# Design And Performance Analysis of Airfoils

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***Abstract-*** *This research provides a stable, high-efficiency, high angle of attack, airfoil. The means of accomplishing these improvements is based on the concepts of KF airfoils. A primary objective of this research is to improve the efficiency of the airfoil and to obtain higher ratio of useful work output to energy input, thereby saving significant energy resources. NACA (National Advisory Committee for Aeronautics) airfoils have been generated according to the NACA standards. The effects of fluid flow have been studied for the two airfoils 4415 and 0015 through Computational fluid dynamics (CFD). Both these airfoils are studied by varying the angle of attack and recording the lift and drag values. By modifying the design of these airfoils and using the concepts of Kline-Fogleman(KF) airfoil a new design was formulated. Varying the angle of attack, the lift and drag values of the new airfoil is recorded.*

*This stable high angle of attack airfoil is improving aviation safety. Private aircraft accidents involve the plane stalling. Higher attack angles along with higher lift/drag ratios would enhance glide capabilities.*

*A secondary objective of this research is to reduce mechanical force input required for pitching airfoils such as rotary wings, propeller, rotors and impeller, saving weight in the construction.*

***Keywords-*** Angle of Attack, CFD Analysis, NACA 4415, NACA 0015, KF airfoil, Lift, Drag

## I. INTRODUCTION

It is a fact that a body in motion through a fluid experiences a resultant force which, in most cases is mainly a resistance to the motion. A certain type of body exists, however for which the component of the resultant force normal to the direction of motion is many times greater than the component resisting the motion, and the possibility of the flight of an airplane depends on the use of these bodies called airfoils. Airfoil is such an aerodynamic shape that in motion splits the air and passes it above and below the wing. The wing’s upper surface is shaped so the air rushing over the top speeds up. This decreases the air pressure above the wing. The air flowing below the wing moves comparatively slower, so it’s air pressure remain the same. Since higher air pressure always tries to move toward lower air pressure, the air below the wing pushes the wing upward creating lift. The faster an airplane moves, the more lift there is. And when the force of lift is greater than the force of gravity, the airplane is able to fly.

## II. AIRFOIL NOMENCLATURE

An airfoil body is shaped such that when placed in an airstream, it produces an aerodynamic force. This force is utilized for different purposes such as the cross sections of wings, propeller blades, windmill blades, compressor and turbine blades in a jet engine.
The basic geometry of an airfoil is shown in Figure 1.

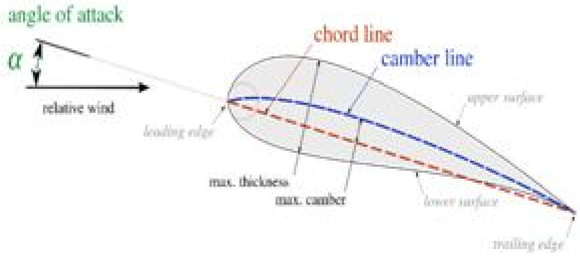


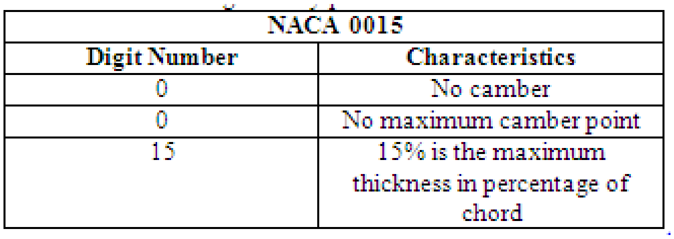
Figure 1:Basic nomenclature of an airfoil

The terminologies associated with airfoil are leading edge, trailing edge, chord length, angle of attack, camber and thickness (Figure 1).The leading edge is the point at the front of the airfoil having maximum curvature. The trailing edge is a point having maximum curvature at the rear of the airfoil. The chord line is a straight line connecting the leading and trailing edges of the airfoil. The chord length, or simply chord is the length of the chord line and is the characteristic dimension of the airfoil. The airfoils used in present study for CFD were modelled according to the NACA standard.

### A. NACA AIRFOILS

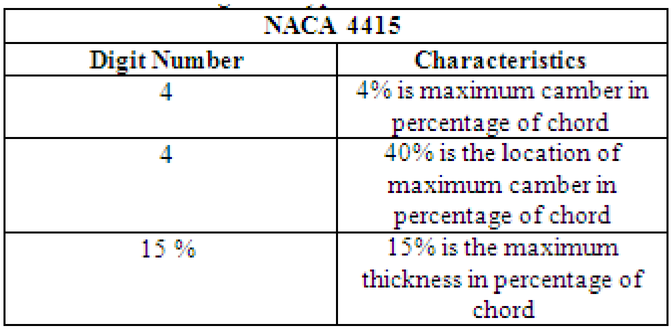
The NACA 0015 airfoil has a certain geometry defined by its number itself, shown in table 1 and the NACA 4415 geometry defined in table 2.

Table 1: Shows the geometry parameters of NACA 0015 airfoil



| NACA 0015 | |
|---|---|
| **Digit Number** | **Characteristics** |
| 0 | No camber |
| 0 | No maximum camber point |
| 15 | 15% is the maximum thickness in percentage of chord |

Table2:Showsthe geometry parameters of NACA 4415 airfoil



| NACA 4415 | |
|---|---|
| **Digit Number** | **Characteristics** |
| 4 | 4% is maximum camber in percentage of chord |
| 4 | 40% is the location of maximum camber in percentage of chord |
| 15 % | 15% is the maximum thickness in percentage of chord |

## B. COEFFICIENT OF LIFT AND DRAG

The drag equation,

$$F_d = \frac{1}{2} (\rho\, v^2 C_d S)$$

So coefficient of drag is given by the,

$$Cd = 2F_d / (\rho\, v^2 S)$$

This equation states that the drag force on any object is proportional to the density of the fluid, proportional to the square of the relative speed between the object and the fluid and proportional to the span of the airfoil. In fluid dynamics the term Cd / Cl is a dimensionless quantity which is used to denote the drag or resistance of an object in a fluid environment such as air or water. A lower drag coefficient indicates that the object will have less aerodynamic drag. The drag coefficient is always associated with the surface area. The drag coefficient of any object comprises the effects of the two basic components of fluid dynamic drag: skin friction and form drag. The drag coefficient of a lifting air foil or hydrofoil also includes the effects of lift induced drag. The drag coefficient of a complete structure such as an aircraft/plane also includes the effects of interference drag. For automobiles and many other objects, the reference area is the projected frontal area of the vehicle. This may not necessarily be the cross sectional area of the vehicle, depending on where the cross section is taken and for an air foil the surface area is a plane wings area.

The lift equation,

$$L= \frac{1}{2}(\rho\, v^2 S\, C_l)$$

So coefficient to flift is given by,

$$C_l = L/ (\tfrac{1}{2}\rho\, v^2 S) = 2L/ (\rho\, v^2 S)$$

A fluid flowing past the surface of a body such as an air foil exerts a force on it. Lift is the component of this force that is perpendicular to the on coming flow/ relative wind direction. It contrasts with the drag force, which is the component of the force parallel to the to the flow direction. If the fluid is air, the force is called an aerodynamic lift force.

## III. METHODOLOGY

### A. MESHING

The co-ordinates were downloaded from Airfoil tools database. The dat file was given in terms of x and y coordinates. The z coordinates were added to it and ansys readable file was created. A fine mesh is created around the airfoil for accurate results in Ansys Fluent.

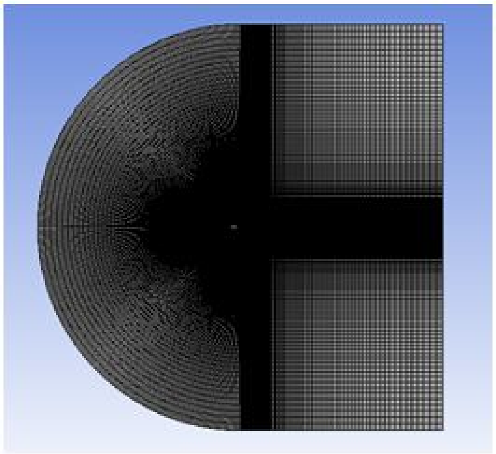


Figure 2: Meshed model in Ansys Fluent

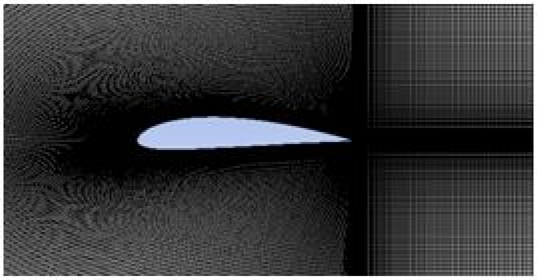


Figure 3: View of the meshed airfoil

### B. CFD ANALYSIS

The mesh file is imported in the fluent software for further analysis. With a better quality mesh the accuracy of the results varies slightly. This can be used as a validation procedure to obtain good results. The input parameters given were velocity, type of model, number of iterations. The fluent solver yields the result of coefficient of lift and drag, pressure and velocity variations.

Table 3: Shows the input parameters for CFD analysis of airfoils

| | |
|---|---|
| Inlet Velocity | 15m/s |
| Density(air) | 1.225kg/m$^3$ |
| Viscosity(air) | 1.7894e-05 Ns/m$^2$ |
| Model | k-ε turbulence model |
| Number of iterations | 1000 |
| Reynolds Number | 1000000 |

The result of CFD analysis is shown as follows,

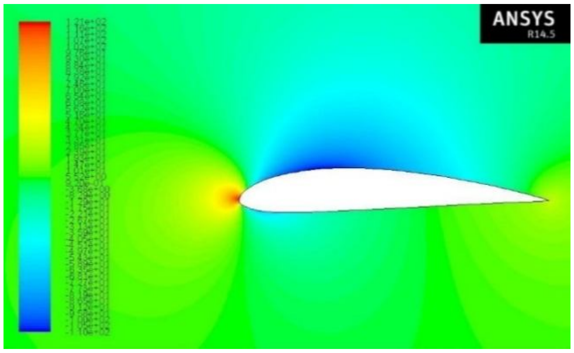


Figure 4: Pressure contours of NACA 4415airfoil at 0 degree

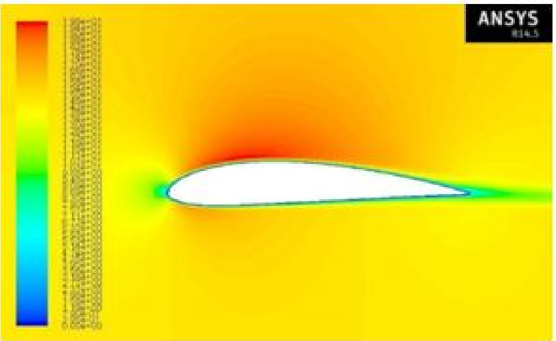


Figure 5: Velocity contours NACA 4415 airfoil at 0 degree

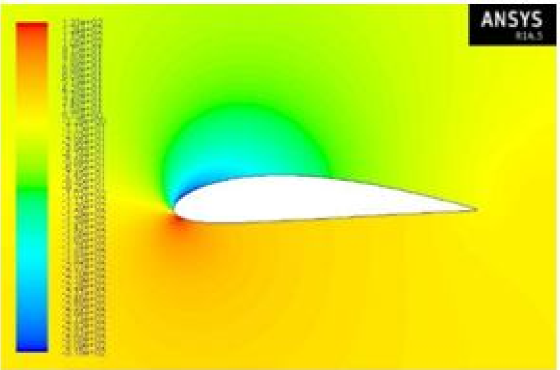


Figure 6: Pressure contours of NACA 4415 airfoil at 10 degree

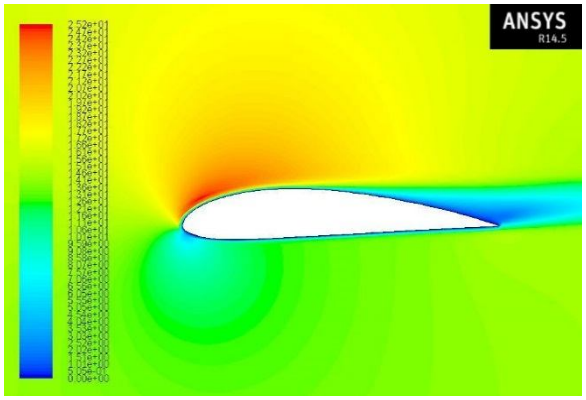


Figure 7: Velocity contours of NACA 4415 airfoilat 10 degree

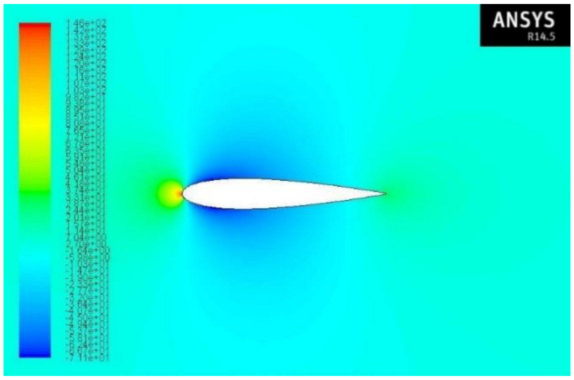


Figure 8: Pressure contours of NACA 0015 airfoil at 0 degree

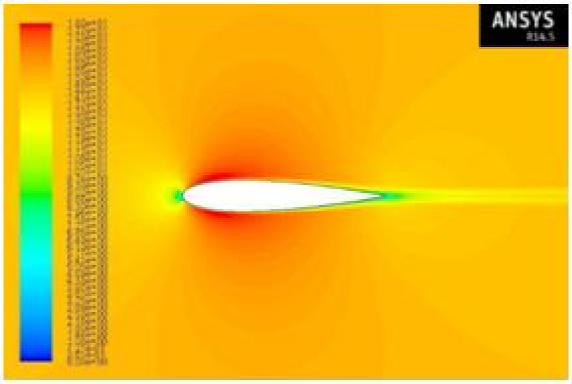


Figure 9: Velocity contours of NACA 0015 airfoil at 0 degree

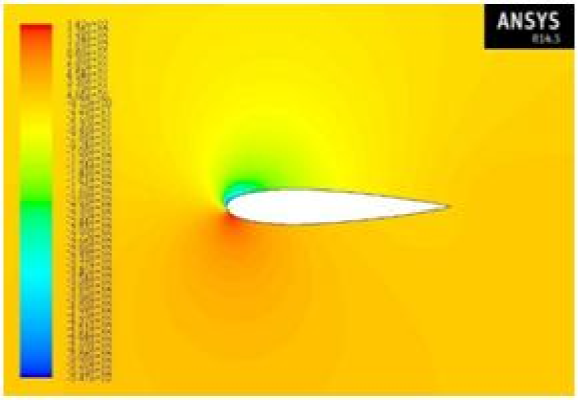


Figure 10: Pressure contours of NACA 0015 airfoil at 10 degree

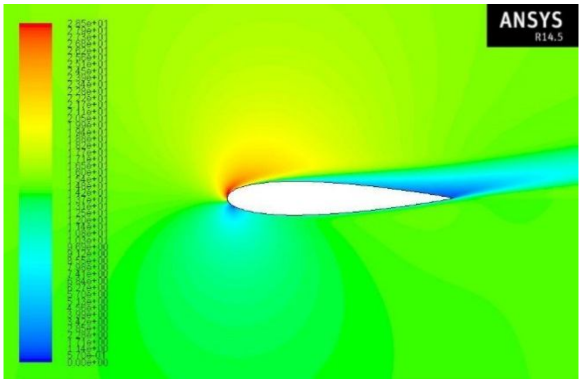


Figure 11: Velocity contours of NACA 0015 airfoil at 10 degree

Table 4: Lift and Drag coefficients

| Angle of attack | NACA 4415 | | NACA 0015 | |
|---|---|---|---|---|
| | Cl | Cd | Cl | Cd |
| 0 | 0.3864 | 0.0106 | 0 | 0.0097 |
| 4 | 0.7724 | 0.031 | 0.2896 | 0.01976 |
| 8 | 1.0949 | 0.1222 | 0.6733 | 0.04169 |
| 12 | 1.1654 | 0.2263 | 0.7578 | 0.101 |
| 16 | 1.0606 | 0.3335 | 0.6975 | 0.2564 |

The stall angle for the airfoils,
NACA 4415- 10 degree
NACA 0015- 10 degree

## IV. CONCEPT FOR NEW DESIGN

### A. KF AIRFOILS

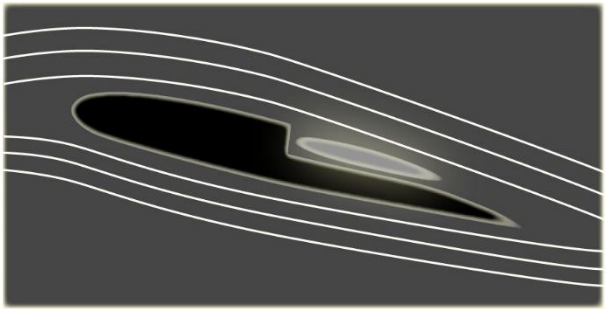


Figure 12: KF airfoil

The Kline- Fogleman airfoils have been extensively used in RC planes. These airfoils potentially generated better, stable and higher take-off angles.

- The flow of air around the profile is similar to the conventional airfoils. A step is cut at the desired location usually at the mid-section.
- This step creates a vortex when the air flows around it. Since the step occurs suddenly the flow path does not get deviated at particular velocities.
- Slower the flow velocity higher turbulence generated at the step creating additional drag.
- Formation of the vortex in the step makes the region lower in pressure. But the velocity is high enough to make the flow to not get deviated.
- Creating a region of lower pressure at the top of the airfoil gives us additional lift.

### B. NEW DESIGN

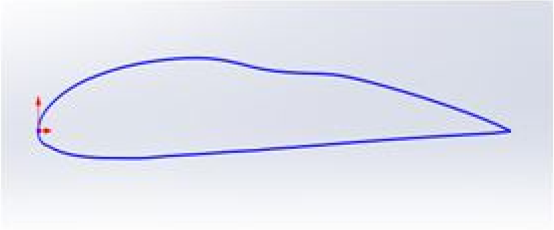


Figure 13: Model of the new design

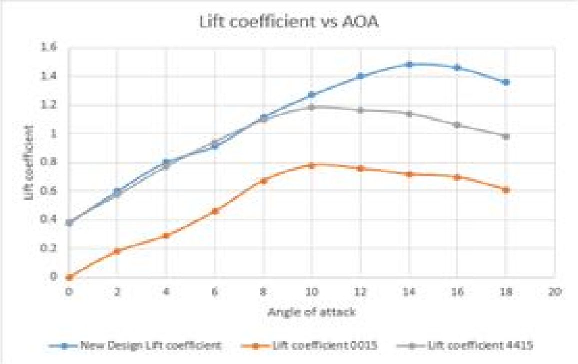
The KF airfoils have steps in their profile which enable them to have more stability while flying at critical angles. But the KF airfoils have not gained popularity in the actual planes rather they are widely used in the RC plane models. We have implemented this idea in our design with a modification of our own. NACA 4415 profile was take for the modification so that we could generate lift even at 0 degree of angle of attack.

At the maximum camber point we split the profile up to a certain distance and generated a new plane. The NACA 0015 profile was generated at that maximum camber point and scaled down so that the curvature of the airfoil can be used to provide the modified step. Combining the 2 models of airfoil and modifying the design yielded better results and we were able to increase the stall angle.

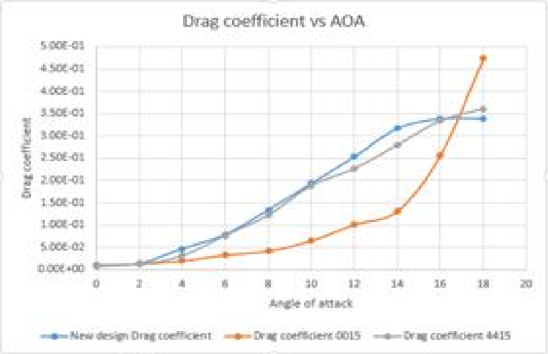
### C. RESULTS

Table 5: Lift and Drag for new design

| NEW DESIGN | | |
|---|---|---|
| Angle of attack | Cl | Cd |
| 0 | 0.3769 | 7.17E-03 |
| 4 | 0.8033 | 0.0468 |
| 8 | 1.1172 | 0.134 |
| 12 | 1.4002 | 0.2533 |
| 14 | 1.4864 | 0.3175 |
| 16 | 1.4629 | 0.3390 |



Graph 1: Comparison of Lift



Graph 2: Comparison of drag

- The modified design with the step can be seen as a filleted edge such that the flow follows the profile even at higher angles without deviating.
- Creating the cut in the profile provides a region of lower pressure almost equal to vacuum pressure.
- The region of higher pressure gets pushed in the step as the higher pressure always flows towards the lower pressure.
- This allows the aircraft to fly with stability at critical angles of attack.
- STALL ANGLE = 14 degree

## VI. CONCLUSION

The purpose of the new modified design is to increase the stall angle so that the aircraft can take off with shorter runways. It can be clearly seen from the research that the new airfoil generates lift even at higher angles than the conventional airfoils. This property of the airfoil would benefit in modern aerial vehicles and reduce the space needed for establishing runways.

The drag value is almost the same as that of the NACA 4415 airfoil as the modified step becomes of no use at higher angles. The bottom of the airfoil will be the major contributor for the drag. But the amount of material used is considerably reduced with a drastic improvement in lift.

## REFERENCES

[1] Abhay Sharma concluded that the behaviour of the NACA 0015 airfoil at different angles of attack has been studied using CFD and the same has been confirmed by the real time flow analysis in the experimental wind tunnel.

[2] Amit Singh Dhakadconcluded that that two blade propeller and the three blade propeller produce the same thrust with constant power. Therefore keeping the weight into consideration it is better to have two blade propellers for flying bike. And the propeller is lightly loaded.

[3] S.S.Benadictconcluded that bi-convex airfoil with a slightly curved leading edge and estimating the coefficient of pressure, lift at supersonic and hypersonic speeds is done in ANSYS FLUENT.

[4] K.Harish Kumar concluded that the airfoil with wedge profile is more stable and contributes for better performance for operation at AOA less than 10 degrees up to Mach 1 and up to stall angle beyond Mach 1. This shows that Supercritical airfoil with wedge profile is more stable and gives good performance characteristics at transonic Mach regime.

[5] http://m selig.ae.illinois.edu/ads/aircraft.html.

[6] Karna S.Patelconcluded that at zero degree of AOA there is no lift force generated and to increase amount of lift force and value of lift coefficient then we have to increase the value of AOA. By doing that both drag force and drag coefficient increases but the amount of increment in drag force and drag coefficient is quite lower compared to lift force.

[7] Low speed airfoil data vol.2 by M. S. Selig, C. A.Lyon, P.Giguere, C.P Ninham, J. J. Guglielmo.

[8] T.Prashanth concluded that at the given conditions of input velocity 130 m/s results in maximum lifting force at 22 degree AOA. The lift force generated at the maximum angle of attack for the geometric section is about 50.58N.

[9] Md. Shamim Mahmud concluded that the bi-camber profile acts perfectly in vortex condition. The lesser vortex effect in bi-camber profile, higher is the lift force and lower the drag force, hence increases the lift by drag ratio which is higher than NACA profile.