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Design and Analysis of Aircraft Wing using Composite Materials for varying Angle of Attack

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Abstract

In present scenario, the design of Aircraft became challenging due to problem that are encountered in engineering practice. Different analysesare done in the past to develop a better Aircraft. However, there are many parameters that influences the Aircraft design are drag, lift, static and dynamic pressures, winglets design, angle of attack, vortex developed, gravity and angle of flight. In this context, an aircraft wing is developed by changing the material for finding better material suitable. The 3D model of NACA 4412 profile is designed in CATIA V5 and exported to commercial Ansys 14.5 Software. By applying the boundary conditions similar to the working environment the analysis is carried. The structural analysis of aircraft wing made of materials such as AA7075 and a composite GLARE (glass-reinforced aluminum laminate) is done under steady inertia loading. Modal analysis also done for defining the natural frequency and mode shape of continuous structures. Further, by varying the angle of attack (AOA) from 0^0 to 8^0 for an inlet velocity of 10m/s the static and dynamic pressure of aerofoil and pressure coefficients are determined by using Computational Fluid Dynamics (CFD). The pressure based steady state solver with K-Ɛ turbulence scheme is used for determining the pressures and their coefficients. The results of the analysis are stated in the literature.

Keywords:

Air craft wing;
Composite materials;
Angle of attack;
Computational Fluid Dynamics;
Glass reinforced composites.

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1. Introduction

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The need of composites in Aerospace industries is increasing predominantly due to their higher strength, less in weight, reliable and durable compared to the metal and their alloys. In present scenario, all the frames of aircraft are made of fiber based composites, due to increased technological advancements in the composites made of fibers and it will further increased for construction of space and air crafts. In this context, the need of the composites is need to be discussed. In the past, the mechanical properties of vacuum bagged carbon and glass fiber reinforced epoxy hybrid composites were studied [1] and it is evident that mechanical properties are improved. The advancements in composite materials in aerospace is discussed by [2], [3] for commercial applications such as Industrial, Marine, aerospace and recreational structures due to no corrosiveness, less fatigue cracking and fuel efficiency. The applications of the composites and their importance n aerospace industries are discussed by Nayak et al [4]. The control of varying environment with time varying structure for practical implementation with actuators and sensors for turbulence flow is studied by Granichin et al[5]. Furthermore, the mechanical behavior of glass reinforced with carbon fiber for varying temperature and strain rate is studied by Elanchezhian et al[6].

This present work mainly focuses on the structural analysis of aircraft wing made of materials such as AA7075 and a composite GLARE (glass-reinforced aluminum laminate) is done under steady inertia loading. Modal analysis is done for defining the natural frequency and mode shape of continuous structure. Further, by varying the angle of attack (AOA) from 0^0 to 8^0 for an inlet velocity of 10m/s the static and dynamic pressure of aerofoil and pressure coefficients are determined by using Computational Fluid Dynamics (CFD). The pressure based steady state solver with K-Ɛ turbulence scheme is used for determining the pressures and their coefficients.

2. Research Method

Structural Analysis

The aircraft wing Assembly is modeled in CATIA V5 and save the part as IGES for Exporting into Ansys Workbench 14.5 Environment. Apply material properties for aircraft wing. Mesh the aircraft wing and define boundary condition with one end is fixed. Define type of Analysis for both AA7075 and composite material GLARE as Static Structural. Apply the pressure on aircraft wing. Modal analysis is used to determine the natural frequencies and mode shapes of a continuous structure. Build the model similar to static analysis. Use top-down or bottom-up techniques. Apply loads and obtain solution. Only valid loads are zero-value displacement constraints. Other loads can be specified but are ignored. Expand the modes and review results.

Table 1Properties of AA7075

Youngs modulus	7.17E+10 Pa
Density	2810 Kg/m^3
Poisons ratio	0.33
Bulk modulus	7.092E+10 Pa
Shear modulus	2.6955E+10 Pa

Table 2Properties of GLARE

Young’s modulus	2.7E+11 Pa

Density	1760 Kg/m^3
Poisons ratio	0.36
Bulk modulus	3.2143E+11Pa
Shear modulus	9.9265E+10 Pa

Fluent Analysis

Numerical algorithm: Standard k–ε turbulence viscosity model with SIMPLE pressure-velocity coupling and First-Order Upwind discretization scheme was used for the analysis.

Boundary conditions: Boundary conditions were specified at inlet with a velocity of 10 m/s.
Solution initialization: Standard initialization was used and was computed from inlet.

Table 3 FLUENT input parameters

Solver	Pressure based steady state
Viscous laminar	k–ε
Density(kg/m3)	1.225
Viscosity(kg/m –s)	1.7894×10^{-5}
Inlet velocity(m/s)	10
Pressure	Standard

3. Results and Analysis

Structural Analysis

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can, however. Include steady inertia loads (such as gravity and rotational velocity), and time varying loads that can be approximated as static equivalent loads. Static analysis determines the displacements, stresses, strains and forces in structures and components caused by loads that do not induce significant inertia and damping effect. Steady loading and response conditions are assumed; that is, the loads and structures response are assumed to vary slowly with respect to time.

Structural analysis of Aircraft wing AA7075

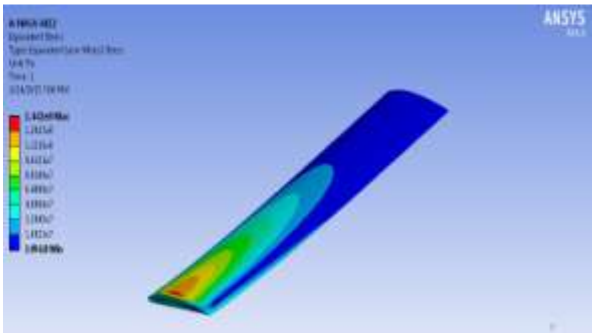

Figure 1Von-Mises stress of AA7075

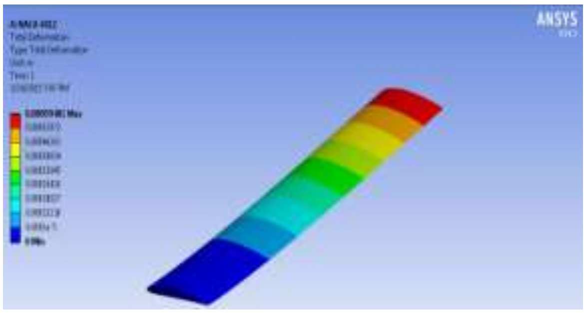

Figure 2Total deformation of AA7075

Structural analysis of composite aircraft wing

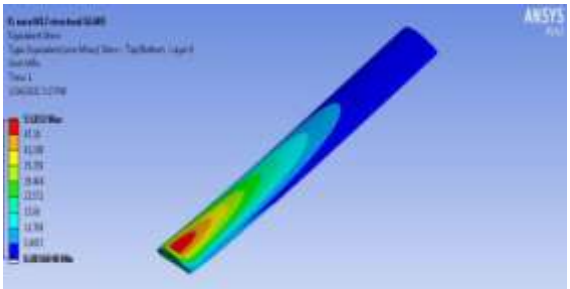

Figure 3Von-mises stress of composite aircraft wing

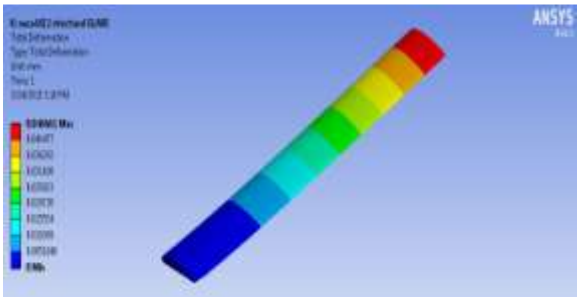

Figure 4Total deformation of composite aircraft wing

Model Analysis of Aircraft wing

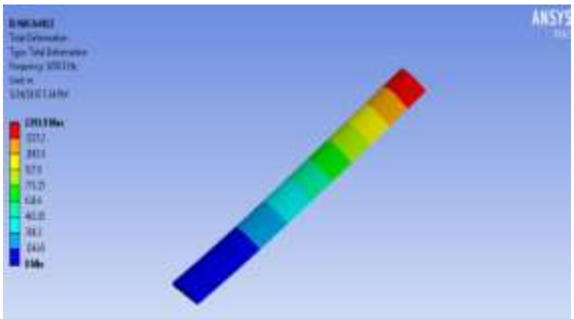

Figure 51st mode

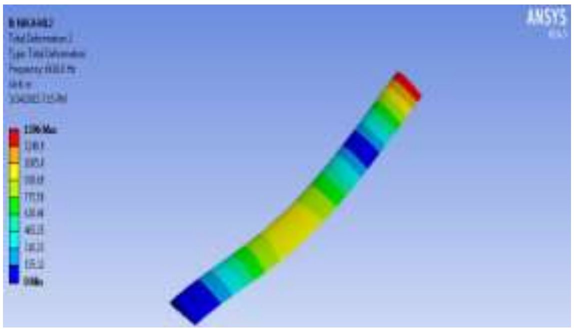

Figure 62nd mode

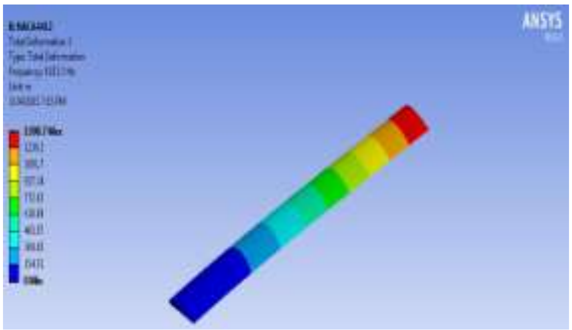

Figure 73rd mode

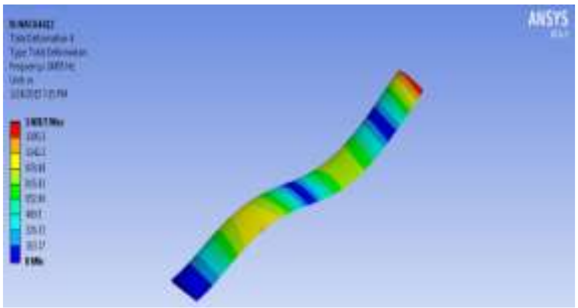

Figure 84th mode

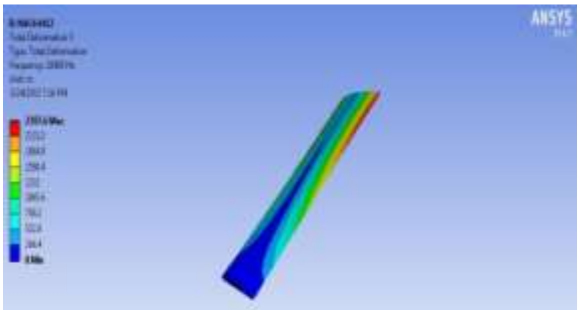

Figure 95th mode

Fluent Analysis

Results of Static and Dynamic Pressure Contours

It is important to study static and dynamic pressure contours on an airfoil at V sound with varying angle of attacks to understand the impacts on lift and stagnation point. The sum of static and dynamic pressure is the total pressure, and its difference on the upper and lower surface of the airfoil is the cause of lift.

In fluid mechanics a stagnation point is a point in a flow field where the local velocity of the fluid is zero. The stagnation point is the dividing point for the flow to go above or below the airfoil. Stagnation points exist at the surface of objects in the flow field, where the fluid is brought to rest by the object. The Bernoulli's equation shows that the static pressure is highest when the velocity is zero and hence static pressure is at its maximum value at stagnation points. This static pressure is called the stagnation pressure. At this point dynamic pressure is zero as it is a function of the square of velocity.

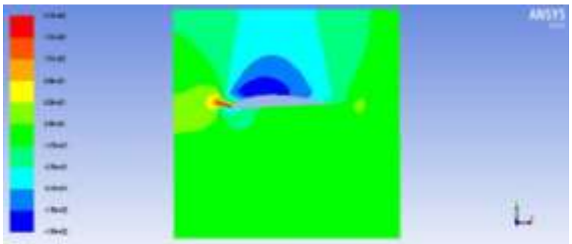

Figure 10Static pressure on airfoil (AOA 0^0)

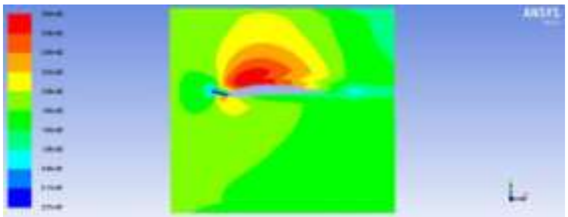

Figure 11Dynamic pressure on airfoil (AOA 0^0)

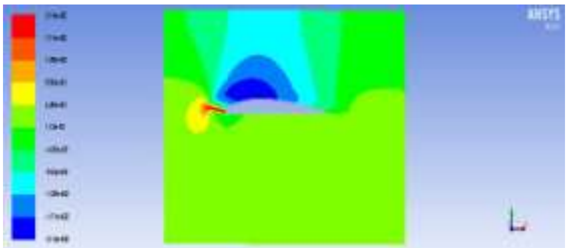

Figure 12Static pressure on airfoil (AOA 2^0)

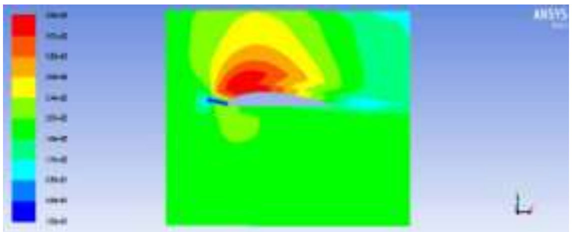

Figure 13Dynamic pressure on airfoil (AOA 2^0)

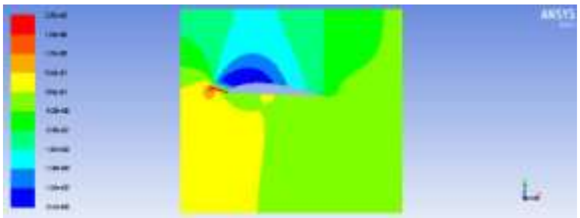

Figure 14Static pressure on airfoil (AOA 4^0)

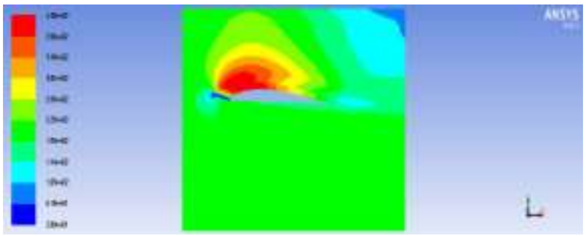

Figure 15Dynamic pressure on airfoil (AOA 4^0)

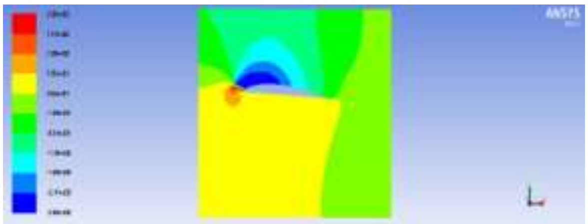

Figure 16Static pressure on airfoil (AOA 6^0)

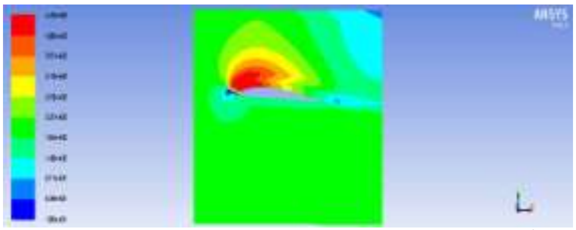

Figure 17Dynamic pressure on airfoil (AOA 6^0)

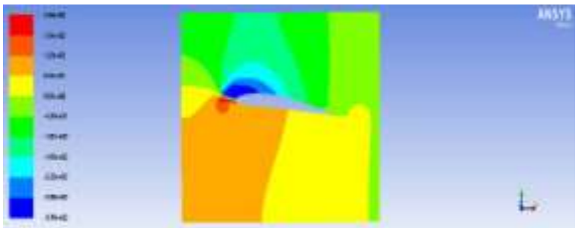

Figure 18Static pressure on airfoil (AOA 8^0)

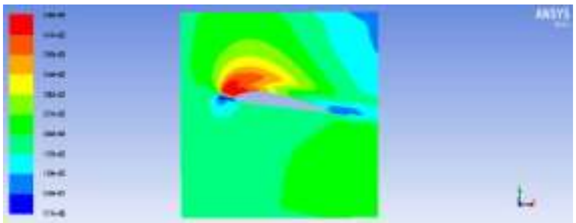

Figure 19Dynamic pressure on airfoil (AOA 8^0)

From Figure 10 to Figure 19show the static and dynamic pressure distribution on different surfaces (i.e. lower surface, upper surface and leading edge) on an airfoil with angle of attack 0^0 to 8^0 for an increment of 2^0.

Results of Pressure Co-efficient Contours

From the contours, it is observed that there is a region of high pressure at the leading edge (stagnation point) and region of low pressure on the upper surface of airfoil. From Bernoulli equation, we know that whenever there is high velocity, we have low pressure and vice versa. Figure 20 to Figure 25 shows the simulation outcomes of coefficient pressure at angles of attack 0° to 10° with NACA4412 airfoil model. The pressure coefficient on the lower surface of the airfoil was greater than that of the incoming flow stream and as a result it effectively “pushed” the airfoil upward, normal to the incoming flow stream.

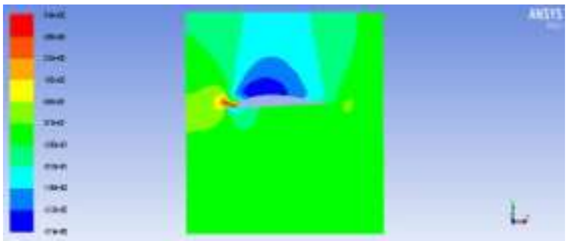

Figure 20 Pressure coefficient at AOA 0^0

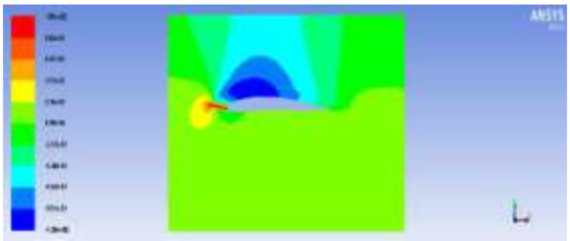

Figure 21 Pressure coefficient at AOA 2^0

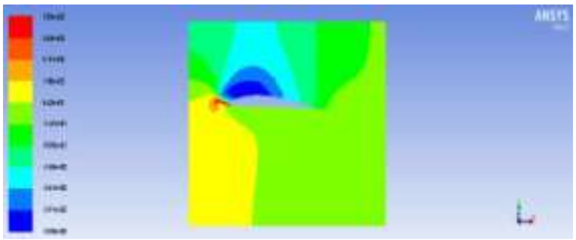

Figure 22 Pressure coefficient at AOA 4^0

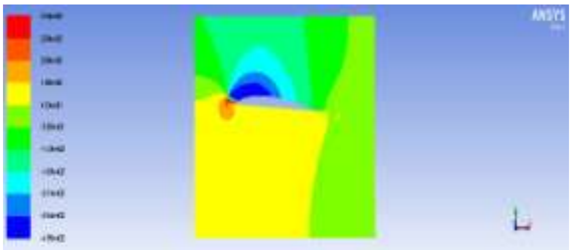

Figure 23 Pressure coefficient at AOA 6^0

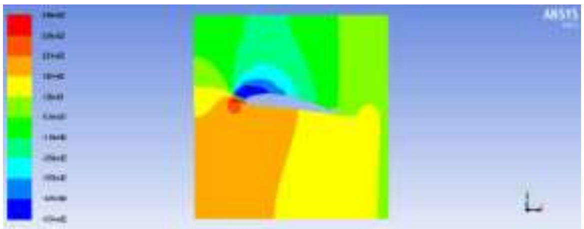

Figure 24 Pressure coefficient at AOA 8^0

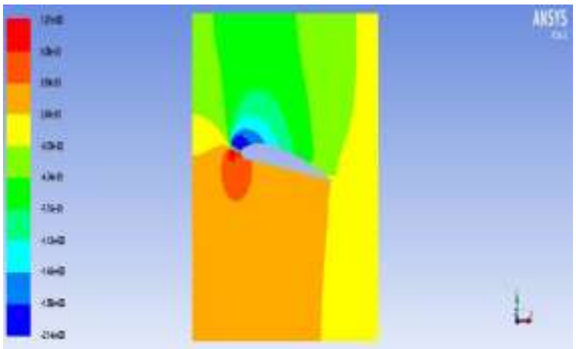

Figure 25 Pressure coefficient at AOA 10^0

Table 4 Comparison between aluminium alloy and composite material

Parameter	**AA7075**	**GLARE**
Von-mises stress (MPa)	144	53.032
Total deformation (mm)	0.59	0.046

Table 5Effect of angle of attack on static pressure, dynamic pressure and coefficient of pressure

Angle of attack	**Static pressure (Pa)**	**Dynamic pressure (Pa)**	**Max Coefficient of pressure**
0	213.43	362.36	348.53
2	214.27	395.72	106
4	224.56	429.53	369.16
6	226.43	443.25	369.53
8	238.53	496.26	388.53
10	250.06	579.06	127

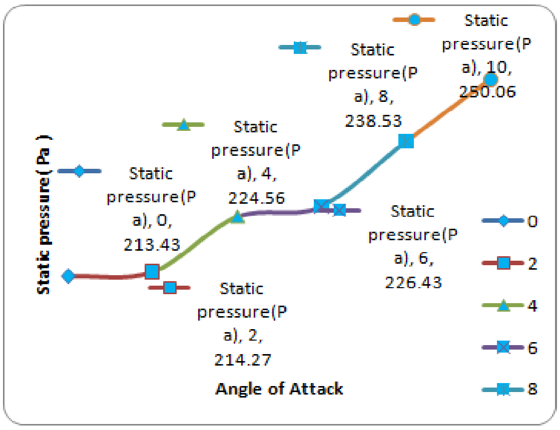

Figure 26Static pressure

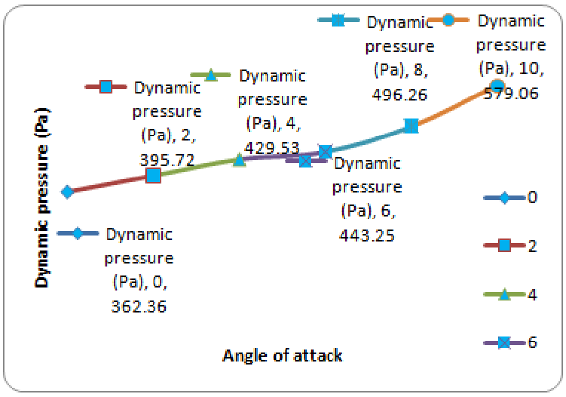

Figure 27Dynamic pressure

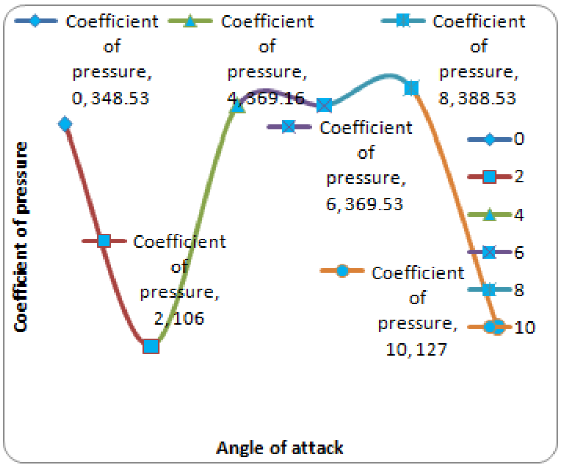

Figure 28Coefficient of pressure

4. Conclusion

From the investigation, it is concluded that for AA7075 material, the maximum deformation appears at the end of aircraft wing surface and the maximum von misses stress appears at the starting fixed face. For composite material GLARE, the maximum Von- misses stress appears at the starting fixed face and the maximum deformation appears at the end of aircraft wing surface. It is observed that, aircraft wing with AA7075 has higher stresses and deformation compared to the composite material GLARE. Further, it is observed that, dynamic pressure on leading edge is decreasing with increasing the angle of attack while static pressure on lower surface is increasing with increasing the angle of attack and it is increased with increasing the angle of attack is increased. Dynamic pressure on lower surface is decreasing with increasing angle of attack.
Maximum dynamic pressure occurs at upper surface near and around maximum camber and minimum static pressure occurs at and around the same location. It can be seen that the minimum dynamic pressure and maximum static pressure occurs at the leading edge of the airfoil, this is the stagnation point. The stagnation point has moved further away from the leading edge. Therefore, as the angle of attack is increased the stagnation point moves away from leading edge on the lower surface of theairfoil.

From the analysis of NACA 4412 airfoil conclude that at 0˚ pressure coefficient of upper surface indicate negative pressure. When increase the angle of attack we can understand the decrease the pressure coefficient on upper surface and increase on lower Surface also became the maximum at 8˚.

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