Analysis of Ground Effect on Aircraft Aerodynamics with Special Focus on the Boeing 737

Shehzad Serang, Aerospace Engineering

Mentor: Dr. Ali Ahmadi

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Abstract:

Airplane wings generate lift by using an airfoil to move the air that flows around them. When an airplane flies close to the ground it comes into ground effect. The ground interferes with the air's ability to move around the wing, increasing the lift and decreasing the induced drag. The purpose of this project was to study and research ground effect as it is not commonly taught in the classroom. Using computational tools, simulations and analyses were performed to quantify this effect. In order to make the research more applicable, the analyses were performed on a Boeing 737 wing, as the 737 is the most produced commercial jet airliner in the world. The study found an increase in lift and decrease in drag as expected, however it was for a specific airplane and the quantitative data should not be used as a generalization for all aircraft.

Literature Review:

Nicolai and Carichner [3] argued that an AR = 4 wing had a lift coefficient increase of 65%, but a drag decrease of 25%, when approaching the ground. On the contrary, McCormick [2] showed that an AR = 6 wing had an increase in lift of only 20%, but a drag decrease of 60% when approaching the ground. These two sources agreed that there was an increase in lift and decrease in induced drag, but disagreed on how much. This could be due to different shaped wings, however neither source explained the specifics of the wing geometries or test conditions used in their analysis. For this reason, this project aimed to be specific with its analysis; clearly defining the shape of the wing and under what conditions, in order to more appropriately understand ground effect.

Approach:

To quantify the effect of ground influence on a 3-dimensional wing, it was necessary to use a computational software. Three software programs were considered; AVL, XFLR5, and Ansys Fluent. According to Dantsker and Vahora [1], Ansys Fluent predicts the most accurate data compared to flight testing, however it is computationally expensive and difficult to learn. AVL is easy to learn, however it is the most inaccurate due to its lack of viscous effects. For these reasons, XFLR5 was used to perform this analysis. It is similar to Ansys Fluent in accuracy, but easier to learn and quicker to run like AVL. For the purposes of this project, XFLR5 was an acceptable computational program to use.

Once the software was chosen, many example calculations were performed to ensure that the software was accurately predicting ground effect as compared to references [2] and [3]. After the results were verified, the project proceeded with the analysis. Online sources were used to generate the Boeing 737-700 wing geometry shown in Figure 1 below. The wing had a span of 112 ft, with a root chord of 22 ft and tip chord of 5 ft. The total wing reference area was 1,263 ft^2. The airfoils chosen for the root, mid, and tip section were NACA 21015, 22012, and 24010 respectively as these were the closest airfoils to the 737 that were able to be analyzed in XFLR5. Figure 2 below shows the aerodynamic loads acting on the wing during landing. The lift and induced drag coefficients were used to develop the graphs in Figures 3, 4, and 5.

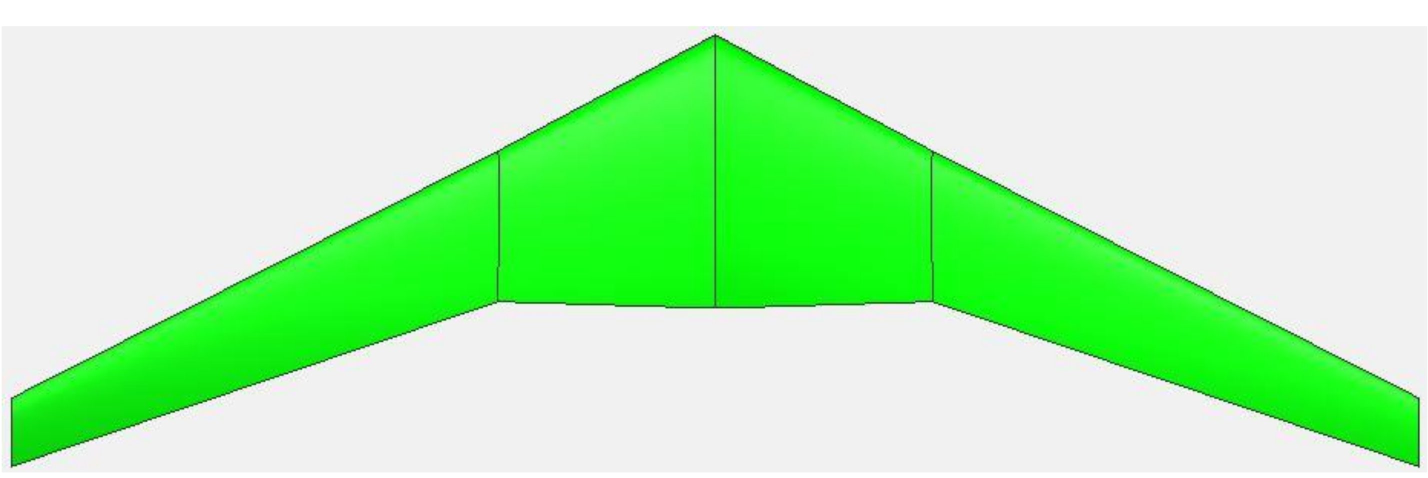

Figure 1: Top View of Wing Model Used in Analysis

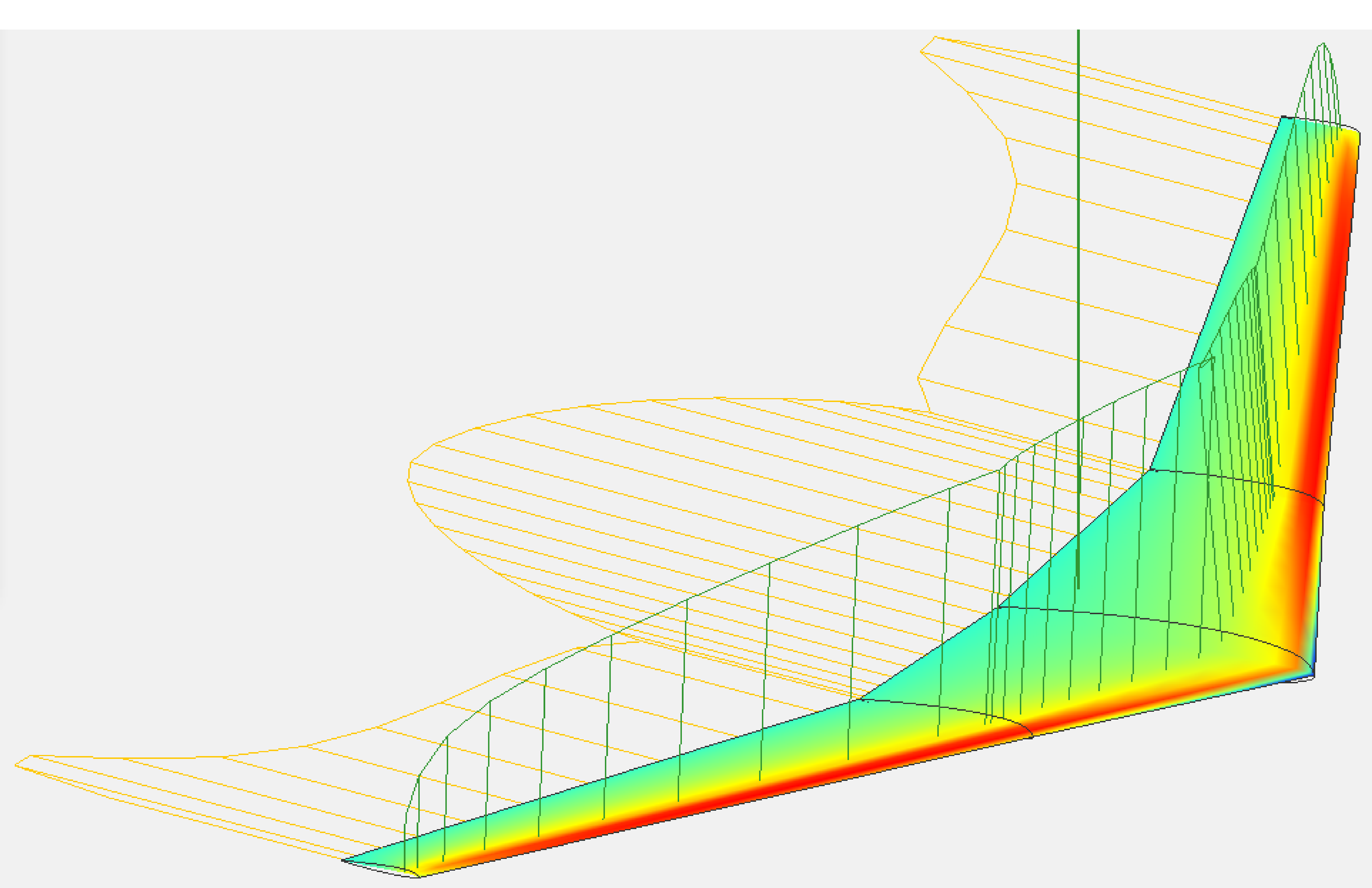

Figure 2: Aerodynamic Loads and Pressure Contour on the Wing

Analysis and Results:

The analysis was performed in XFLR5 using the ring vortex lattice method. It was run at 232 ft/s, or 137 knots, as this is a typical average landing speed of a 737. Also, the analysis was performed at standard sea level conditions.

Figures 3, 4, and 5 shown below were constructed using data gathered from XFLR5. All three graphs compared the data with a unitless relationship, semispan over height above ground (b/2h), because this was a common parameter to measure ground effect as described by [2] and [3]. When the wing approached the ground, h would decrease, and therefore the parameter increased.

Figure 5 below shows that the 737 wing has a 36% increase in lift and 38% decrease in induced drag just before touchdown. The lift appeared to increase exponentially as the wing approached the ground, however the induced drag appeared to decrease rapidly and then started to level out.

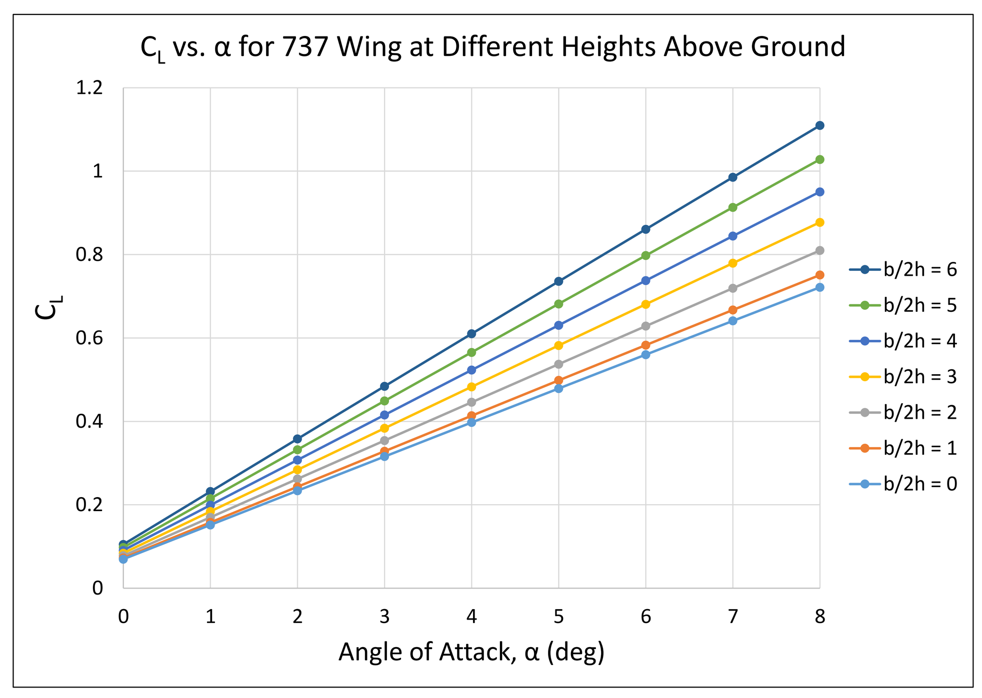

Figure 3

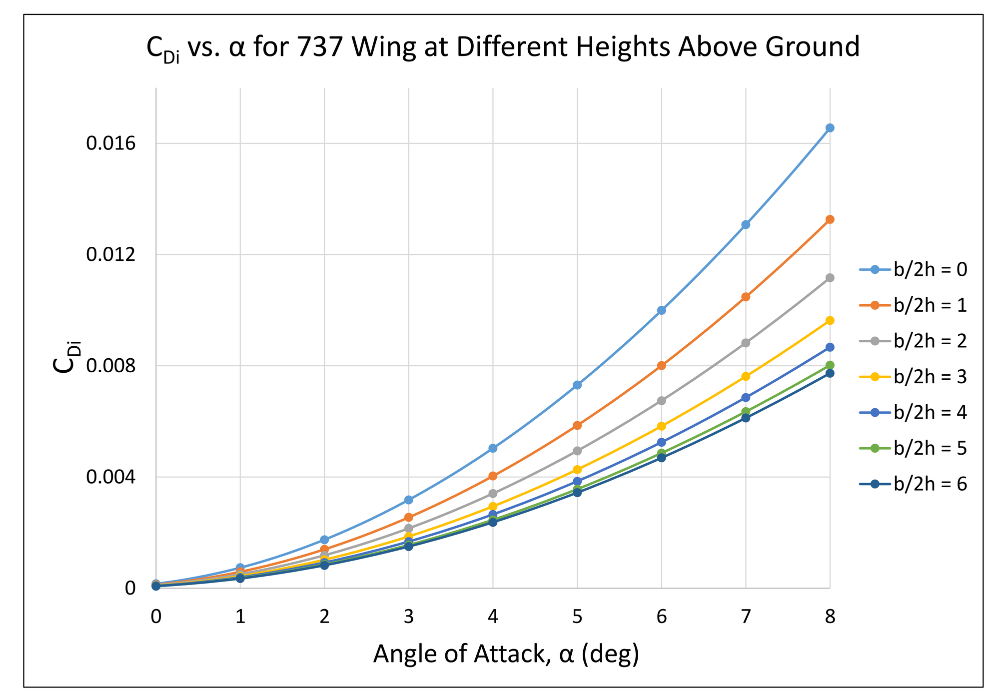

Figure 4

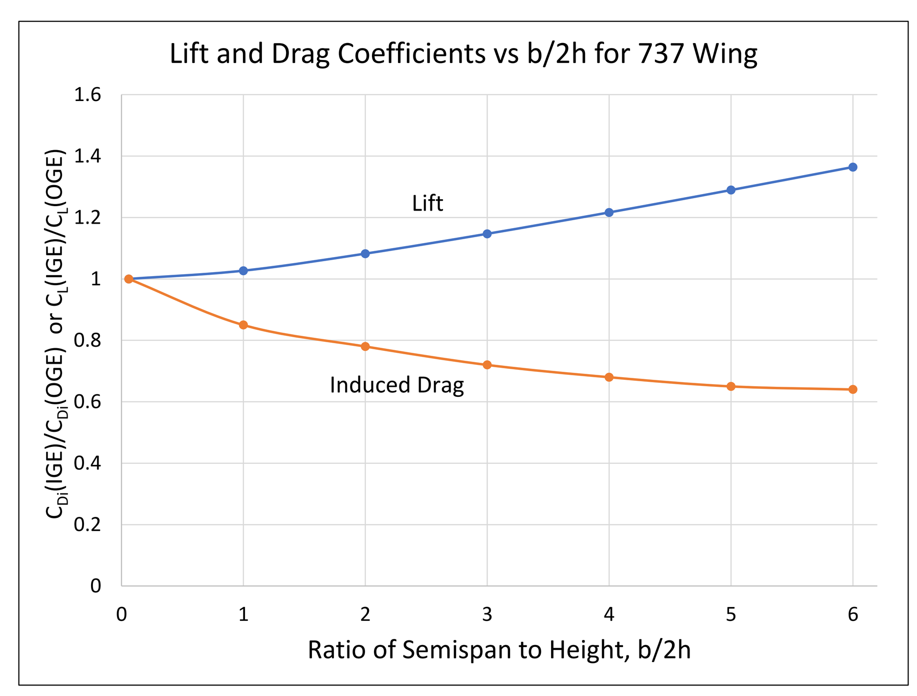

Figure 5

Conclusions and Future Work:

In conclusion, the analysis predicted an increase in lift and decrease in induced drag on a similar order of magnitude to those predicted by [2] and [3]. This showed that the theory used to explain simple geometry wings can also describe more complex geometries. Furthermore, it showed that XFLR5 can reasonably estimate ground effect properties compared to [2] and [3].

In the future, further analysis can be done in XFLR5 by varying the flap configurations, or by adding fuselage and tail surfaces to the aircraft geometry. Alternatively, the analysis can be performed in more depth using Ansys Fluent. Special consideration can be taken to see how the ground effect varies with speed, as well as with variations in atmospherics conditions.

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References:

[1] Dantsker, Or, and Moiz Vahora. "Comparison of Aerodynamic Characterization Methods for Design of Unmanned Aerial Vehicles." *2018 AIAA Aerospace Sciences Meeting*, 2018.

[2] McCormick, Barnes W. *Aerodynamics, Aeronautics, and Flight Mechanics*. John Wiley & Sons, Inc., 1995.

[3] Nicolai, Leland M., and Grant Carichner. *Fundamentals of Aircraft and Airship Design*. Vol. 1, American Institute of Aeronautics and Astronautics, 2010.