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Ground Effect on Aerofoil Performance

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Abstract: -- The CFD simulation over a NACA 0012 aerofoil was carried out at subsonic speed of M=0.3 and Re=3×106 by varying AOA from 0^0 to 16^0 with a ground clearance of 2c under normal atmospheric conditions. Fine structured grid was created using GAMBIT and the analysis was carried out in ANSYS 16.0. Standard K-epsilon model was used to determine the flow characteristics. Lift and Drag forces were measured, pressure distribution on aerofoil was obtained and velocity survey over the surface was carried out. These values of lift coefficient was compared with the standard values (i.e. when aerofoil is away from ground). It was observed that lift coefficient was high when aerofoil is closer to ground. A strong suction effect was observed on lower surface of an aerofoil for lower values of AoA. It was found that higher values of pressure coefficient are obtained on lower surface when aerofoil is closer to ground. This region of high pressure almost extends over the entire lower surface for higher AoA. the drag was higher close to the ground mainly due to the modification of the lower surface pressure distribution. It was also observed that reverse flow was started to occur at higher AoA.

Keywords: AoA, Lift, Drag, ground effect

I. INTRODUCTION

One of the most misunderstood aerodynamic effects is ground effect. It is the phenomena when an aerofoil is operating close to a boundary such as the ground or water. The flow around an airfoil or a wing is considerably modified under the influence of ground effect. As we operate an aerofoil close to a boundary there is a modification of the airflow such that the wingtip vortices, upwash and downwash are impacted. In many general aviation this effect produces greater lift and less drag for a given angle of attack [1]. Ground effect is caused by ground interference with airflow patterns around an aircraft when the aircraft is within one wingspan of the surface. If the approach airspeed is too fast, the aircraft will tend to float down the runway, delaying touchdown of the aircraft [2]. When an aircraft flies at a ground level approximately at or below the length of the aircraft's wingspan , there occurs, depending on airfoil and aircraft design, an often noticeable ground effect. This is caused primarily by the ground interrupting the wingtip vortices and downwash behind the wing. When a wing is flown very close to the ground, wingtip vortices are unable to form effectively due to the obstruction of the ground. The result is lower induced drag, which increases the speed and lift of the aircraft[3][4]. A wing generates lift by deflecting the oncoming air mass (relative wind) downward[5]. The deflected or "turned" flow of air creates a resultant force on the wing in the opposite direction (Newton's 3rd law). The resultant force is identified as lift. Flying close to a surface increases air pressure on the lower wing surface, nicknamed the "ram" or "cushion" effect, and thereby improves the aircraft lift-to-drag ratio. The lower/nearer the wing is with regards to the ground, the more pronounced the ground effect becomes. While in the ground effect, the wing requires a lower angle of attack to produce the same amount of lift. If the angle of attack and velocity remain constant, an increase in the lift coefficient ensues[6] which accounts for the "floating" effect.

II. BACKGROUND

R. Ahmed, T. Takasaki and Y. Kohama studied The flow characteristics over a NACA4412 aerofoil are studied in a low turbulence wind tunnel with moving ground simulation at a Reynolds number of 3*e5 by varying the angle of attack from 0º to10º and ground clearance of the trailing edge from 5% of chord to 100%. It was observed that strong suction effect on the lower surface at an angle of attack of 0 deg at the smallest ground clearance caused laminar separation well ahead of the trailing edge. For angles upto 4deg, the lift decreased whereas for higher angles, it increased due to a higher pressure on the lower surface. The drag was higher close to the ground for all angles investigated mainly due to the modification of the lower surface pressure distribution [7].

M.R. Ahmed, S.D. Sharma studied The flow characteristics over a symmetrical aerofoil NACA 0015 are studied experimentally in a low speed wind tunnel. Experiments were carried out by varying the angle of attack, a, from 0º to 10º and ground clearance of the trailing edge from the minimum possible value to one chord length. It was found that high values of pressure coefficient are obtained on the lower surface when the aerofoil is close to the ground. This region of high pressure extended almost over the entire lower surface for higher angles of attack. As a result, higher values of lift coefficient are obtained when the aerofoil is close to the ground. The pressure distribution on the upper surface did not change significantly with ground clearance for higher angles of attack. The upper surface suction causes an adverse pressure gradient especially for higher angles of attack, resulting in rapid decay of kinetic energy over the upper surface, leading to a thicker wake and higher turbulence level and hence a higher drag [8].

Siva V conducted a detailed Study and Computational Fluid Dynamics investigation in ground effect phenomena around a symmetrical aerofoil-NACA 0015- when in close proximity to the ground The analysis was carried out by varying the angle of attack from 0^0 to 10^0 and ground clearance of the trailing edge from minimum possible value to one chord length. It was found that high values of pressure coefficient are obtained on the lower surface when the aerofoil is close to the ground. This region of high pressure extended almost over the entire lower surface for higher angles of attack. As a result, higher values of lift coefficient are obtained when the aerofoil is close to the ground. The pressure distribution on the upper surface did not change significantly with ground clearance for higher angles of attack [9].

M. Rafiuddin Ahmed studied the flow characteristics over a NACA4415 aerofoil experimentally at a Reynolds number of 2.4e5 by varying the angle of attack from 0º to 10º and ground clearance of the trailing edge from five percent of chord to eighty percent. A strong suction effect was observed on the lower surface for angles of attack of 0º and 2.5º at small ground clearances. For the angle of attack of 0º, a separation bubble formed on the lower surface for the smallest ground clearance while for 2.5º, laminar separation occurred from the lower surface well ahead of the trailing edge. Increased suction was observed on the upper surface for small ground clearances. For the angle of attack of 10º, the flow on the upper surface could not withstand the adverse pressure gradient at small ground clearances and separated from the surface resulting in a loss of lift and an increase in drag[10].

III. COMPUTATION METHODOLOGY

Aerodynamic characteristics of NACA 0012 airfoil in ground effect are numerically investigated by solving the compressible 2D Reynolds averaged Navier-Stokes equations and standard k-epsilon turbulence model with finite volume method. In the present study, aerodynamic characteristics of NACA 0012 are simulated at ground clearance of 2c and different angles of attack. The Mach number was M=0.3 and the Reynolds number was 3×106. The present work aims at studying the aerodynamic characteristics of a two-dimensional airfoil of NACA 0012 in ground effect, many factors such as ground clearances, AoA, compressibility and viscous are considered. Influences of wing in ground effect on aerodynamic characteristics are investigated. Figure 1 shows meshes in computation domain. Ground clearance is defined by distance from the ground to trailing edge of airfoil to the chord length c.

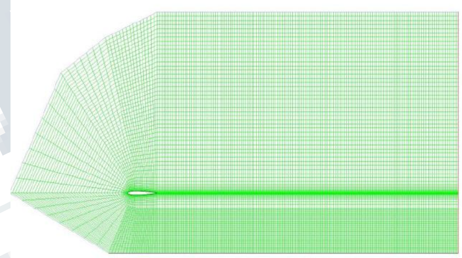

Figure 1: structured grid around the airfoil for ground clearence of 2c

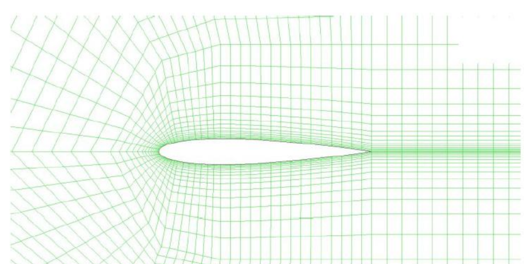

Figure 2: Enlarged portion near the airfoil

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The Farfeild conditions assigned for various zones are as stated in the table

Zone	Type
Inlet	Velocity Inlet
Outlet	Pressure Outlet
Aerofoil	Wall
Ground	Wall

References values are computed from inlet. Various boundary
conditions used for analysis is listed below in the table.

R_e	3×10^6
Density (kg/m^3)	1.225
AoA	0^o to 16^o
Viscosity (kg/m-s)	1.7894e^{-5}
M	0.3

IV. RESULTS AND DISCUSSIONS

The results are presented and discussed in this section. The value of lift, drag and moment obtained for various angle of attacks are listed in a table below.

Table 1 represents the values of coefficient of lift and drag under normal conditions (i.e. when aerofoil is in air without any effect of ground) and table 2 represents the values of coefficient of lift and drag under ground clearance of 2c.

Table 1

AOA	Coefficient of Lift	Coefficient of Drag
0	-0.0000233	1.4823e-02
2	0.21582	1.4703e-02
4	0.42564	1.6037e-02
6	0.632	1.8305e-02
8	0.8288	2.1902e-02
10	1.01	2.7232e-02
12	1.1637	3.5452e-02
14	1.2576	5.1458e-02
16	1.0045	8.3626e-02

Table 2

AOA	Coefficient of Lift	Coefficient of Drag
0	0.0022249	0.037148
2	0.7238	0.056408
4	1.3806	0.09795
6	1.9659	0.21495
8	2.7756	0.36912
10	2.8734	0.47852
12	3.0931	0.60709
14	2.7896	0.6613
16	2.0644	0.70354

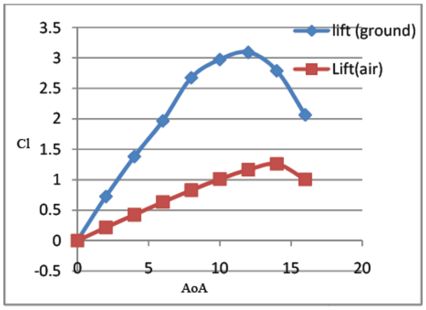

Figure 3: graph of CL vs. AoA

The above graph is the comparison for aerofoil under ground clearance of 2c and aerofoil in free air. It is observed that lift coefficient is comparatively high when the aerofoil is closer to ground.

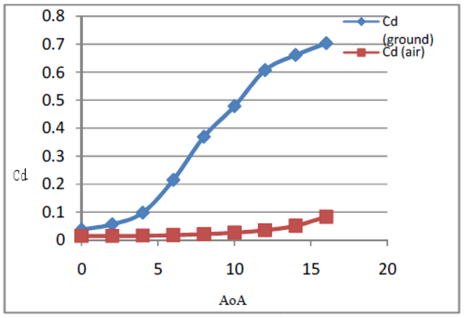

Figure 4: graph of CD vs. AoA

The above figure shows the comparssion of C attack. It is found that drag coefficient for the aerofoil with ground clearance 2c is high compared to the drag coefficient of aerofoil in free air.

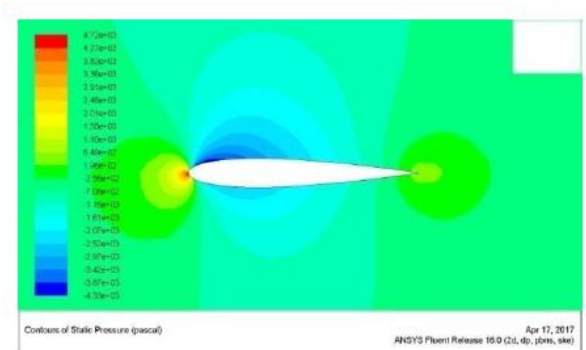

Figure 5: Contours of static pressure for Ao

In the above figure 5 the pressure di aerofoil is displayed. We can observe that near the leading edge the pressure is high, comparatively pressur the trailing edge and low pressure around the top and bottom surface of the aerofoil.

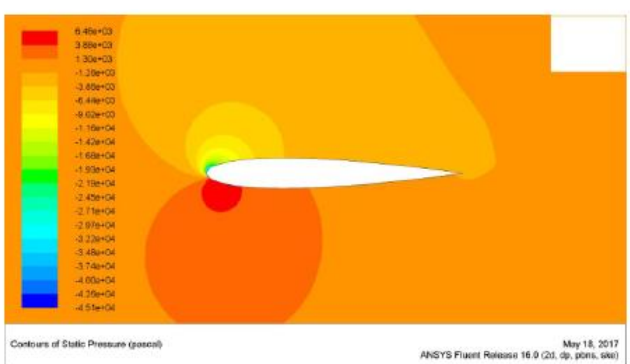

Figure 6: contours of static pressure for AoA 16^{0}.

As the AoA increases the suction pressure near the lower surface increases hence very high pressure is formed near the lower part of the leading edge, at the upper surface of aerofoil the pressure is low.

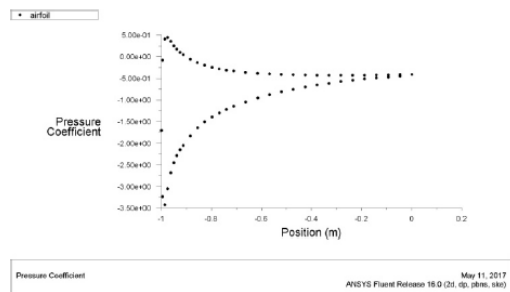

Figure 7: Pressure coefficient over the surface of aerofoil for AoA 2^{0}.

The above figure 7 shows the coefficient of pressure over the various positions on the aerofoil for AoA 2^{0}. It is observed that pressure coefficient first decreases rapidly and then increases gradually.

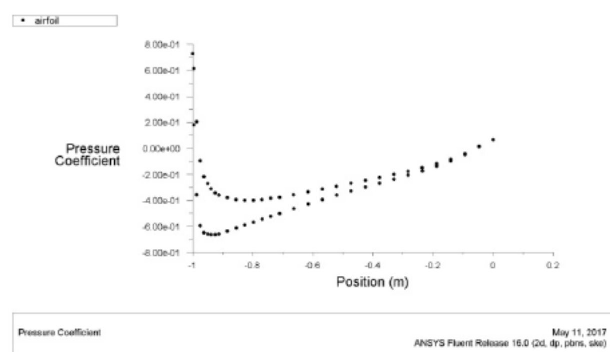

Figure 8: pressure coefficient over the surface of aerofoil for AoA 16^{0}.

The above figure 8 shows the pressure coefficient over various positions on aerofoil for AOA 16^{0}. The pressure at the lower surface increases as the AoA increases. We can observe in the figure that pressure increases at the lower surface of the aerofoil, whereas the pressure above the aerofoil surface tends to decrease.

V. CONCLUSIONS

Result have been presented for computation of flow over a NACA 0012 airfoil using flow governing equations in conjunction with a standard k-epsilon turbulence model for closure. The flow over an airfoil with respect to the ground is analysed using FLUENT and results have been plotted and discussed.

The important conclusions from the present work are:

- Lift coefficient was much higher when the aerofoil was closer to ground due to the modified airflow in the wing tip vortices, upwash and downwash.
- The drag coefficient is higher close to the ground for all the angles examined mainly due to modification in the pressure distribution on the lower surface.
- At higher angles of attack, high values of pressure coefficient were recorded on the lower surface with the high pressure region extending almost till the trailing edge of the airfoil, which resulted in higher lift force. The pressure distribution on the upper surface did not show significant variation with ground clearance, especially for higher angles of attack; hence, the higher lift force was mainly due to modification of pressure distribution on the lower surface.
- For the angle of attack of 12^0, the flow was found to separate from the surface very early, resulting in a thick and highly turbulent wake region.

NOMENCLATURE

c – Chord length

CL- Coefficient of lift

CD- Coefficient of drag

AoA- Angle of attack

CFD- Computational Fluid Dynamics

NACA- National Advisory Committee for Aeronautics

M- Mach number

Re- Reynolds number

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