Ground Effect on a Slender 65º Delta Wing with Sideslip, Image Method, using Euler

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Abstract (Interactive Paper)

With growing focus on supersonic and hypersonic flight, slender-wing ground performance, take-off and landing is of interest. It is well known that pitching moment behaviour at high angles of attack is usually non-linear with vortex flows being present. Nearness to ground alters the behaviour further. This paper gives an understanding of ground effect, using the well-known ICE delta wing with leading edge sweep 65º. Predictions are with an Euler CFD solver.

Keywords: Aircraft Design & Integrated Systems, Applied Aerodynamics, Flight Dynamics & Control

1. Introduction and Geometry

With growing focus on supersonic and hypersonic flight, slender-wing ground performance, take-off and landing is of interest. High lift at high angles of attack (AoA near 14º) and sideslip (AoS 10º) are involved and flow non-linearities can occur because of vortical flows arising. Pitching moment behaviour is particularly important.

The traditional experimental way is to mount a model in a wind tunnel with moving floor. Because of costs, this is useful in the later stage of a research programme. Nevertheless, modern CFD can be used in early stages. In this paper we are using the well-known ICE delta planform ([1], 65º LE sweep, span b), **Figure 1**. Linear theory or panel methods do not capture the flow non-linearities.

Here, the CFD modelling is via the "image method". So, the model at a given AoA and height h from the ground and its reflected image in the ground are needed. The ground plane is effectively virtual. We can choose the flow parameters simply with AoS being the only definition required. AoA is from the model geometry being rotated. However, this process does mean a great deal of geometry handling, mesh creation and solutions with various values of AoA and h/b, **Figure 2**. Mach number is fixed at 0.3 for Euler runs with SU2 CFD solver. The wing is planar (i.e. not designed for camber and twist).

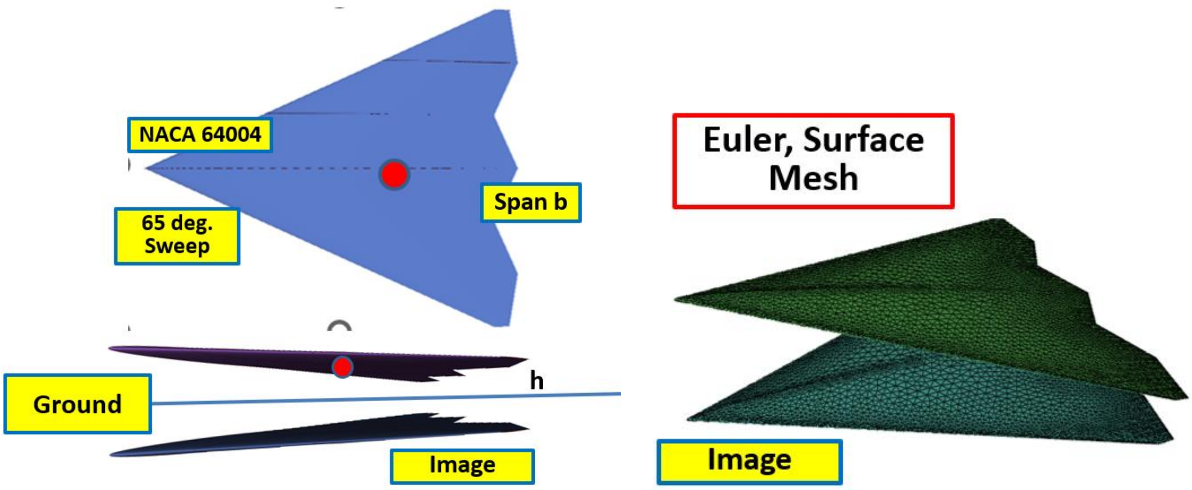

Figure 1 Model Geometry, Its Reflection in "ground" & Euler Surface Meshes

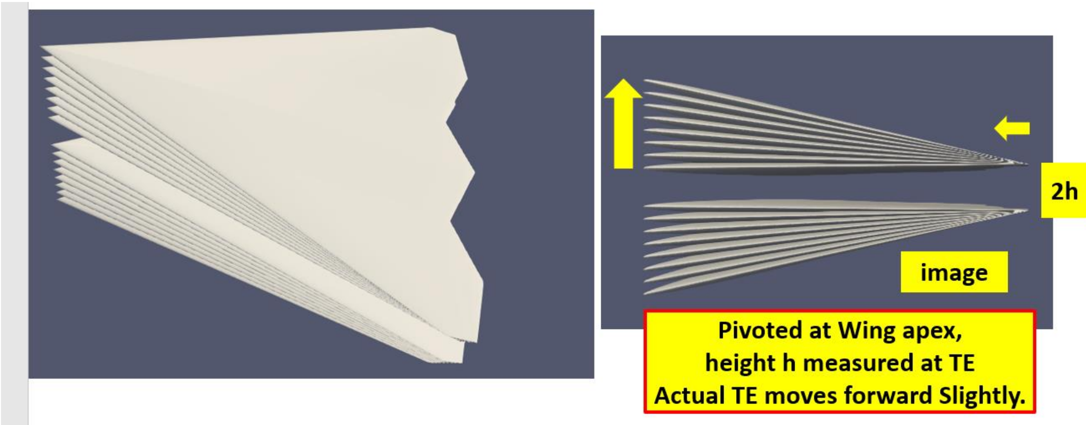

Figure 2 Geometry Variation in AoA for each Sideslip angle (AoS), given h/b

The salient geometry and flow particulars are**:**

semi-span s=10 units, b = 20

h measured at Wing TE from ground z=0, (h/b 0.0609, 0.15. 0.2, 0.4, 0.8, 1.2) & Free Air
Root chord 23.0, cref 11.5, Area S 230
Moments about 15, 0, 0 on Wing (unstable)
Flow conditions: Mach 0.3, AoA 0º (2 º) 14 º, AoS 0º (4º) 12º.

2. Symmetric Case, Ground Effect

Longitudinal results, forces and moments are in **Figures 3-4**, as function of AoA and h/b. Essentially CL and CD both drop as height from the ground increases. Note the strong non-linearity in Cm around AoA 5º, particularly for low h/b.

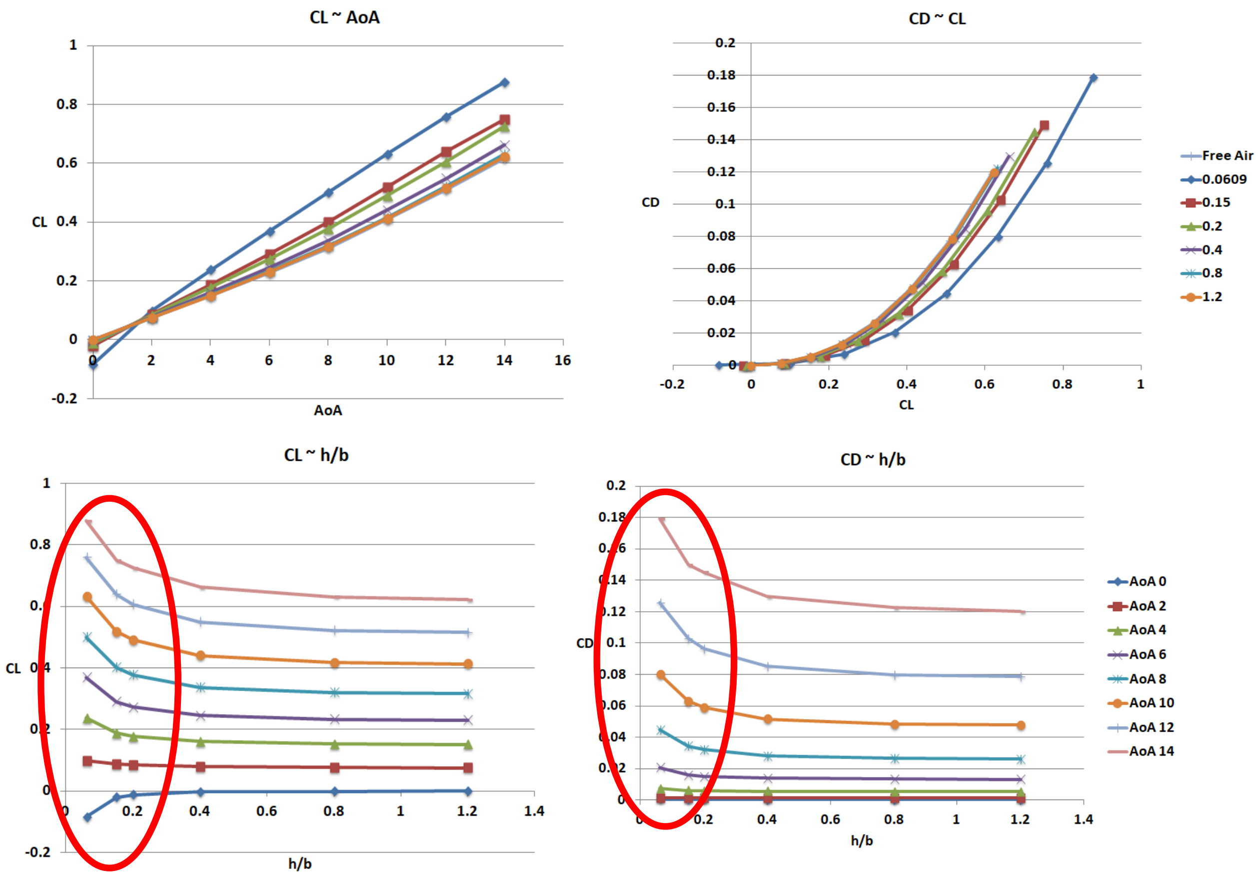

Figure 3 Variation of CL & CD with height parameter h/b

It is interesting to focus on the Cm behaviour, **Figure 4.** The Implication is that ground effect is unstable to AoA about 5º. Beyond that ground effect is stable. This behaviour is very much related to the effect of vortices appearing and causing the effective centre of lift to move aft as AoA increases. **Figure 5** with surface Cp distributions, gives an idea of the vortex development with AoA increasing.

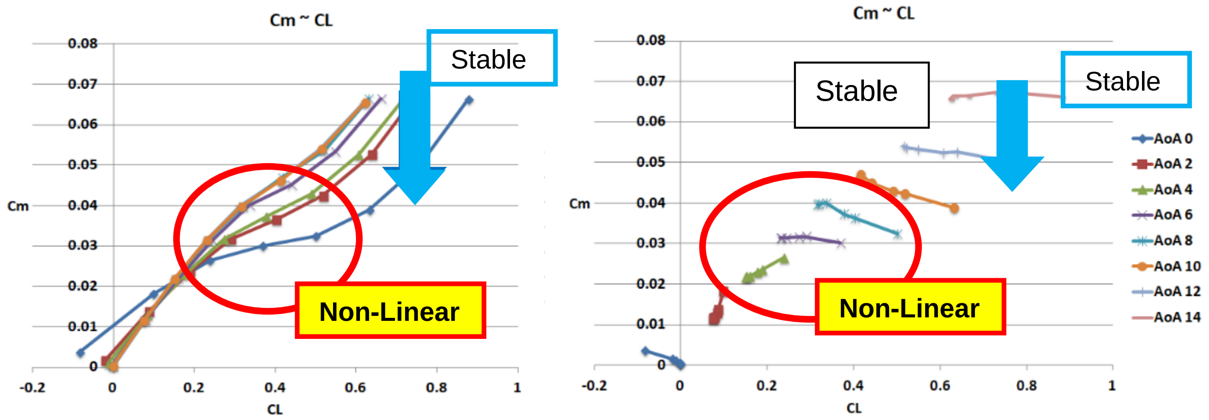

Figure 4 Variation Cm ~ CL, h/b and AoA vary

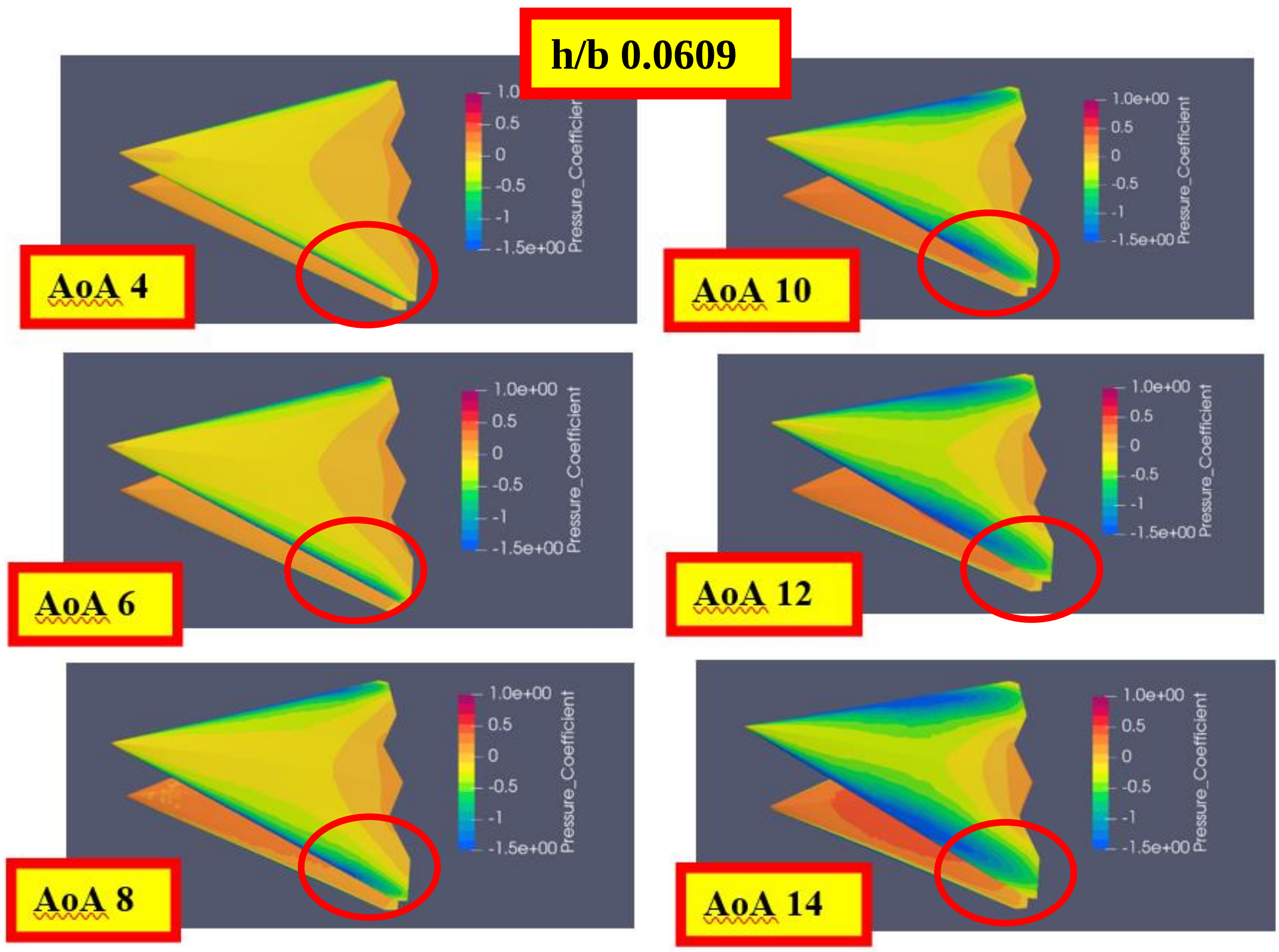

Figure 5 Surface Flow Cp Distribution with AoA 4º to 14º

3. Sideslip Effects in Free Air

Longitudinal and Lateral forces and moments graphs with respect to AoS are shown in **Figure 6** for free air. The relationships appear practically linear, except for Cm. The Cm slopes change character at AoA 5º. The effect is not to marked, however.

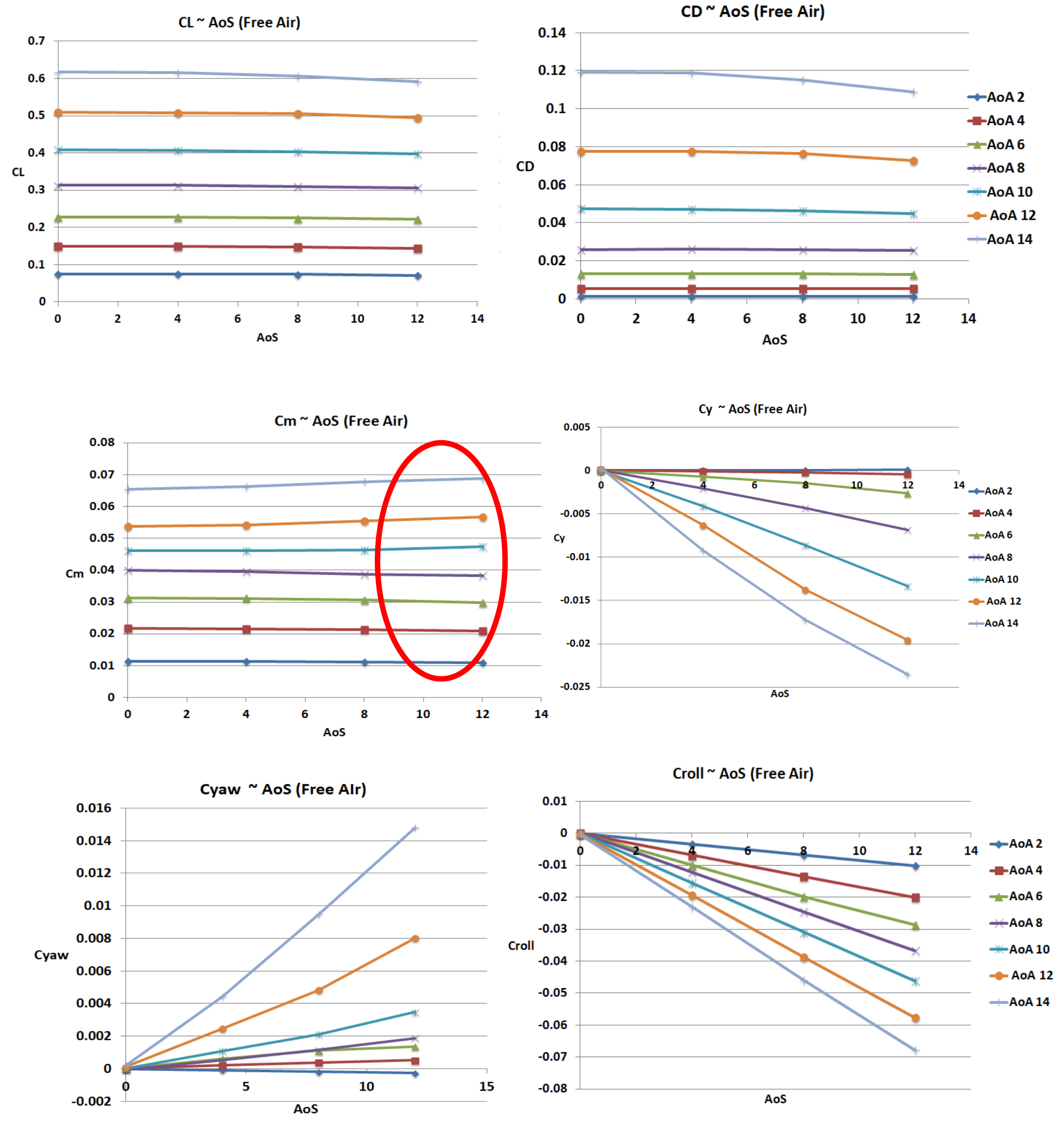

Figure 6 Effect of AoS on Longitudinal and Lateral, Forces and Moments, Free Air

Figure 7 with surface Cp distributions for AoA 10º & 14º, gives an idea of the vortex development with AoS increasing from 4º to 12º. Note the marked differences between the vortex flows on windward (port) side and the leeward (starboard) side.

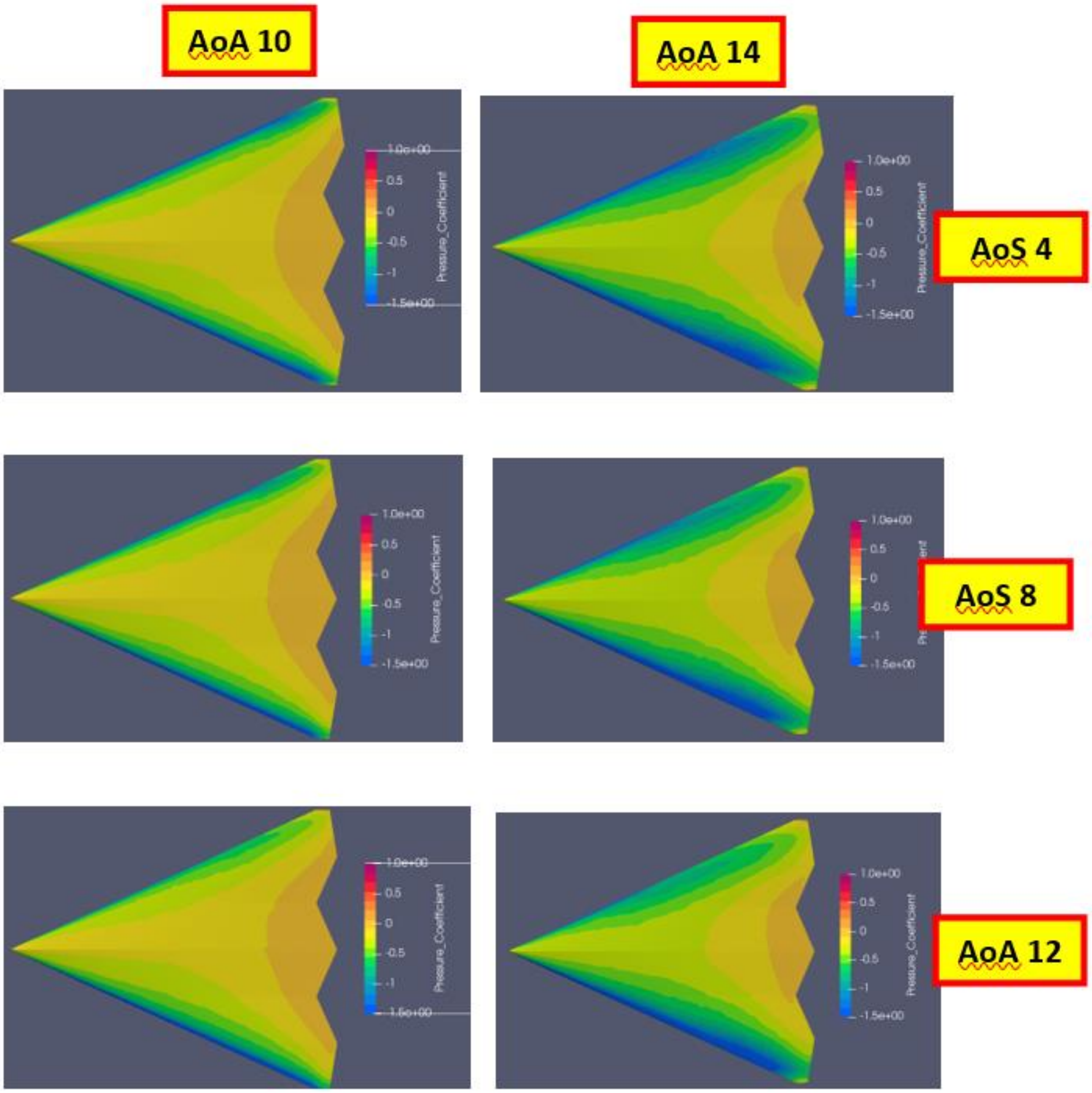

Figure 7 Surface Flow Cp Distribution with AoA 10º & 14º. Effect of AoS, Free Air

4. Sideslip Effects in Ground Effect

Longitudinal and Lateral forces and moments graphs with respect to AoS are shown for three different heights (h/b 0.15, 0.4 and 0.8) in **Figures 8-10.**

As in the previous case for free air, the various relationships show very similar behaviour.

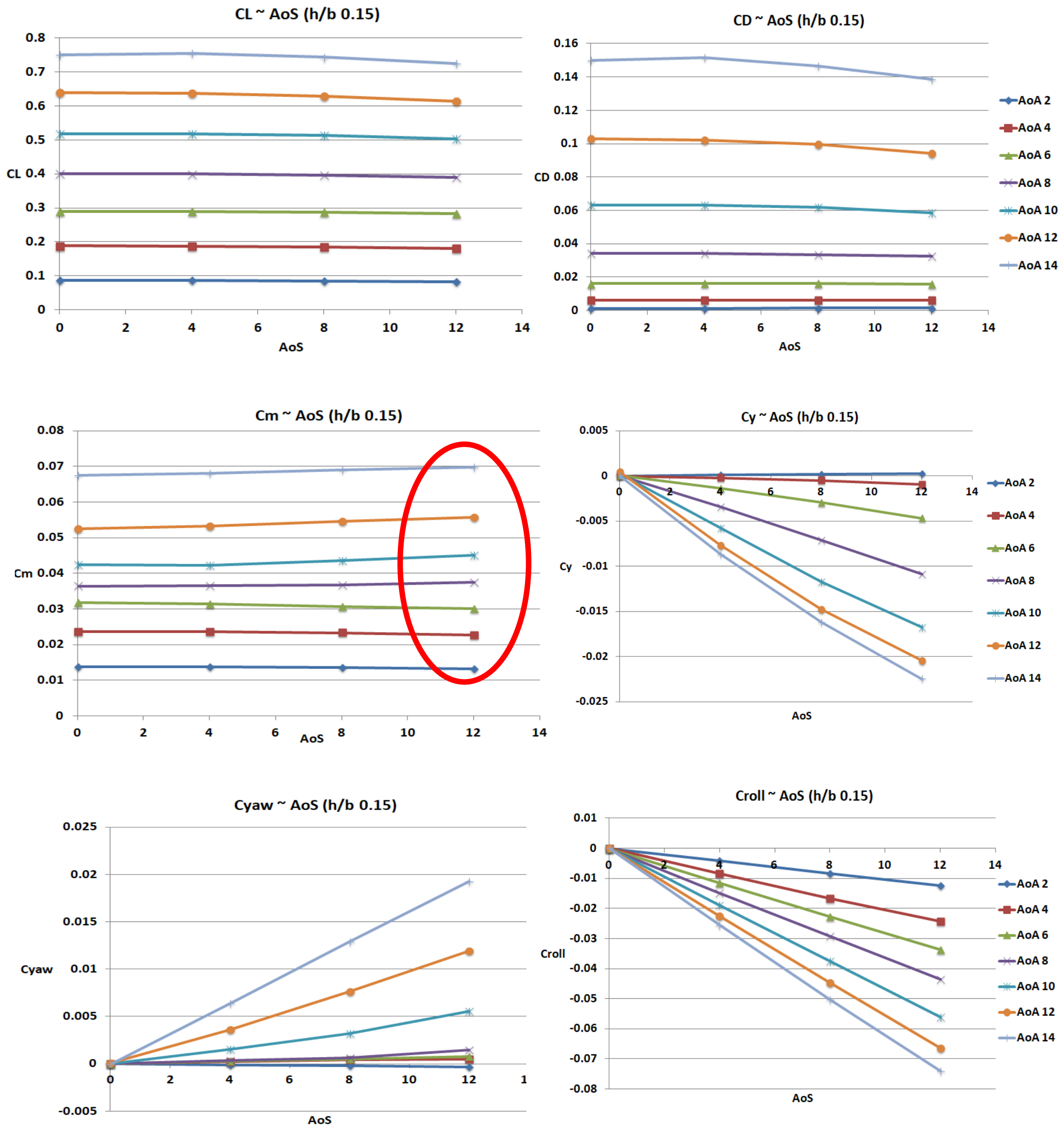

Figure 8 Effect of AoS on Longitudinal and Lateral, Forces and Moments, h/b 0.15

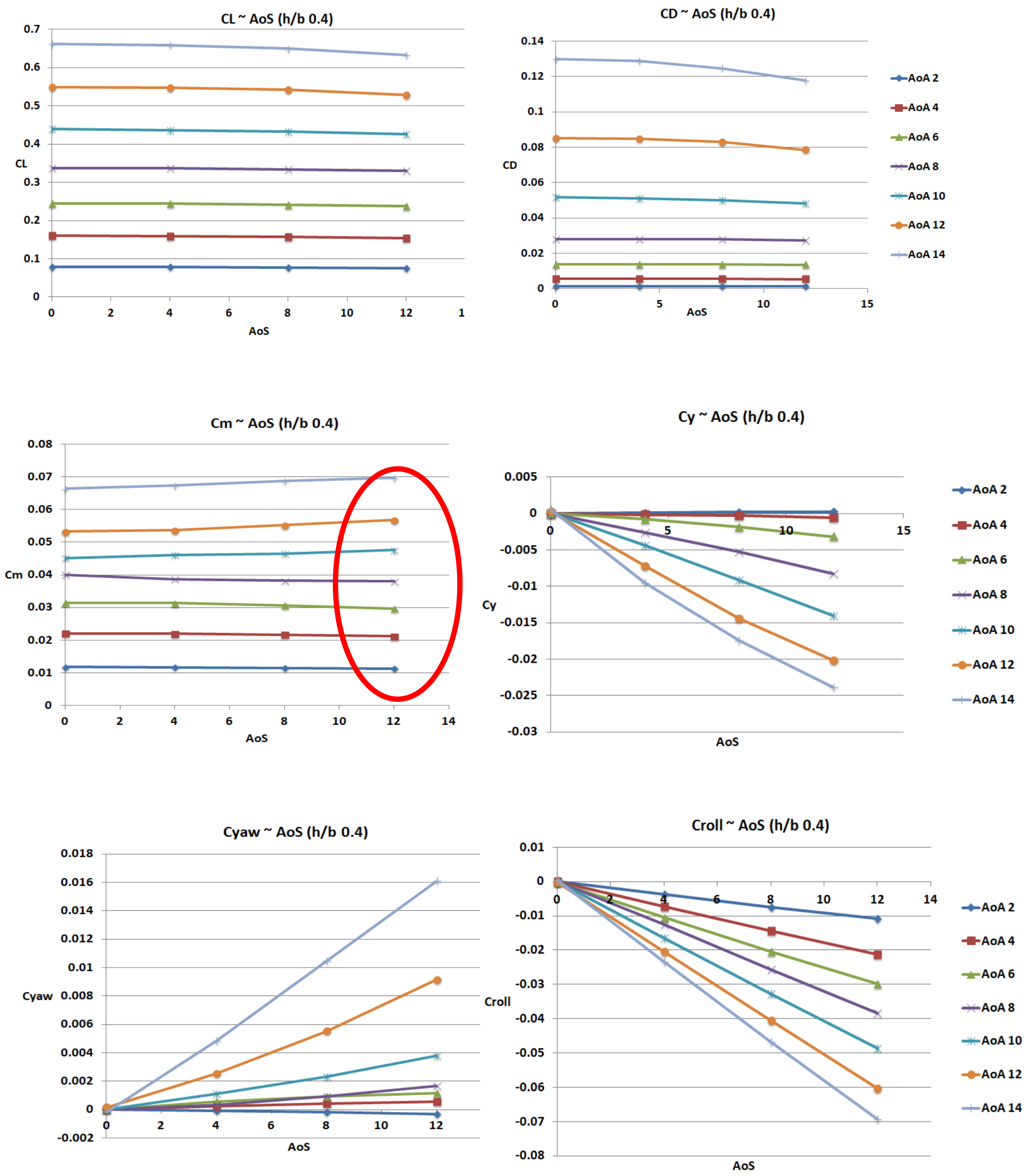

Figure 9 Effect of AoS on Longitudinal and Lateral, Forces and Moments, h/b 0.4

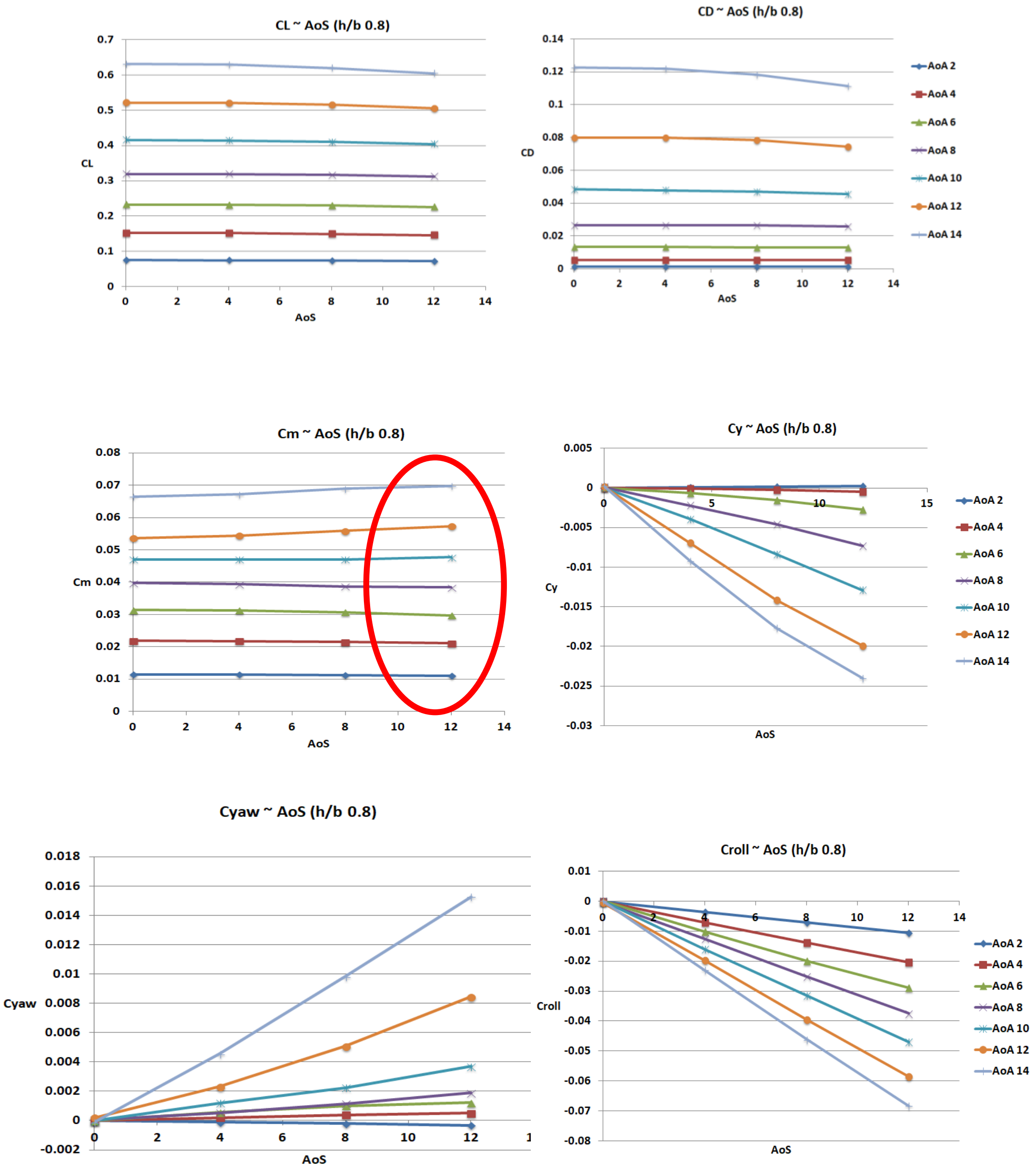

Figure 10 Effect of AoS on Longitudinal and Lateral, Forces and Moments, h/b 0.8

5. Conclusions

High speed slender aircraft have a challenging ground performance in terms of high CL requirements at high AoA and AoS. Many non-linearities occur because of vortical flows. Pitching moment behaviour is particularly important.

Here we have used an image method for modelling the ground effects on the well-known ICE planform. After a sizeable matrix of runs (AoA, AoS & h/b variations), using SU2 in Euler mode, we infer:

- For given AoA, CL and CD both increase as h/b reduces.
- For given CL, CD increases as h/b reduces.
- Non linearities exist in Cm; AoA above about 6º. So neutral point position changes and that implies varying static margin due to ground effect.
- Limited work on sideslip effects shows that CL, CD trends are linear with AOS. But non-linearities appear in Cm at AoA near 6º.

Work so far has been on a planar wing configuration. We need to extend the scope of the programme to a designed wing. Vertical surfaces need to be included – these may affect the vortex flows in sideslip. Next logical state is towards trimmed flight with control effects (elevons) included.

6. Acknowledgements

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7. Copyright Statement

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9. References

[1]. Innovative Control Effectors (ICE) Wing originally proposed by AFRL, USA in 1980's. Several reports on the web. A recent one is by Zhang, N. et al, "Research on multi-task command allocation method for flying wing aircraft, IOP conference Series Material and engineering 892(1):012039, April 2020. DOI 10.1088/1757-899X/892/1/012039.