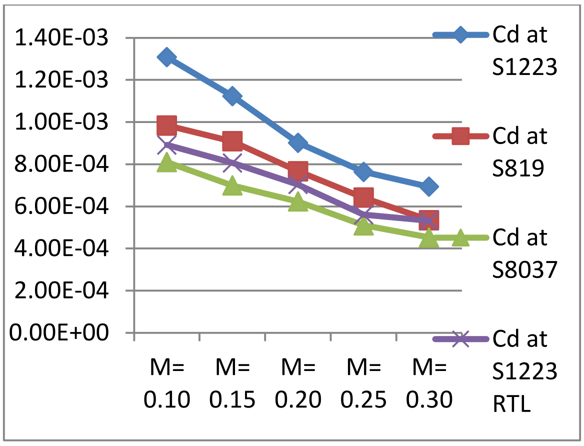


Fig. 3: Coefficient of Drag verses Mach Number

From the table 3, it can be observed that, for all the airfoils value of drag coefficient continuously decreases from 0.10 to 0.30 mach number. From figure 3, it is clear that, S1223 produces the highest amount of drag coefficient at various mach number whereas, S8037 produces lowest amount of drag coefficient at various mach numbers. S1223 RTL airfoil is at the second lowest position in the graph of drag coefficient at different Mach numbert.

C. 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 hold it in the air. It is a vector quantity and it acts through the center of pressure of the flying object. The lift is generated by the difference in velocity of flying object and fluid, around that flying object. It takes no difference whether the object is passing through the fluid or the fluid is flowing over an object.

Lift is generally measured as a non-dimensional coefficient, Coefficient of Lift (C_L).

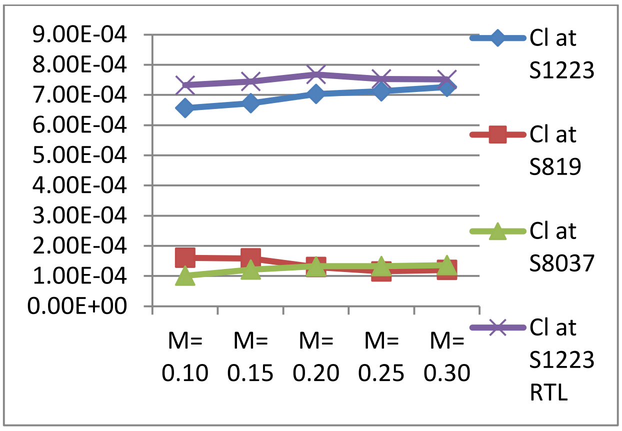
$$C_L = \frac{L}{(1/2)\rho V^2 A}$$

where, L is the Lift Force, ρ is the density of fluid, V is the flow speed and A is the relative plan area.

Here, Coefficient of Lift is generated over the four airfoils at different Mach Number to perform a comparative analysis of these airfoils on the basis of their predicted lift coefficient at mach number from 0.10 to 0.30. Table 4 and Figure 4 represents the variation of lift coefficient at different mach number for these four airfoils.

Fig. 4: Coefficient of Lift at different Mach Number

M	C_l at S1223	C_l at S819	C_l at S8037	C_l at S1223 RTL
0.10	6.5673e-04	1.6060e-04	1.0143e-04	7.3219e-04
0.15	6.7267e-04	1.5862e-04	1.2138e-04	7.4447e-04
0.20	7.0332e-04	1.3010e-04	1.3227e-04	7.6784e-04
0.25	7.1202e-04	1.1564e-04	1.3298e-04	7.5282e-04
0.30	7.2674e-04	1.2047e-04	1.3604e-04	7.5120e-04



Fir. 4: Coefficient of Lift verses Mach Number

As Shown in the table 4, For S8037, S1223 and S1223 RTL the value of coefficient of lift keep increasing from mach number 0.10 to 0.30, but in the case of S819 airfoil, the value of coefficient of lift keep decreasing from mach number 0.10 to 0.25 but there is a slight increment in this value at 0.30 mach number

In the figure 4, The value of lift coefficient for S8037 airfoil is lowest at mach number 0.10 but it keep increasing with the increment of mach number and crosses the curve of S819 airfoil at mach number 0.20. The maximum lift coefficient is generated by S1223 RTL among all these four airfoils under the selected range of mach number. The value of lift coefficient for S1223 RTL airfoil keep increasing from mach number of 0.10 to 0.20 but for further increment of mach number lift coefficient keep decreasing up to the value of mach number 0.30. S1223 airfoil, produces the second highest amount of lift coefficient that can be seen in the table 4 and figure 4. For S1223 airfoil, the value of coefficient of lift keep increasing from mach number 0.10 to 0.30.

D. Coefficient of Moment

Coefficient of Moment is generally known as the Pitching Moment. Pitch Moment is a moment which acts on the pitching axis of the object moving or traveling through a fluid medium. It acts on the aerodynamic center of the airfoil rather than the center of pressure of the airfoil. The pitching moment coefficient does not vary with the lift coefficient on the Aerodynamic Center. The aerodynamic center of an airfoil is generally close to 0.25 times of chord behind the leading edge of the airfoil. The aerodynamic center is a point on the chord line of the airfoil at which the pitching moment coefficient does not vary with the change in angle of attack.

The Pitching Moment (C_m) is generally defined as;

$$C_m = \frac{M}{P\,S\,c}$$

where, M is the Pitching Moment, P is the dynamic pressure, S is the relative plan area and c is the chord length of the airfoil.

The airfoil moment (M) is dependent on air speed, wing area and the chord length. The aircraft becomes unstable in pitch if the tail is required to produce positive or upward lift in order to balance the sum of the airfoil and lift moments. This would be indicated by a negative or nose down tail moment, and is most likely to occur at low airspeeds.

Table 5: Coefficient of Moment of airfoils at different Mach number

M	C_m at S1223	C_m at S819	C_m at S8037	C_m at S1223 RTL
0.10	4.9707e-07	1.0022e-07	9.8015e-08	4.8075e-07
0.15	5.1371e-07	9.8571e-08	9.2766e-08	4.8140e-07
0.20	4.8763e-07	8.6479e-08	9.1921e-08	4.7896e-07
0.25	4.6713e-07	7.8680e-08	6.7716e-08	4.7199e-07
0.30	4.4377e-07	7.8757e-08	6.9833e-08	4.6982e-07

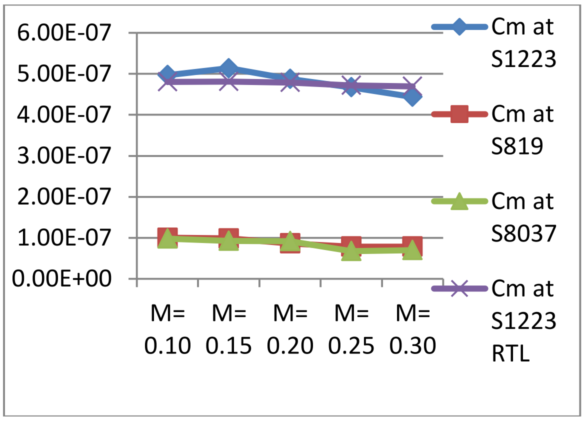


Fig. 5: Coefficient of Moment verses Mach Number

From the table 5 and figure 5 it can be observed that, from mach number 0.10 to 0.20 S1223 airfoil showing the maximum moment coefficient than other airfoils, because the moment coefficient of S1223 airfoil keep decreasing from mach number 0.15 to 0.30, the values of moment coefficient of S1223 airfoil gets lower to that of S1223 RTL airfoil at mach number 0.25 and 0.30. The lowest value of moment coefficient has been shown by the S8037 airfoil among all these airfoils.

V. CONCLUSION

In this paper, analysis of four airfoils has been carried out at low mach number from 0.10 to 0.30 by using SIMPLE scheme, Green-Gause Cell Based gradient and Spalart-Allamas Model. For the design of an aircraft it is most desirable to choose a suitable airfoil to design its wings. so that, desirable amount of lift can be generated under the specified boundary conditions for that aircraft. For this purpose, Lift-to-Drag ratio and coefficient of moment are the most important values to be taken care for proper aerodynamic design of the wing

From the analysis, It can be concluded that. Airfoil S1223 RTL showing the maximum drag-to-lift ratio, maximum value of coefficient of lift and the second lowest value of drag coefficient at mach numbers from 0.10 to 0.30. The coefficient of moment or pitching moment is another factor which needs to be considered while selecting airfoils for the wing of an aircraft. So on the basis of these values at different mach numbers, the selection must be S1223 RTL airfoil among these four airfoils for the specified conditions.

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