# NUMERICAL INVESTIGATION OF GROUND EFFECT ON AERODYNAMICS OF WINGED BODY RE-ENTRY CONFIGURATION

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## ABSTRACT

*Aerodynamics of a winged body re-entry vehicle during landing is affected by ground effect. In this paper, effect of ground proximity on aerodynamics of re-entry vehicle is investigated by performing computational fluid dynamics simulations in ANSYS Fluent using overset mesh approach. The effect of ground proximity is studied at alpha up to 20˚ by varying height from the ground. The lift, drag and nose-down pitching moment show increase as vehicle approaches the ground. A clear increase is observed in windward pressure coefficient on fuselage as well as wing due to ground effect. The effects on leeward side pressure distribution are also presented for fuselage and wing. The changes in fuselage leeward side are negligible and that on wing leeward side are not uni-directional.*

**Keywords:** Ground effect, Aerodynamics, Unbounded flow, Wing body configuration, Overset mesh, FLUENT

## INTRODUCTION

Aerodynamics of a winged body re-entry vehicle during landing plays an important role for the overall mission. The aerodynamic coefficients under influence of ground proximity could vary significantly as compared to that in unbounded flow. Because landing is the most critical phase of flight, it is of practical significance to investigate aerodynamic behavior of winged body in ground effect.

In moderate range of angle of attack the lift, drag and nose-down pitching moment increase with reduction in ground proximity and the windward side is major contributor to the variation in aerodynamic coefficients [1]. The pressure rise on windward side is also observed for airfoil in ground effect [2], which is the main reason for aerodynamic changes in ground effect. The leeward side of airfoil is also affected by ground effect leading to reduced suction globally except that leading edge suction is enhanced. Apart from numerical investigations [1], wind-tunnel experiments [3, 4] also show enhancement of lift, drag and nose-down pitching moment due to ground proximity. The recent efforts on engineering method for estimating ground effect [5] also indicate similar trends.

The variation of aerodynamic coefficients for a winged body re-entry configuration under influence of ground proximity is analyzed numerically and presented in this paper. Flow physics for unbounded flow and in ground effect are presented for a typical moderate angle of attack.

## ANALYSIS DETAILS

The objective of this study is to evaluate ground proximity effect on aerodynamics of winged body reentry vehicle with landing gear from CFD. Simulations are carried out at various heights from ground and typical angles of attack, and aerodynamic coefficients are evaluated. Schematic of winged body re-entry vehicle in ground proximity is shown in Fig 1(a). The configuration studied is a low aspect ratio double delta winged body vehicle. h is defined as height of c.g. from ground and h' is defined as height of main landing gear wheel bottom to ground. Height is non-dimensionalzed with 'b' i.e. wing span.

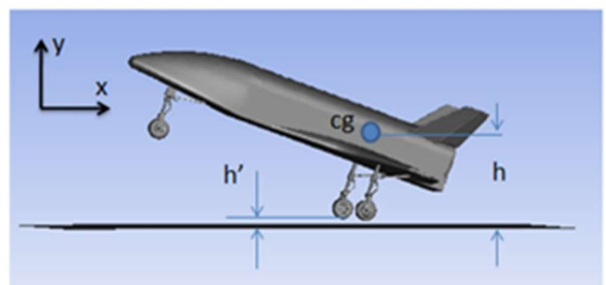


**FIGURE1:** (a) SCHEMATIC OF WINGED BODY RE-ENTRY CONFIGURATION IN GROUND PROXIMITY

The mesh around RLV-LEX is unstructured tetrahedral with prism layers. The grid is clustered to capture fuselage, wings, vertical tails and landing gear wake/vortices. The total cell count is 11.5 million. Another mesh for ground wall and free domain is generated, which serves as a background mesh for overset operation. Overset meshing approach allows to orient RLV-LEX w.r.t. ground at different attitude and heights without generating new grids.

The range of heights studied for ground effect investigation is h'/b=0.034 to 0.382 at angles of attack 2.2˚, 10˚, 15˚ and 20˚. The lowest height is governed by the landing gear height itself, hence winged body cannot be brought very close to the ground. The simulations are carried out for a scaled model with $V\infty$=20m/s and ground velocity=20m/s corresponding to Re=0.38million based on mean aerodynamic chord. Ground velocity is simulated by imposing wall tangential velocity boundary condition. Aerodynamic coefficients are non-dimensionalzed using reference area as wing area, reference length as mean aerodynamic chord and all moment coefficients are reported about center of gravity.

ANSYS Fluent pressure based coupled solver has been used with SST k-ω turbulence model for all the simulations. Velocity inlet, pressure outlet and moving wall boundary conditions are used with sufficiently large domain (D is fuselage base height) as shown in Fig 1(b). Convergence for lift, and drag coefficients is shown in

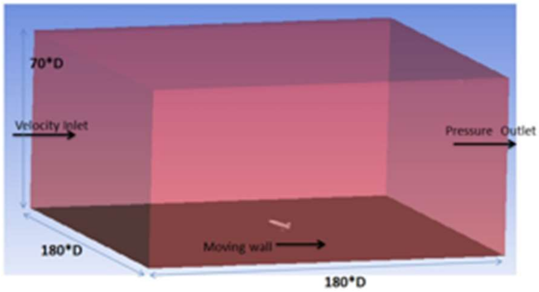


**FIGURE 1(b):** COMPUTATIONAL DOMAIN

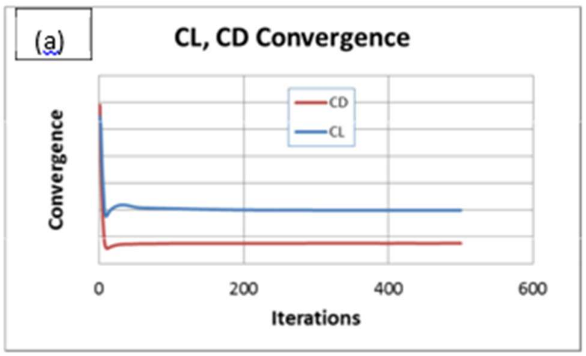


**FIGURE 2(a)** CONVERGENCE OF AERODYNAMIC COEFFICIENTS

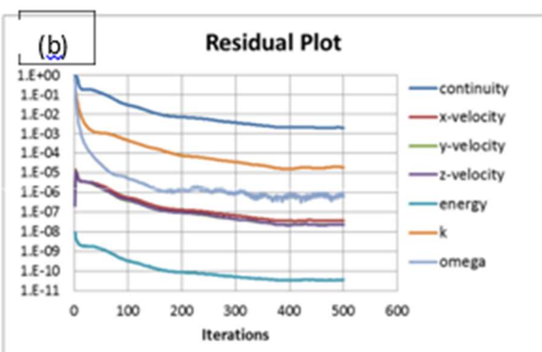


**FIGURE 2(b):** RESIDUAL PLOT

Fig 2(a) and scaled residual plot is shown in Fig 2 b) for a typical run. All coefficients show good convergence within 500 iterations.

## RESULTS AND DISCUSSIONS

The variation of aerodynamic coefficients for unbounded flow and in ground effect at lowest height studied is shown in Fig 3 and Fig 4. Increase in lift, drag and nose-down pitching moment is observed under the influence of ground effect. Ground proximity has small influence on aerodynamic efficiency at alpha 10˚ and

Higher values of Cp on windward side are evident from contour plots. On wing leeward side, differences are observed in Cp but not unidirectional.

$15^0$however aat other angles, aerodynamic efficiency s unchanged

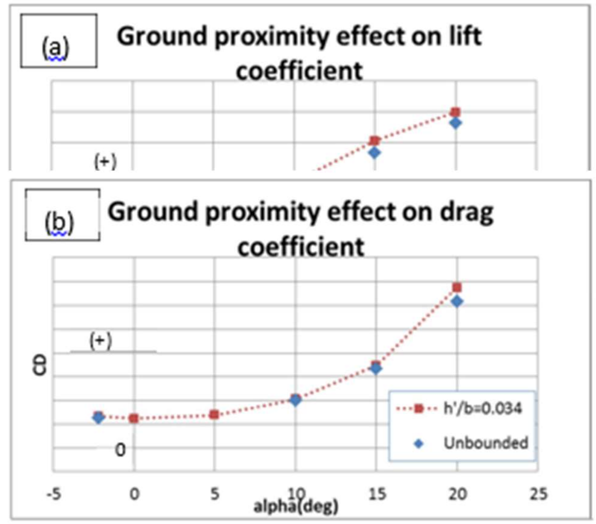


**FIGURE 3:** GROUND PROXIMITY EFFECT ON AERODYNAMIC COEFFICIENTS; (A) CL; (B) CD

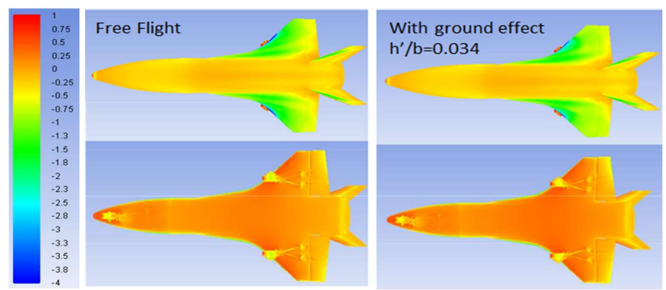


**FIGURE 5:** COEFFICIENT OF PRESSURE (Cp) CONTOUR ON BODY FOR LEEWARD AND WINDWARD SIDE

The values of Cp are plotted with length at fuselage mid plane and shown in Fig 6. The maximum change in Cp due to ground proximity effect is +0.1 on windward side. Due to rear portion being closer to ground, Cp change seems to build up from x/L=0.4m to x/L=0.8m. The difference on leeward side Cp on fuselage is insignificant. For wing main landing gear plane, the variation of Cp with axial distance is shown in Fig 6(b). On the windward side, maximum change in Cp is +0.1 and the observation is consistent with that on fuselage. On the leeward side, slightly higher leading edge suction is observed in presence of ground proximity. Higher suction is seen at

The incremental change in aerodynamic coefficients due to ground effect is shown in Fig 7. The incremental coefficients show diminishing trend as the vehicle goes away from ground. It is observed that ΔCL at α=15˚ is higher than that at alpha=20˚. But ΔCD and ΔCm are highest at α=20˚. Fore and aft axial sections, but lower suction is observed in the mid axial section

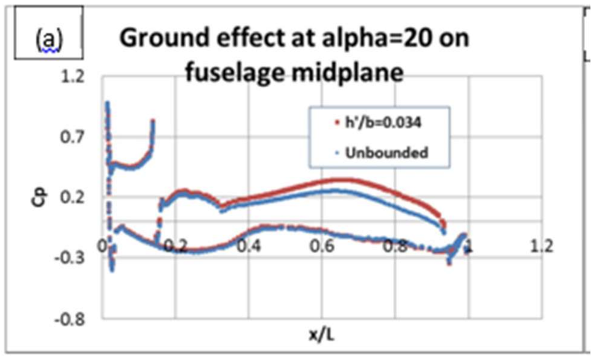


**FIGURE 6(a)**

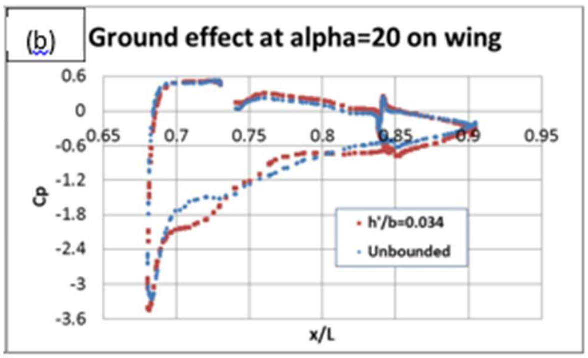


**FIGURE 6(b)**

**FIGURE 6:** PRESSURE COEFFICIENT VARIATION FOR (a) FUSELAGE MID PLANE (b) WING

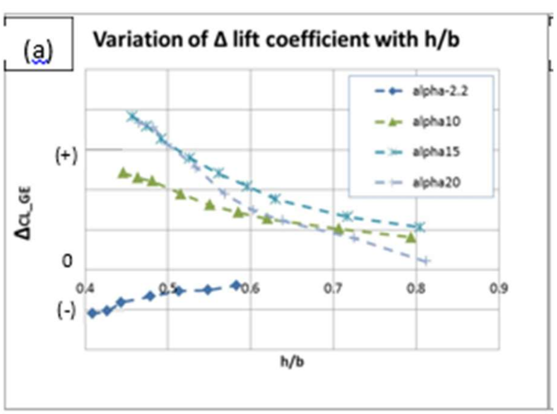


**FIGURE 7(a)**

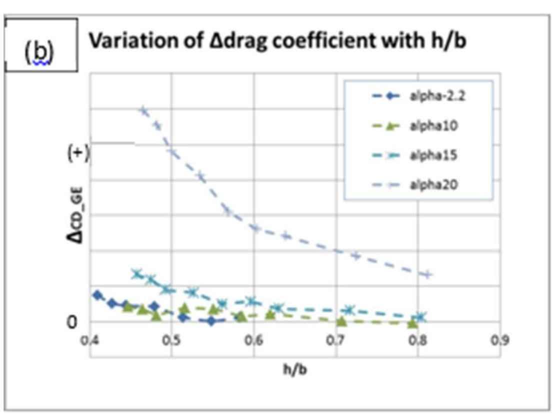


**FIGURE 7(b)**

**FIGURE 7:** INCREMENTAL AERODYNAMIC COEFFICIENTS DUE TO GROUND p ROXIMITY EFFECT (a) CL; (b) CD

## CONCLUSIONS

conclusion CFD simulations carried for investigating influence of ground effect show 10% higher lift, 8% higher drag and 17% higher nose-down pitching moment and insignificant change in aerodynamic efficiency. The effect of ground proximity on surface pressure shows perceptible change on windward side of fuselage as well as wing. The effects on leeward side are not uni-directional on the wing with fore and aft section showing higher suction and mid-section showing loss of suction. Incremental lift coefficient is higher for α 15˚ as compared to alpha 20˚, however incremental drag at α 20˚ is higher than the value at alpha 15˚.

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