Effect of Ground on Flow Structure of Non-Slender Delta and Reverse Delta Wings

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Motivation and Objective:

Flight condition of aircrafts proximity to the ground, so-called "Ground Effect" (GE), is among one of the most recent research areas since the aerodynamic performance and stability of wing in ground effect (WIG) crafts significantly vary due to the flow dynamics associated with the interaction between the wing and the surface. Aircrafts operate in ground effect during the standard landing and take-off conditions. In addition, WIG crafts are often designed to operate steadily on water surface for maritime applications.

Figure 1 Unmanned combat air vehicles and fixed-wing micro air vehicles (Gursul et al., 2005)

The reversed delta wing (RDW) planform is a derivative planform of delta wing (DW) and designed for the GE applications. In the present study, ground effect of non-slender DW and RDW with sweep angle of $\Lambda = 45^0$ at static ground effect (SGE) condition in the absence of heave and pitch motion was investigated, experimentally. The SGE condition was simulated with both static ground and dynamic ground boundary conditions using an elevated ground system as well as a moving belt mechanism.

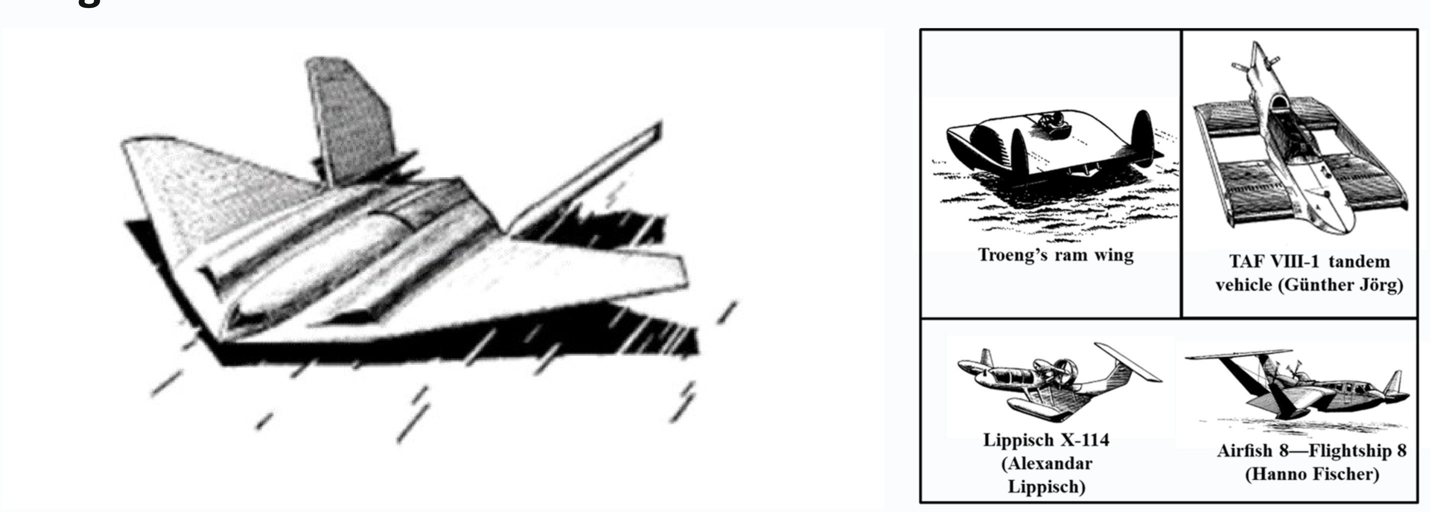

Figure 2 Different ground effect vehicles (Rozhdestvensky, 2006)

First, an experimental set up, which includes an elevated ground system as well as a moving belt mechanism, was designed and constructed to investigate the GE scenarios at different angle of attack and height values compared to out of ground condition. Then, the intensity of the GE and the stability characteristics of the wings were examined. Finally, the effects of thickness-to-chord (t/c) ratio, anhedral angle δ and cropping ratio (Cr%) from trailing-edge on the aerodynamics of non-slender RDWs in comparison to non-slender DWs were investigated for both in ground effect (IGE) and out of ground effect (OGE) scenarios.

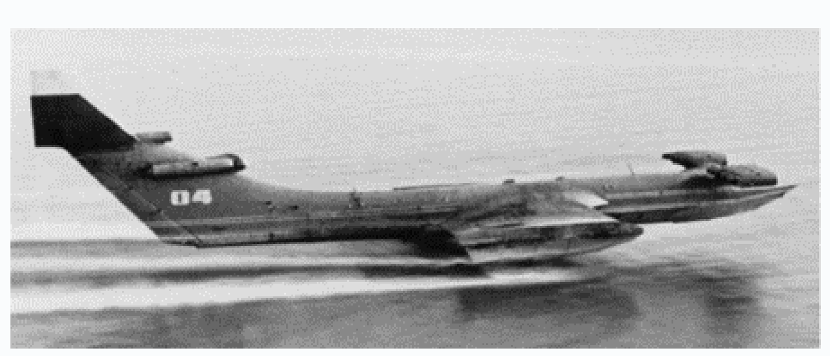

Figure 3 KM Caspian Sea Monster (Jones, 2005)

Figure 4 Race Car Tunnel Testing (Zhang et al., 2006)

Methodology:

Experiments were performed in a low-speed wind tunnel. Two base delta wing and two base reverse delta wing models representing thick and thin configurations having t/c = 1.1% and 5.9%, and additional four thin reverse delta wing models with t/c = 1.1% as well as having different anhedral angles $\delta = 0^0$, 15^0 and 30^0 and cropping ratios Cr = 0%, and 30% are tested at Re = 90,000 for angles of attack varying between $0 \le \alpha \le 35$ degrees and non-dimensional heights between $3\% \le h/c \le 113\%$.

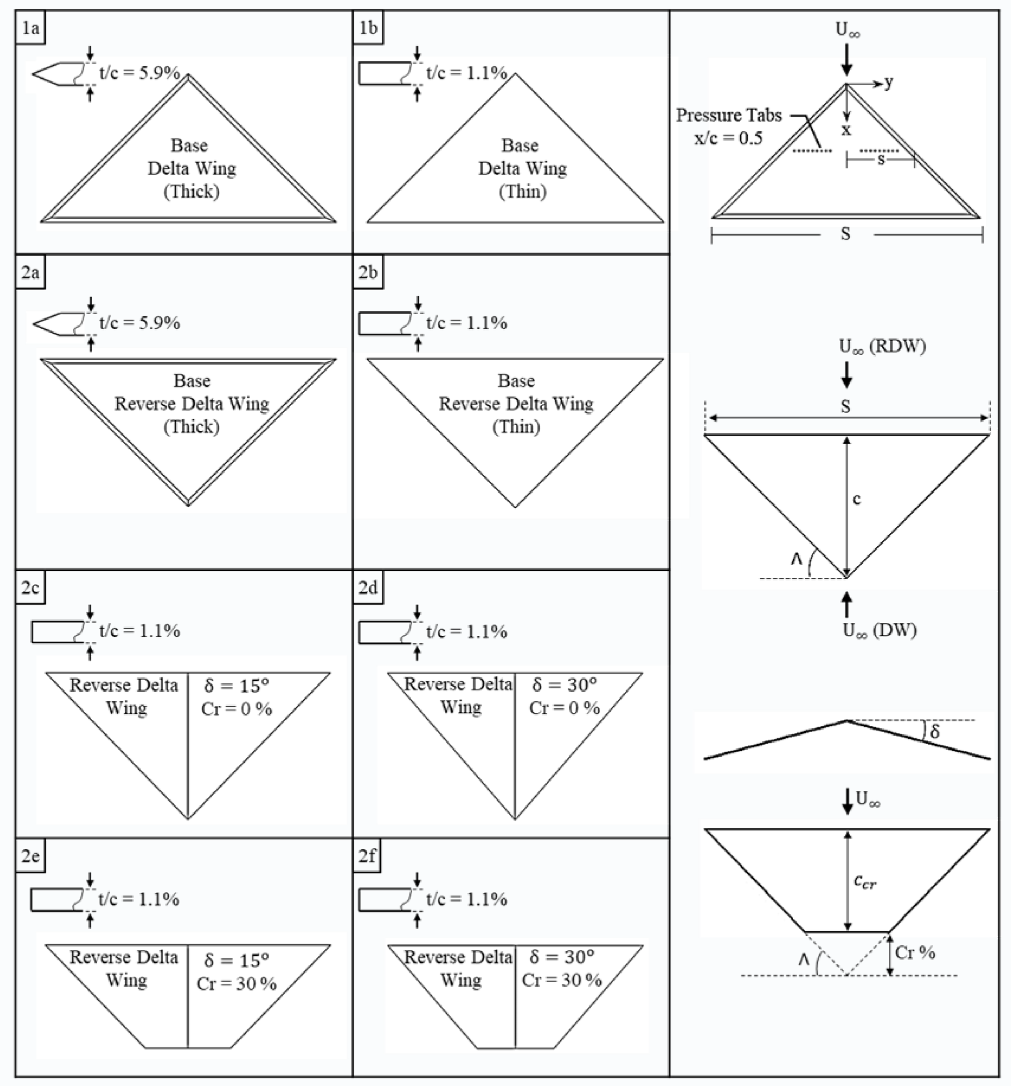

Figure 5 Geometric details of the wings used in experiments

Test Cases:

Reynolds Number

9×10^4

Angle of Attack	*Height*
$0 \le \alpha \le 35$ deg	$3\% \le h/c \le 113\%$

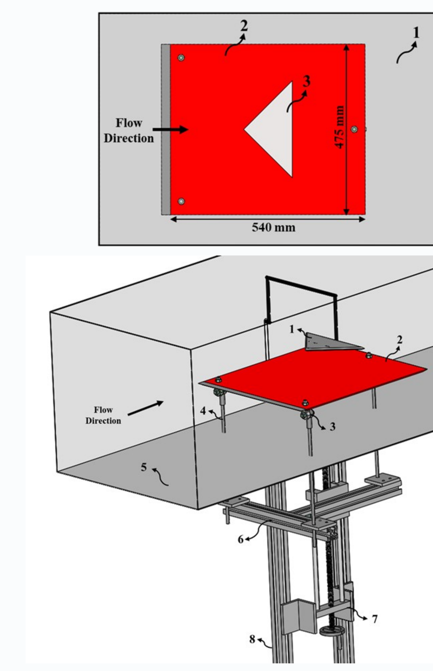

Figure 6 Schematic representation of static ground system

The intensity of the GE and the stability characteristics of the wings were examined using force and moment, and surface pressure measurements. The static ground condition was simulated with a fixed flat plate and dynamic ground condition with a moving belt mechanism. The static ground condition was further simulated with the Belt Off condition, where the tunnel floor represented the ground, hence static ground effect was demonstrated with three different fidelity levels.

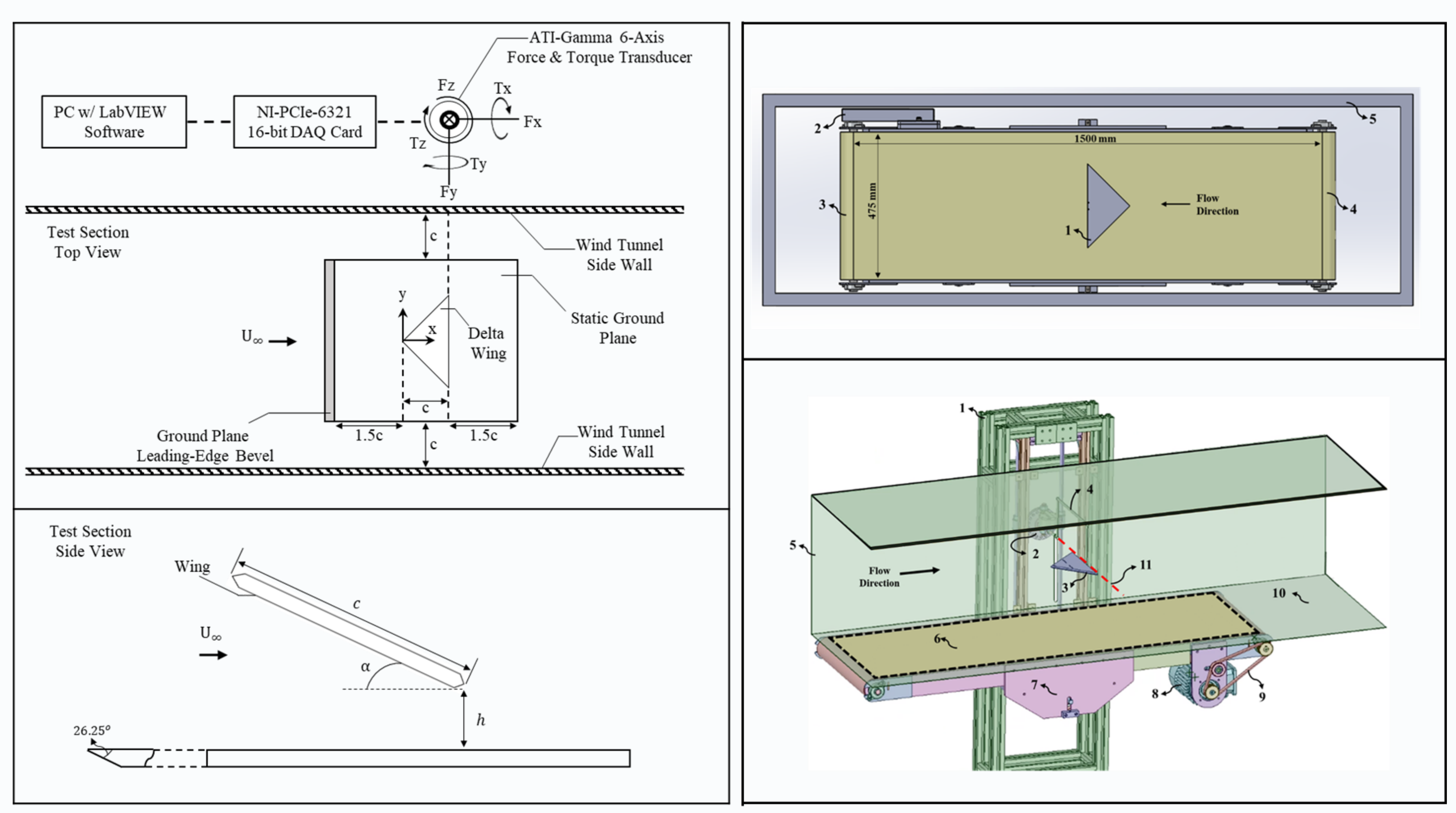

Figure 7 Schematic representation of static and dynamic ground systems together with force measurement and model positioning systems

Results:

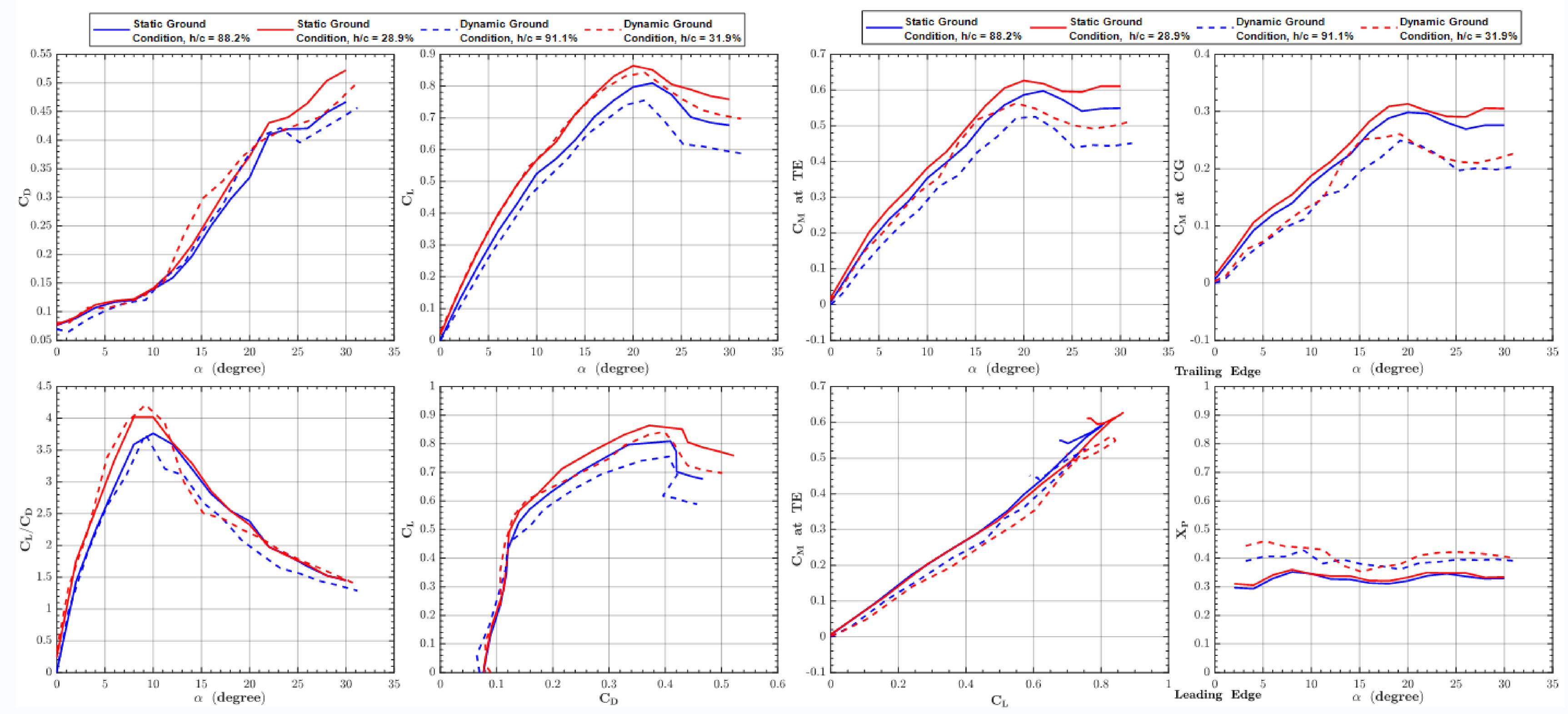

Figure 8 Variation of aerodynamic coefficients with respect to Static and Dynamic Ground Conditions

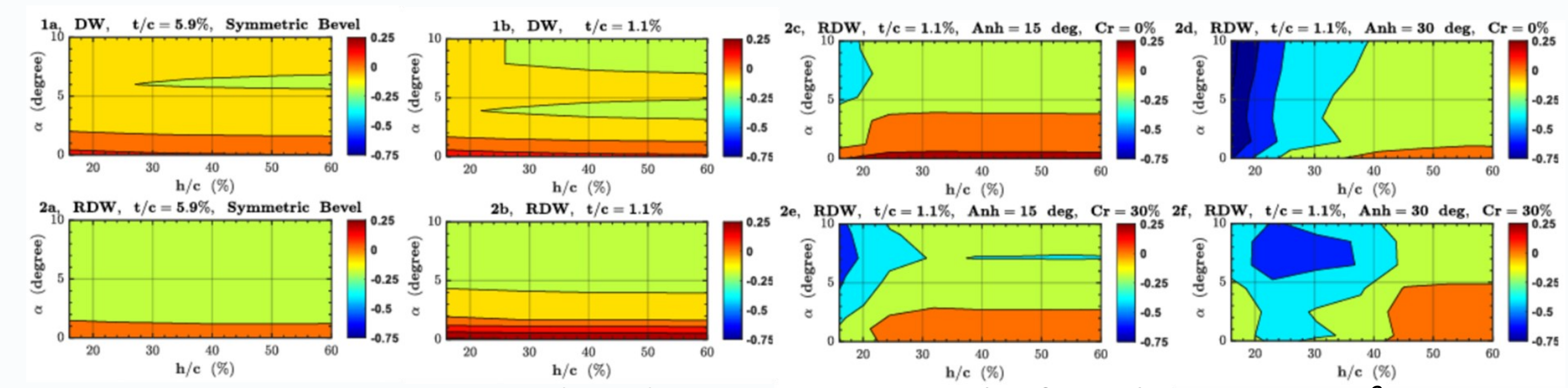

Figure 9 Static Ground Condition – H.S. – Low Angle of Attack Range, $\alpha \le 10^0$

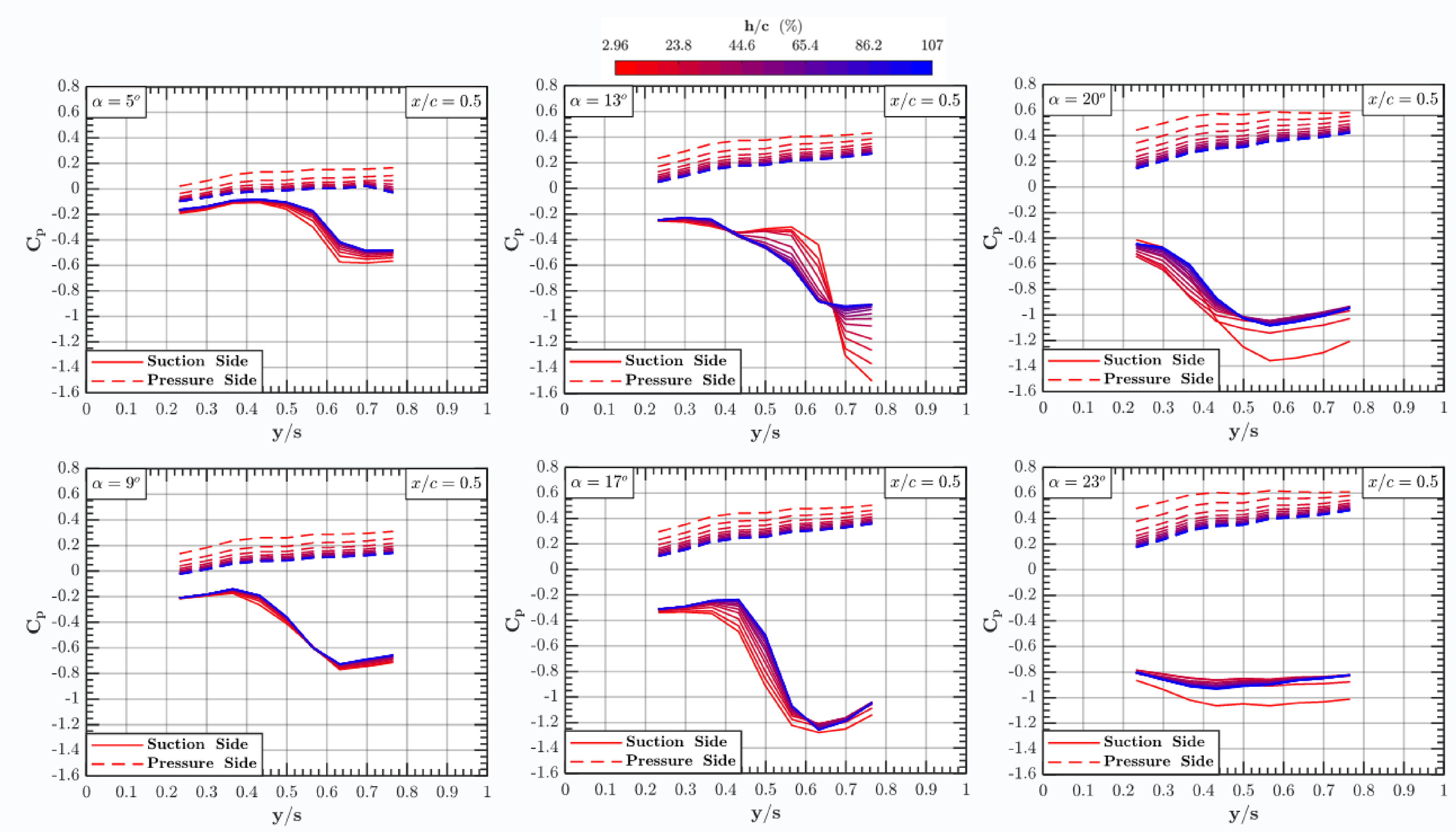

Figure 10 Variation C_P distributions for static ground boundary condition with ground effect intensity

Conclusions:

1) The GE intensity is favourable for aerodynamic performance and the longitudinal static stability characteristics are strongly dependent on ground boundary condition such that interchanging stability characteristics were observed varying with both h and α.
2) Compared to the stationary ground plane, the dynamic ground plane possesses a relatively thinner boundary layer. Consequently, the distribution of displacement thickness across the stationary ground plane's boundary layer varies significantly in both the direction of streamwise and transverse directions. This variation causes the effective shape of the ground plane to deviate from flat, resulting in angular flow around the model. This flow angularity impacts the measured lift-to-drag ratio of the model.