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Research Paper

# Investigation on airfoil operating in Ground Effect region

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**Abstract**

The idea of using a wing in ground effect vehicle has been suggested with the objective of developing a very economical and efficient means of rapid transportation across water bodies. This paper investigates into wing in ground effect airfoil geometry. ANSYS is used to perform the CFD analysis of the airfoils. CFD analysis has been performed on various airfoils operating in the ground effect region and a special class of airfoil called DHMTU has been found to have maximum aerodynamic efficiency. The DHMTU studied here is DHMTU 8-40-2-10-3-6-2-15. Aerodynamic efficiency for this particular airfoil has been determined through CFD analysis at various angles of attack. It has been found that the DHMTU possesses superior aerodynamic efficiency at low angle of attack and the maximum aerodynamic efficiency is found at $6^0$ angle of attack. From CFD analysis it has also been determined that as the proximity to the ground reduces, the value of lift increases. The characteristics of this airfoil at various air speeds have also been determined through CFD analysis. These studies have illustrated the unique characteristics of the DHMTU airfoils and indicated areas for further optimization of the design of ground effect airfoils. The use of this airfoil for the ground effect vehicle can further lead to increase in efficiency of the craft.

**Abbreviations:**

| | |
|---|---|
| CFD | Computational Fluid Dynamics |
| DHMTU | Department Of Hydro-Mechanics of the Marine Technical University |
| NACA | National Advisory Committee on Aeronautics |
| L/D | Lift to Drag Ratio |
| WIG | Wing in Ground |
| V | Free stream velocity |
| Re | Reynolds number |
| h/c | Height to Chord Ratio |
| CL | Coefficient of lift |
| CD | Coefficient of drag |
| AOA | Angle Of Attack |

***Keywords***: *Airfoil; Aerodynamic Efficiency; Angle Of Attack; Coefficient of Lift and Drag; Height/Chord Ratio.*

## 1. Introduction

Ground effect is a phenomenon in which a lift generating device such as an airfoil flying close to the ground experiences an extra amount of lift in comparison to when it is flying away from the ground, due to this the aerodynamic efficiency of the device increases. The increase in aerodynamic efficiency is due to chord dominated ground effect and span dominated ground effect. Ground effect region is up to 50% chord length height from the ground. [1], [2].

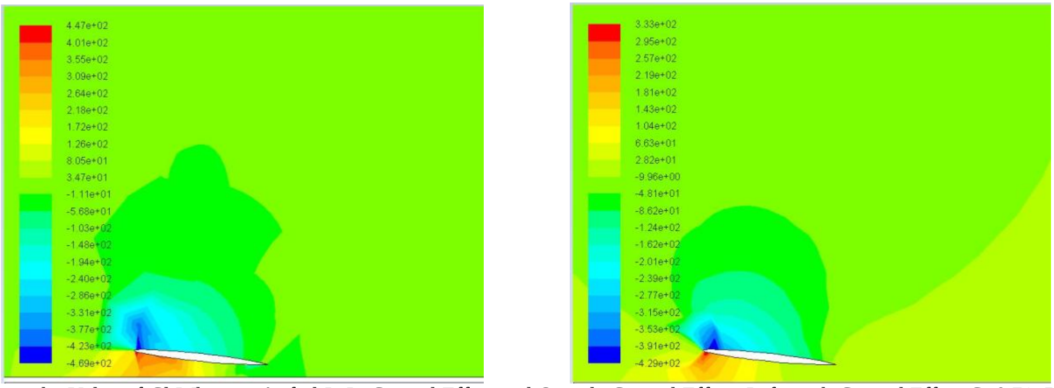

**Fig. 1:** Effect on the Value of Cl When an Airfoil Is In Ground Effect and Outside Ground Effect. Left: with Ground Effect $C_l$=0.71. Right: without Ground Effect $C_l$=0.558

Chord dominated ground effect is due to ram effect which occurs when the h/c ratio decreases, as this ratio decreases high pressure builds up under the wing resulting in increase in lift also as this ratio approaches 0 the air can even stagnate under the wing resulting in occurrence of highest possible pressure under the wing. The high pressure created can be seen in the following figures.

Span dominated ground effect is due to decrease in drag when the lift generating device approaches the ground. Drag on a body is due to skin friction drag and induced drag. Skin friction drag depends on the wetted area and hence remains constant. Induced drag is due to formation of vortices. As the body approaches the ground vortices get bounded i.e. they are not able to form completely, consequently the drag reduces. The vortices are pushed outward by the ground; apparently the effective aspect ratio of the wing becomes higher than the geometric aspect ratio. [3].

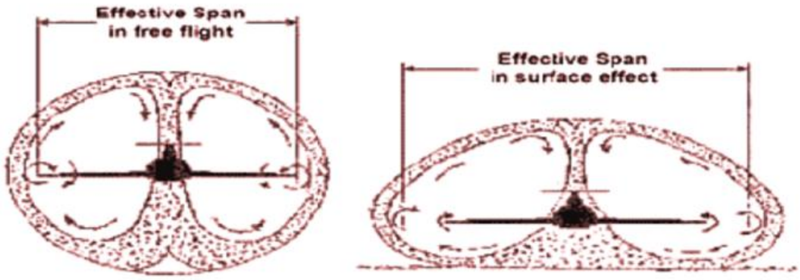


**Fig. 2:** Vortex Strength of an Aircraft in Flight. LEFT: Out of Ground Effect. RIGHT: In Ground Effect [1].

WIG craft have been proposed for rapid transportation system, heavy lift and military services. Operational advantages possessed by WIG craft are:

- Low visibility for radar and other electronic detection devices.
- High payload capability compared to conventional vessels.
- As the craft will not be operated at high altitudes, the fuselage (or cabin) of the craft need not be constructed for pressurization, as for commercial aircraft.
- Speeds of up to 400 knots at low operating altitude

However factors like wave impact, take-off and landing loads as well as bird strike all have to be taken into consideration in the design process.

In the past, aircrafts like the KM1 (Caspian Sea monster) have been developed. It was a ground effect vehicle developed by a Soviet design bureau. KM1 had a maximum take-off weight of 544 tons, wing span of 37.6m, total length of 92m and a claimed top-operational speed of 500kmph (270 knots). [4]

In order for an airfoil to operate effectively in the ground effect region it must possess high aerodynamic efficiency and high controllability that is there should be gradual change in the value of $C_L$ with height. Also for an airfoil operating in ground effect region engineers look for an airfoil having a flat lower portion because an airfoil having convex lower portion may lead to suction effect under the lower surface and if the lower portion is concave it may lead to instability. A new family of airfoil sections known as the DHMTU (Department Of Hydro-Mechanics Of The Marine Technical University) series having a flat lower portion and a S shaped camber line were developed for the WIG crafts.

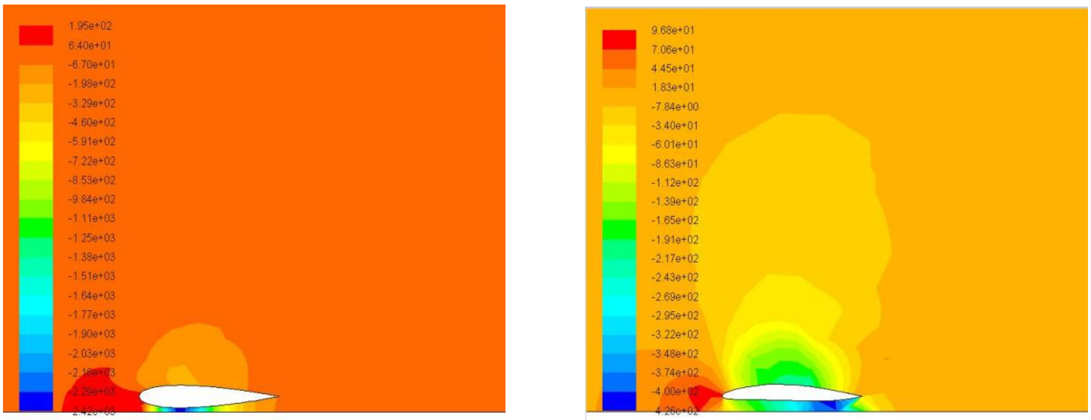


**Fig. 3:** Airfoils Operating in Strong Ground Effect Region at Low AOA. LEFT: Suction Effect Is Very High on a NACA 0015 Profile, $C_L$=-1.2. RIGHT: Suction Effect Is Very Small On A DHMTU, $C_L$=-0.1. [5]

## 2. Materials and methods

The CFD analysis done in this paper is done using ANSYS15 FLUENT. 2D analysis has been done using double precision option in the fluent launcher section. The governing equations are continuity equation and momentum equation. The velocity is chosen as 30m/s. This value is fixed by calculating the stalling speed of the model being fabricated. The boundary conditions that were given are velocity, turbulent kinetic energy, turbulent dissipation rate at inlet, gauge pressure, turbulent backflow length and turbulent intensity at outlet and the ground was given no slip boundary condition. Rests of the surfaces were given symmetric boundary conditions. The values of turbulent kinetic energy, turbulent dissipation rate, turbulent backflow length and turbulent intensity in the inlet and outlet section were calculated using the formulas given in the fluent manual. The reference values were fixed based upon the WIG craft design. The solution methods that were used were second order upwind for momentum, turbulent kinetic energy and turbulent dissipation rate, second order for pressure and green gauss cell based for gradient.

## 3. Methodology

The methodology has been selected to obtain an efficient design. This design will form the basis of fabrication of WIG crafts. The approach has been taken to compare various airfoils shapes operating in the ground effect region and then choosing the most efficient airfoil and further optimizing the angle of attack of that airfoil such that it provides the maximum aerodynamic efficiency.
A DHMTU section is described by 8 numbers which define the geometry of upper and lower surface. The format being DHMTU a-b-c-d-e-f-g-h, the section analyzed is the DHMTU 8-40-2-10-3-60-20-15 for reasons of brevity it is known throughout this paper as DHMTU. [6].

**Table 1:** Nomenclature of Dhmtu Airfoil [2].

| Prefix | Definition | Value |
|---|---|---|
| a | Maximum ordinate of upper surface(%C) | 8 |
| b | Position of maximum ordinate(%C) | 40 |
| c | Ordinate of start of the flat section(%C, below the horizontal is positive) | 2 |
| d | Position of start of flat section(%C) | 10 |
| e | Ordinate of the end of flat section(%C, below the horizontal is positive) | 3 |
| f | Position of end of flat section(%C) | 60 |
| g | Slope parameter of the upper trailing edge | 20 |
| h | Nose radius parameter | 15 |

## 4. Analysis

### 4.1. CFD analysis for different airfoils at 6 degree angle of attack in ground effect region (h/c=20%) at 30m/s

Comparison of DHMTU airfoil with other airfoils used for ground effect vehicles shows that, DHMTU has the maximum lift coefficient in the ground effect region and hence it provides maximum lift to the vehicle. [7].

**Table 2:** $C_l$ Values of Different Airfoils at 6 Degree Angle of Attack in Ground Effect Region (H/C=20%) at 30m/S.

| Airfoil | $C_L$ |
|---|---|
| DHMTU | 0.778 |
| GLENN MARTIN 2 | 0.734 |
| CLARK Y | 0.736 |
| NACA 2412 | 0.73 |
| NACA 16006 | 0.715 |

## 4.2. CFD analysis of DHMTU airfoil at different angle of attacks at 30m/s

Table 3 provides indication that as the AOA increases the value of $C_L$ increases up to a certain point and later it decreases. The maximum value of $C_L$ is at $13^0$ AOA and its value is 1.15. It can be seen that the maximum value of aerodynamic efficiency is at $6^0$ AOA and its value is 16.04. The aerodynamic efficiency is high at low values of AOA. [8], [9].

**Table 3:** Table of Aerodynamic Efficiency of Dhmtu Airfoil at Different Angle of Attacks.

| AOA | $C_L$ | $C_D$ | L/D |
|---|---|---|---|
| 3 | 0.4 | 0.03 | 13.33 |
| 4 | 0.51 | 0.035 | 14.57 |
| 5 | 0.6 | 0.04 | 15 |
| 6 | 0.77 | 0.048 | 16.04 |
| 7 | 0.8 | 0.055 | 14.545 |
| 8 | 0.91 | 0.063 | 14.44 |
| 9 | 1.1 | 0.077 | 14.28 |
| 12 | 1.13 | 0.1 | 11.3 |
| 13 | 1.15 | 0.11 | 10.45 |
| 14 | 0.98 | 0.12 | 8.16 |
| 15 | 0.86 | 0.14 | 6.14 |

The value of $C_L$ increases till $13^0$ AOA after that it starts decreasing. This is due to stalling, due to stalling there is increase in the value of drag and also lift decreases due to wake formation.

## 4.3. CFD analysis for DHMTU airfoils at various heights above the sea level in ground effect region at 6 degree angle of attack at 30m/s

It can be inferred from Table 4 that as the proximity to the ground increases the value of $C_L$ and hence lift force increases. [10].

**Table 4:** Variation of $C_l$ with Height in Ground Effect Region

| h/c % | $C_L$ |
|---|---|
| 20 | 0.778 |
| 30 | 0.76 |
| 40 | 0.594 |
| 50 | 0.584 |
| 60 | 0.568 |
| 100 | 0.5 |

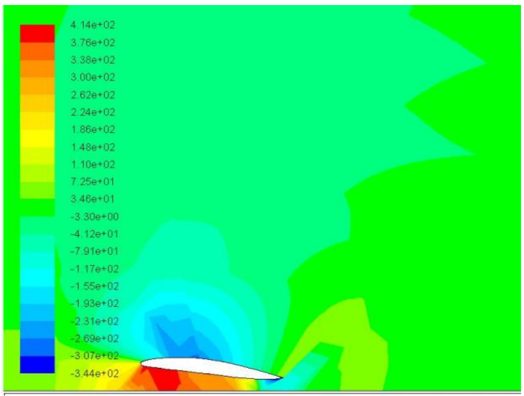


**Fig. 4:** CFD Analysis of DHMTU Airfoil at $6^0$ AOA, V=30m/S, H/C=20%

# 5. Conclusion

An optimum wing configuration for the ground effect region was obtained. The research conducted earlier shows that DHMTU airfoil is having superior lift performance when compared to other airfoils operating in the ground-effect zone. It has also been observed that as the proximity to ground increases that value of $C_L$ increases and hence lifts force increases, this is due to the increase in ram effect i.e. the amount of air trapped beneath the airfoil increases hence increasing the difference between the amount of air below and above the airfoil. It was observed that the DHMTU offers superior aerodynamic efficiency at low AOA and has the maximum aerodynamic efficiency at $6^0$ AOA.

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# References

[1] John D Anderson, Introduction to Flight Tata McGraw - Hill Education, France, Airfoils Wings and other Aerodynamic shapes.
[2] A.C. Kermode, Mechanics of flight, Pearson Higher Education, United Kingdom, Airfoils Subsonic speeds, 2012.
[3] 2010 Liang Yun • Alan Bliault • Johnny Doo, WIG Craft and Ekranoplan (Springer)
[4] Kirill V. Rozhdestvensky, Wing-in-ground effect vehicles, Progress in Aerospace Sciences 42 (2006) 211– 283 http://dx.doi.org/10.1016/j.paerosci.2006.10.001.
[5] M.R. Ahmed, S.D. Sharma, An investigation on the aerodynamics of a symmetrical airfoil in ground effect, Experimental Thermal and Fluid Science 29 (2005) 633–647 http://dx.doi.org/10.1016/j.expthermflusci.2004.09.001.
[6] N.Moore, Professor P A.Wilson, A J.Peters, An Investigation Into Wing In Ground Effect Airfoil Geometry, School of Engineering Sciences, University of Southampton, SO17 1BJ, UK QinetiQ Haslar.
[7] S.C. Rhodesa and A.T. Sayersb, Experimental Investigation: Stability Criteria of an Uncambered Airfoil in Ground Effect, R & D Journal of the South African Institution of Mechanical Engineering 2009, 25
[8] Ng Geok Hean, Wing in Ground (WIG) Aircraft – Aerodynamics, National University of Singapore.
[9] Daniel J. Walter, Study of Aerofoils at High Angle of Attack, in Ground Effect, School Of Aerospace, Mechanical & Manufacturing Engineering Portfolio Of Science, Engineering & Technology Rmit University.
[10] E.M. Smutsa and A.T. Sayersa, CFD Study of a Wing in Close Proximity to a Flat and Wavy Ground Plane, R & D Journal of the South African Institution of Mechanical Engineering 2011, 27, 1-9.