Effect of Bleeding on Aerodynamics of Non-Slender Delta Wing in Ground Effect

Oğuzhan Yılmaz, Göktuğ Koçak , Dr. Murat Kadri Aktaş and Dr. Mehmet Metin Yavuz

Motivation and Objective:

Ground effect is an aerodynamic phenomenon that alters the flow field of flying objects near the ground, leading to increased lift and improved lift-to-drag ratios. Wing-in-ground-effect (WIG) vehicles utilize these benefits. Delta-wing integrated aerial vehicles also experience ground effect during take-off and landing, especially in maritime operations. Understanding the aerodynamic behavior of delta wings in this context is essential.

Recent studies by Celik et al. (2017) and Kayacan et al. (2020) have utilized the passive bleeding technique to manage flow structures in non-slender delta wings. This method exploits the pressure difference between the wing's pressure and suction sides, using open slots to delay flow separation and stall angle of attack.

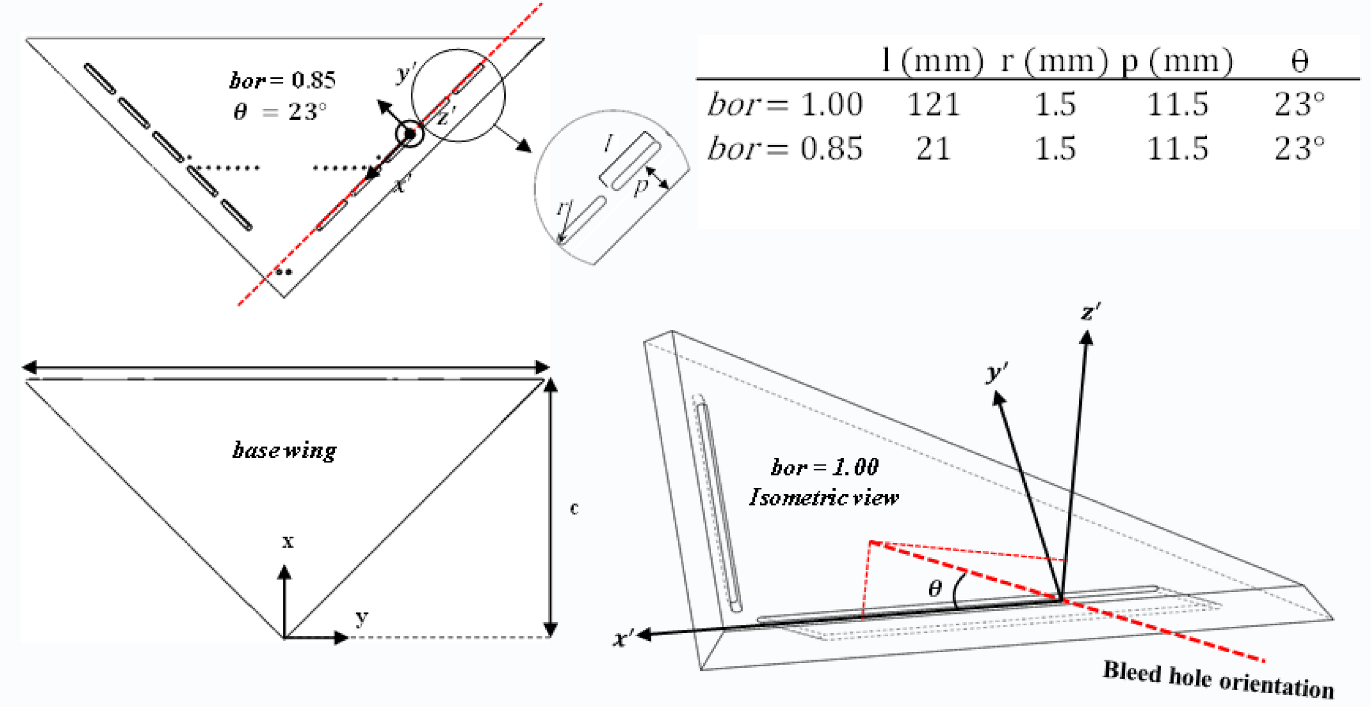
Additionally, the ground effect can increase the pitching moment coefficient in the pitch-up direction, potentially leading to a trim loss and a tumbling event. Therefore, controlling longitudinal stability is crucial in these situations.

Although there are few studies on the ground effect physics of slender delta wings, available literature for non-slender delta wings in ground effect is even less, especially regarding flow control in ground effect. Therefore, the primary purpose of this study is to characterize the impact of the passive bleeding technique on the aerodynamic coefficients, flow field and longitudinal static stability of a non-slender delta wing in SGE conditions. This is achieved with both static and dynamic boundary conditions, simulated with a fixed plate and a moving belt mechanism, respectively. To the authors knowledge, the current work is novel in the literature investigating the effect of passive bleeding in ground effect for delta wings considering flow structures, aerodynamic coefficients, and longitudinal static stability characteristics.

Figure 1 Northrop Grumman delta wing integrated UCAV.

Methodology:

The experiments were conducted in the wind tunnel in the Fluid Mechanics Laboratory of the Department of Mechanical Engineering at Middle East Technical University. The wind tunnel is a low-speed, suction-type, open loop with a transparent test section, and airflow is provided by an axial fan. The test section is 2000 mm long, 750 mm wide, and 510 mm deep. The wind tunnel's turbulence intensity is less than 1%. The delta wings tested in this study had a 45-degree sweep angle and a main chord length of 135 mm. Therefore, a Reynolds number of $Re = 9x10^4$ based on chord length, a freestream velocity of 11.7 m/s was used, and for the highest angle of attack value, the blockage ratio was below 2.3%. Fig. 2 illustrates the schematic representations of the models used in this study: span (S) and chord (c). Both models had an 8 mm thickness, which resulted in a 5.9% t/c ratio and a 45-degree sharp leading-edge bevel. The models were manufactured using rapid prototyping 3D printing technique using fine polyamide PA2200 particles with 0.15 mm diameters to ensure surface smoothness. In Fig. 3, the details of the force measurement system and ground boundary conditions, including static and dynamic conditions, are given.



	l (mm)	r (mm)	p (mm)	θ
bor = 1.00	121	1.5	11.5	23°
bor = 0.85	21	1.5	11.5	23°

Figure 2 Schematic representations of the models used in experiments.

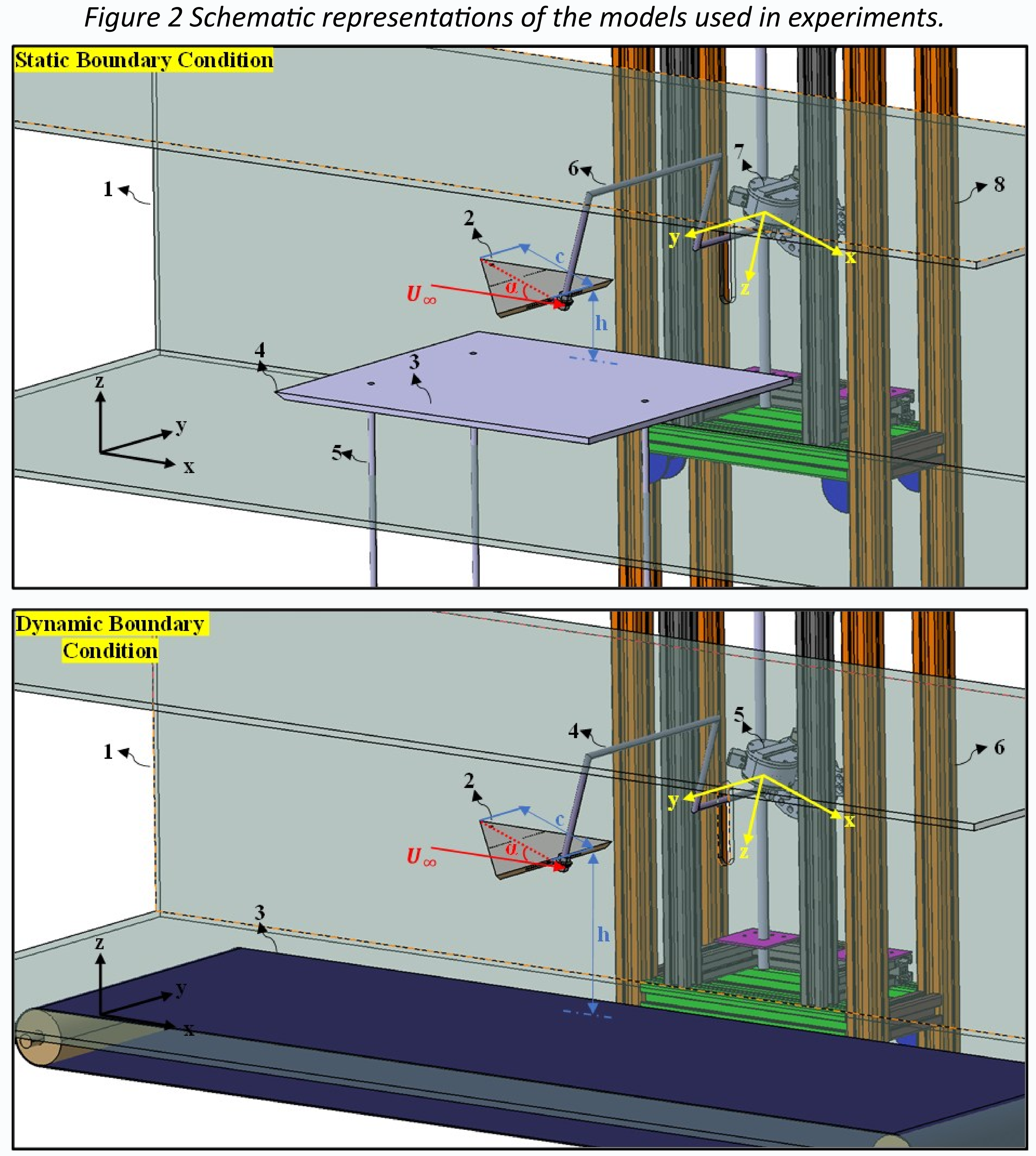


Figure 3 Top: static; bottom: dynamic boundary condition; force measurement system and ground distance distance schematic.

Results:

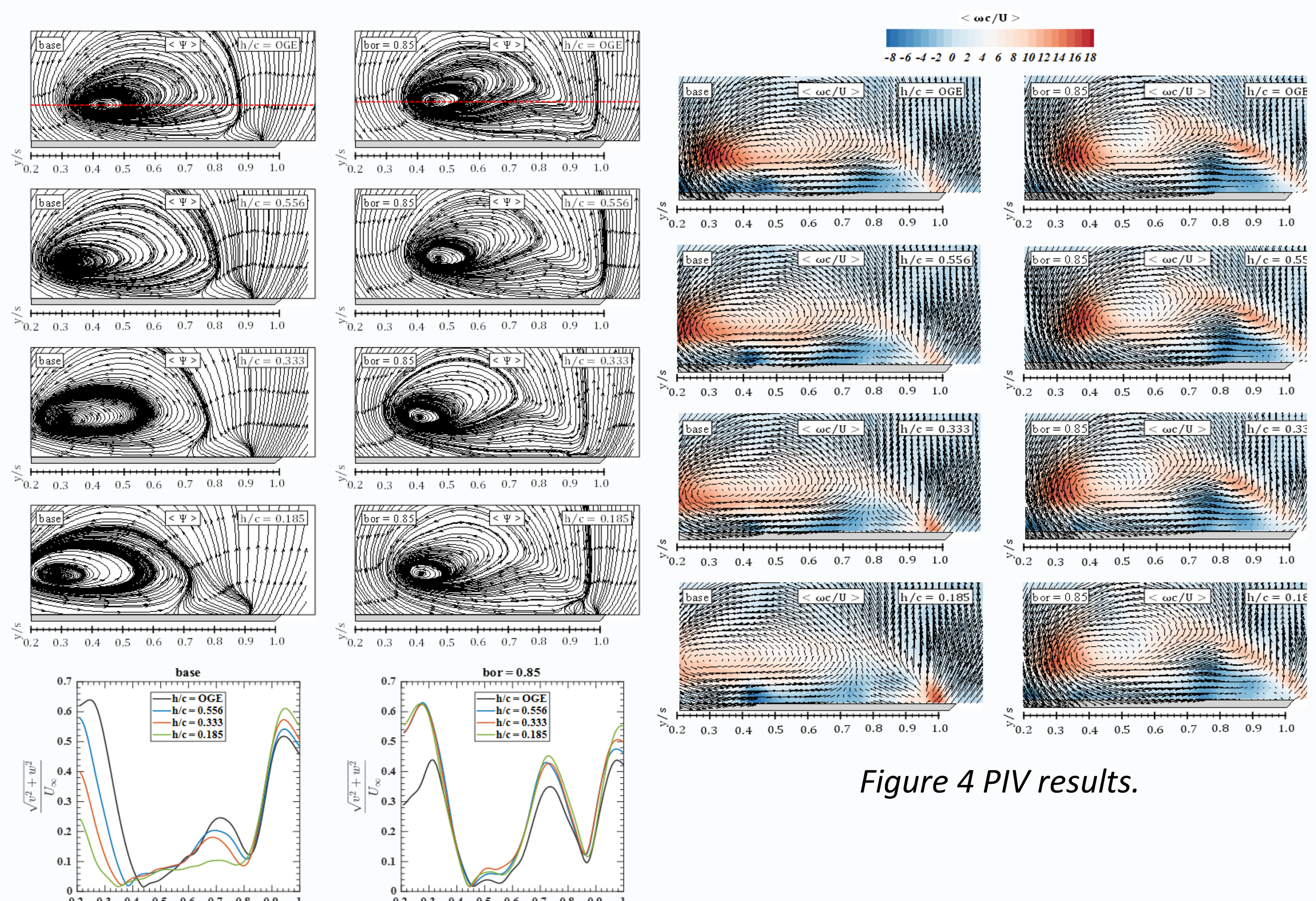


Figure 4 PIV results.

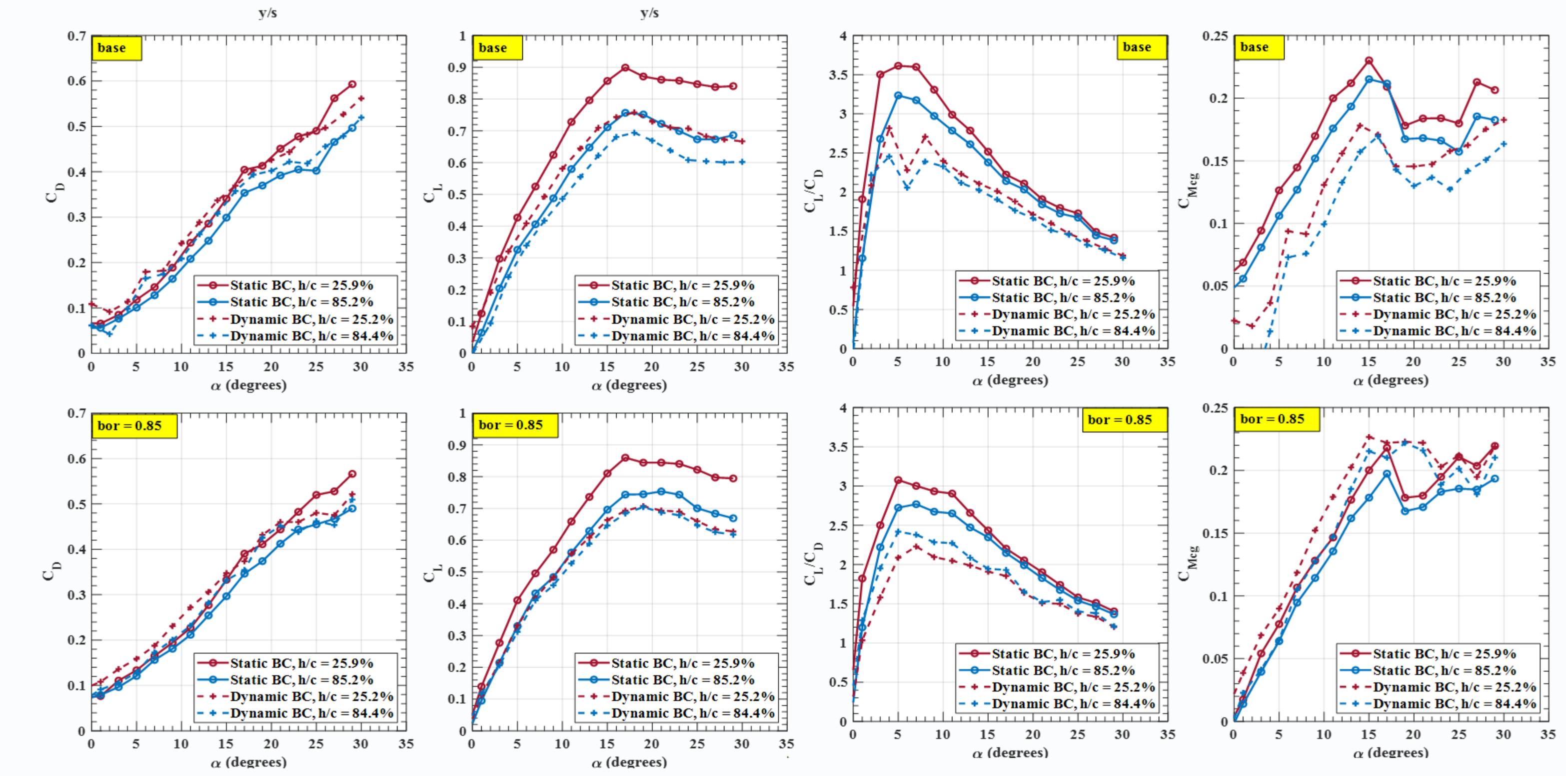


Figure 5 Aerodynamic coefficients.

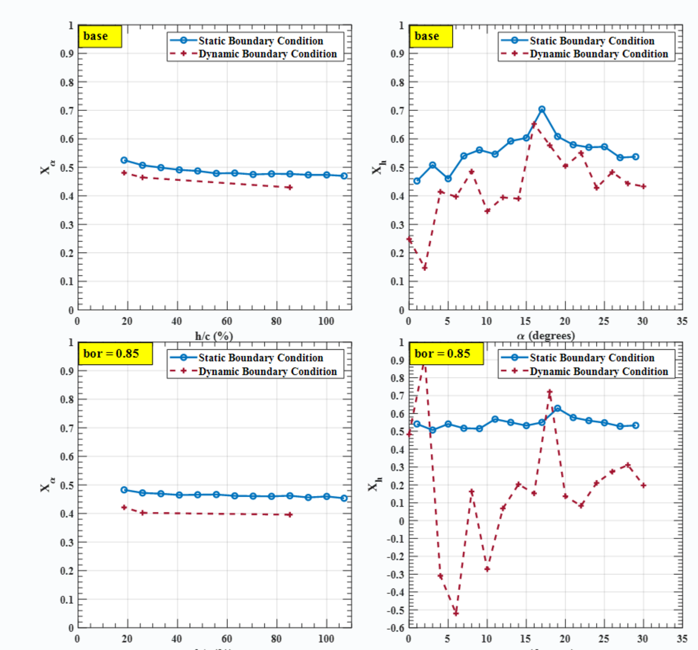


Figure 6 Longitudinal static stability.

Conclusions:

- At high angle of attack, α = 17°, bleeding in ground effect reduces the adverse effects introduced by the ground proximity, potentially delaying stall.
- Regarding aerodynamic coefficients, bleeding overall reduces their sensitivity to the ground. In addition, the dynamic boundary condition results in decreased magnitudes of the aerodynamic coefficients and does not negatively affect stall angle delay provided by the bleeding mechanism, unlike the static boundary condition.