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CFD OF PERMEABLE THIN AIRFOILS

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ABSTRACT

This paper presents the results on of the effect of permeability on the aerodynamic performance of a permeable airfoil. CFD is carried using the StarCCM+ package. The behavior of Lift slope, pitching moment and aerodynamic as function of permeability are presented. These results reflect the effect of permeability on a symmetrical NACA 0008 airfoil. Furthermore, the results of CFD work is compared to analytical solution. The trend change of lift slope and aerodynamic center as a function of change in permeability of CFD result is similar to the analytical solution.

INTRODUCTION

Birds flying are usually the inspiration of researchers in aerospace in general and in aerodynamics field specifically where the basic idea of flying were inspired from birds. Birds wings have been studied in both structural aerodynamic aspects. Wing structure has been studies by [Bachmann et al, 2012; Macleod,1980] where they studied the strength of birds structure. The aerodynamic aspect was also studied by several researches such as [Jacob, 1998] where he studied the airfoil shape and concluded that adaptive wings from birds can be applicable for low Reynolds number applications. The porosity of birds was studied by [Muller and Patone,1998] where they studied the transmissivity of flow from upper to lower surface and vice versa and found only 10% different in flow transmissivity direction. [Bae et al., 2012] used CFD to studied the effect of porosity on trailing edge on 2D-flat plat at a very low Reynolds number (1000) to find a relation between pressure drop and flow velocity.

Studying the natural flyers are difficult especially in experiment as their structure, agility and control are very complex and sophisticated [Shyy et al.,2008]. Standard wings and airfoils are commonly known as solid surfaces; however, birds wing have many criteria that conventional wings do not have such as flexibility and porosity. The birds wing surface allow the flow to pass through at certain flying conditions. Most of the research about bird's wing

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focus on the flexibility and wing profile. these types of wing still lack the study on the permeability/ porosity effect on aerodynamic performance.

Before proceeding to this work, it is important to define the terms porosity (P) and permeability. Porosity is defined as ratio of the open area of a known surface to its total area or the ration of open volume of a known object to its total volume. There are many examples of porous geometries such as sponge, honeycomb structure and open-cell porous metals.

Permeability is related to the porous region but it depends also on flow properties, and it is known as the ability of the medium/ flow to pass through a porous region. Permeability is a function of porosity and Reynolds number.

[Iosilevskii, 2011] has developed an analytical solution for permeable thin symmetric airfoils and its effect on aerodynamic performance. The solution presents the changes in lift slope of a thin airfoil as a function of permeability. The airfoil is divided into two segments where the front part toward the leading edge is the impermeable region and the aft segment toward the trailing edge is the permeable region. The permeability value of the permeable aft region varies from low to high values. It is to be noted that if the permeability value of the permeability region is zero it implies that the region is impermeable. The location point between permeable region and impermeable region of an airfoil is defined as 'a' in the chord wise direction, where it has a range of [-1,1]. The 'a' value determine the percentage of each segment as ratio of the chord length where the chord length varies from [-1,1]. The entire airfoil is a permeable region (no forward impermeable part) when 'a' = -1, and the airfoil is totally impermeable when 'a' =1 (no aft permeable part), and when 'a' =0, it indicates that 50% of the airfoil (chord wise) is permeable and another half is impermeable. see (Figure 1)

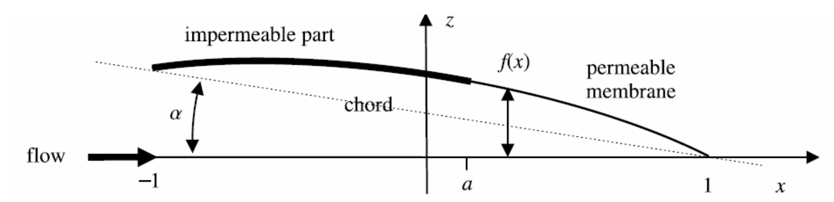

Figure 1: airfoil mean surface [Iosilevskii, 2011]

This paper focusses on CFD solutions for symmetrical permeable thin airfoil (NACA 0008) to evaluate and observe the effect of permeability on aerodynamic permeance. The results will be compared with the analytical solution. Mainly lift slope change as function of permeability will be shown and compared with the analytical solution of [1].

METHOD

StarCCM+ is the CFD package used to run the cases of permeable airfoils. For a thin permeable airfoil section, NACA0008 is used. The CFD cases are performed at different values of 'a' (-1, -0.6,-0.2,0,0.2,0.5,0.8). Figure 2 shows the geometry in one case at 'a' = -0.6 and Figure 3 shows a sample mesh of another case at 'a' =0.

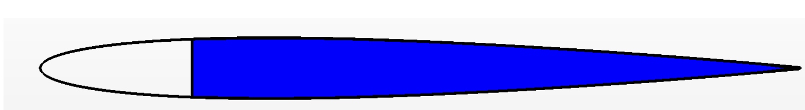

Figure 2: Airfoil geometry at 'a' = -0.6

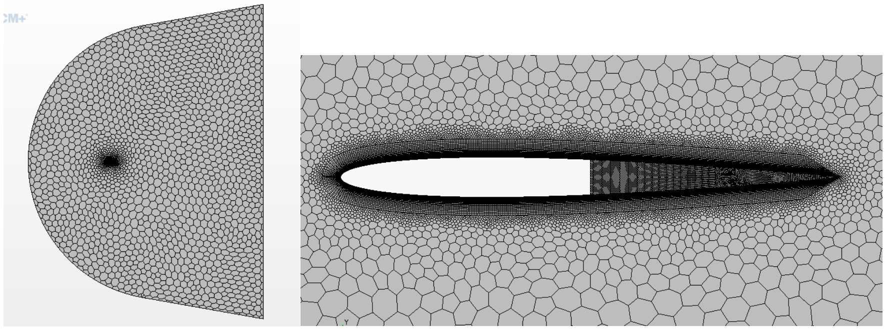

Figure 3: Mesh of permeable airfoil at ‘a’ = 0

Permeability in StarCCM+ software can be achieved using the following equation of pressure drop through the porous medium

$$-\nabla p = \frac{\mu}{k_p} v + \beta \rho v^2 \qquad (1)$$

Where the beta factor β must be deduced depending on the particular flow and medium of interest, and is commonly determined through experiment.

$$-\frac{dp}{L} = \frac{150\mu(1-P)^2 v}{P^3 D_p^2} + \frac{1.75\rho(1-P)v^2}{P^3 D_p} \qquad (2)$$

dp/L is the pressure gradient per unit length, ρ is density (kg/m3), Dp is the mean diameter of particles in the porous medium (m) and ‘P’ is the volume porosity (dimensionless). Comparing Eq. (1) and Eq. (2) the dimensional permeability k_p is given as

$$\frac{1}{k_p} = \frac{150(1-\mathrm{P})^2}{X^3 D_p^2} \quad (3)$$

The dimensionless permeability ε can be obtained using the following equation [Iosilevskii, 2011].

$$\varepsilon = \frac{k_p R}{c^2 t} \qquad (4)$$

Where ε is the dimensionless permeability, R is the Reynolds number, c is the chord length and t is the thickness.

The physical properties of the flow used in the CFD analysis are as follows

Flow speed = 20 m/s

Turbulence model = kw-SST

Reynolds number = 3.45 x10^5

RESULTS

Permeability effects on the lift slope is shown in (Figure 4) where the gradient of lift decreases significantly as the permeability increases. (Figure 5) represents the lift slope changes as a function of porosity. The trend behavior of lift slope is similar to the analytical solution (Figure 6). Permeability changes the aerodynamic center due to changes in lift is shown in (Figure 7), this behavior trend is close to the analytical solution (Figure 8), the aerodynamic center moves towards the leading edge of the airfoil for all values of ‘a’ except at ‘a’ = -1, when the entire airfoil is permeable, the aerodynamic center moves towards the trailing edge as the permeability increases.

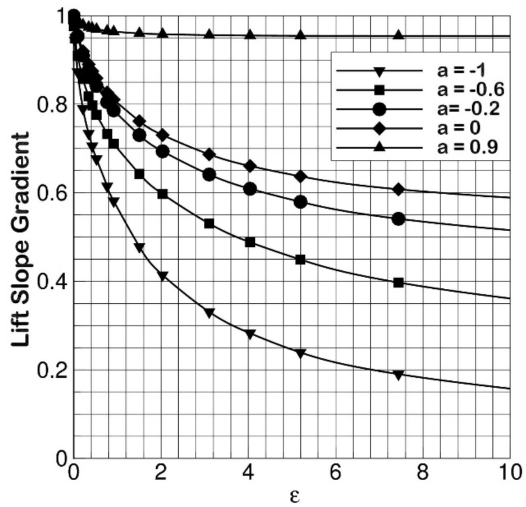

Figure 4: Lift slope of airfoil vs permeability, CFD solution.

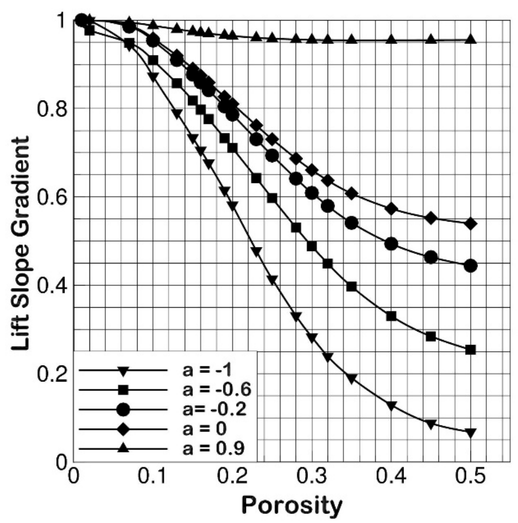

Figure 5: Lift slope of airfoil vs porosity, analytical solution

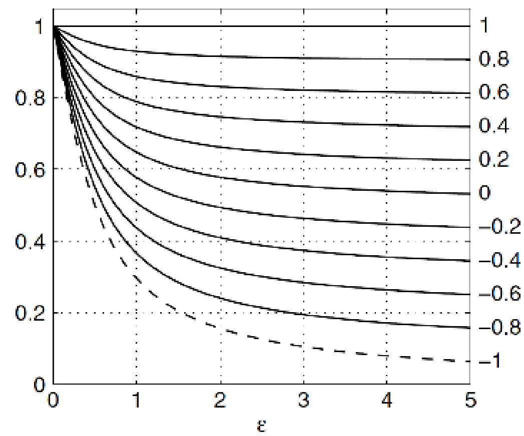

Figure 6: Lift slope of airfoil vs permeability, analytical solution [Iosilevskii, 2011]

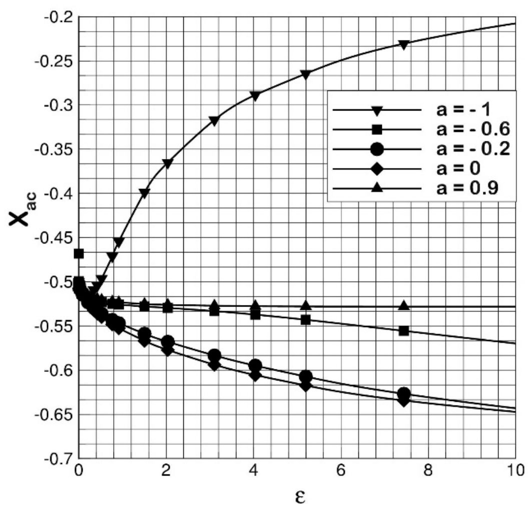

Figure 7: Aerodynamic center vs permeability, CFD solution

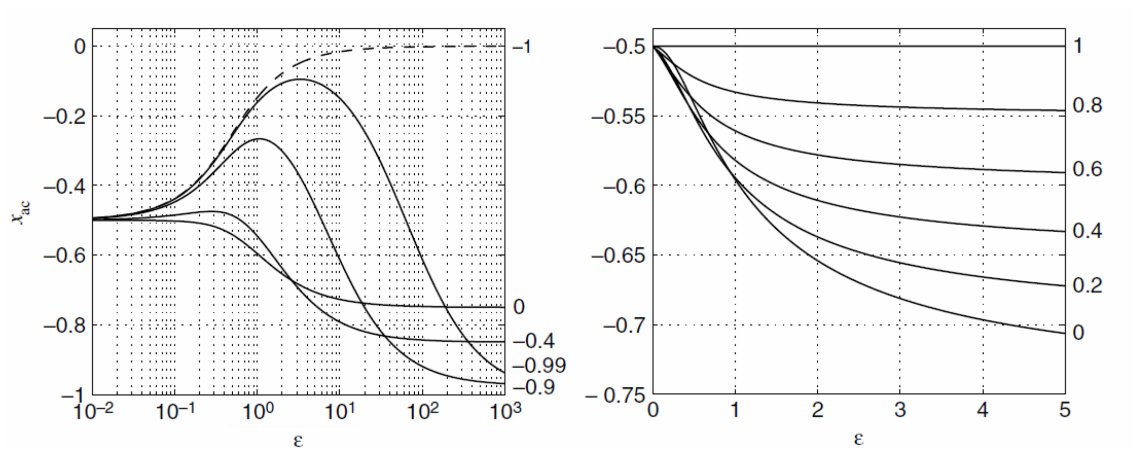

Figure 8: Analytical aerodynamic center vs permeability [Iosilevskii, 2011]

(Figure 9) to (Figure 12) show the flow field changes as the porosity changes where in (Figure 7&8), the scalar velocity and streamlines are shown at angle of attack α = 6 degrees and it can be seen that the flow is smooth over all the airfoil as the porosity values is 0.02 which lead to a values of permeability close to zero. However, when the porosity increases to a value of 0.45 (permeability >10), the flow behavior changes on the upper surface as shown in Figure 11 and Figure 12 where there is a disturbance in the flow created by the permeable region. Effects of permeability can also be seen in lift coefficients, and moments coefficients in (Figure 13, and Figure 14) respectively, where the lift slope changes as the porosity increases. Likewise, the moment coefficients curves changes at different porosity.

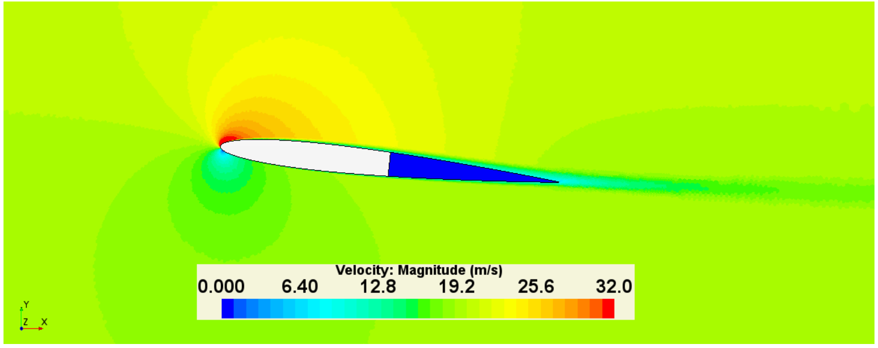

Figure 9: Velocity at porosity of 0.02

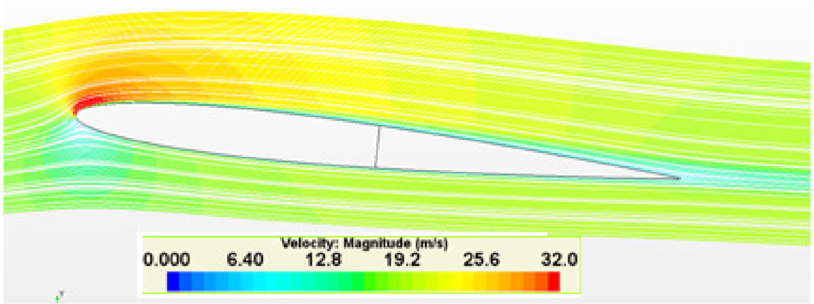

Figure 10: Streamlines at porosity of 0.02

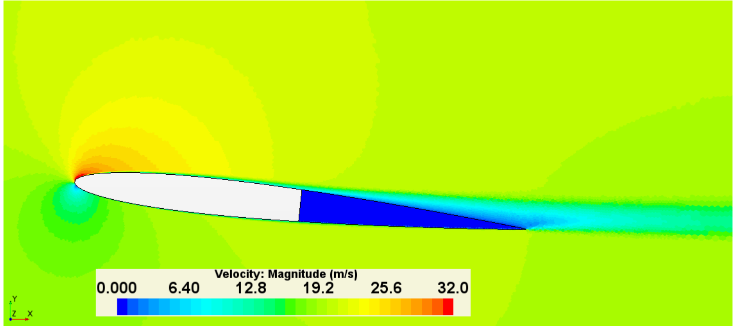

Figure 11: Velocity at porosity of 0.45

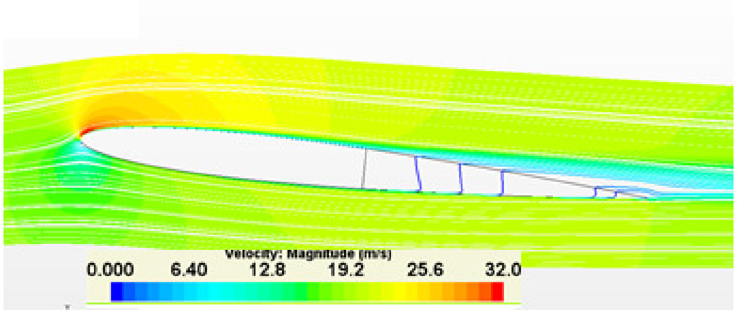

Figure 12: Streamlines at porosity of 0.45

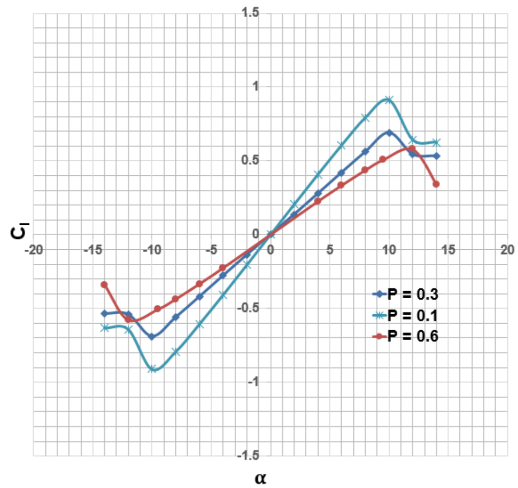

Figure 13: C_l vs α at different porosity (P) values, [a=0]

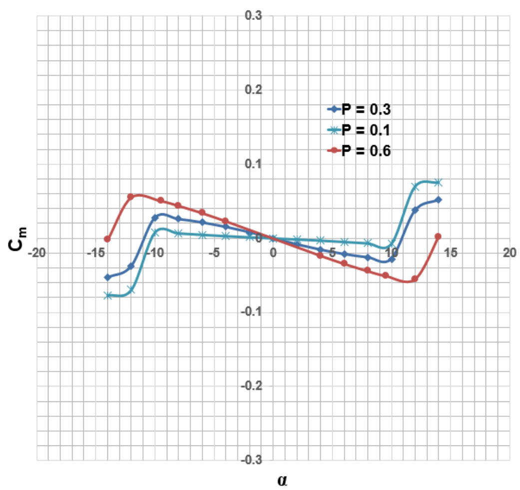

Figure 14: C_m vs α at different porosity (P) values [a=0]

CONCLUSION

CFD simulation on a NACA 0008 permeable airfoil to study the changes in aerodynamic behavior are presented. The results show that the trend of the behavior of lift slope as the permeability changes is similar to the analytical solution. Lift and moment are sensitive to permeability changes. The change of lift slope is due to effect of permeable surface which creates a disturbance of the flow on the upper surface which causes the lift to drop. The moment changes as well and this change affects the aerodynamic center.

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