University of Zawia Journal of Engineering Sciences and Technology (UZJEST)
Volume 4, Issue 2, (2026), pp 64-74-, ISSN 3006-2764

Effect of Inverted V-Tail Size Reduction on the Aerodynamic Characteristics and Longitudinal Stability of a Small UAV

Khalifa Alrgeg [*1], Amyir Alrujeebi [1]

[1] Aeronautical Engineering Department, Engineering College, University of Zawia, Zawia, Libya
*Corresponding author email: k.alrageg@zu.edu.ly

Received: 22-07-2026 | Accepted: 21-08-2026 | Available online: 24-08-2026 | DOI:10.26629/uzjest.2026.06

ABSTRACT

This paper investigates the aerodynamic characteristics and longitudinal stability of an aircraft equipped with an inverted V-tail configuration, using numerical analysis in the context of preliminary aircraft design. The main goal is to study the effect of V-Tail size reduction on the aerodynamic and longitudinal stability performance. The reduction in the modified configuration (tail span) was kept at 12.5 % of the original configuration. The study focuses on the evaluation of lift, drag, and pitching moment coefficients over a specified range of angles of attack under defined flight conditions. The analysis is conducted using the XFLR5 software as the primary computational tool, exploiting its three-dimensional flow analysis capabilities based on the Vortex Lattice Method and Lifting Line Theory to model the wing and tail and to examine the aerodynamic interaction between them. The numerical settings and simulation inputs are carefully defined to ensure result consistency and suitability for comparative analysis. The behavior of aerodynamic efficiency parameters and the pitching moment coefficient as functions of the angle of attack is analyzed. A comparison of the drag polar (C_L vs. C_D) and the lift-to-drag ratio (C_L /C_D) for both configurations reveals that the modified configuration achieves a maximum aerodynamic efficiency of approximately (C_L /C_D) max ≈ 29, which is comparable to, and slightly higher than, that of the original configuration. From longitudinal stability point of view, a comparison between the two configurations shows a relative convergence of the pitching moment curves for the modified case across different control surface deflection angles, compared to the original configuration with a reduction varying according to the corresponding deflection angle (maximum value 24%) in the pitching moment coefficient C_m.

Keywords: Inverted V-tail, Longitudinal Stability, XFLR5 Numerical Analysis package, Tail Span Reduction

دراسة تأثير تغير باع ذيل الطائرة على الخصائص الأيروديناميكية والأستقرار الطولى للطائرة

خليفة الرقيق[1]، أمير الرجيبي[1]

[1]قسم هندسة الطيران، كلية الهندسة، جامعة الزاوية، الزاوية، ليبيا

ملخـــــص البحـــــث

تتناول هذه الورقة دراسة الخصائص الديناميكيا الهوائية وسلوك الاستقرار الطولي لطائرة مزودة بذيل على شكل حرف **V** معكوس، وذلك باستخدام التحليل العددي ضمن إطار التصميم الأولي للطائرات. يركّز البحث على تحليل معاملات الرفع والمقاومة وعزم

"Articles published in *Univ Zawia J Eng Sci Technol* are licensed under a Creative Commons Attribution-NonCommercial 4.0 International License."

الانحناء الطولي في حالة تم تقليص باع ذيل الطائرة بنسبة تقارب 12.5% ضمن مجال محدد من زوايا الهجوم وتحت شروط طيران محددة، كما تم الاعتماد على برنامج **XFLR5** في هذا البحث، حيث استُخدمت إمكانياته في تحليل الجريان ثلاثي الأبعاد، بالاعتماد على طريقة الشبكة الدوامية(**Vortex Lattice Method**) ونظرية الخط الرافع(**Lifting Line Theory**) لنمذجة الجناح والذيل ودراسة التفاعل الإيروديناميكي بينهما، جرى تحديد الإعدادات العددية ومدخلات المحاكاة بعناية لضمان اتساق النتائج وقابليتها للتحليل المقارن، تم تحليل سلوك معاملات الكفاءة الإيروديناميكية ومعامل عزم الدوران الطولي بدلالة زاوية الهجوم، مع مناقشة تأثير اعتماد الذيل على شكل حرف **V** معكوس على الأداء الإيروديناميكي وخصائص الاستقرار الطولي مقارنة بالحالة المرجعية. حيث أظهرت النتائج ان خصائص الاستقرار الطولى تقاربا واضحا مع نقص فى معامل عزم الدوران الطولى بنسب مختلفة كان اقصاها حوالى 24% مقارنة باشكل الاساسى لذيل الطائرة

الكلمات الدالة: ذيل المعكوس على شكل حرف V ,الأستقرار الطولى,برنامج XFLR5 للتحليل العددى,تغير باع الذيل

1- Introduction

Over the past two decades, unmanned aerial vehicles (UAVs) have experienced significant expansion across a wide range of applications, from military and surveillance operations to civilian uses such as aerial imaging, precision agriculture, and engineering surveying [1,2]. As these applications continue to evolve in complexity, achieving high aerodynamic efficiency has become a critical requirement for extending flight endurance and enhancing overall aircraft performance [3]. In this context, the empennage plays a vital role in aircraft design, as it not only ensures longitudinal and lateral stability but also directly influences the overall weight and aerodynamic drag of the aircraft.

The inverted V-tail configuration has emerged as a promising design alternative due to its ability to integrate the functions of both horizontal and vertical stabilizers into two inclined surfaces, thereby reducing structural complexity and weight. From an aerodynamic perspective, this configuration contributes to minimizing interference drag at the junction between the tail and the fuselage, while also improving control surface effectiveness under high angles of attack [4]. However, the design of such configurations requires careful analysis to achieve an appropriate balance between stability and control authority.

Previous studies in aircraft design have extensively examined various tail configurations, including conventional, T-tail, and V-tail arrangements, demonstrating the potential weight reduction benefits of the inverted V-tail. Nevertheless, a notable research gap remains regarding the extent to which the dimensions of inverted V-tails can be reduced—particularly in small-scale UAVs—without compromising longitudinal stability characteristics. In practice, designers often adopt conservative sizing approaches to ensure stability, which may lead to unnecessary weight penalties [5,6]. Aerodynamic surface geometry significantly affects flow behavior and aerodynamic performance. Surface modifications can improve airfoil characteristics [7], while changes in aerodynamic geometry influence turbulent flow and force generation [8]. Numerical methods have also been successfully applied to predict complex flow fields and solve the Navier–Stokes equations accurately [9,10]. These studies provide a useful foundation for investigating the effect of inverted V-tail size reduction on the aerodynamic characteristics and longitudinal stability of a small UAV.

This study aims to address this gap by conducting a numerical investigation into the effects of reducing the inverted V-tail span on the longitudinal stability of a UAV. Using XFLR5 and applying both the Lifting Line Theory (LLT) and the Vortex Lattice Method (VLM), the relationship between tail surface reduction and variations in the aerodynamic center and neutral point is analyzed. The findings are expected to provide a clear engineering framework for optimizing tail dimensions, achieving an effective balance between weight

reduction and aerodynamic stability requirements.

2- Methodology

This study adopts a comparative analytical approach to investigate the effect of reducing the span of an inverted V-tail on the longitudinal stability characteristics of a small unmanned aerial vehicle (UAV). The investigation was conducted using numerical aerodynamic simulations to evaluate the influence of tail geometry on the aircraft's stability behavior while maintaining all other design parameters unchanged.

A baseline UAV configuration equipped with an inverted V-tail was selected as the reference model (original case). A second configuration was then developed by reducing the tail span while preserving the same wing geometry, airfoil sections, tail moment arm, center of gravity, and flight conditions. This approach ensured that any observed differences in the aerodynamic characteristics could be attributed solely to the modification of the tail geometry.

The aerodynamic analyses were performed using the XFLR5 software based on the three-dimensional Vortex Lattice Method (VLM), which provides an efficient numerical approach for predicting the aerodynamic characteristics and static stability of low-speed aircraft configurations. The simulations were carried out over a specified range of angles of attack under identical operating conditions for both configurations.

To ensure a consistent and unbiased comparison, all numerical input parameters, including Reynolds number, flight velocity, altitude, aircraft mass, air density, and reference point location, were kept constant throughout the study. The only design variable was the inverted V-tail span, allowing the isolated assessment of its influence on the aerodynamic performance and longitudinal stability.

Table (1) Numerical analysis input parameters for the reference and modified configurations.

Category	**Parameter**		**Value / Description**
Software	Analysis Tool		XFLR5
	Analysis Method		Vortex Lattice Method (VLM) – 3D Analysis
Aircraft Model	Configuration		Wing and V-Tail (Fuselage Neglected)
Geometry	V-Tail Cant Angle		32°
	Tail Moment Arm		1.147 m
Airfoils	Wing Airfoil		SD-7062
	Tail Airfoil		NACA 0015
Wing Geometry	Root Chord		0.390 m
	Tip Chord		0.325 m
	Wingspan		3.940 m
Tail Geometry	Tail Chord		0.230 m
	Tail span	Reference case	1.37 m
		Modified	1.20 m
	Deflections angles		0°, ± 2°, ± 4° , ± 6°
Flight Conditions	Angle of Attack Range		−6° to +12°
	Angle of Attack Step (Δ)		1°
	Reynolds Number Sweep		3×10^4 – 3×10^6
	Total Mass		24 kg
	Free stream velocity (V_∞)		25 m/s
	Altitude		900 m
	Air Density		1.147 kg/m³
	Air Temperature		9 °C

Reference	Center of Gravity (CG)	0.114 m (MAC)
	Moment Reference Point	At CG
Control Surfaces	Control Type	Ruddervator only

As shown in **Table (1)**, all numerical input parameters were maintained unchanged for both configurations, except for the inverted V-tail span, which was intentionally reduced in the modified model. This ensured that the observed variations in aerodynamic performance and longitudinal stability resulted solely from the geometric modification of the tail rather than from changes in operating or reference conditions.

The aerodynamic performance of both configurations was evaluated by comparing the principal longitudinal stability parameters, including the lift coefficient, pitching moment coefficient, lift-to-drag ratio, and static margin. The obtained results were then analyzed to quantify the effect of tail span reduction on the aircraft's stability characteristics and overall aerodynamic efficiency.

3- Validation

XFLR5 was adopted as the primary numerical tool for the three-dimensional aerodynamic analysis of the investigated configurations, due to its suitability for low-Reynolds-number wing and tail analyses. The software employs the Vortex Lattice Method (VLM) for three-dimensional analysis, while XFOIL is used to determine the two-dimensional aerodynamic characteristics of the airfoil sections.

The reliability of the adopted computational approach was assessed by comparing the XFOIL results for the selected airfoil with published reference data from the NACA Airfoil Database [11,12].

The comparison included the variations of the lift coefficient (C_L), lift–drag characteristics (C_L) vs. (C_D), lift coefficient -to- drag coefficient ratio (C_L/C_D), and pitching moment coefficient (C_M), as presented in Figures (1–4). The numerical results show good agreement with the reference data over most of the investigated angle-of-attack range, with minor deviations appearing mainly at higher angles of attack. These differences are consistent with the limitations of the numerical approach, particularly the idealized flow assumptions and the neglect of nonlinear effects associated with flow separation.

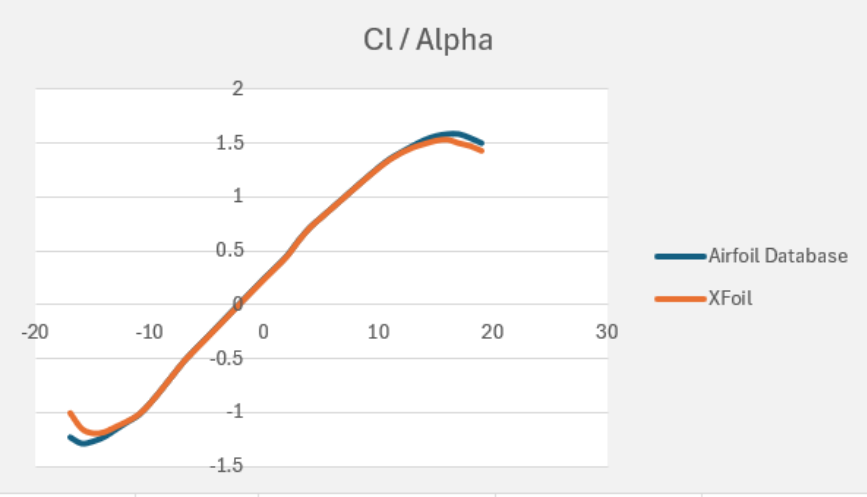

Figure 1. Comparison of the lift coefficient (C_L) versus angle of attack (α).

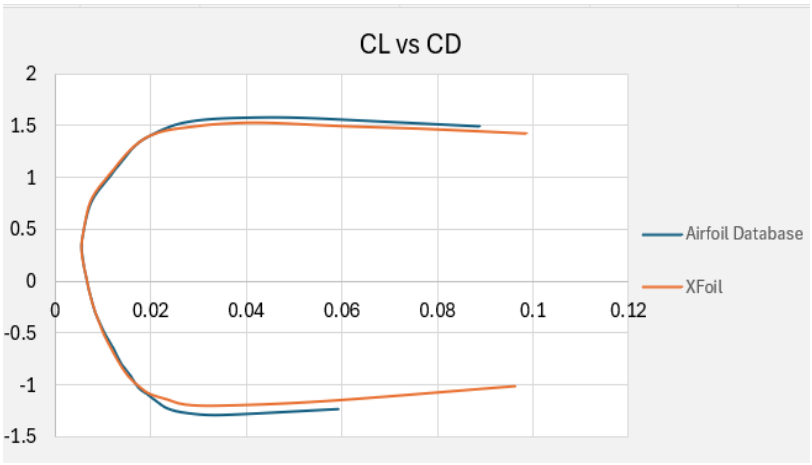

Figure 2. Comparison of the relationship between the lift coefficient (C_L) and the drag coefficient (C_D)

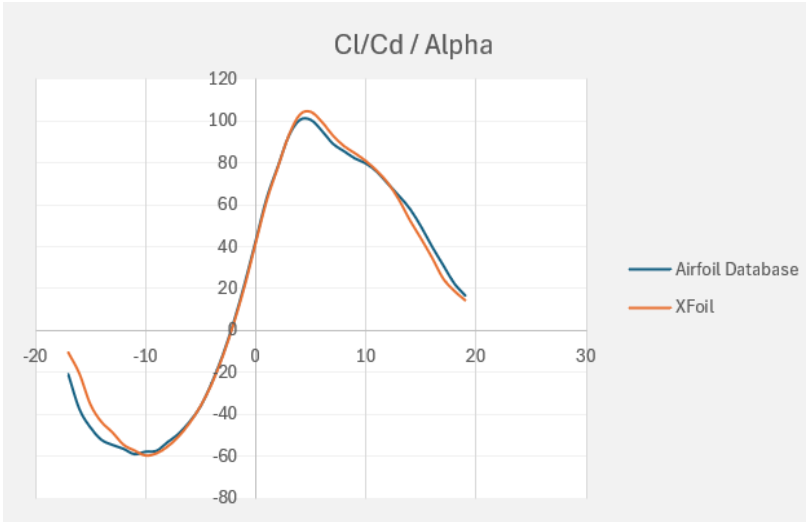

Figure 3. Comparison of the lift coefficient -to- drag coefficient ratio (C_L / C_D) variation with angle of attack (α)

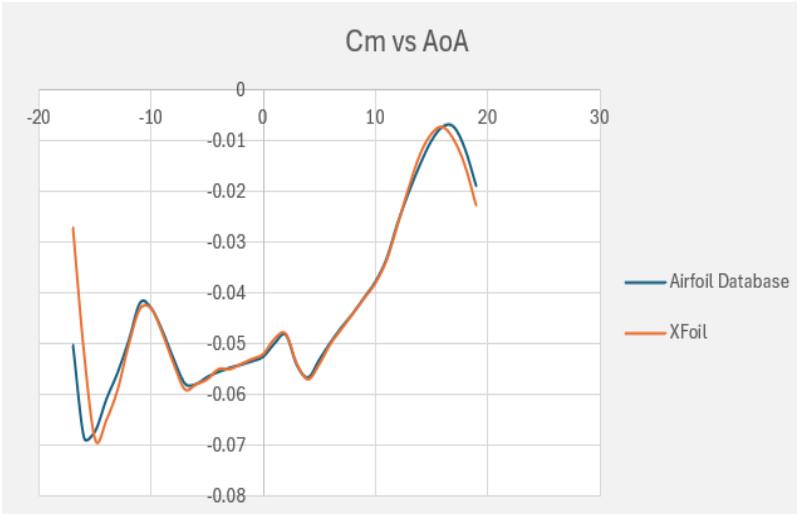

Figure 4 Comparison of Cm variation with angle of attack

The percentage errors between the numerical and reference results were also evaluated, as summarized in Table (2). The obtained errors remain within acceptable limits and do not significantly affect the representation of the general aerodynamic behavior of the selected airfoil over the operating range considered. Accordingly, the comparison supports the reliability of XFOIL for the present application and, given its role in providing the sectional aerodynamic data used by XFLR5, supports the use of XFLR5 for the subsequent three-dimensional aerodynamic and longitudinal stability analyses.

Table 2. Percentage error between XFOIL results and reference data from the Airfoil Database for selected aerodynamic coefficients.

Alpha [Degree]	**C_L/C_d / Alpha [%]**	**C_M / Alpha [%]**	**C_L / Alpha [%]**	**C_L / C_d [%]**
-6	2	0	1	2
-5	0	1	2	0
-4	2	1	3	2
-3	6	1	6	6
-2	2	0	2	2
-1	5	1	4	5
0	0	0	0	2
1	2	2	2	2
2	1	0	1	1
3	0	0	0	0
4	3	1	0	3
5	4	2	0	4
6	4	1	0	4
7	4	1	0	4
8	3	0	0	3
9	3	0	0	3
10	1	1	0	1
11	0	1	0	0
12	0	1	0	0

4- Results and Discussion.

4.1 Lift Characteristics.

Reducing the span of the inverted V-tail has a negligible influence on the lift characteristics of the aircraft. As shown in **Figs. 5** and **6**, both the original and modified configurations exhibit an almost identical linear variation of the lift coefficient with angle of attack throughout the investigated range. The close agreement between the two lift curves indicates that the proposed geometric modification does not alter the overall lift response or the lift-curve slope within the pre-stall operating conditions.

This behavior is expected from an aerodynamic standpoint, since the primary contribution to lift is provided by the main wing, whereas the tail surfaces are principally intended to ensure stability, trim, and control rather than to generate a significant portion of the total aerodynamic lift. Consequently, reducing the tail span produces only a limited influence on the overall lifting capability of the aircraft while preserving the linear lift response over the investigated range of angles of attack.

The preservation of the lift characteristics is an important outcome of the proposed modification. Because the

aircraft maintains essentially the same lift behavior after reducing the tail span, any subsequent differences observed in aerodynamic efficiency or longitudinal stability can reasonably be attributed to the change in tail geometry rather than to changes in the fundamental lift-producing mechanism. This provides a consistent basis for evaluating the aerodynamic implications of the modified configuration in the following sections.

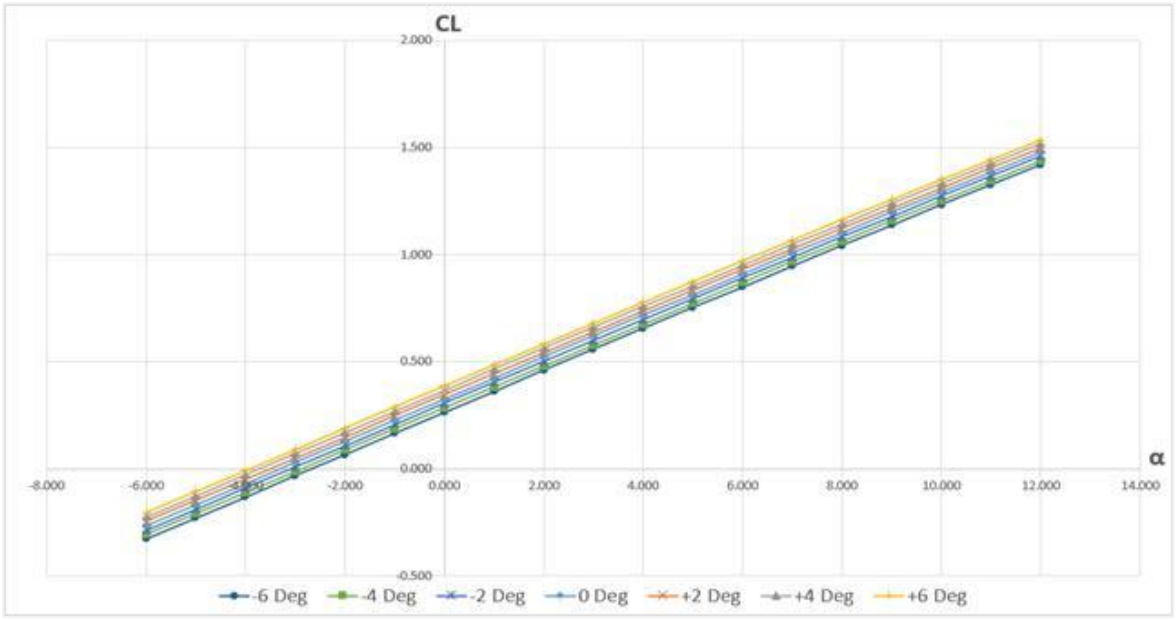

Figure 5. Lift coefficient as a function of angle of attack for the original inverted V-tail configuration.

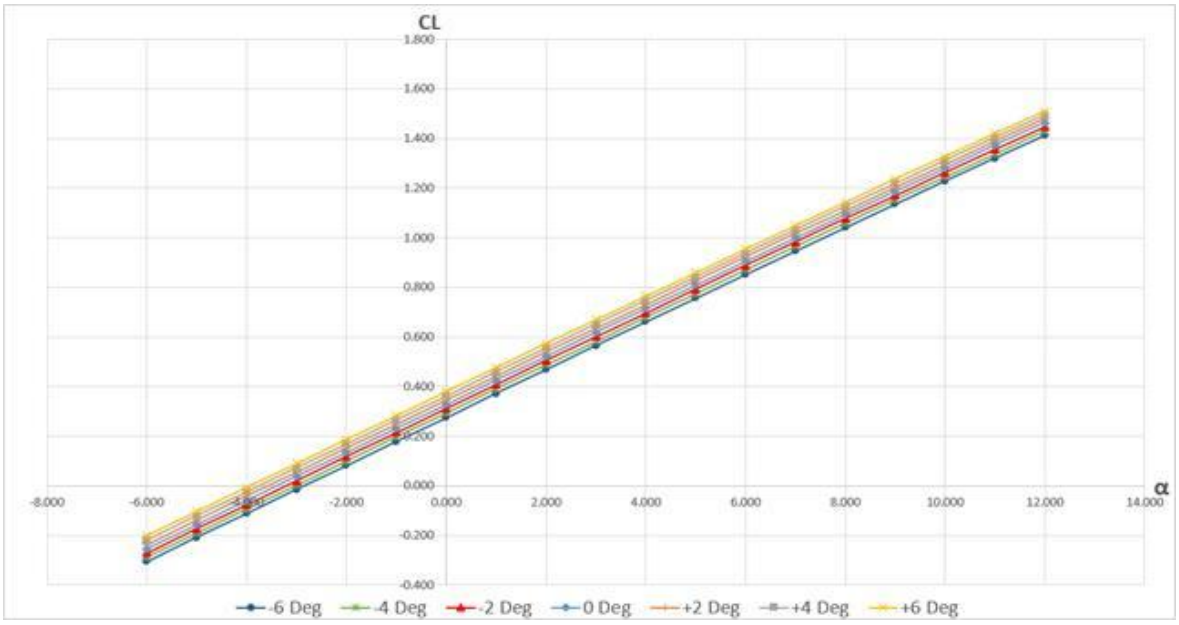

Figure 6. Lift coefficient as a function of angle of attack for the modified inverted V-tail configuration.

4.2 Aerodynamic Efficiency.

Reducing the span of the inverted V-tail improves the aerodynamic efficiency of the aircraft without introducing an observable aerodynamic penalty. As presented in Figures **7** and **8**, both configurations exhibit the

characteristic variation of the lift coefficient -to-drag coefficient ratio with angle of attack, reaching a maximum value before gradually decreasing at higher angles of attack. Although the overall behavior remains comparable, the modified configuration consistently achieves a slightly higher peak lift-to-drag ratio than the original configuration.

The improvement in aerodynamic efficiency is primarily associated with the reduction in tail wetted area. Decreasing the exposed surface reduces the skin-friction component of drag, while the aerodynamic characteristics of the lifting surfaces remain largely unchanged, as demonstrated by the preserved lift behavior discussed in the previous section. Consequently, the reduction in parasitic drag is sufficient to produce a marginal increase in the lift-to-drag ratio without adversely affecting the overall aerodynamic performance.

An equally important observation is that the aerodynamic efficiency curves preserve their general shape over the investigated elevator deflections, indicating that the influence of the proposed geometric modification remains consistent under different control surface positions. This suggests that the observed improvement originates predominantly from the modified tail geometry rather than from changes in the aerodynamic response associated with elevator deflection.

The ability to achieve a modest improvement in aerodynamic efficiency while maintaining essentially unchanged lift characteristics demonstrates that reducing the tail span can provide a measurable aerodynamic benefit without compromising the aircraft's primary lifting performance. The remaining question is therefore not whether the aircraft continues to produce adequate lift, but whether these aerodynamic gains are achieved while preserving the longitudinal stability characteristics required for safe flight.

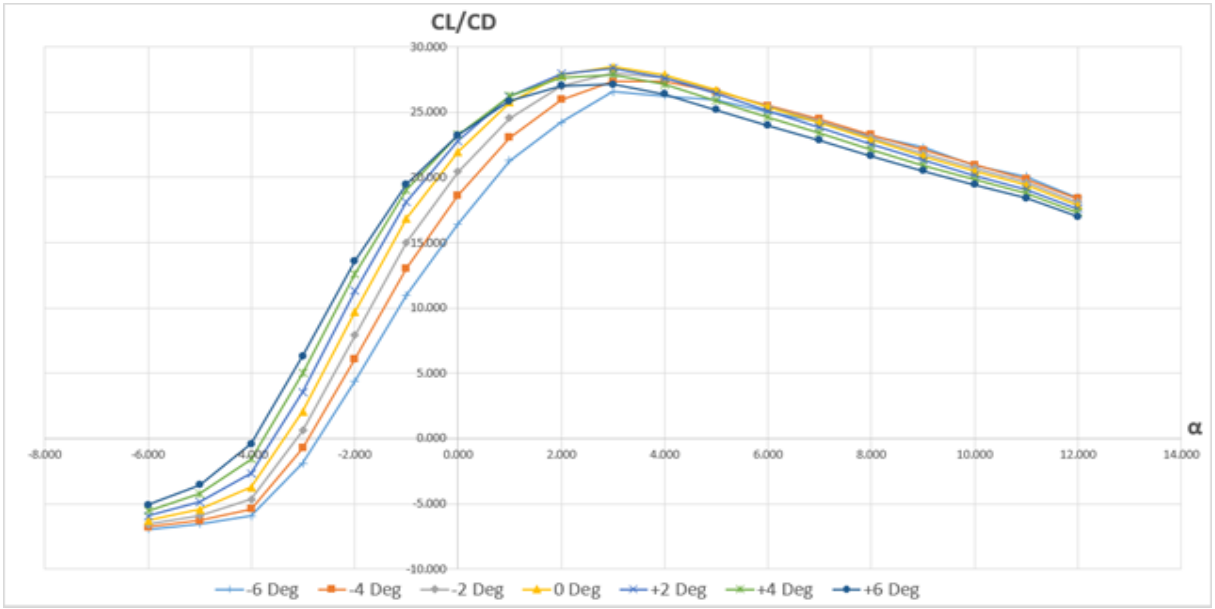

Figure 7. Lift coefficient -to-drag coefficient ratio as a function of angle of attack for the original inverted V-tail configuration.

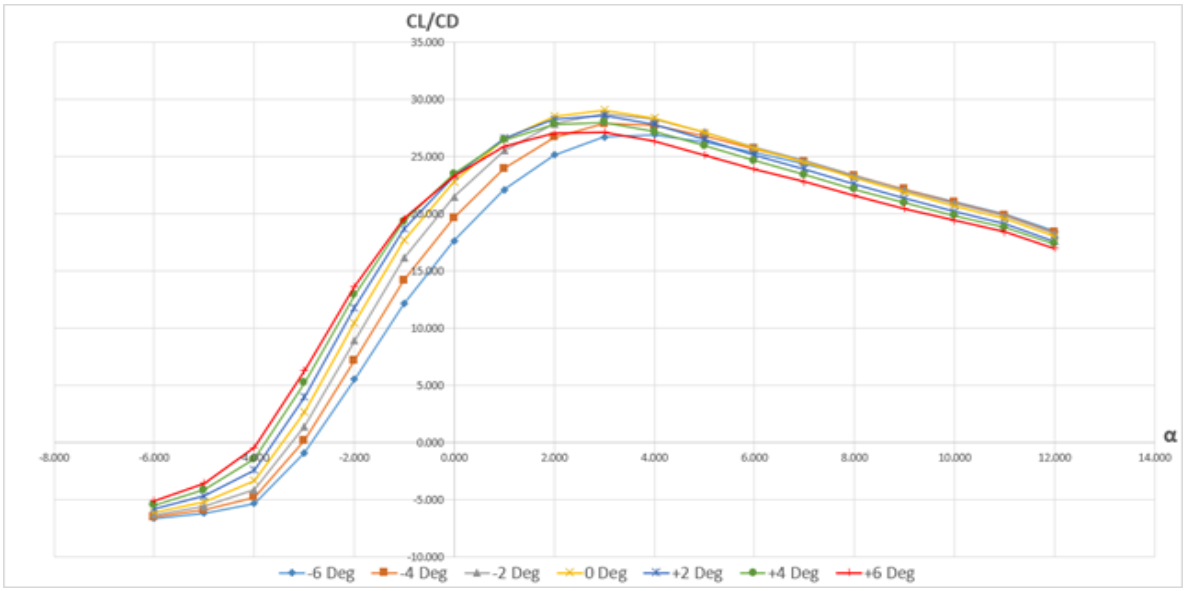

Figure 8. Lift coefficient -to-drag coefficient ratio as a function of angle of attack for the modified inverted V-tail configuration.

4.3 Longitudinal Stability Characteristics.

The effect of reducing the inverted V-tail span on the aircraft's longitudinal stability was assessed by examining the variation of the pitching moment coefficient with angle of attack. As shown in the figures 9 and 10, both configurations retain an approximately linear decrease in the pitching moment coefficient throughout the investigated angle-of-attack range, indicating that the proposed geometric modification preserves the fundamental longitudinal static stability characteristics of the aircraft.

The similarity in the slope of the pitching moment curves suggests that the restoring tendency of the aircraft remains essentially unchanged despite the reduction in tail span. This behavior indicates that the modified configuration continues to satisfy the longitudinal static stability requirement within the investigated flight envelope. Therefore, the reduction in tail geometry does not alter the inherent stability mechanism but rather influences the magnitude of the aerodynamic moment generated by the tail.

A more noticeable difference is observed in the relative spacing between the pitching moment curves corresponding to the investigated elevator deflections. Compared with the original configuration, the modified tail produces a smaller variation in pitching moment for the same control input. This behavior is consistent with the reduction in tail aerodynamic loading associated with the decreased lifting surface, resulting in a lower pitching moment without affecting the overall stability trend.

From an aerodynamic design perspective, these findings indicate that the proposed modification preserves the stability characteristics required for normal flight while reducing the available control authority. This represents a practical design compromise in which a modest reduction in control effectiveness is accompanied by improved aerodynamic efficiency and reduced tail size. Within the investigated operating conditions, the modified configuration therefore achieves a balanced aerodynamic performance while maintaining the longitudinal stability characteristics required for safe operation.

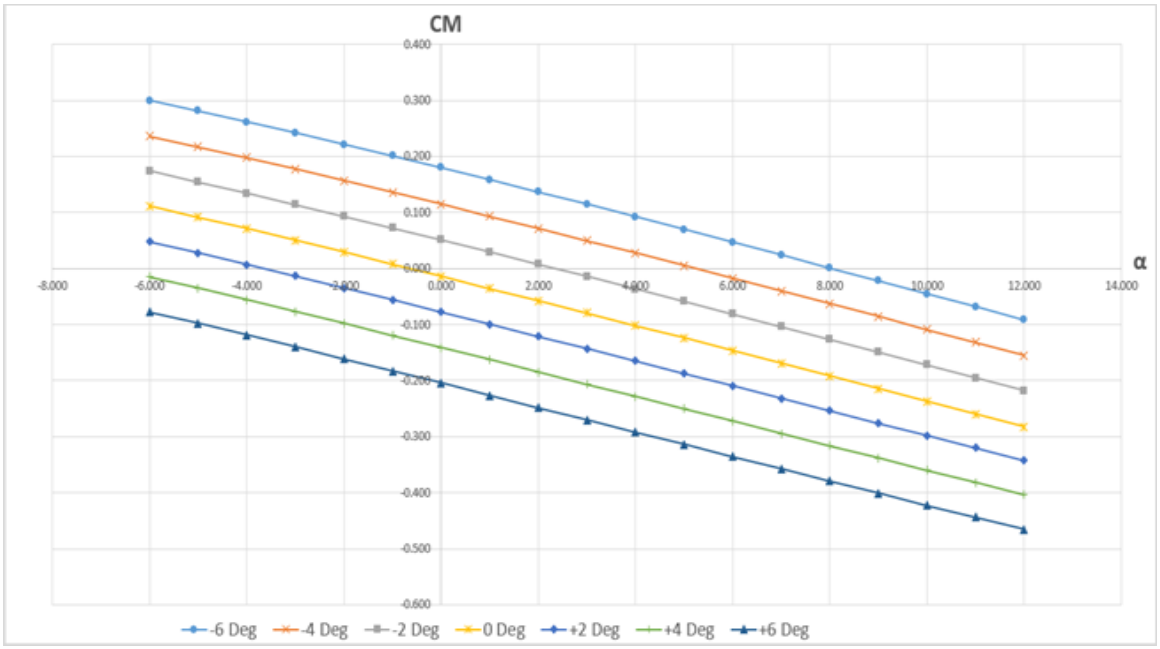

Figure 9. Pitching moment coefficient as a function of angle of attack for the original inverted V-tail configuration.

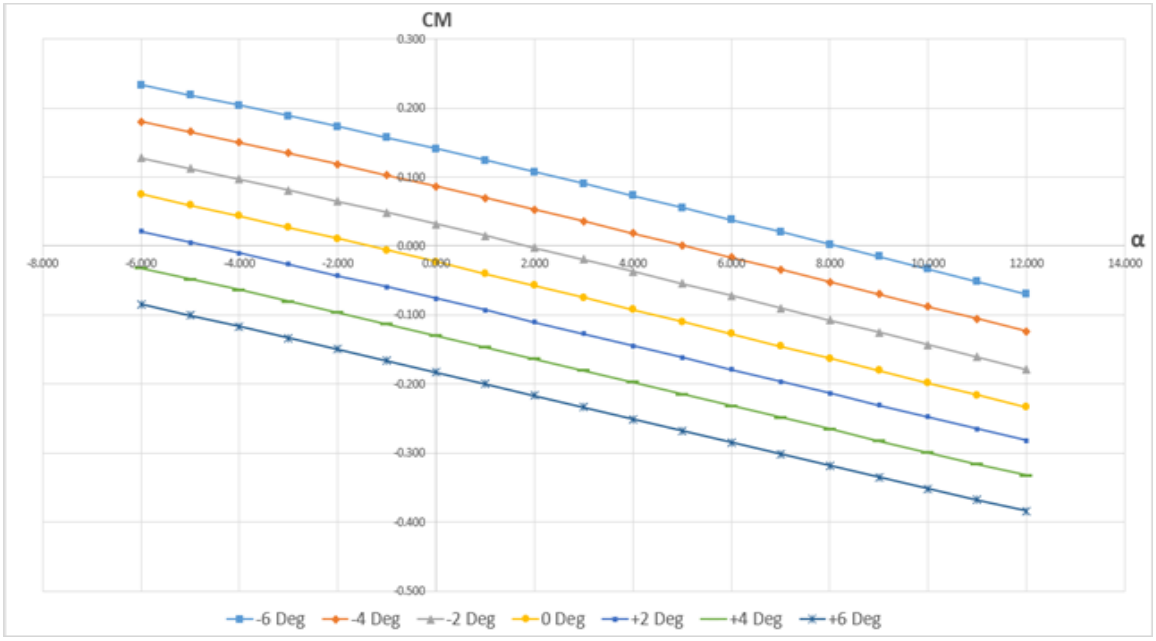

Figure 10. Pitching moment coefficient as a function of angle of attack for the modified inverted V-tail configuration.

5- Conclusion

The present findings demonstrate that reducing the span of an inverted V-tail does not necessarily require a compromise between aerodynamic efficiency and longitudinal static stability. Within the investigated operating conditions, the proposed geometric modification preserves the aircraft's fundamental aerodynamic characteristics while reducing the aerodynamic contribution of the tail. These findings indicate that the original tail geometry possesses sufficient design margin to accommodate geometric optimization,

supporting the use of tail sizing as an effective approach for improving aerodynamic efficiency without degrading the essential flight characteristics of the aircraft.

REFERENCES

[1] J. John D. Anderson, Introduction to Flight, "McGraw-Hill Education", 2016.

[2] Y. Zhang and e. al., Static Stability Analysis of UAV with Inverted V-Tail, 2019.

[3] Nelson, R. C., Flight Stability and Automatic Control, "McGraw-Hill", 1998.

[4] E. Nikolaou, S. Kilimtzidis, V. Lappas, and V. Kostopoulos, 'Analytical Methodology for Early-Stage Design and Stability Assessment of V-Tail Class-I UAVs', *Aerospace*, vol. 13, no. 7, p. 658, Jul. 2026, doi: 10.3390/aerospace13070658.

[5] Y. Öz, N. Ünal, E. Kök, C. Budak, E. A. Ünal, and M. Yildiz, 'Comparative Aerodynamic Analysis of Four Tail Configurations in Unmanned Aerial Vehicles Using Computational Fluid Dynamics', *Aircraft Engineering and Aerospace Technology*, vol. 98, no. 3, pp. 357–365, Dec. 2025, doi: 10.1108/aeat-03-2025-0123.

[6] Wang, X., Liu, Y., Chen, C. et al. ''Numerical analysis of longitudinal stability for twin-boom UAVs with different tail configurations '', *Aerospace systems* , AS 8, 673–681 (2025).

[7] Omer, Elhassen Ali Ahmed, Hana Moftah Momen, and Rayan Nassr Yahia. 'Enhancement of Airfoil Aerodynamic Characteristics by Surface Modifications'. *University of Zawia Journal of Engineering Sciences and Technology* 1, no. 1 (2024): 60–71. https://doi.org/10.26629/uzjest.2023.06.

[8] Omer, Elhassen, Ali Alkharboushi, and Zainab Ahmed. 'Numerical Study of Turbulent Flow Aerodynamics Around a Multi-Element Airfoil'. *University of Zawia Journal of Engineering Sciences and Technology* 3, no. 1 (2025): 26–42. https://doi.org/10.26629/uzjest.2025.03.

[9] Jolgam, Shaban A., Ahmed R. Ballil, Andrzej F. Nowakowski, and Abdulmaged K. Shati. 'Numerical Simulations of Compressible Two-Component Flows with General Equation of State'. *University of Zawia Journal of Engineering Sciences and Technology* 2, no. 1 (2024): 61–80. https://doi.org/10.26629/uzjest.2024.07.

[10] Elfaghi, Abdulhafid, Ashraf Ali Omar, and Waqar Asrar. 'Higher-Order Compact-Flow Field-Dependent Variation (HOC-FDV) Method for Solving Two-Dimensional Navier-Stokes Equations'. *International Journal for Computational Methods in Engineering Science and Mechanics* 16, no. 4 (2015): 256–63. https://doi.org/10.1080/15502287.2015.1048386.

[11] Airfoiltools, "Airfoil Database," [Online]. Available: http://airfoiltools.com/airfoil/details?airfoil=naca2412-il.

[12] Lesalli, P. V. "Preliminary Design and Static Stability Analysis of V-Tail Small Fixed-wing Unmanned Aerial Vehicle Purposed for Racing Plane Pilots and Anti-drone Training Platform Using XFLR-5." In *Adisutjipto Aerospace, Science and Engineering International Conference (AASEIC 2024)*, pp. 75-87. Atlantis Press, 2025.