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Comparison of Aerodynamic Behaviour between NACA 0018 and NACA 0012 Airfoils at Low Reynolds Number Through CFD Analysis

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ABSTRACT
For better designing of an airfoil, the aerodynamic characteristics of the airfoil need to be investigated both experimentally and numerically. Coefficient of lift (C_L), coefficient of drag (C_D), variation of C_L/C_D ratio with angle of attack is very important parameters in CFD analysis. In this study the above parameters are investigated for two symmetric airfoils (NACA0018 and NACA0012) at two different low Reynolds numbers of 300,000 and 700,000. This numerical results show that the stall angle for NACA0018 airfoil at Re=300,000 is less than 17 degree and at Re=700,000 for the same airfoil it is 17.5 degree and this happened due to the increased velocity. C_L increases more linearly than C_D up to about 10 degree so that C_L/C_D ratio increases with the angle of attack and then decreases after or near about 10 degree. It has been also found that higher the Reynolds number, greater the value of C_L/C_D ratio. Besides, it is evident from this simulation that NACA 0012 produces more lift than NACA 0018 for the same Reynolds number. That's why, NACA 0012 airfoil may be verily used for aircraft application whereas NACA 0018 airfoil may be used in VAWT (Vertical Axis Wind Turbine) And HAWT (Horizontal Axis Wind Turbine) to capture the wind energy and convert it to useable energy which is one form of renewable energy.

Keywords: *Airfoil, reynolds number, NACA, angle of attack, velocity*

INTRODUCTION

The aerodynamic characteristics of any airfoil need to be analyzed and that's why different parameters associated with aerodynamics are must be investigated both experimentally and numerically for required performance of airfoil.[5] An airfoil might be characterized as the cross-sectional shape of a wing, blade (of a rotor, propeller or turbine), or sail. When an airfoil-shaped body moved through a fluid, it generates an aerodynamic force.[8] It has two components. The perpendicular component is known as lift whereas the parallel component is known as drag. Generally subsonic flight (Mach number is less than 1) airfoils have a special shape with a rounded leading edge, followed by a sharp trailing edge. The foils which are used in water is called hydrofoils. Coefficient of lift (C_L), coefficient of drag (C_D), variation of C_L/C_D ratio with angle of attack is important parameters in Computational Fluid Dynamics (CFD) analysis. Various modeling like Standard k-ε, RNG k-ε, SST k-ω etc. are frequently used to determine these parameters of an airfoil, both symmetric and asymmetric. In this study the above parameters are investigated for two symmetric airfoils

(NACA0018 and NACA0012) at two different low Reynolds numbers of 300,000 and 700,000. NACA stands for National Advisory Committee for Aeronautics. A commercial CFD code, the FLUENT (version 14.5), is used in this study. SST k-ω turbulence model is used for calculating C_L, C_D variation with angle of attack. We have validated our numerical simulation with a known experimental investigation.

LITERATURE REVIEW

Sereez *et al.* [2] analyzed aerodynamic static hysteresis at stall conditions for NACA0018 airfoil in the TsAGI'sT-124 low turbulence wind tunnel. Comparisons of computational simulation results with experimental wind tunnel data were made for 2D NACA0018 [1] and NACA0012 airfoils at low Reynolds numbers Re =300,000. The study was about the variation of static hysteresis loop with width of airfoil in static tests.

Jacobs and Sherman [10] studied about symmetric airfoil in NACA variable-density wind tunnel over a big range of Reynolds number.[4,6,7] The tests were done to provide information from which the variations of airfoil section characteristics with changes in the Reynolds number could be guessed and methods of allowing for these differences in practice could be examined.

Timmer [11] carried out an experiment with a balance and wake rake measurements on a 0.25 m chord model having a NACA 0018 airfoil in the Delft University low-turbulence wind tunnel. The test revealed that lower surface laminar separation bubble dominates over the flow and noise characteristics at Reynolds numbers between 150000 and 1000000. [9] This study gave the experimental data for C_D vs. angle of attack and C_L vs. angle of attack.

NUMERCAL APPROACH

Basics of CFD

Computational fluid dynamics constitutes a relatively new approach in the philosophical study and development of the whole discipline of fluid dynamics. The improvement of the super-fast computer along with the innovation of exact numerical algorithms for solving real world physical problems on these digital computers has established the method we practice fluid dynamics nowadays. Computational fluid dynamics is now an equal partner with pure theory and pure experiment in the analysis and solution of fluid dynamics problems. Put on the fundamental laws of mechanics to either of fluid, we acquire the basic governing equations for that fluid.

Governing Equation

The conservation of mass equation is in vector form

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho V) = 0 \qquad (1)$$

And the conservation of momentum equation is

$$\rho\frac{\partial V}{\partial t} + \rho\big((V.)V\big)V == -\nabla\rho + \rho g \ + \nabla.\tau(2)$$

Where, ∇ is the velocity vector.

The governing equation for the present study is the Continuity Equation (Conservation of Mass) and Navier-Stokes Equation (Conservation of Momentum) for incompressible (density, ρ is constant) flow.

Conservation of mass

$$\frac{1}{\rho}\frac{\partial \rho}{\partial t} + \frac{\partial(u)}{\partial x} + \frac{\partial(v)}{\partial y} + \frac{\partial(w)}{\partial z} = 0 \qquad ; For\ 3D\ flow \qquad (3)$$

$$\frac{1}{\rho}\frac{\partial \rho}{\partial t} + \frac{\partial(u)}{\partial x} + \frac{\partial(v)}{\partial y} = 0 \qquad ; For\ 2D\ flow \qquad (4)$$

Conservation of momentum

For 3-D flow,

$$\rho\left(\frac{\partial(u)}{\partial t}+u\frac{\partial(u)}{\partial x}+v\frac{\partial(u)}{\partial y}+w\frac{\partial(u)}{\partial z}\right)+\frac{\partial(\rho)}{\partial x}=\mu\left(\frac{\partial^2(u)}{\partial x^2}+\frac{\partial^2(u)}{\partial y^2}+\frac{\partial^2(u)}{\partial z^2}\right) \quad (5)$$

$$\rho\left(\frac{\partial(v)}{\partial t}+u\frac{\partial(v)}{\partial x}+v\frac{\partial(v)}{\partial y}+w\frac{\partial(v)}{\partial z}\right)+\frac{\partial(\rho)}{\partial y}=\mu\left(\frac{\partial^2(v)}{\partial x^2}+\frac{\partial^2(v)}{\partial y^2}+\frac{\partial^2(v)}{\partial z^2}\right) \quad (6)$$

$$\rho\left(\frac{\partial(w)}{\partial t}+u\frac{\partial(w)}{\partial x}+v\frac{\partial(w)}{\partial y}+w\frac{\partial(w)}{\partial z}\right)+\frac{\partial(\rho)}{\partial z}=\mu\left(\frac{\partial^2(w)}{\partial x^2}+\frac{\partial^2(w)}{\partial y^2}+\frac{\partial^2(w)}{\partial z^2}\right) \quad (7)$$

Geometry

Figure 1 and Figure 2 depict the airfoil used in present study. The chord length is 1m for both airfoils. The radius of the 'C' of the C-shaped mesh is 12.5m. The maximum thickness for NACA0012 airfoil is 12% of the chord length and for NACA0018 it is 18% of the chord length.

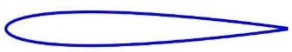

Fig.1: *NACA 0012 Airfoil*

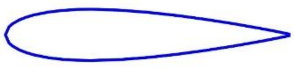

Fig.2: *NACA 0018 Airfoil*

Meshing

Grid system is very important for quality CFD analysis. In the present study, a 2D unstructured mesh is employed with total number of cells about 89000 in both airfoils. The maximum and minimum face area is 2.323256 m^2 and 2.011792x10^{-4} m^2 respectively for NACA 0012 airfoil [3] which is 3.360926 m^2 and 1.896361x10^{-4} m^2 respectively for NACA 0018 airfoil.

The meshing domain is shown in Figure 3. Zoomed in views of the meshing near the airfoil surfaces are given in Figure 4.

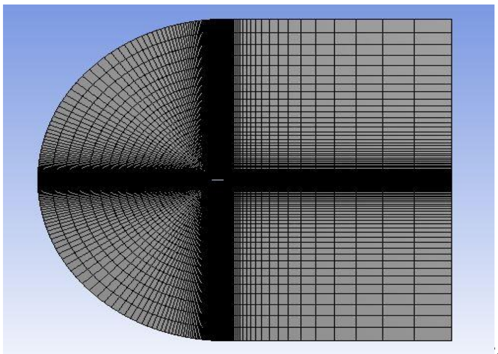

Fig. 3: *Meshing Domain for NACA 0018 Airfoil.*

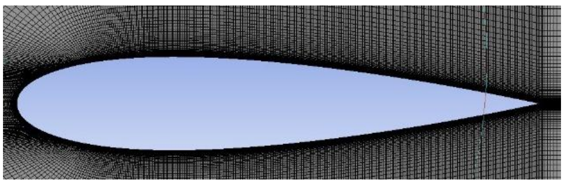

Fig.4: *Magnified View of Meshing for NACA0018 Airfoil.*

Solver Setting

ANSYS FLUENT is used for computation. SST k-ω turbulence model is used for calculating C_L, C_D variation with angle of attack. This CFD tool solved the governing integral equations for the conservation of mass and momentum.[12]

Table 1: *Solver Setting.*

Solver	Velocity formulation	2D Space	Time
Pressure based	Absolute	Planer	Steady

Boundary Conditions

Inlet: Velocity inlet boundary condition is used. For Re=300,000 the inlet velocity was used 4.38 m/s and for Re=700,000 the inlet velocity was 10.23 m/s.

Outlet: Pressure outlet boundary condition is used. At the outlet boundary, gauge pressure is maintained as 0 Pa.

Wall: At all solid boundaries in the flow geometry stationary wall with the no-slip condition has been used. It can be mathematically expressed as,

u_{wall}=0 m/s, and v_{wall}=0 m/s

Solution Method

In this study Coupled scheme was used for pressure-velocity coupling. This solver is more advantageous than the pressure-based segregated algorithm. The pressure-based algorithm has a more strong and useful single phase implementation for steady-state flows. In the spatial discretization gradient was least squares cell based, Pressure was second order, momentum was second order upwind, and turbulent kinetic energy and specific dissipation rate were used as first order upwind. Courant-Friedrichs-Lewy (CFL) number was kept 0.9 and explicit relaxation factors for pressure and momentum were both 0.75.

RESULTS AND DISCUSSION

Validation

For validation here we have used two experimental investigation. One is Jacobs [10] in 1937 and another is Timmer [11] in 2008. Our calculated results have nearly matched with these both experimental results. We have validated our results for NACA0018 airfoil differently at Re=300000 and Re=700000. The graphical results of validation are shown below:

Table 2 *Comparison between C_L and C_D of our Models and the Available Experimental Data for NACA 0018 at Re =300,000.*

C_L			
AOA	Our Study	Jacob	Timmer
5°	0.43726	0.48	0.47
10°	0.85221	0.85	0.93
15°	1.2207	1.00	1.04
C_D			
AOA	Our Study	Jacob	Timmer
5°	0.017397	0.024	.023
10°	0.025715	0.028	0.027
15°	0.051888	0.04	0.06

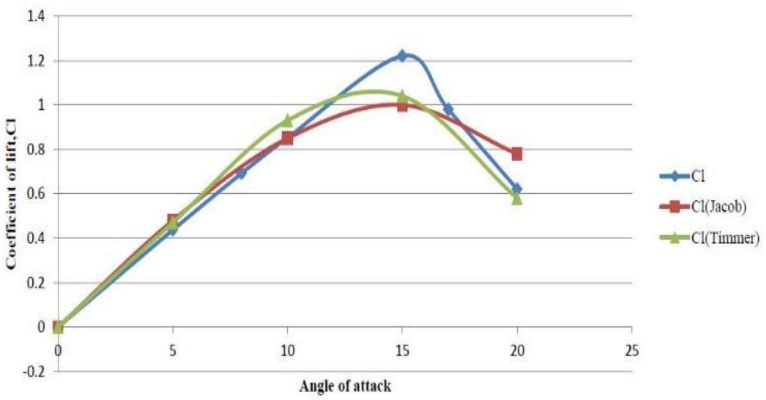

Fig. 5: *Comparison between the Calculated Coefficient of Lift (C_L) of our Models and the Available Experimental Data for NACA 0018 at Re =300,000.*

From Figure 5, it is evident that the C_L is proportional with angle of attack up to the stall angle (which is almost 16 degree) and beyond that angle C_L suddenly falls. This is due to back flow of the air stream.

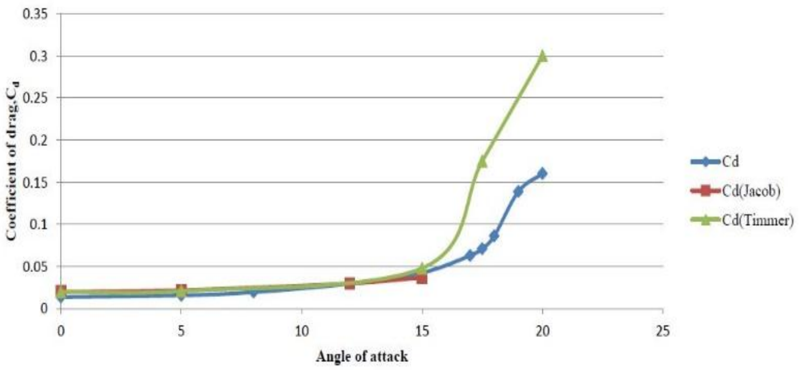

Fig. 6: *Comparison between the Calculated Coefficient of Drag (CD) of our Models and the Available Experimental Data for NACA 0018 at Re =700,000.*

From these graphs, it can be said that our simulation work is valid. Up to stall angle our studied data almost matches with the experimental data, but after the stall angles the characteristics is unpredictable.

RESULTS

Effect of the Shape (Maximum Thickness) of the Airfoil on Cl/Cd ratio

We know the thrust is a very important parameter for flying of airplane. The thrust required for an airplane to fly at a given velocity in steady level flight is

$$TR = \frac{W}{Cl/Cd} \qquad (8)$$

Where TR is Thrust required and W is Weight of the airplane. Here from Equation 8, we see that thrust required is inversely proportional with C_L/C_D ratio. Higher the value of C_L/C_D ratio, lower the amount of thrust required. That's why, in aerodynamics of airplane it is often desired to maximize the C_L/C_D ratio.

In our study, it has been noticed the variation C_L/C_D ratio with angle of attack for both airfoils at different Reynold's numbers and found an interesting result.

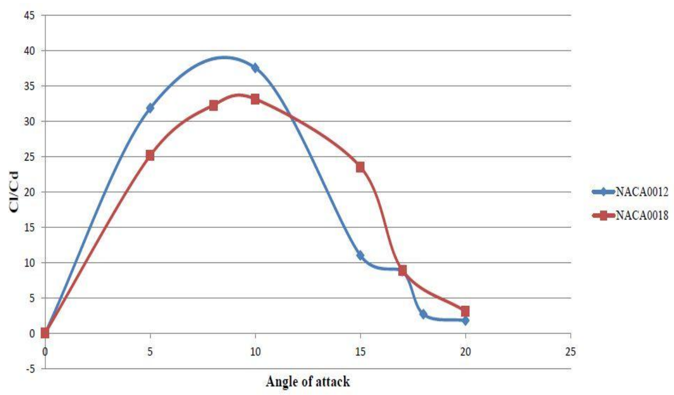

Fig. 7: *Variation of C_L/C_D ratio with Angle of Attack for NACA0018 and NACA0012 at Re=300,000.*

From Figure 7, it is evident that the maximum value of C_L/C_D ratio is higher for NACA0012 over NACA0018 for same Reynolds number (300,000). The cause of this phenomena may be the thickness if the airfoil. As the thickness of NACA0012 is lower than the NACA0018, so it faces comparatively less frictional drag. As a consequence, the C_L/C_D ratio slightly increases.

After the peak point the C_L/C_D ratio decreases rapidly in case of NACA0012 airfoil while the ratio decreases slowly for NACA0018 airfoil.

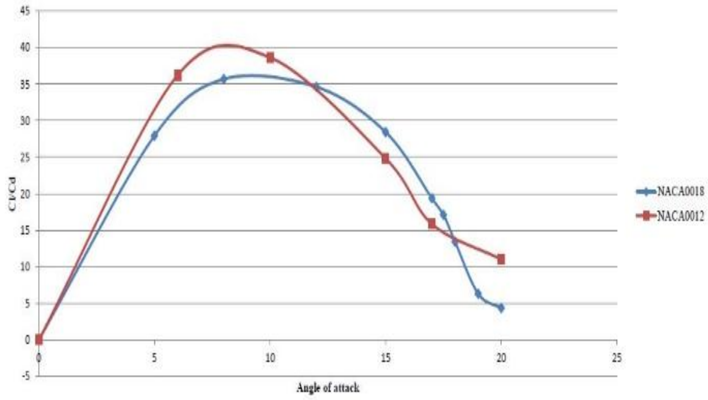

Fig. 8: *Variation of C_L/C_D Ratio with Angle of Attack for NACA0018 and NACA0012 at Re=700,000.*

In Figure 8, the variation has been illustrated for Re=700,000. Here it is seen that the maximum value of the ratio is slightly higher than for Re=300,000. This phenomena is due to the increase in Reynolds number i.e. velocity. The maximum ratio is compared in the following table:

Table: 3 *Comparison of Maximum C_L/C_D with Re=300,000 and Re=700,000.*

Airfoil	Re=300,000	Re=700,000
NACA0012	38.023	40.056
NACA0018	33.89	36.42

From the above comparison, it is clear that the maximum C_L/C_D ratio is always greater for NACA0012 airfoil than NACA0018 airfoil. For this reason NACA0012 airfoil is extensively used in aircraft where Lift is of prime concern and on the contrary NACA0018 airfoil is used in the vertical axis wind turbine blades and other cases where lift is not of prime interest.

Effect of Reynolds Number (Free-Stream Velocity) on the CL/CD Ratio

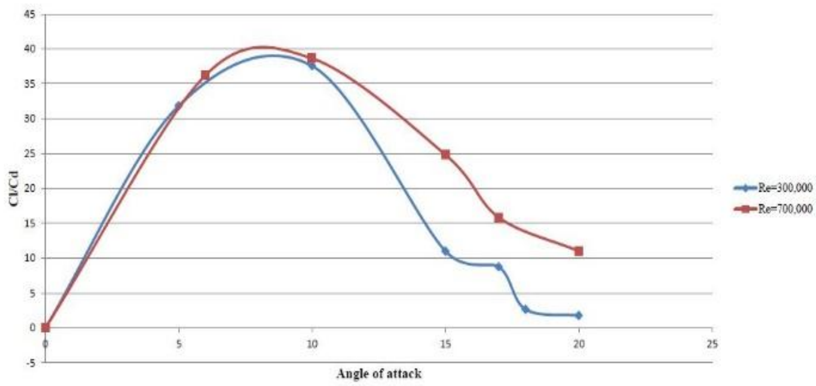

Fig. 9: *Variation of C_L/C_D Ratio with Angle of Attack for NACA0012 at Re=300,000 and Re=700,000.*

From Figure 9, it is seen that up to about 5 degree of angle of attack, the C_L/C_D ratio is slightly higher for re=300,000 but the maximum value of the ratio is higher for Re=700,000. After the highest point, the ratio decreases so fast for Re=300,000. This happens because for lower Reynolds number as the velocity is lower and the flow tends to be attached to the surface and therefore, drag increased and overall C_L/C_D ratio is decreased more.

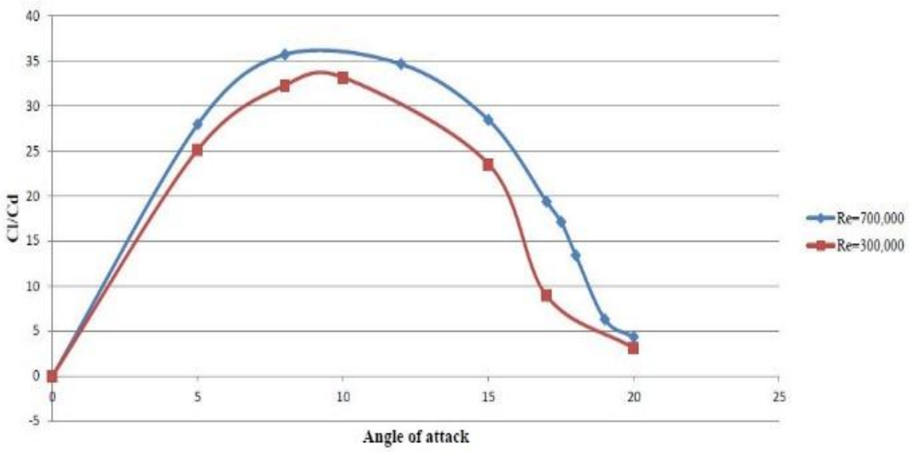

Fig.10: *Variation of C_L/C_D with angle of attack for NACA0018 at Re=300,000 and Re=700,000*

From the Figure 10, it is seen that the C_L/C_D ratio is always lower unlike for the NACA0012 airfoil where initially the ratio is slightly higher for Re=300,000.

CONCLUSION

In this study, we have tried to find some aerodynamic properties and finally found that C_L/C_D ratio is always higher for NACA 0012 than NACA 0018 airfoil. At the same time, with the increase of Reynold's number, C_L/C_D ratio increases for both airfoils. We have also noticed the almost a linear increment of C_L/C_D ratio with the increment of angle of attack. But after a certain angle of attack, the C_L/C_D ratio abruptly falls down. So this angle is very crucial for aerodynamics. It is clear from our study that NACA 0012 generates more lift than NACA 0018 for the same Reynolds number. That's why, NACA 0012 airfoil may be verily used for aircraft application whereas NACA 0018 airfoil may be used in VAWT (Vertical Axis Wind Turbine) And HAWT (Horizontal Axis Wind Turbine) to adopt the wind energy through the wind turbine blades and convert it to useful energy which is one popular form of renewable energy.

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NOMENCLATURE

Symbol	Meaning	Unit
α	Angle of attack	(K)
P	Pressure	(Pa)
c	Chord length	(m)
x	Any distance from leading edge	(m)
u	X-component velocity	(m/s)
v	Y-component velocity	(m/s)
w	Z-component velocity	(m/s)
V_∞	Free-stream velocity	(m/s)
τ	Shear stress	(N/m^2)
μ	Viscosity	(Pa-s)
ρ	Density	(kg/m^3)
Re	Reynolds number ($\rho V_\infty L/ \mu$)	Dimension Less
t	Time	(s)
C_L	Coefficient of lift	Dimension Less
C_D	Coefficient of drag	Dimension Less

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