

## Investigation of Ground Effect on 2D Airfoils Using Panel Method

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### Abstract

Ground effect is the increased lift (force) and decreased aerodynamic drag that an aircraft's/formula car's wings generates when they are close to a fixed surface. When landing, ground effect can give the pilot the feeling that the aircraft is "floating". In cars, Ground effect is a term applied to a series of aerodynamic effects used in car design, which has been exploited to create downforce, particularly in racing cars.

In this project, we look into what changes do ground effect have in creating the required downforce for the formula car.

**Keywords:** Ground effect, Vortex panel method, Method of image

### Introduction

The aerodynamic properties of most 2D airfoils can be predicted quite accurately using 2D inviscid panel method or vortex panel method. This approach is applicable for any arbitrary 2D body and is simpler in approach as compared to other more complex methods such as computational fluid dynamics (CFD).

The vortex panel method not only increases the overall simplicity of the calculations but also provides great flexibility in testing by considerably reducing the overall time required to get the results.

### Vortex Panel Method

#### Panel distribution

The first step in the solution of the potential function is to divide the airfoil into small panels. Many different methods are available to give the distribution of panels over an airfoil. In our case, to generate the panels, the airfoil is first plotted by importing its points in x, y format from a .DAT extension file [1,2].

Then, a circle is plotted with its diameter equal to the chord length of the airfoil such that the leading and trailing edge of the airfoil touch the circle at two ends. The circle is then superimposed onto the airfoil by generating the y coordinates using interpolation.

#### Boundary condition

There are two boundary conditions to be followed to satisfy the flow over the airfoil. The boundary conditions are as follows:

1. The flow through the surface i.e.,  $V_n=0$
2. Kutta condition at the trailing edge.

For N number of panels, there would be N+1 number of variables to be solved, the boundary condition of no flow through the surface is applied at the centre of each panel thereby giving N equations in N+1 unknowns. The (N+1) th unknown is found by applying kutta condition at the trailing edge of the airfoil.

### Ground Effect

#### Introduction to ground effect

Ground effect is the increased lift (force) and decreased aerodynamic drag that an aircraft's/formula car's wings generate when they are close to a fixed surface. When landing, ground effect can give the pilot the feeling that the aircraft is "floating" [3].

### Ground effect calculations using python

Ground effect can be seen as the flow around a 2D airfoil in the vicinity of a line at which the normal velocity is zero. This line is treated as the ground in our case. To actually incorporate this condition into real calculations, we do something known as mirror imaging of the body with respect to a line which in effect is our ground.

The calculations are done for two airfoils instead of one in this case using the same python code. Their effect on each other give rise to the ground effect. The results for ground effect have been discussed in the coming sections [4-6].

### Results

Consider the below diagram with an airfoil (NACA2412) at 5 degree angle of attack. In case of ground effect, we create a mirror image of the airfoil along the x-axis.

The lift curve for an airfoil in ground effect gave the following results at different values of h/c is given below in Figure 1.

The change in coefficient of lift with respect to its height from the ground is given in Figure 2. The dotted yellow curve in the figure represents the change in Cl as calculated using the following expression:

$$Cl(\text{ground}) = Cl \times (H/C) - 0.11.$$

The solid blue line represents the coefficient of lift using the python code. As can be seen, there is a stark difference between the values of Cl between the two curves. The maximum error calculate is around 17%. This error can be further reduced using higher order panel method.

The ground effect has been the prime focus of this project due to its application in formula one. The basic goal while trying to account for the ground effect was to increase the lift and see its variation as the height from the ground was increased or decreased. The results

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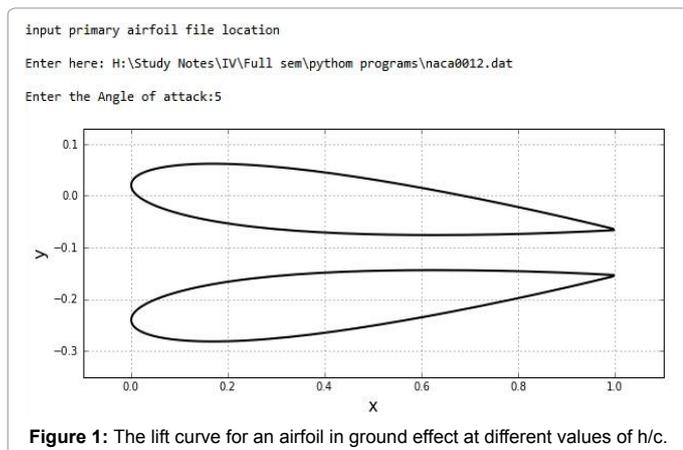


Figure 1: The lift curve for an airfoil in ground effect at different values of h/c.

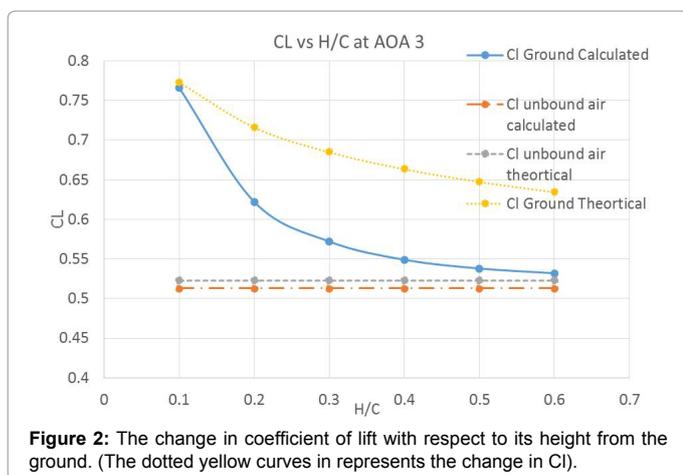


Figure 2: The change in coefficient of lift with respect to its height from the ground. (The dotted yellow curves in represents the change in Cl).

obtained clearly showed an increase in lift at the same angle of attack when the airfoil was subject to ground proximity. This increase was more apparent when the airfoil was brought closer to the ground. The results were then matched with CFD results from the available literature and a 10% variation in results was seen.

## Conclusions

The vortex panel method was used to get primary data for any given airfoil section. The following conclusions were drawn from this project

1. The results from vortex panel method give a pretty close approximation (under 8%) to the experimental data, depending on the number of panels chosen by the user.

2. The lift coefficient varies with number of panels. The right number of panels required also depend on the angle of attack. For low angle of attack, the panel requirement is also low and for high number angle of attack the panel requirement is also high.

3. Ground effect is expected to increase the coefficient of lift. The same is seen when we applied vortex panel method on NACA2412.

4. The second thing in ground effect is the change in coefficient of lift with respect to the change in height from the ground. It was seen that the coefficient of lift decreased with an increase in height from the ground.

5. In case of multi element airfoils, we see that the overall lift coefficient increases.

6. The variation in coefficient of lift was also seen with the distance between the primary and secondary airfoils. The lift coefficient can be seen to increase when the distance increases along the x-axis. Although, along the y-axis, the lift coefficient decreases and then increases.

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