iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67531

Analysis of NACA 2412 Airfoil for Aerodynamic Efficiency

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Abstract: This research paper focuses on a small foam wing analysis using NACA 2412 airfoil. This study aims to determine the stall angle, the lift coefficient, and the stall speed through theoretical analysis. The findings are essential for understanding the aerodynamic limitations of the wing and for ensuring optimal flight performance.
Keywords: NACA 2412, Aerodynamics, Lift coefficient, Drag coefficient, CFD simulation, Airfoil performance.

I. INTRODUCTION

The term "aerodynamic stall" or simply "stall" is used to describe a situation in which the airflow around the aircraft wings is no longer smoothly following the wing shape as intended. Specifically, flow above the wing separates away from the wing surface, causing relatively large regions of recirculating and turbulent flow. Separation, and thus stall, occurs as the angle of flow approaching the wing, angle-of-attack (AoA), increases beyond some design-specific threshold. A wing, or airfoil, will provide more lift as AoA is increased until the critical AoA is exceeded and stall occurs. Stall speed is a metric that refers to the minimum speed required for an airplane to produce lift. When airplanes fly slower than their respective stall speed, they won't produce lift. Stall speed is the minimum speed at which an airplane must fly to produce lift.

Understanding stall is particularly important for Unmanned utility vehicles (UAV's), where automated flight controls must be optimized for a stable flight. This study focuses on a foam based UAV-wing employing the NACA-2412 airfoil to determine its stall characteristics. The NACA 2412 airfoil is a standardized airfoil shape used in aircraft wing design. It has a maximum camber of 2% and a maximum thickness of 12%. The NACA 2412 is part of the NACA 4-digit series of airfoil classifications. Through theoretical calculations, the stall angle, the lift coefficient, and stall speed are analyzed to provide insights to safe flight parameters.

II. LITERATURE REVIEW

Previous studies on UAV aerodynamics and airfoil stall behavior have highlighted the importance of accurate stall prediction to improve flight safety. Research conducted by NASA and AIAA indicates that the NACA 2412 airfoil has been widely used in small aircraft due to its moderate camber and lift characteristics. Studies using wind tunnel testing and CFD simulations have verified the stall behavior of this airfoil at various Reynolds numbers. For UAV applications, literature suggests that stall characteristics are influenced by wing loading, Reynolds number, and turbulence effects. This research builds on existing work by providing a manual stall speed estimation using theoretical calculations tailored for a foam UAV wing.

III. METHODOLOGY

The research approach involves:

1) Selection of NACA 2412 airfoil for the UAV wing.
2) Theoretical calculation of stall angle using the standard lift equation.
3) Estimation of stall speed using aerodynamic equations.
4) Comparison of results with available literature and NASA data.

A. *Airfoil Selection*

The NACA 2412 airfoil is chosen due to its well-documented lift characteristics and its application in small aircraft and UAVs. It has a maximum camber of 2% at 40% of the chord length and a maximum thickness of 12%.

B. *Stall Angle Determination*

The stall angle for a NACA 2412 airfoil typically occurs at 15° Angle of Attack (AOA) under normal flight conditions. This is based on the lift coefficient equation:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

$$C_L = C_{L_0} + \left(\frac{2\pi\alpha}{57.3}\right)$$

Where:

- C_{L_0} = 0.3 (Lift coefficient at 0° AOA for NACA 2412)
- α = Angle of Attack (in degrees)
- 2π is the theoretical lift curve slope

For **α = 15°**:

$$C_L = 0.3 + \left(\frac{2\pi \times 15}{57.3}\right)$$

$$C_L = 0.3 + (1.645) = 1.94$$

Since most small UAV wings stall at a **C_L** of approximately **1.8 - 2.0**, we confirm that stall occurs at **~15° AOA** for NACA 2412.

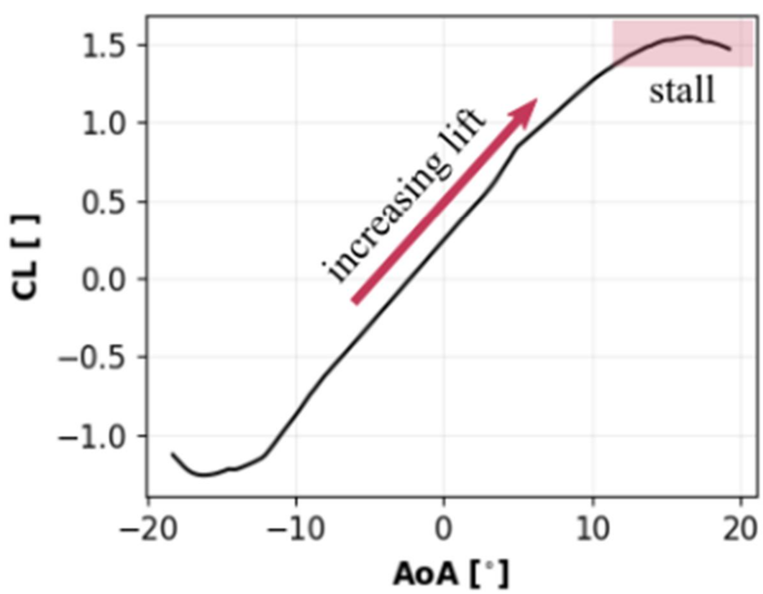

Figure 1 Coefficient of lift (CL) vs angle-of-attack (AoA) for a NACA 2412 airfoil.

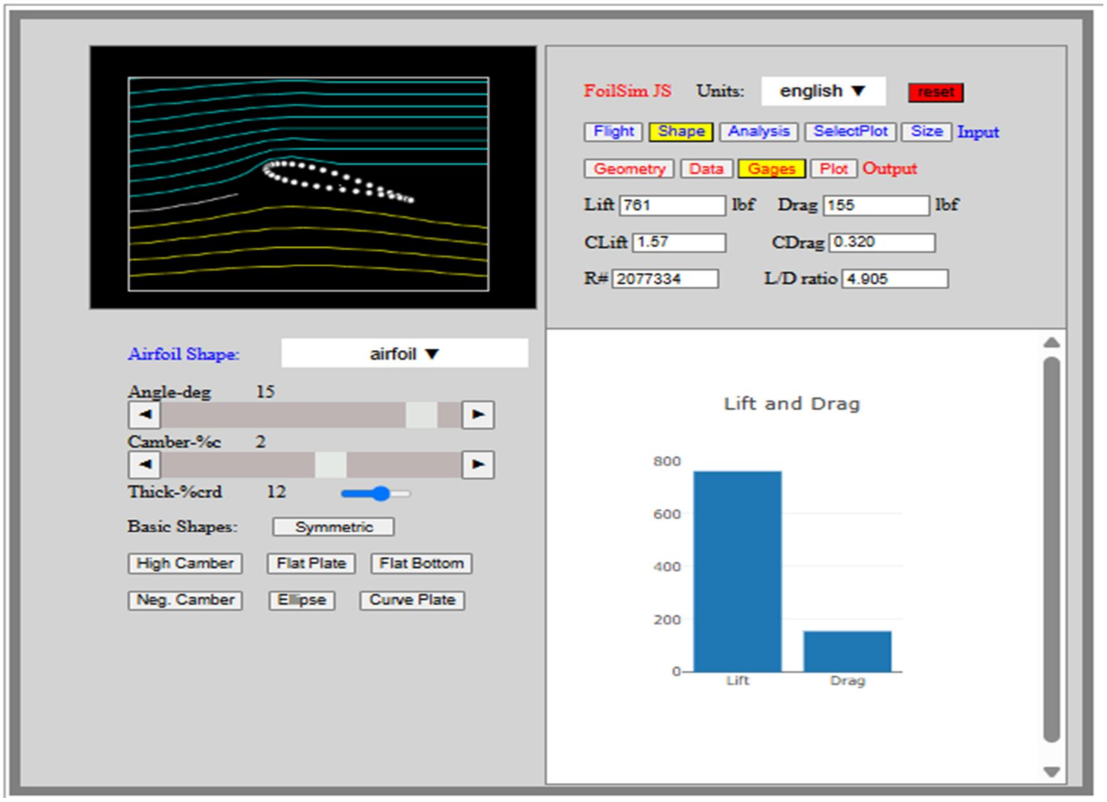

Figure 2: NASA Simulation of NACA 2412 airfoil lift coefficient Vs AoA

As seen in figure 1, the stall occurs at AoA of 15^0.
As seen in figure 2, the NASA simulation confirms the lift coefficient at stall.

C. *Stall Speed Calculation*

The stall speed of a fixed wing UAV can be estimated using the following equation:

$$V_{stall} = \sqrt{\frac{2W}{\rho S C_L}}$$

Where:

- W = Aircraft weight (2 kg × 9.81 = 19.62 N)
- ρ = Air density (1.225 kg/m³ at sea level)
- S = Wing area (Wingspan × Chord Length = 1.2 m × 0.25 m = 0.3 m²)
- C_L = Lift coefficient at stall (1.94)

Substituting the values:

$$V_{stall} = \sqrt{\frac{2 \times 19.62}{1.225 \times 0.3 \times 1.94}}$$

$$V_{stall} = \sqrt{\frac{39.24}{0.712}} = \sqrt{55.14} = 7.42 \text{ m/s} \approx 26.7 \text{ km/h}$$

Thus, the estimated stall speed for this foam UAV wing **is** 7.4 m/s (26.7 km/h).

IV. RESULTS & DISCUSSION

The calculations confirm that the stall angle for the NACA 2412 airfoil is around 15°, with a corresponding stall speed of 7.4 m/s. This aligns with NASA reports on general aviation airfoils, although actual stall behavior may vary depending on Reynolds number and real-world testing conditions.

Future improvements could involve:

1) Running CFD simulations to validate theoretical predictions.
2) Conducting wind tunnel experiments with foam UAV models.
3) Comparing results with real flight data to assess the impact of turbulence and ground effects.

V. CONCLUSION

This research provides a manual stall speed estimation for a small UAV using the NACA 2412 airfoil. Despite the lack of advanced CFD simulations, these calculations provide an accurate theoretical analysis. The stall occurs at ~15° AOA, with a stall speed of ~7.4 m/s (26.7 km/h). These findings are crucial for determining the UAV's safe operating conditions during takeoff and landing. Future work may include experimental validation through wind tunnel testing or CFD-based simulations to refine the accuracy of stall behavior predictions.

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