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Flow Field Investigation of Flat Bottom Aerofoil under Ground Effect

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Abstract : *The trend of research in the automotive industry is towards mass green transportation with high speed and efficiency. Ground Effect Vehicles (GEV) is one of the choices with good Lift-Drag Ratio at high speeds. The research paper deals with the investigation of flow field over the NACA 6321 flat bottom aerofoil under the effect of ground. Experimental investigation of pressure distribution over the aerofoil with and without ground effect is carried out for various angles of attack (AOA) and height-chord (h/c) ratio. The results from experiments are compared with numerical results. It is perceived that the variation of pressure distribution under the ground effect increases the included area indicating the improvement in the aerodynamic forces.*
Keywords: *Flow Field Investigation, Ground Effect Vehicles, Pressure Distribution, Wind Tunnel Testing*

I. Introduction

Ground Effect Vehicles (GEV) are one of among the best solutions available for high speed surface transportation as well as green transportation both on water and land as they have very good fuel economy when compared to the other means. Figure 1 represents the variation of Lift-Drag with respect to the speed for all modes of transportation. A very significant feature in the diagram is the present modes of transportation are below the indicated red line termed as “Technology Line”. GEV’s falls below the technology line with a cruise speed of 100 to 400 km/h and L/D ratio of 15 to 30 represented by a yellow triangle [1]. The phenomenon in which a lift generating device, like wing, moving very close to the ground surface increasing the lift-to-drag ratio is termed as **“ground effect”**, which is used by Wing in Ground (WIG) vehicles.

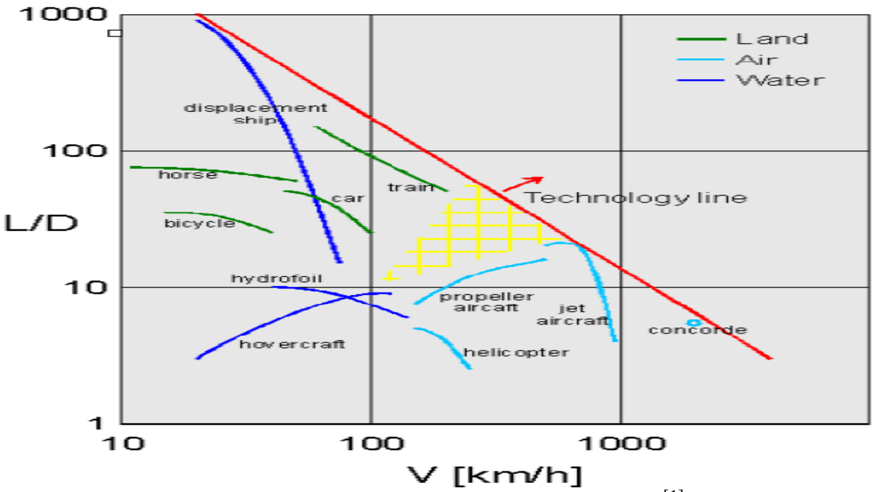

Figure 1. Von Karman-Gabriel Diagram [1]

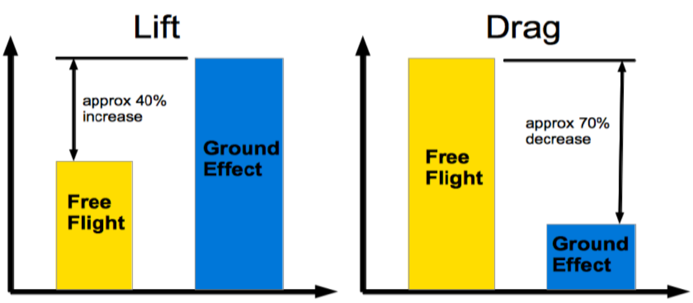

Figure 2. Comparison of ground effect with free flight condition.

The figure 2 shows the approximate percentage increase in lift and decrement in drag due to the presence of ground effect when compared with free flight condition. Figure 3 illustrates the categories of the Ground Effect phenomena namely, Span Dominated Ground Effect (SDGE) dominant in the wings with high aspect ratios enhancing the lift by creating high pressure on the pressure side and the other is Chord Dominant Ground Effect (CDGE) significant in the wings with low aspect ratio thereby decreasing the induced drag as the space between the wing and ground reduces and does not allow the wing tip vortices to develop.

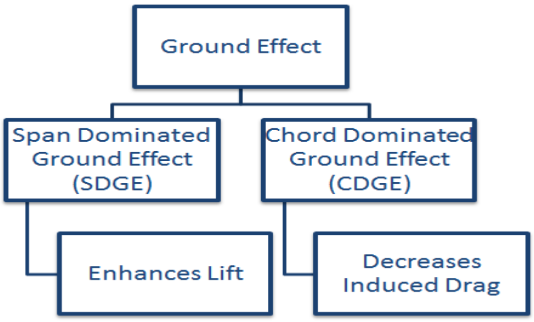

Figure 3. Types of ground effect

II. Literature Review

Michael Halloran and Sean O'Meara explained the theory of efficiency of wings operating in ground effect, its historical background and development of WIG craft. This report attempts to outline the areas of technology from 1960 to 1970's where relevant advances have been made to this development [1]. **Tomasz Abramowski** investigated the wing approaching the ground or sea surface and the study compares the NACA and Munk M15 flat bottom aerofoils at an angle of attack 3. From the investigation it is concluded that there was no enough space for the vortices to fully develop when a wing is approaching the ground thereby reducing the induced drag [2]. **Elliot G. Reid** described the flight test that was made with a Vought VE-7 airplane to determine the effect of flying close to the ground and found that the drag of an airplane is significantly reduced [3]. **S. Diasinos** conducted the 2D numerical analysis of aerofoil and cylinder to compare and demonstrate the effect of the objects, when operating in the close proximity to the ground. From the analysis, it was determined that the aerofoil generates lift [4]. **Moore** et. al. compared the characteristics of symmetrical aerofoil with that of DHMTU flat bottom aerofoil and concluded that flat bottom aerofoils are effective for the applications in the ground effect vehicles. This paper also provides the characteristics that an WIG craft aerofoil must possess [5]. **Hussain** et. al. experimentally studied the ground effect by varying the height-to-chord ratio (H/C) and it was concluded that maximum coefficient of lift was increased by 8% when the height ratio, H/C reduced from 1 to 0.1 [6]. **Ng Geok Hean** analyzed different type of aerofoils under the ground effect and found that symmetric aerofoils will produce sufficient lift. However, if a symmetrical airfoil is used, the convergent and divergent area between airfoil and the ground plane will cause a drop in static pressure which creates a suction force which pulls the craft to the ground. Therefore it is better to choose a flat bottom airfoil for ground effect vehicles [7]. **Adi Maimun** et. al. numerically studied the ground effect aerodynamic characteristics of the flat bottom aerofoil with the end plates. The results of the CFD simulation indicate a reduction on lift and drag coefficients but there is an increment in lift to drag ratio [8]. **Alexander Nebylov** investigated the stability provisions of WIG flight by means of automatic control. The requirements for motion control systems are reviewed and their criteria for their improvement are studied and concluded that the WIG craft is effective when the altitude of flight is less than 10 – 15% of the wing chord [9]. The objective of this research paper is to study the pressure distribution around the NACA 6321 flat bottom aerofoil under the ground effect using the smooth and rough surface.

III. Experimental Setup

The subsonic wind tunnel used for the study is suction type with an axial flow fan driven by 15HP, 440V, 50 cycles, 3 phase AC motor as shown in figure 4. It consists of an entrance section with a containing flow straighter and screens. This section is followed by contraction zone, test section and a diffuser. The duct contains butterfly value for controlling air velocity inside the duct. Air velocity is adjusted by the shutter valve, with a maximum velocity of 70m/s. Air passes through the honey comb screen and a nozzle with 11:1 contraction ratio to the test section of 1 x 0.3 x 0.3 m. The wind tunnel is calibrated for the velocity at the test section by varying the height of the shutter valve. The mean velocity at the test section was measured by a pitot-static tube by taking average static pressure at 5 points along the length of the wind tunnel. The experiments are carried out on the NACA 6321 flat bottom aerofoil with 165 mm chord length and the span of 300 mm mounted in the test section. 14 pressure tapings is drilled on the upper surface and lower surface of the NACA 6321 aerofoil. Figure 4 shows the position of the pressure taping on the aerofoil. The 14 pressure taps were connected to the multi column manometer to measure the pressure at the individual points. The effect of ground effect to the aerofoil is provided by the adjustable flat pate which is placed at the test section.

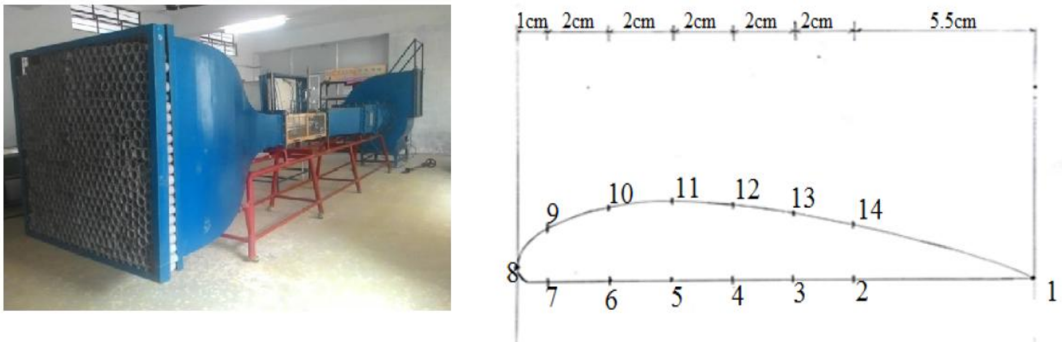

Figure 4. Subsonic Wind Tunnel and NACA 6321 Aerofoil with pressure tapings

IV. Results And Discussions

After calibrating the wind tunnel, NACA 6321 flat bottom aerofoil is placed in the test section and the pressure tapings are connected to the corresponding pressure tubes in the 14 column manometer. The shutter valve is kept at a height to produce a velocity of 20 m/s. The pressure values on the corresponding pressure tapings in the aerofoil at zero angle of attack (AOA) are noted from the multi column manometer. The value of the co-efficient of pressure is calculated and the graph is plotted between co-efficient of pressure and (x/c) ratio. The comparison is made between theoretical and the experimental data which is shown in the following Figure 5.

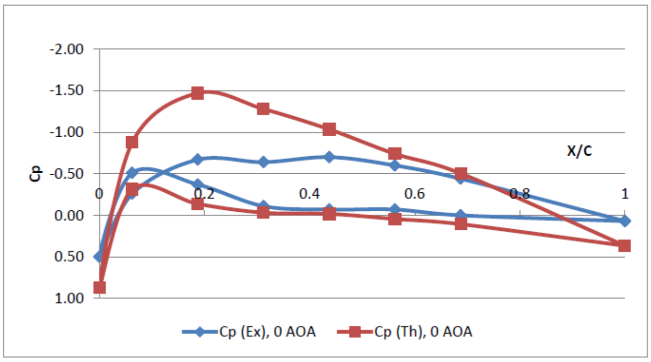

Figure 5. Pressure coefficient of Suction side and Pressure side at 0 AOA

In order to study the effect of ground on the pressure distribution over the aerofoil, a flat aluminium plate of dimension 1 x 0.3 x0.3 m is kept in the test section. The NACA 6321 aerofoil is mounted on the test section and the shutter valve is opened for 20 m/s velocity. Height-Chord ratio (H/C) is the main parameter in determining the effect of ground on the aerofoil. Therefore, the readings are taken in different h/c ratios of 0.6, 0.4, 0.1 and the results are plotted. The rough surface is made by bonding the emery paper on it, so that effect of rough surface is provided to the aerofoil when the air passes through it. The experiments are repeated by mounting a rough plate in the test section.

The figure 6 shows the pressure distribution plot for the aerofoil at 0^0 AOA without ground effect and with ground effect by both the smooth and rough surface at H/C ratio of 0.6. From the figure it is inferred that the pressure coefficient values are increased when compared with the values without any ground effect. The pressure coefficient values for the one with rough surface are better than that of the smooth surface.

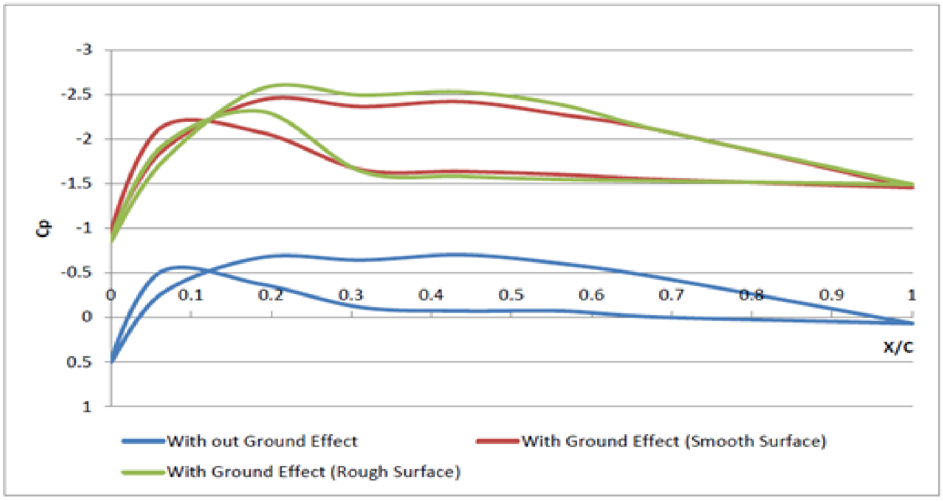

Figure 6. Pressure Distribution at 0 AOA with H/C = 0.6

The figure 7 shows the pressure distribution plot for the aerofoil at 0^0 AOA without ground effect and with ground effect by both the smooth and rough surface at H/C ratio of 0.4. It is inferred that the pressure coefficient values are increased when compared with the values without any ground effect.

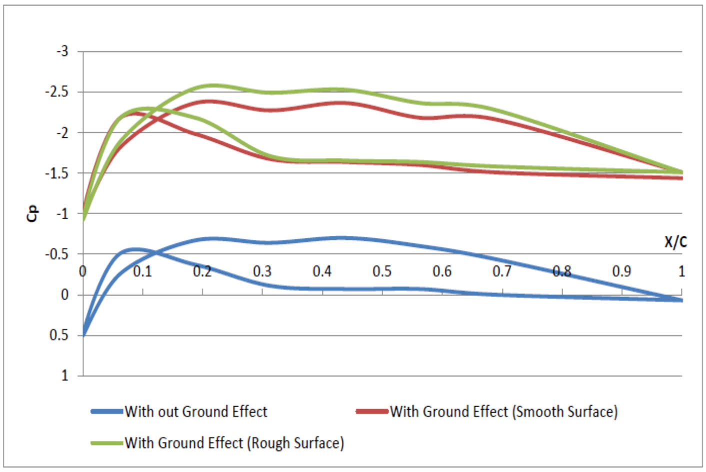

Figure 7. Pressure Distribution at 0 degree AOA with H/C=0.4

The figure 8 shows the pressure distribution plot for the aerofoil at 0^0 AOA without ground effect and with ground effect by both the smooth and rough surface at H/C ratio of 0.1. The area between the pressure distribution curves is directly proportional to the aerodynamic forces.

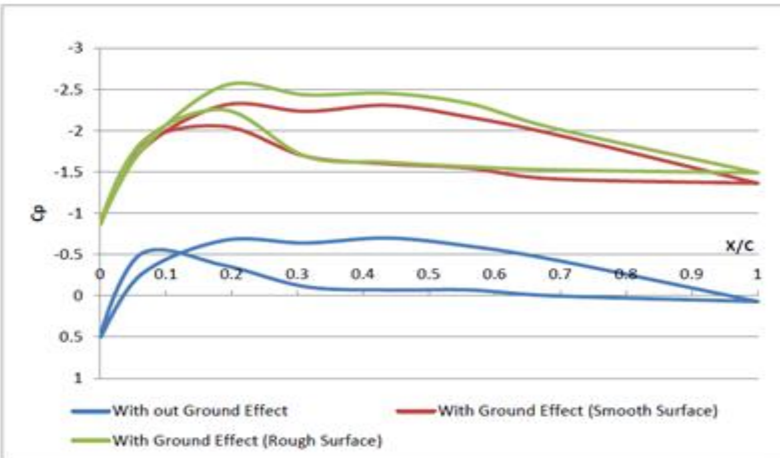

Figure 8. Pressure Distribution at O degree AOA with H/C =0.1

The lift and drag data of the NACA 6321 flat bottom aerofoil is obtained from the load cell and the results obtained from the wind tunnel are compared from the theoretical results. The figure 9 and 10 shows the angle of attack versus Lift, Drag and Lift-Drag ratio respectively. From the results it could be observed that the lift under the ground effect decreases and drag also follows the same trend. This is due to the fact that as the model's aspect ratio is less, therefore the CDGE is dominant. However, the overall Lift-Drag Ratio at the angle of attacks above 1^0 is enhanced.

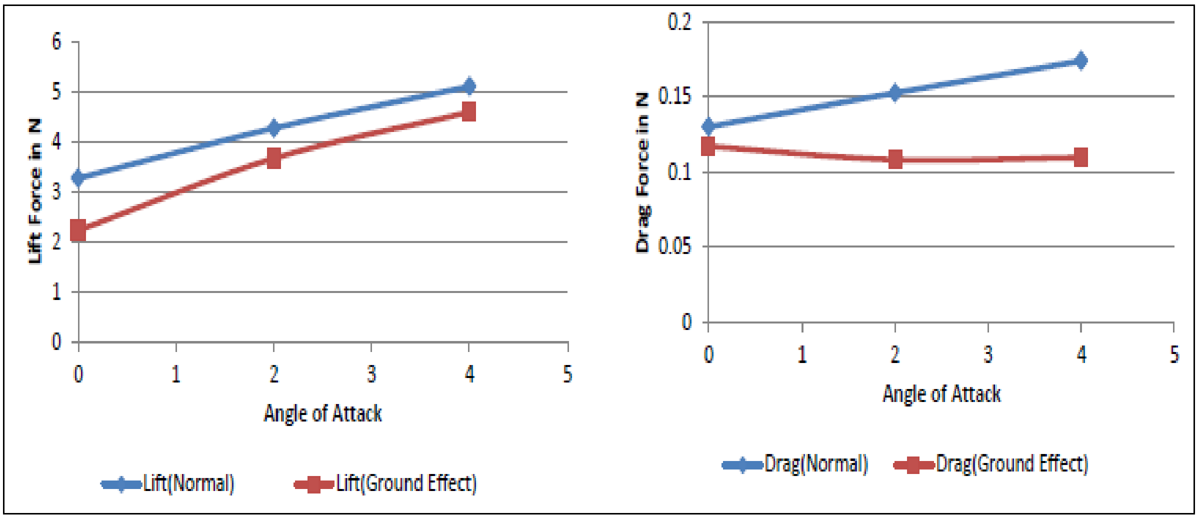

Figure 9. Angle of Attack versus Lift & Drag

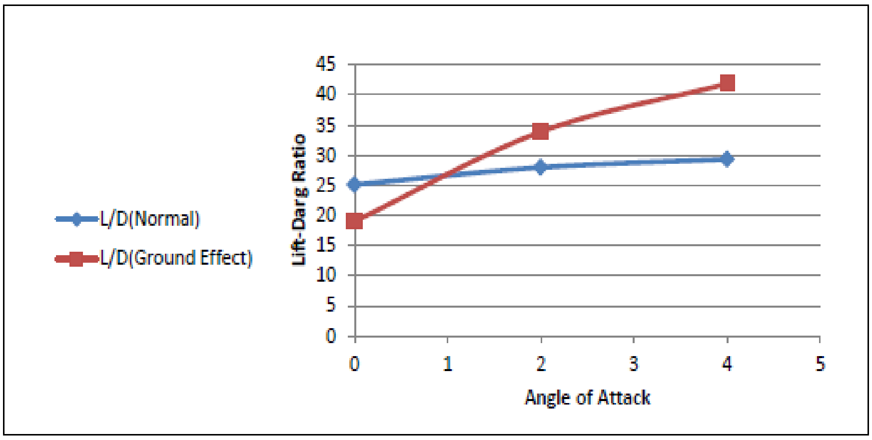

Figure 10. Angle of Attack versus Lift-Drag Ratio

V. Conclusion

The objective of this research work is to obtain the pressure distribution data for a NACA 6321 flat bottom aerofoil under the effect of ground to understand the behaviour of flow when the aerofoil comes into the close proximity to the ground. An adjustable flat plate fixture was designed for the test section of the wind tunnel to study the effect of the ground. The ground effect is provided by both the smooth and rough surface and from the results it is observed that the pressure distribution data varies under the ground effect and area under the curve also improves under the ground effect which indicates the improvement in the aerodynamic forces. The ground effect produced by the rough surface is better than that of the smooth surface. As the model's aspect ratio is less, the Chord Dominated Ground Effect phenomena appears which results in decrease in both lift and drag values, however the over all lift-drag ratio is enhanced. The results obtained from the wind tunnel testing play a significant role in the designing of the ground effect vehicles

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