



DESIGN, SIMULATION, AND KINEMATIC FLIGHT EVALUATION OF AN ASYMMETRIC OBLIQUE WING RC MODEL

¹V. Phaninder reddy, ²M. Sai Charan teja, ³D. Santhosa kumari, ⁴B. Praveen

¹Associate Professor, ²student, ³Student, ⁴Student

¹Aeronautical Engineering,

¹Institute of aeronautical engineering, Hyderabad, India

Abstract: This study evaluates the aerodynamic performance of a variable sweep oblique wing configuration using both computational fluid dynamics (CFD) and physical flight testing. An elliptical wing with a 1 m span and 0.15 m root chord, based on a Clark-Y airfoil, was designed and integrated into a radio-controlled aircraft equipped with a mechanical sweep mechanism. CFD simulations were executed in SimScale using a transient solver under incompressible flow conditions at velocities of 10, 15, and 20 m/s for sweep angles ranging from 0° to 45°. To analyze stall characteristics and boundary layer behavior, simulations included angles of attack up to 10°. By solving the Reynolds-Averaged Navier–Stokes (RANS) equations with the $k-\omega$ SST turbulence model on a high-quality hexahedral mesh, a highly detailed aerodynamic profile was mapped. Results indicate the lift coefficient remains stable across moderate sweep configurations at cruise. Crucially, at a 10° angle of attack, the 45° sweep delayed trailing-edge stall due to spanwise cross flow, preventing the massive drag spikes observed in the unswept baseline. While the 45° sweep successfully reduced profile drag by approximately 32% at 15 m/s, physical flight testing revealed severe roll-yaw coupling and longitudinal instability during transition. These findings establish that the aerodynamic efficiencies of oblique wings are practically achievable for low-speed UAVs only if augmented by active, asymmetric elevon control mixing to counteract the rolling moment shift.

Keywords: Oblique Wing, Variable Sweep, CFD, Low Reynolds number, UAV, Aerodynamics.

I. INTRODUCTION

The demand for improved aerodynamic efficiency has led to the exploration of unconventional aircraft configurations, among which the concept of an oblique wing offers significant potential. In this configuration, the wing pivots asymmetrically about its axis relative to the fuselage, allowing it to align more effectively with the freestream flow and reduce aerodynamic drag. While oblique wings have been mostly studied for high-speed applications, their performance in low Reynolds number regimes, which are typical of UAVs and radio-controlled aircraft, remains insufficiently explored.

At low Reynolds numbers, the aerodynamic behavior is dominated by viscous effects, boundary layer development, and flow separation, making the evaluation of unconventional wing geometries particularly important. Therefore, the effectiveness of oblique wing configurations under such conditions must be investigated using both computational and experimental approaches.

In this study, a variable-sweep oblique-wing RC aircraft was designed and analyzed using CFD simulations and flight testing. An elliptical wing planform with a Clark-Y airfoil was designed and fabricated, and its aerodynamic performance was evaluated at different sweep angles. The aim of this study was to investigate

how changes in the sweep angle affect the lift, drag, and overall aerodynamic performance of the UAV and to evaluate the practicality of using oblique wing designs for low-speed UAV applications.

II. COMPUTATIONAL AND EXPERIMENTAL METHODOLOGY

We approached the aerodynamic analysis using a three-phase process: geometric design, CFD simulation, and physical prototype validation.

Geometric Design: An elliptical wing planform was selected to achieve an efficient lift distribution and minimize the induced drag. The wing had a span of 1 m and a root chord of 0.15 m. The Clark-Y airfoil was chosen specifically for its stable performance and reliable lift characteristics at low values of Reynolds number. A custom variable-sweep mechanism was integrated into the central fuselage, allowing the wing to be manually locked at sweep angles of 0°, 15°, 30°, and 45°.

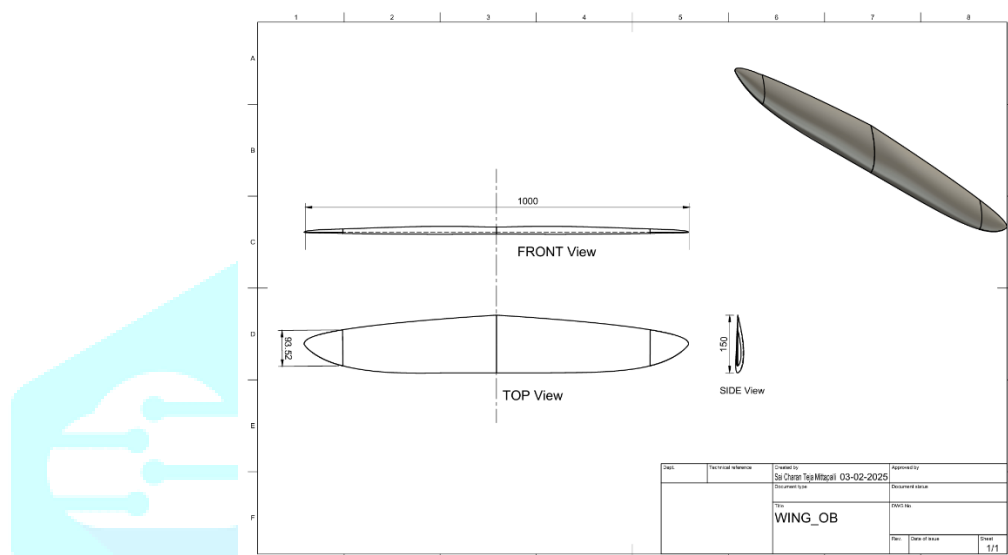


Figure 1 Geometry of the designed oblique wing, showing the elliptical planform with a wingspan of 1 m and root chord of 0.15 m.

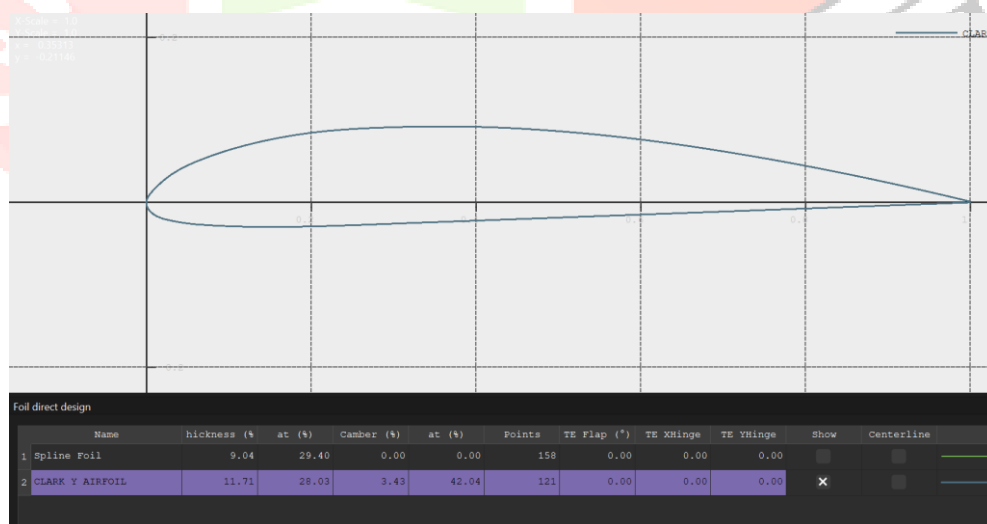


Figure 2 Clark-Y airfoil profile employed in the wing design, selected for low Reynolds number stability

Computational Fluid Dynamics (CFD) Setup: CFD simulations were performed in SimScale using a transient solver to accurately capture time-dependent boundary layer phenomena. The computational domain was discretized using a high-quality hexahedral mesh to minimize numerical diffusion. The RANS equations were solved utilizing the $k-\omega$ SST turbulence model, which is highly effective at predicting adverse pressure gradients and flow separation.

Simulations were conducted strictly within the low Reynolds number regime. Assuming standard sea-level kinematic viscosity, the test velocities of 10, 15, and 20 m/s correspond to Reynolds numbers ($Re = \rho v c / \mu$) of approximately 1.01×10^5 , 1.52×10^5 , and 2.03×10^5 , respectively. The test matrix included sweep angles

(Λ) from 0° to 45° , and angles of attack of 0° , 5° , and 10° to simulate both cruise and aggressive climbing maneuvers.

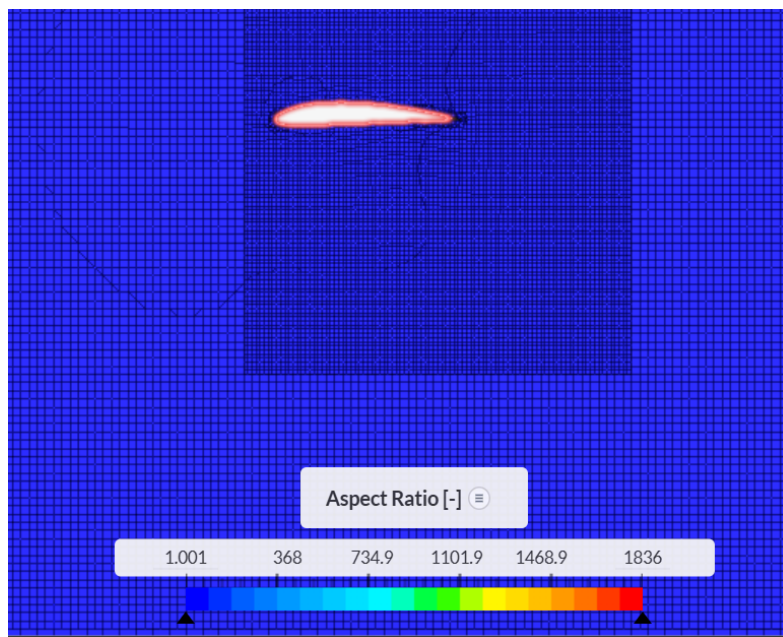


Figure 3 Surface and volumetric hexahedral mesh distribution, highlighting the refinement near the wing surface and pivot joint.

Experimental Prototype Parameters: During the physical validation phase, a lightweight RC prototype using a foam board material with a density of 25% was constructed. The fuselage was created by first printing a 2D design, which was then traced and cut out from a 2 cm thick foam board. The wing was divided into four sections and cut using the hot-wire cutting method. These sections were then assembled using glue sticks, and bamboo sticks were used as spars to reinforce the wings. Slots were created to insert electronics into both the wings and fuselage. Finally, a transparent tape over the entire body to create a smooth surface, which reduces skin friction drag and enhances structural stability.



Figure 4 All up weight of RC plane measure on a weighing scale

The aircraft, complete with all its electronics, had an all-up weight (AUW) of 826 g. Propulsion was achieved using a 1400 kV brushless motor paired with a 10x4.5 propeller, powered by a 3S 2200mAh LiPo battery. This electronic configuration delivered an estimated static thrust of 1200 g, resulting in a robust thrust-to-weight ratio of 1.45:1, which is suitable for flying. The center of gravity (CG) was initially set at 25% of the Mean Aerodynamic Chord (MAC). The wing sweep mechanism was developed by installing an

Mg996r servo motor, which adjusted the wing to different sweep angles, whereas all other control surfaces were managed by sg90 servo motors, which controlled the aircraft moments.



Figure 5 Fabrication process of RC plane before and after assembly

III. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The theoretical foundation of the oblique wing was established by T. Jones in the 1970s [1]. He demonstrated that an asymmetric wing sweep fundamentally reduces aerodynamic wave drag by favorably aligning the wing with the freestream flow, thereby delaying the onset of Mach tuck and drag divergence. His early work, later validated by the NASA AD-1 flight demonstrator, proved that oblique configurations could achieve significantly superior lift-to-drag ratios compared to standard symmetrical swept wings or delta configurations. However, historical research has predominantly focused on transonic and supersonic commercial applications, where the mechanical complexity and severe aeroelastic coupling outweighed the aerodynamic benefits, leading to a pause in commercial development [2].

In recent years, the rise of unmanned aerial systems has sparked renewed interest in asymmetric morphing wings. The variation in the sweep angle directly influences the spanwise pressure distribution and effective aerodynamic center. Recent studies by Ghoreyshi et al. [3] indicate that certain sweep configurations lead to significant profile drag reductions. Furthermore, modern optimization-based studies, such as those by Zhao et al. [4], have utilized adjoint methods to demonstrate that the precise aerodynamic shaping of oblique wings can further improve these efficiencies. Broader reviews on morphing aircraft by Barbarino et al. [5] classify the oblique wing as a highly efficient macro-morphing concept, noting that the asymmetric sweep is mechanically simpler to actuate in UAVs than the symmetrical variable-sweep (swing-wing) mechanism, as it requires only a single central pivot point.

Scaling these high-speed concepts to low Reynolds number regimes introduces severe aerodynamic complications. At the scale of small UAVs ($Re < 5 \times 10^5$), viscous effects dominate the flow field. Mueller [6] indicated that airfoil selection and base wing geometry are the ultimate deciding factors for lift and drag in small-scale aircraft. In this regime, the boundary layer is highly susceptible to laminar separation bubbles (LSB) and early flow detachment. Comprehensive airfoil data compiled by Selig et al. [7] highlighted that the Clark-Y airfoil remains exceptionally stable at low speeds, delaying stall and providing predictable lift curves, which justifies its selection as the baseline airfoil for this experimental configuration.

Modern CFD advancements allow researchers to accurately predict these complex boundary layer behaviors prior to fabrication. Accurate prediction of trailing-edge separation on swept wings requires robust turbulence modeling. The k- ω Shear Stress Transport (SST) model, introduced by Menter [8], has become the industry standard for capturing flow separation. Unlike the standard k- ϵ model, the k- ω SST model effectively resolves the viscous sublayer near the wall while maintaining stability in the freestream, making it highly accurate for predicting adverse pressure gradients on swept wings [9]. This is supported by robust finite-volume numerical methods that minimize numerical diffusion in three-dimensional flow fields [10].

Even with accurate aerodynamic predictions, researchers have noted that asymmetric aerodynamic loading introduces unique stability challenges. When a wing is swept obliquely, the forward-swept semispan experiences an increase in the effective angle of attack, generating more lift, whereas the aft-swept semispan experiences a decrease. Nguyen and Kroo [11] documented that this induces a severe aeroelastic roll-yaw coupling. Furthermore, theoretical aerodynamics dictate that highly swept wings generate strong spanwise cross-flows. According to Anderson [12], this cross-flow thickens the boundary layer toward the wingtips,

which can severely delay the control surface authority (aileron effectiveness) and initiate tip stall if the angle of attack becomes too steep.

Despite these well-documented theories spanning decades, there remains a distinct lack of experimental, real-world validation for oblique wing configurations operating specifically at low Reynolds numbers and at varying angles of attack. Although CFD optimizations exist in the literature, they are rarely corroborated by physical RC flight tests documenting the dynamic transition phase. This study directly addresses this gap by pairing rigorous k-omega SST transient simulations with physical flight dynamics validation.

IV. RESULTS AND DISCUSSION

The evaluated aerodynamic profiles by extracting the lift coefficient (C_L) and drag coefficient (C_D) from the transient CFD results across an extensive test matrix.

Table 1: Computed lift (C_L) and drag (C_D) coefficients for the tested velocities, sweep angles, and angles of attack.

Angle of attack	Sweep (°)	Speed (m/s)	Lift (C_L)	Drag (C_D)
0°	0	10 / 15 / 20	0.29 / 0.30 / 0.30	0.036 / 0.034 / 0.033
	15	10 / 15 / 20	0.28 / 0.28 / 0.29	0.035 / 0.033 / 0.031
	30	10 / 15 / 20	0.22 / 0.22 / 0.22	0.030 / 0.028 / 0.027
	45	10 / 15 / 20	0.12 / 0.12 / 0.12	0.024 / 0.023 / 0.022
5°	0	10 / 15 / 20	0.77 / 0.77 / 0.77	0.059 / 0.058 / 0.057
	45	10 / 15 / 20	0.34 / 0.34 / 0.34	0.033 / 0.032 / 0.031
10°	0	10 / 15 / 20	1.08 / 1.20 / 1.20	0.140 / 0.130 / 0.130
	45	10 / 15 / 20	0.52 / 0.53 / 0.53	0.040 / 0.040 / 0.040

At 0° angle of attack of 0°, the data revealed a clear aerodynamic trade-off governed by the classical sweep theory. Between 0° and 15°, the lift coefficient remained relatively stable (decreasing negligibly from 0.30 to 0.28 at 15 m/s). However, as the sweep is extended to 30° and an extreme 45°, the lift coefficient drops significantly to 0.22 and 0.12, respectively. This is because the effective freestream velocity component normal to the wing leading edge decreases proportionally with the cosine of the sweep angle.

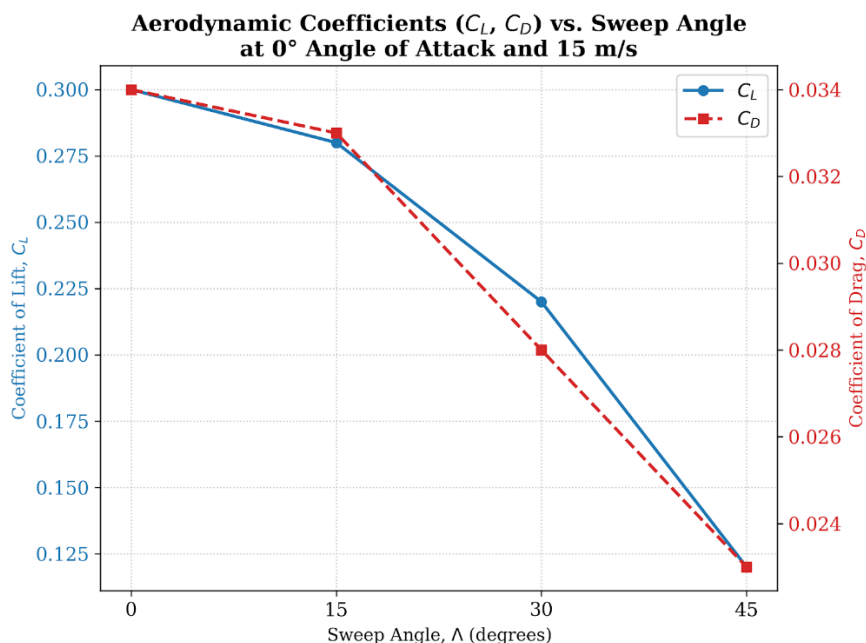


Figure 6 Dual-axis plot of Lift Coefficient (C_L) and Drag Coefficient (C_D) versus sweep angle at a 0° angle of attack (15 m/s). The data illustrates the aerodynamic trade-off: increasing sweep significantly reduces profile drag but incurs a proportional loss in total lift.

In contrast, the drag coefficient exhibited a strict downward trend. At 15 m/s, C_D drops from 0.034 at a 0° sweep to 0.023 at a 45° sweep. This reduction confirms that highly swept configurations align more effectively with the freestream flow, minimizing the effective frontal area and substantially reducing the form drag.

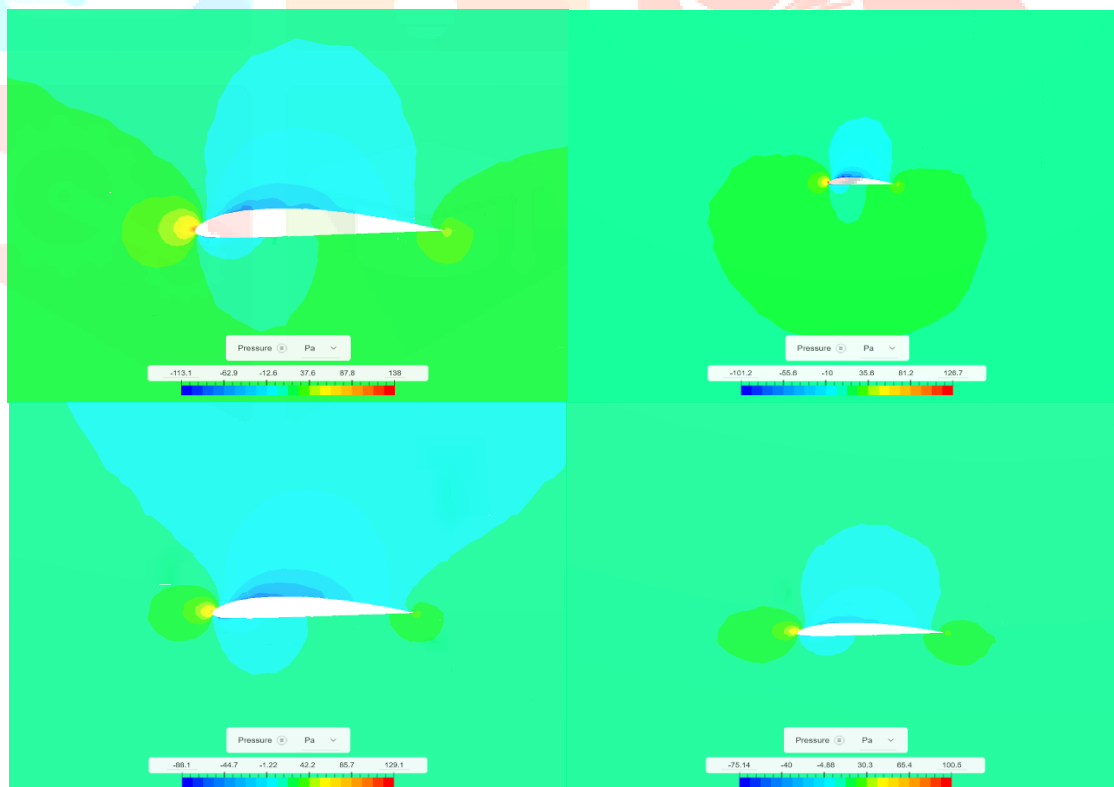


Figure 7 Comparative pressure contours at 15 m/s illustrating flow alignment across 0°, 15°, 30°, and 45° sweeps at 0° α .

As expected, increasing the Angle of attack to 5° resulted in a proportionate increase in lift for both baseline and swept configurations. However, the data at 10° Angle of attack highlighted the critical advantage of the oblique wing in mitigating stall. At a 10° Angle of attack and 15 m/s, the unswept baseline wing (0°) generates substantial lift ($C_L = 1.2$) but suffers a massive drag penalty ($C_D = 0.13$), indicating trailing-edge flow separation and the onset of aerodynamic stall.

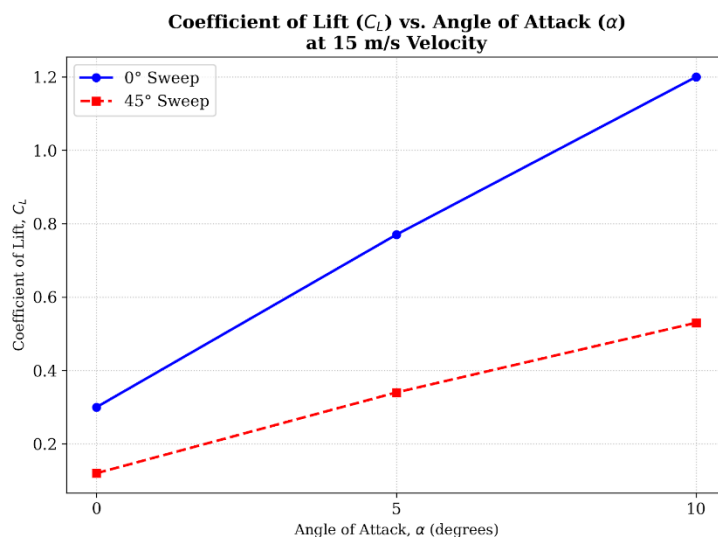


Figure 8 Variation of Lift Coefficient (C_L) with Angle of Attack at 15 m/s. While both configurations show a linear increase in lift, the 45° extreme sweep produces proportionally less lift across the entire flight envelope due to the reduced effective freestream velocity normal to the leading edge.

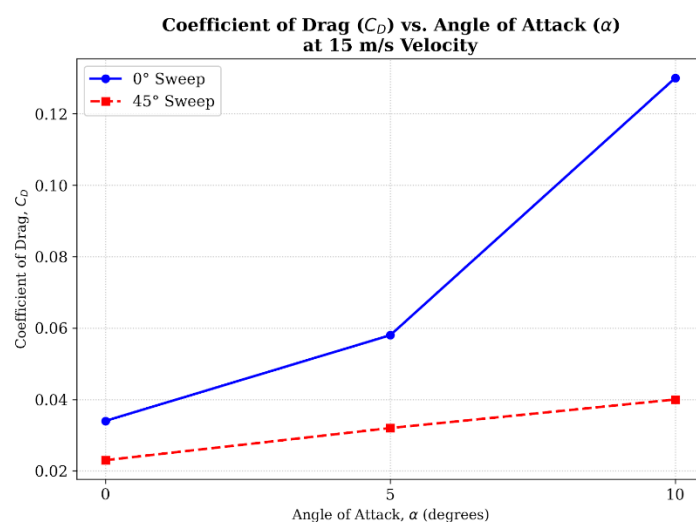


Figure 9 Variation of Drag Coefficient (C_D) with Angle of Attack at 15 m/s. The severe drag spike for the 0° baseline at 10° indicates trailing-edge stall, whereas the 45° swept wing maintains a low, stable drag profile

Remarkably, the 45° sweep configuration at the same 10° Angle of attack maintains a highly stable and low drag coefficient ($C_D = 0.040$). The velocity vectors from the simulation revealed a distinct spanwise flow component across the swept wing. This cross-flow behavior continuously re-energizes the boundary layer, thereby successfully delaying localized separation. Although the extreme sweep sacrifices the absolute maximum lift, it prevents the severe drag spikes associated with stall, offering superior boundary layer stability during high-angle maneuvers.

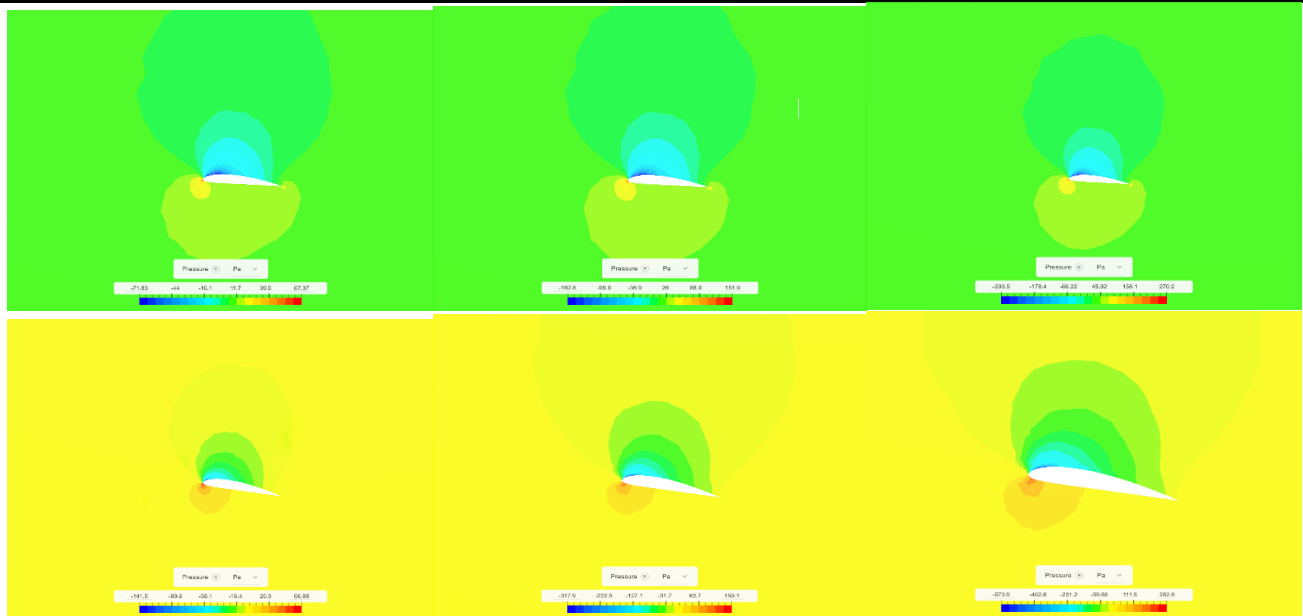


Figure 10 velocity contours of 0° sweep at 5° and 10° Angle of attack at speeds of 10m/s, 15m/s, 20m/s

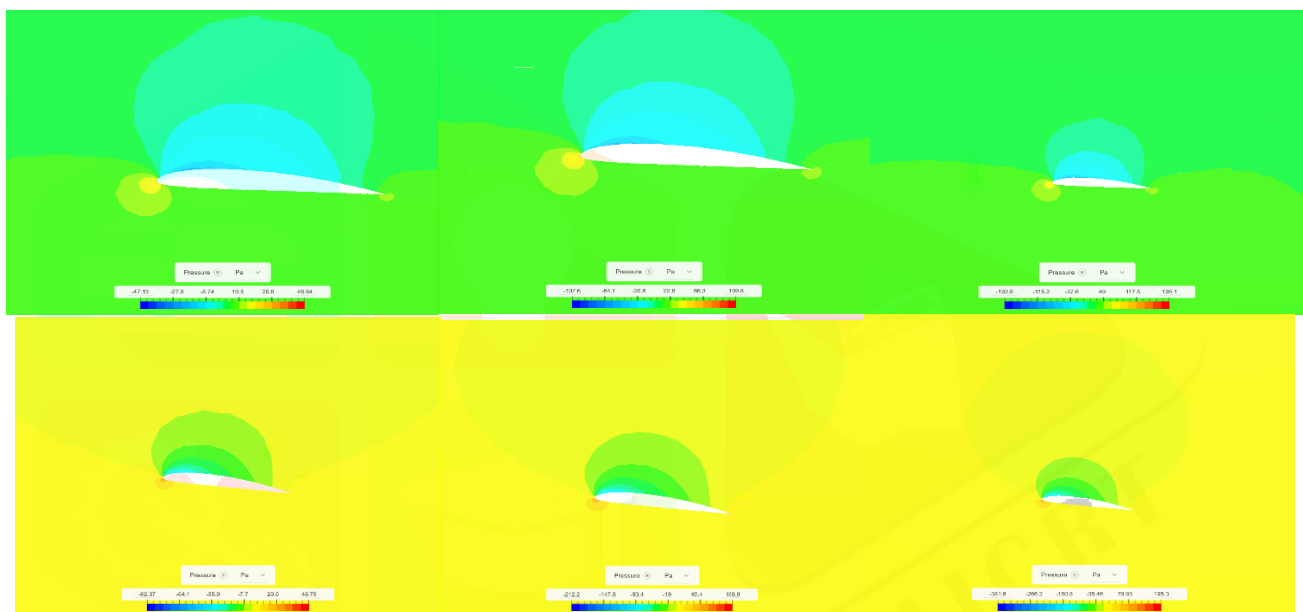


Figure 11 velocity contours of 45° sweep at 5° and 10° Angle of attack at speeds of 10m/s, 15m/s, 20m/s

Hand-launched the RC plane at 100% throttle with the wing sweep at 0°. The aircraft required a distance of approximately 5 to 7 m to establish sufficient airspeed for climb-out. Once established in cruise at the 0° sweep, the aircraft demonstrated excellent pitch stability, verifying the 25% MAC centre of gravity (CG) placement. The lift generated was more than sufficient to maintain the altitude at reduced throttle settings, successfully passing the glide tests. However, High roll sensitivity and a slight yaw drift was observed.



Figure 12 Test flight hand launch, take off, cruise and maneuver

The most critical phase of the flight test occurred during the midair mechanical transition from the 0° to the 45° sweep. During the maiden flight, actuating the sweep mechanism induced a severe, uncontrollable barrel roll, leading to a loss of control. This behaviour perfectly illustrates the primary challenge of oblique wing configurations, as the wing rotates, the forward-swept side experiences an increase in effective angle of attack, while the aft-swept side experiences a decrease. This asymmetric aerodynamic loading generates a large rolling moment.



Figure 13 flight test of RC plane when the wing sweeps in mid flight

Following the initial test, micro-adjustments were made to the CG to better balance the shifted aerodynamic center of the aircraft. In subsequent flights, this CG correction successfully mitigated the violent roll, allowing the aircraft to maintain a flight at a 45° sweep. But the flight was not stable, as it was a manual flight without a gyro onboard.

Once stabilized at the 45° sweep, visual observations highlighted a distinct delay in control surface responsiveness. This physical observation directly correlates with the velocity vectors captured in the CFD simulations (Fig. 11). The extreme 45° angle induced a heavy spanwise cross-flow, which thickened the boundary layer over the ailerons and reduced their aerodynamic authority.

V. CONCLUSION

Variable sweep oblique wings offer a viable structural path for improving low-speed UAV efficiency. Through the design and testing of an elliptical Clark-Y wing, this study confirmed that increasing the sweep angle actively reduces the drag coefficient while preserving lift at moderate parameters.

By pushing the transient CFD analysis to an extreme 45° sweep and 10° angle of attack, we identified critical boundary layer behaviours. While the extreme sweep delays localized trailing-edge separation through spanwise crossflow effectively preventing severe stall-induced drag spikes it introduces complex flight dynamics. Physical flight testing validated these computational models. The aircraft successfully generated lift and flew efficiently, but mid-air sweep transitions induced severe asymmetric rolling moments, and the spanwise cross-flow noticeably delayed aileron authority.

Ultimately, the aerodynamic drag benefits of the oblique wing are practically achievable for small-scale aircraft, provided the flight controller is equipped with active control mixing to counteract the inherent roll-yaw coupling at extreme sweeps.

REFERENCES

- [1] R.T. Jones, "The Oblique Wing: Aircraft Design for Transonic and Low Supersonic Speeds," NASA Technical Report, 1976.
- [2] W.H. Andrews, et al., "Flight testing the AD-1 oblique wing research aircraft," AIAA Aircraft Design, Systems and Technology Meeting, 1981.
- [3] M. Ghoreyshi, R.M. Cummings, and K. Bergeron, "Aerodynamic Effects of Oblique Wing Configurations at Various Sweep Angles," *Aerospace Science and Technology*, vol. 91, pp. 45–56, 2019.
- [4] Y. Zhao, X. Zhang, and L. Wang, "Aerodynamic Shape Optimization of Oblique Wing Aircraft Using Adjoint Methods," *Aerospace Science and Technology*, 2023.
- [5] S. Barbarino, O. Bilgen, R.M. Ajaj, M.I. Friswell, and D.J. Inman, "A review of morphing aircraft," *Journal of Intelligent Material Systems and Structures*, vol. 22, no. 9, pp. 823–877, 2011.
- [6] T.J. Mueller, "Low Reynolds Number Aerodynamics for UAV Applications," *AIAA Journal*, vol. 38, no. 6, pp. 101–110, 2001.
- [7] M.S. Selig, J.J. Guglielmo, A.P. Broeren, and P. Giguere, *Summary of Low-Speed Airfoil Data*, Soaring Society of America, 1995.
- [8] F.R. Menter, "Two-Equation Eddy-Viscosity Turbulence Models for Engineering Applications," *AIAA Journal*, vol. 32, no. 8, pp. 1598–1605, 1994.
- [9] C.L. Rumsey, "Appraisal of Turbulence Models for Low-Reynolds Number Flows," *AIAA Paper*, 2006.
- [10] H.K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Pearson Education, 2007.
- [11] J. Nguyen and I. Kroo, "Aeroelastic and Stability Considerations of Oblique Wing Aircraft," *Journal of Aircraft*, vol. 45, no. 2, pp. 567–576, 2008.
- [12] J.D. Anderson, *Fundamentals of Aerodynamics*, 6th ed., McGraw-Hill Education, 2016.