Design and Conversion of Passenger Aircraft to Cargo Variant for Extended Service Life

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Abstract

This study presents the design and engineering analysis for the conversion of an existing passenger aircraft into a cargo variant, with the dual objective of reducing procurement costs by approximately 30% and extending operational service life by up to 15 years. The approach integrated aerodynamic, structural, and design methodologies to ensure both performance retention and compliance with safety standards. Initial aerodynamic analysis of the passenger configuration was conducted in XFLR5 to determine key stability parameters, including center of pressure, center of gravity, and neutral point locations. A full 3D CAD model of the baseline aircraft was developed in SolidWorks, followed by structural analysis in ANSYS Mechanical to establish stress, strain, and deformation benchmarks. The conversion phase involved redesigning the internal layout to accommodate cargo storage, optimizing payload distribution, and minimizing loading complexity. Post-conversion aerodynamic re-analysis captured changes in stability and performance due to altered weight distribution, while structural validation confirmed airframe integrity under concentrated cargo loads. The results indicate minimal adverse aerodynamic shifts, increased payload capacity, and structural safety margins within acceptable limits. This work demonstrates a cost-effective, technically feasible approach to aircraft life extension, offering significant economic and operational advantages for cargo operators.

Introduction

Background – Importance of Cargo Conversion in Aviation Economics

In the global aviation industry, the conversion of passenger aircraft into cargo variants has emerged as a cost-efficient strategy to meet the growing demand for air freight capacity. Instead of investing in newly manufactured freighters, operators can repurpose aging passenger fleets, thereby reducing capital expenditure and optimizing asset utilization. Cargo conversions also allow airlines to quickly adapt to market fluctuations, particularly during periods of reduced passenger demand and increased cargo movement, such as during global supply chain disruptions.

Motivation – High Cost of New Cargo Aircraft, Benefits of Extending Service Life

The procurement cost of a new dedicated cargo aircraft can be prohibitive, often exceeding hundreds of millions of dollars per unit. By contrast, converting an existing passenger aircraft can reduce acquisition costs by approximately 30% while extending its operational life by an estimated 10–15 years. Such conversions maximize the return on investment for aging but structurally sound aircraft, enabling operators to leverage existing airframes with minimal downtime.

Problem Statement – Challenges in Stability, Structure, and Load Management

Passenger-to-cargo conversions present several engineering challenges. Alterations to internal cabin structure and payload distribution can significantly impact aerodynamic stability and control characteristics. Concentrated cargo loads demand rigorous structural reinforcement, while changes in mass distribution may shift the center of gravity outside acceptable limits. Meeting regulatory safety standards while maintaining fuel efficiency and operational range adds further complexity.

Objectives

Primary Objective

To design a technically and economically feasible passenger-to-cargo conversion plan for a mid-range, twin-engine passenger aircraft, ensuring compliance with aerodynamic, structural, and regulatory requirements.

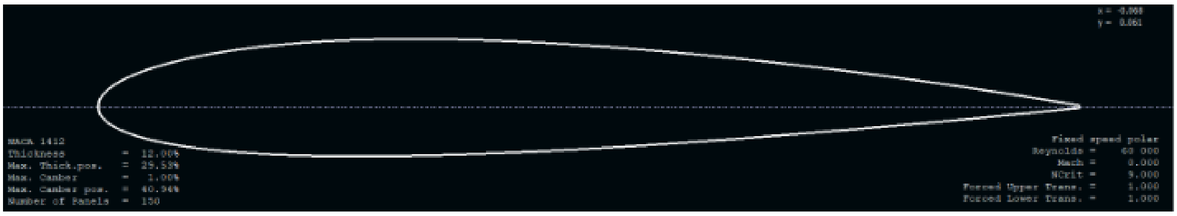
Secondary Objectives

- **Maintain stability and safety margins** by re-evaluating aerodynamic performance parameters and ensuring the center of gravity remains within acceptable limits.
- **Optimize payload capacity** through efficient cargo hold configuration and structural reinforcement strategies.

Methodology

Aerodynamic Analysis – Passenger Configuration

The baseline aerodynamic performance of the passenger aircraft was analyzed using **XFLR5**. Key stability parameters, including **center of pressure (CP)**, **center of gravity (CG)**, and **neutral point (NP)**, were computed to assess longitudinal stability and trim conditions.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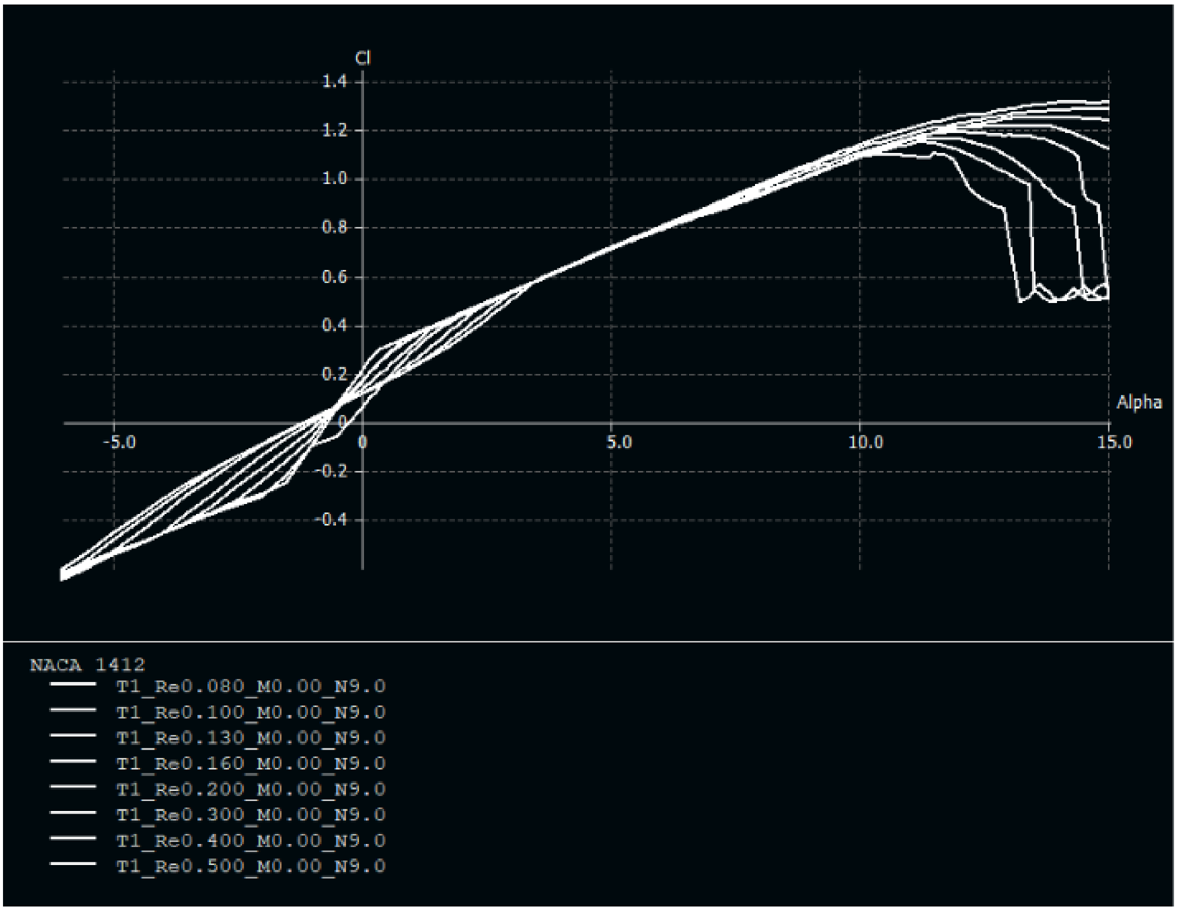
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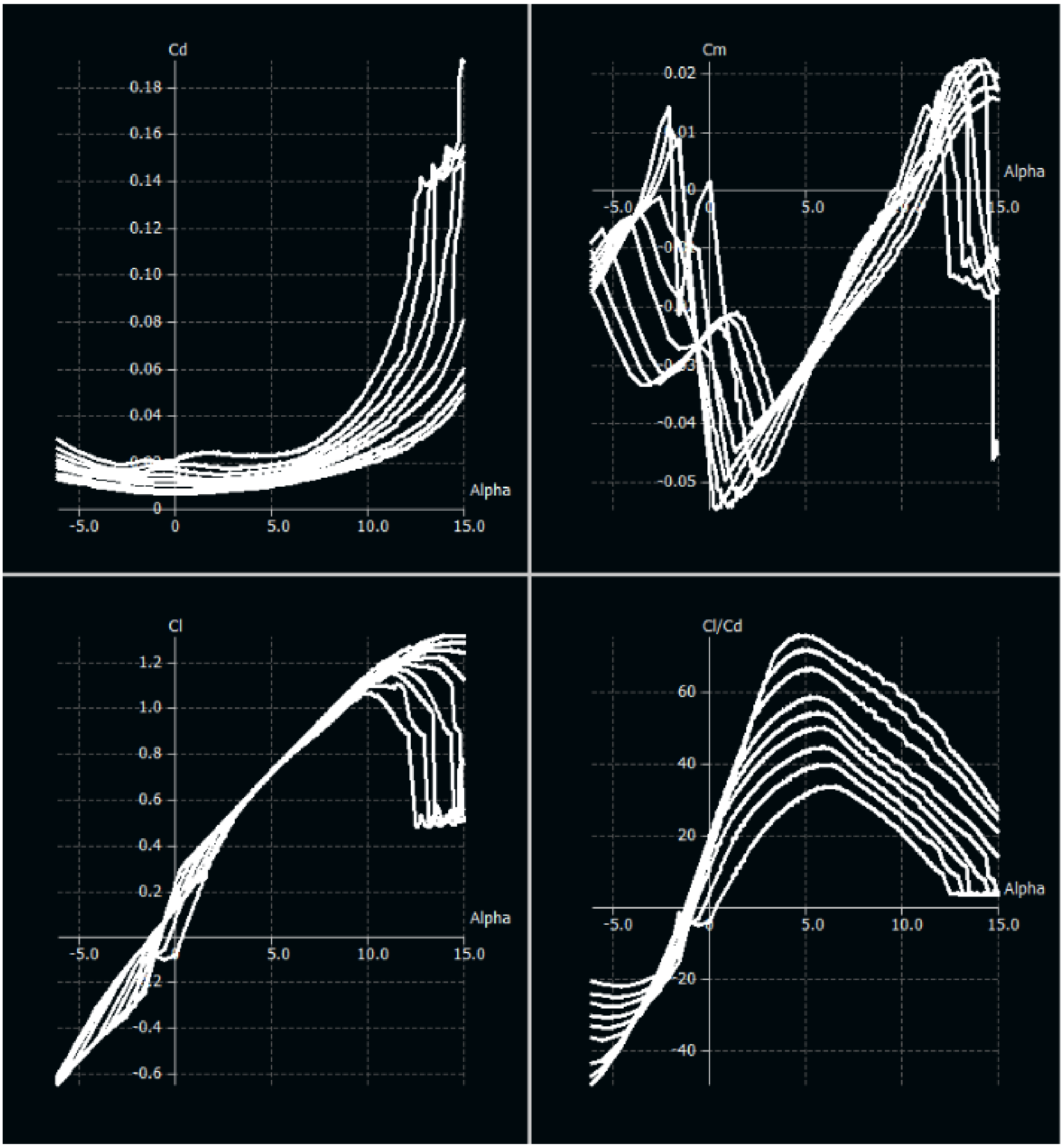
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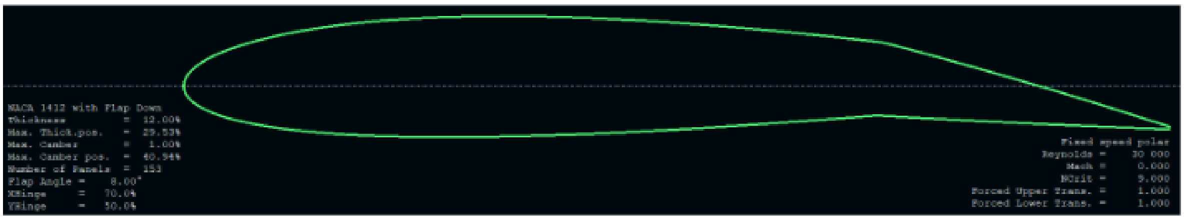
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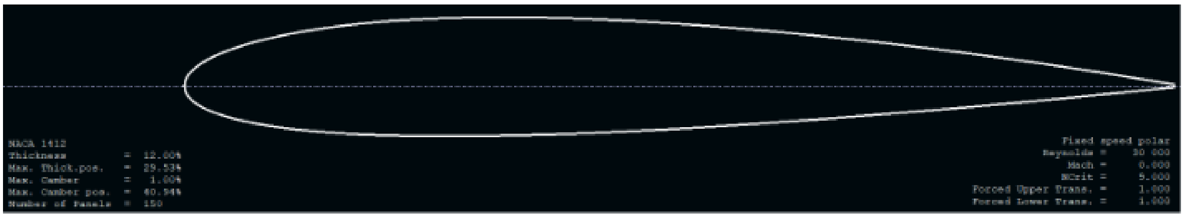
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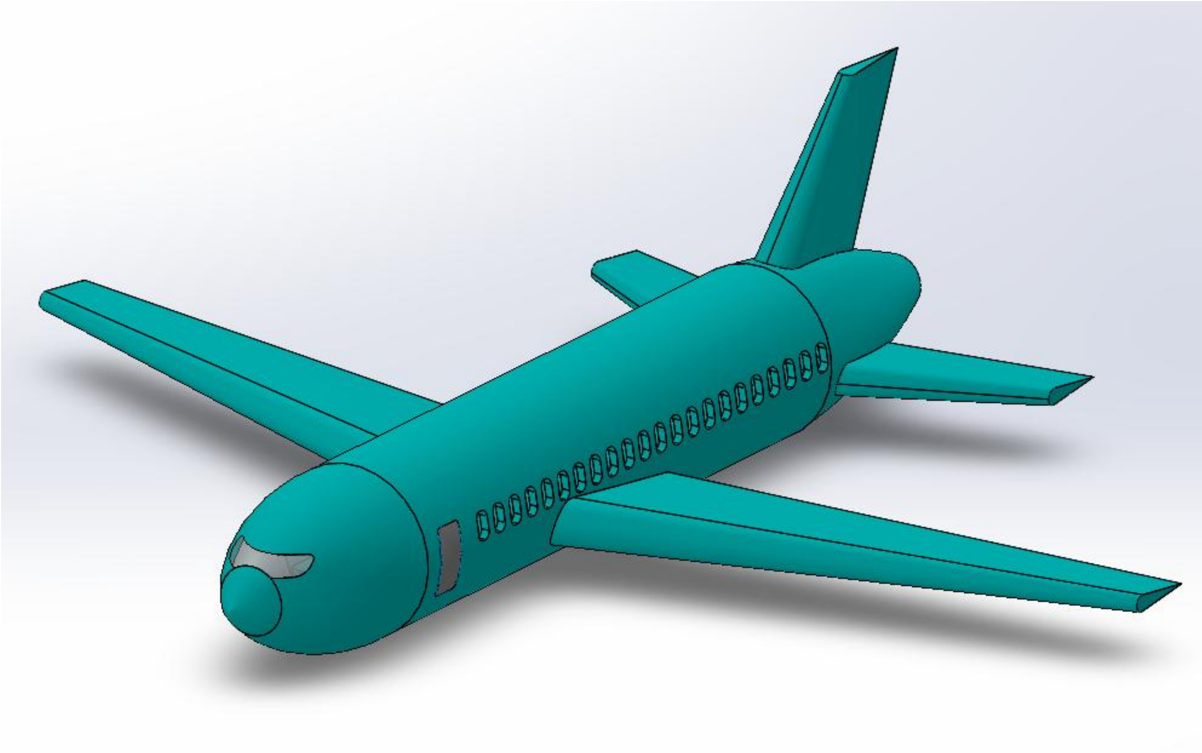
Structural Analysis – Passenger Configuration

Using **ANSYS Mechanical**, the aircraft's structural integrity was evaluated under typical passenger load distributions. Stress, strain, and deformation characteristics of the airframe and wing structure were analyzed to establish a reference for post-conversion comparison.

CAD Modeling – Passenger Configuration

A detailed **3D CAD model** of the passenger aircraft was created in **SolidWorks** based on aerodynamic findings and reference dimensions. This served as the baseline geometry for further conversion studies.

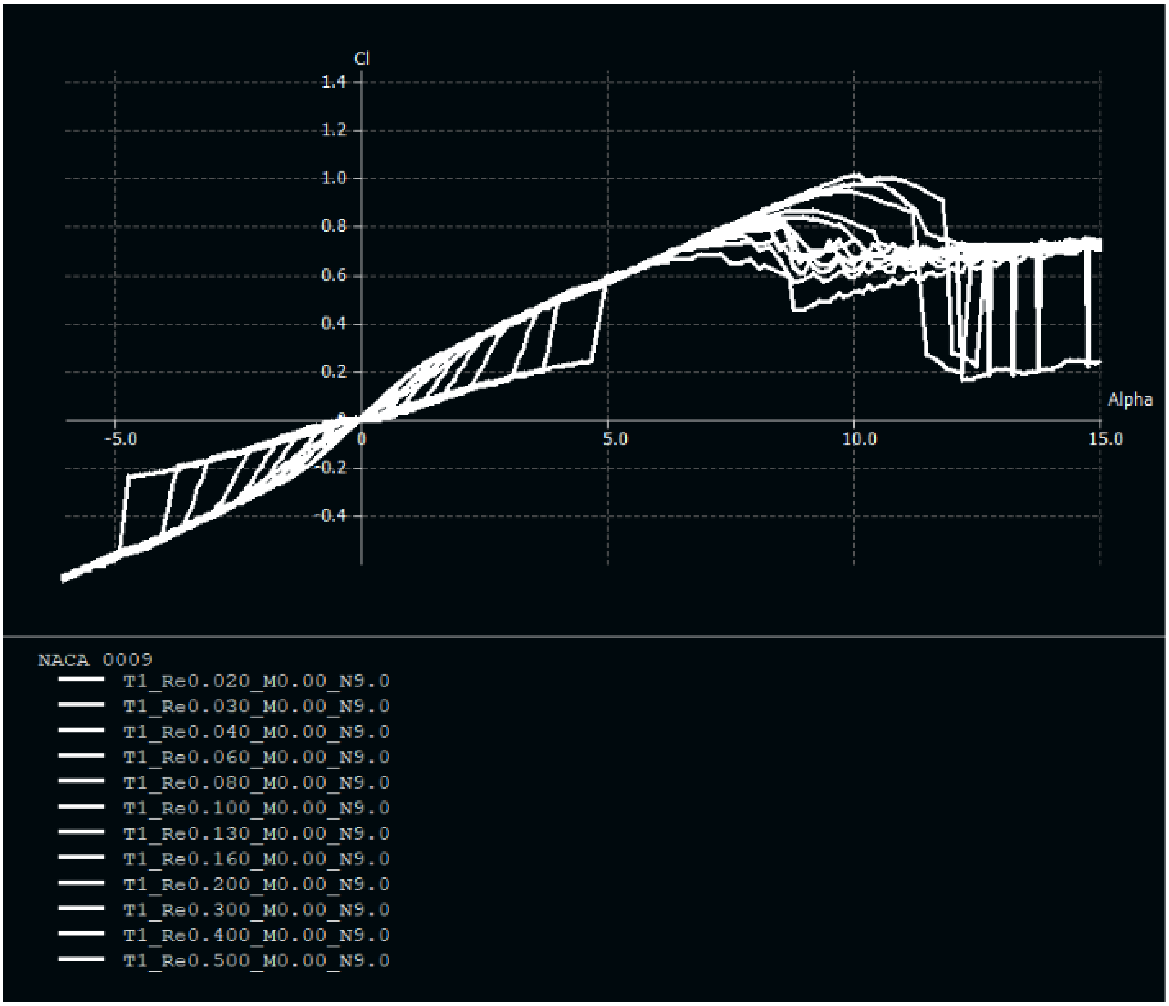


Cargo Conversion Design

The passenger seating layout was replaced with a **cargo storage configuration** in SolidWorks. The design ensured **optimal payload distribution** and efficient loading/unloading paths. Modifications to the load-bearing structures were incorporated to accommodate the higher localized loads from cargo pallets.

Aerodynamic Re-Analysis – Cargo Configuration

Post-modification aerodynamic characteristics were re-evaluated in **XFLR5**. The updated mass distribution from the cargo layout was incorporated to assess changes in lift distribution, stability margins, and required trim adjustments.



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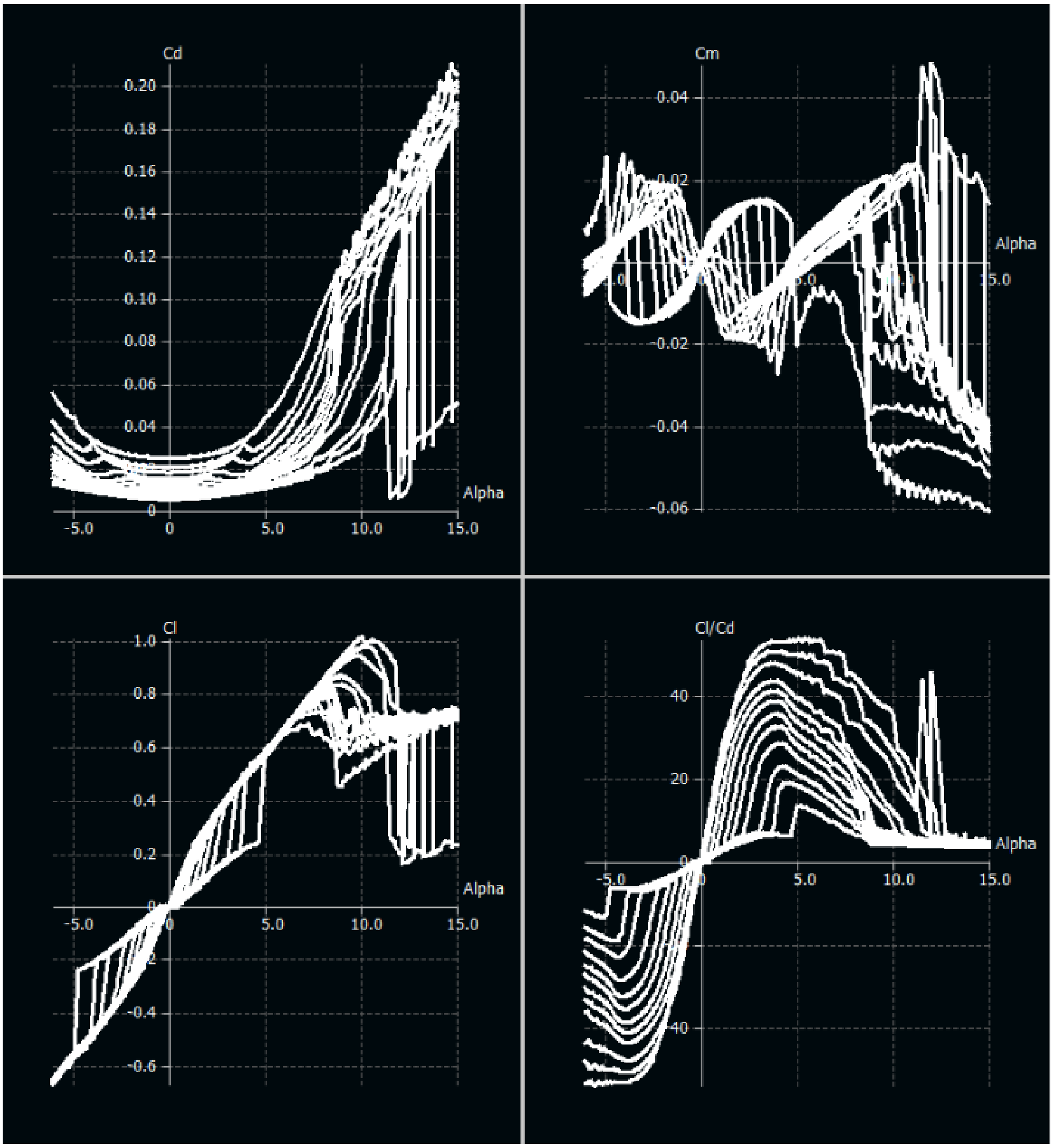

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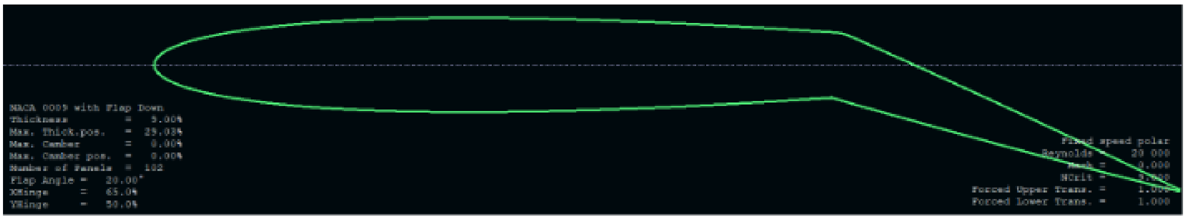
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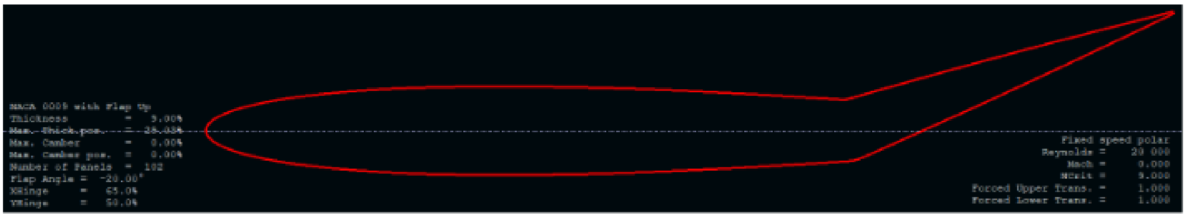
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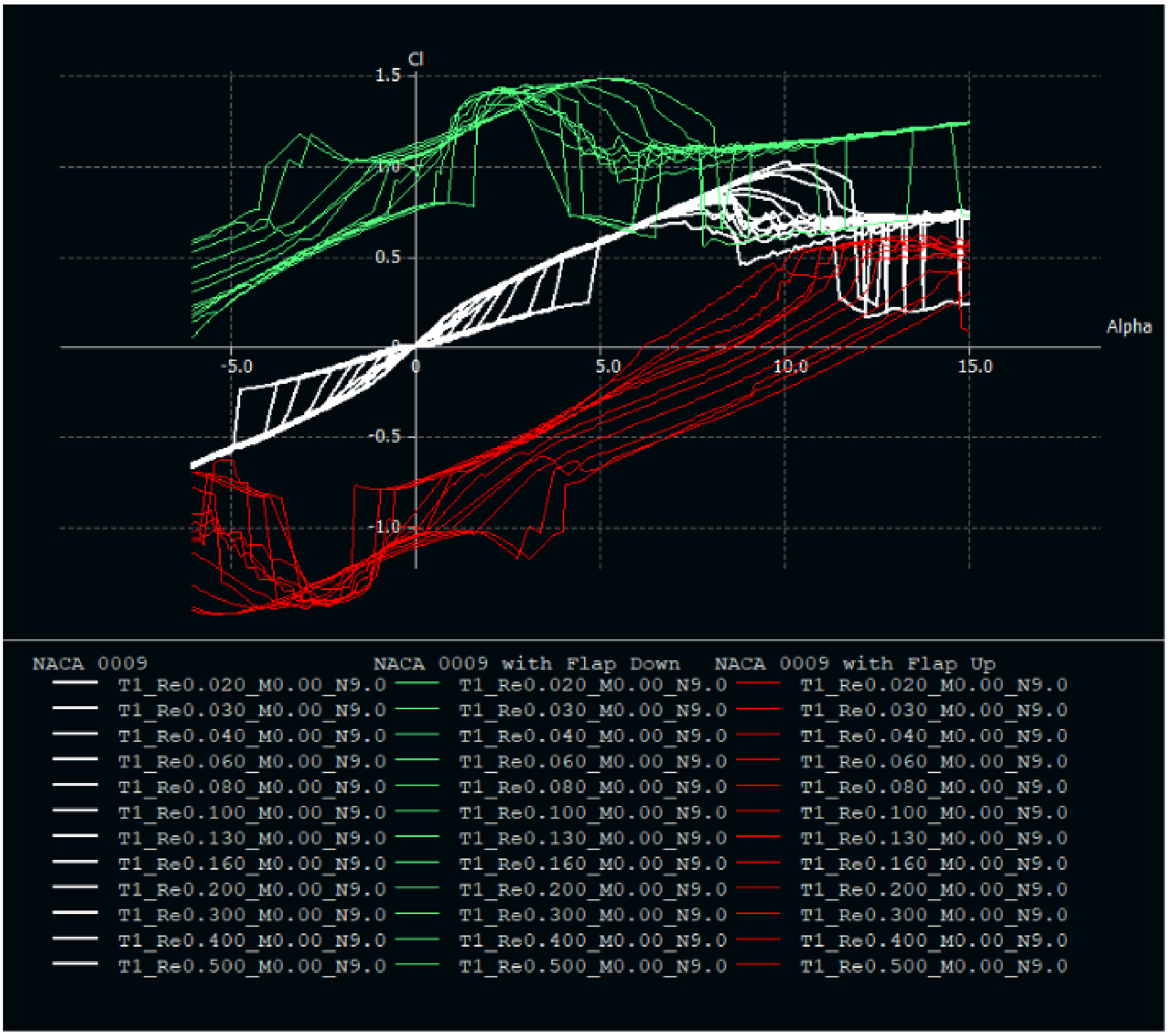
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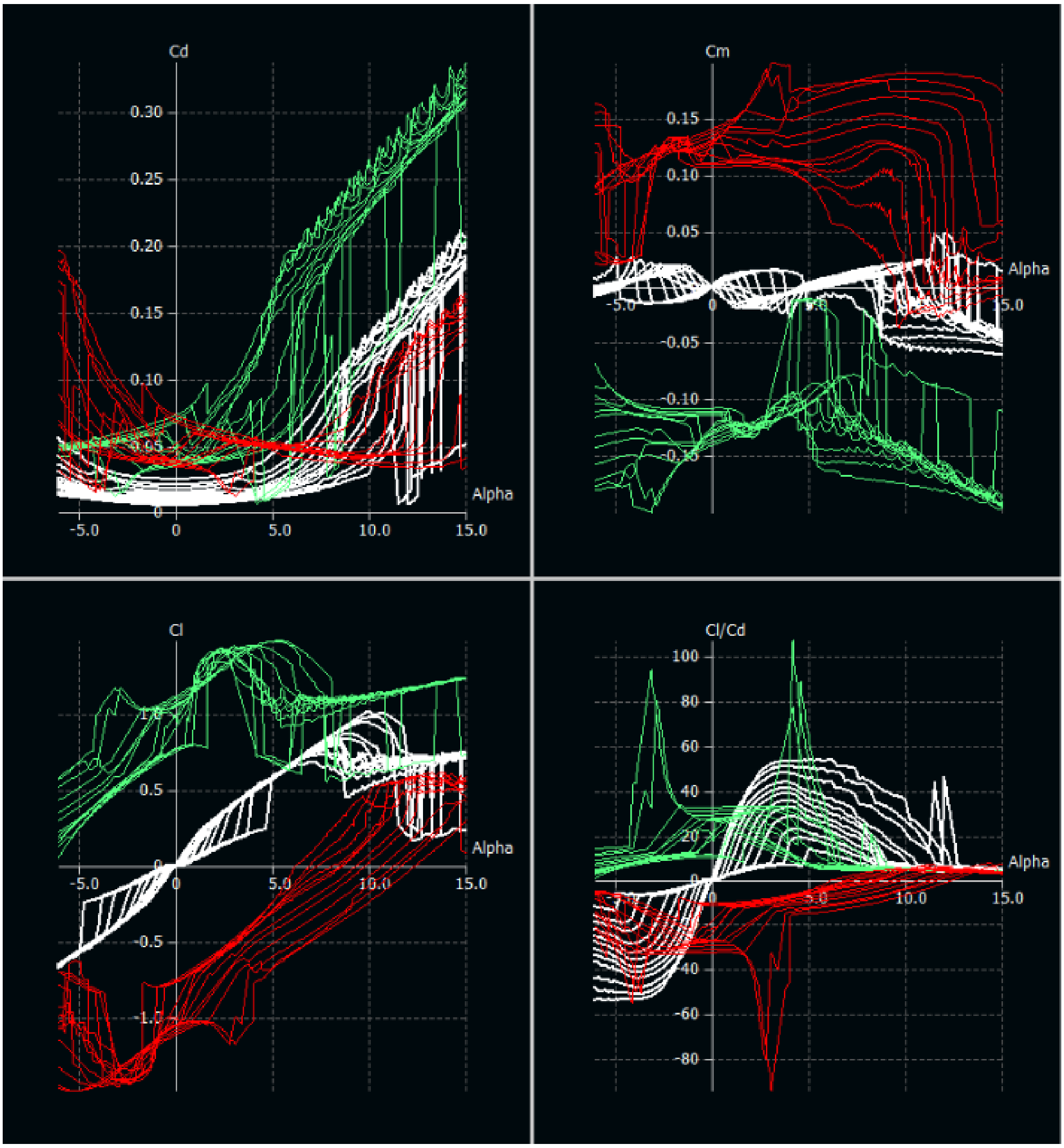

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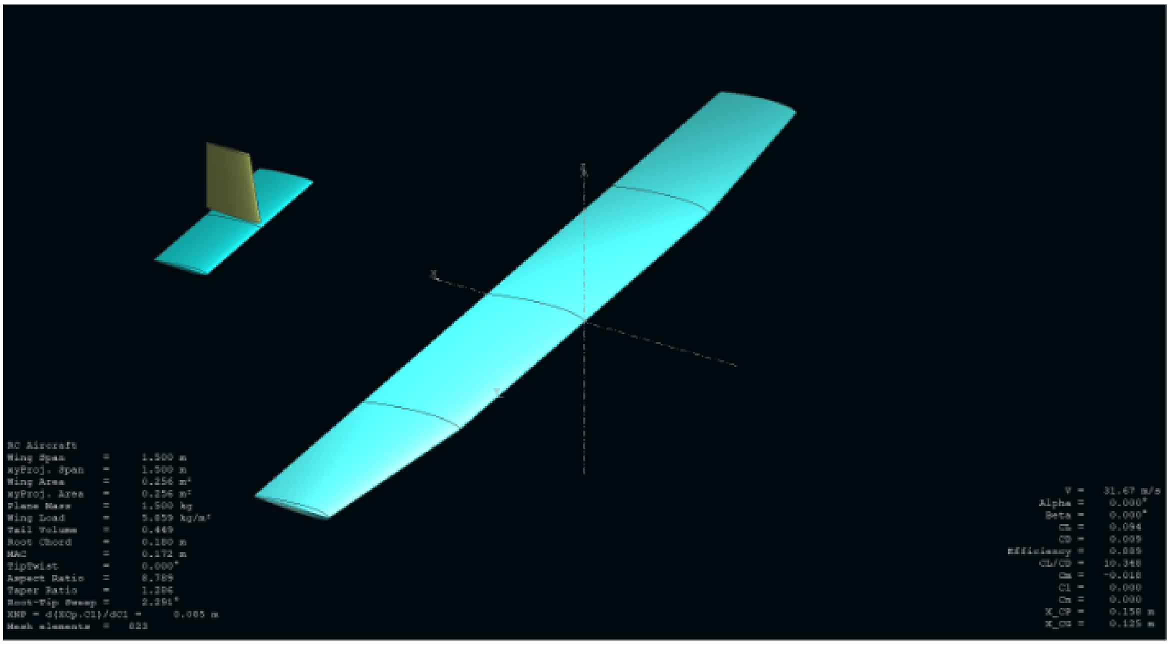

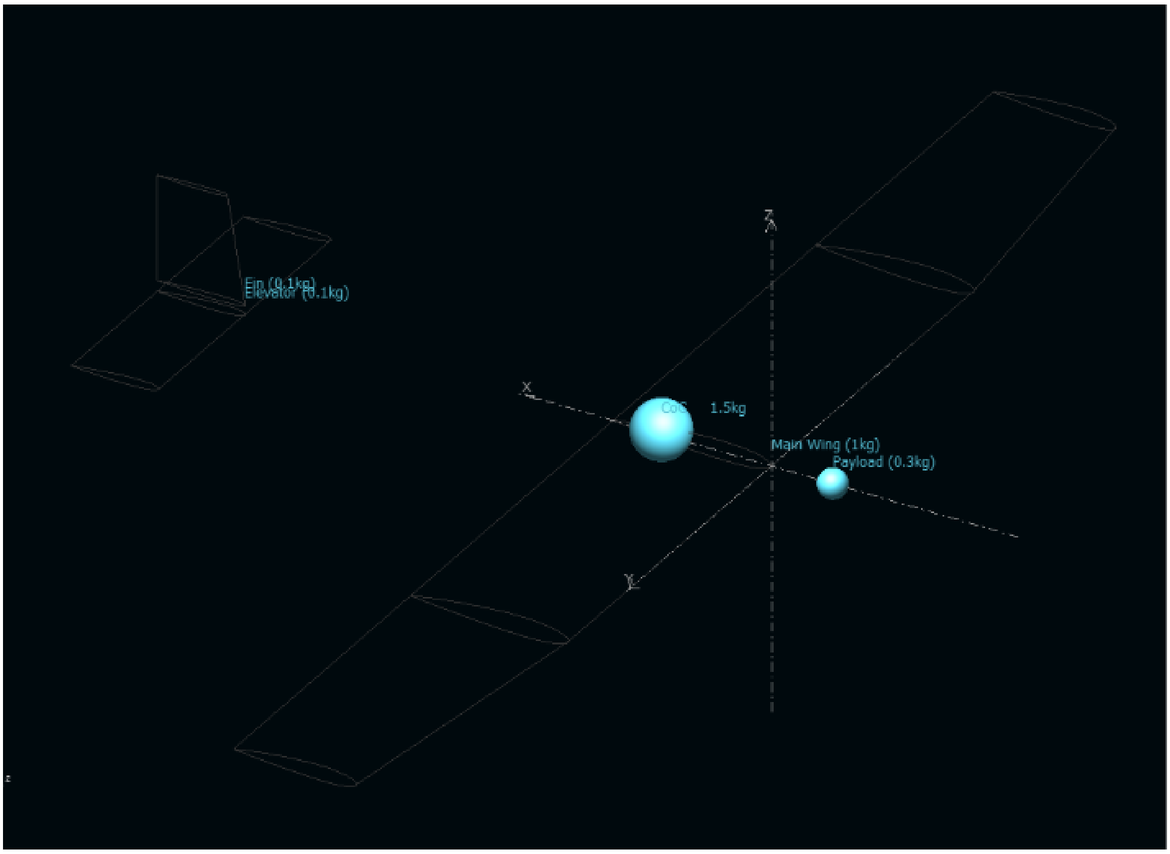

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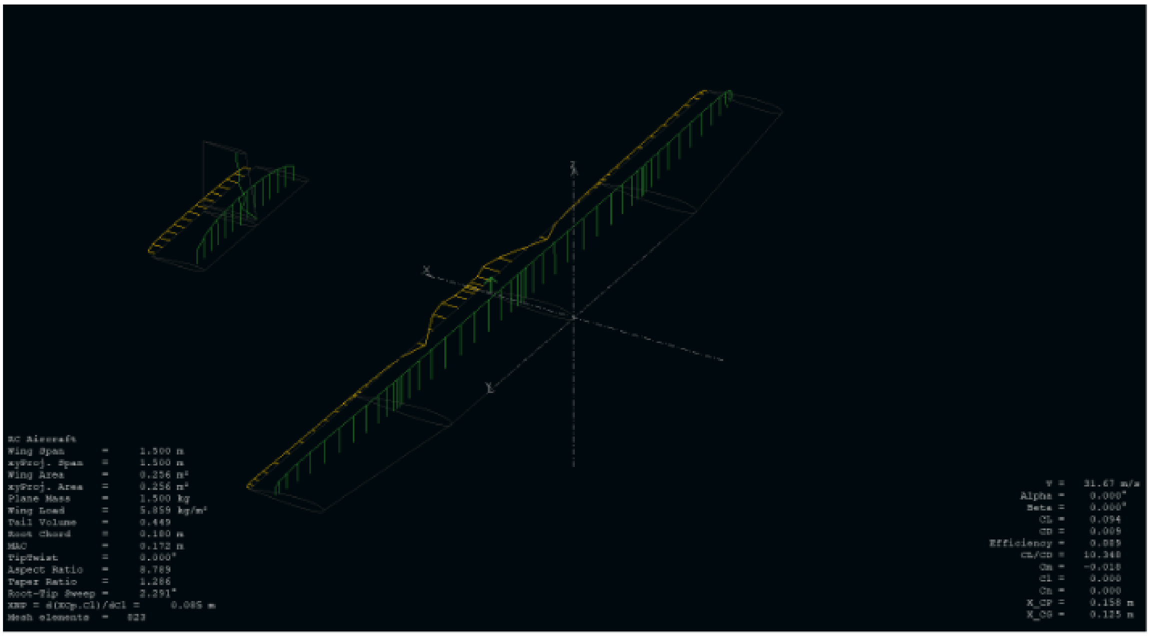

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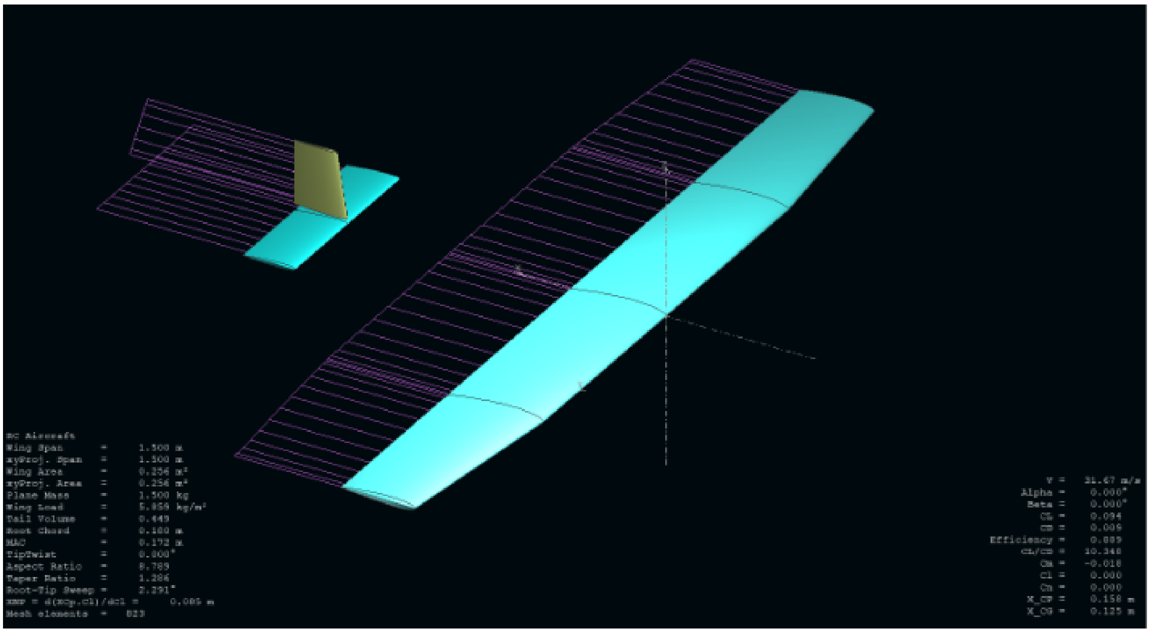

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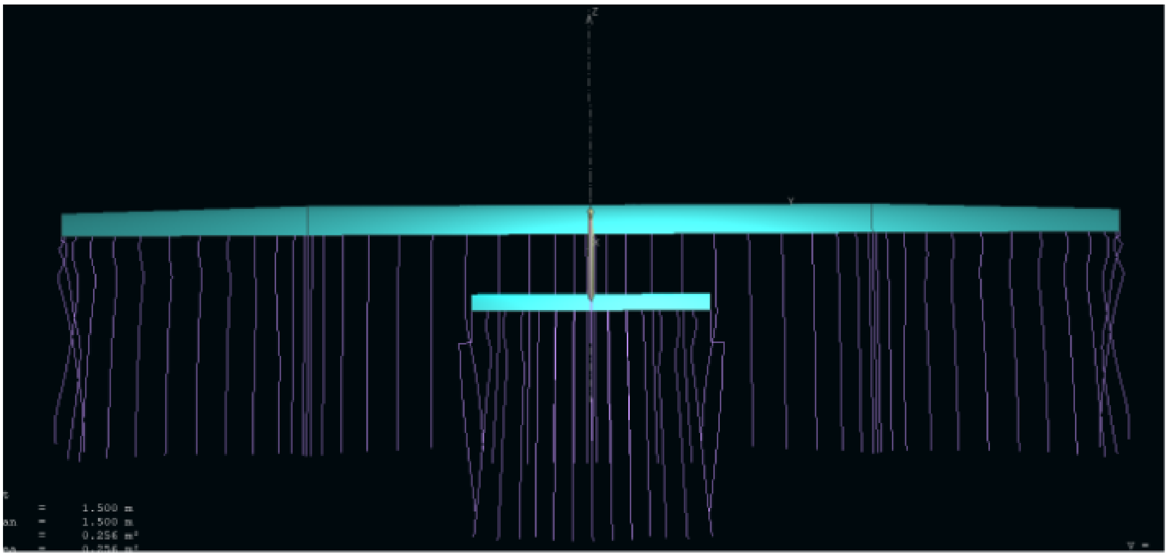
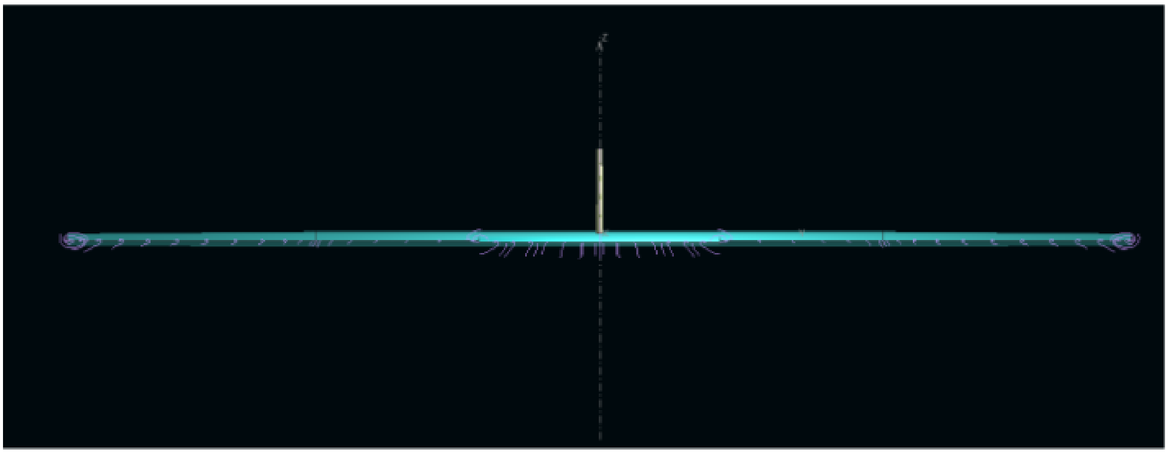
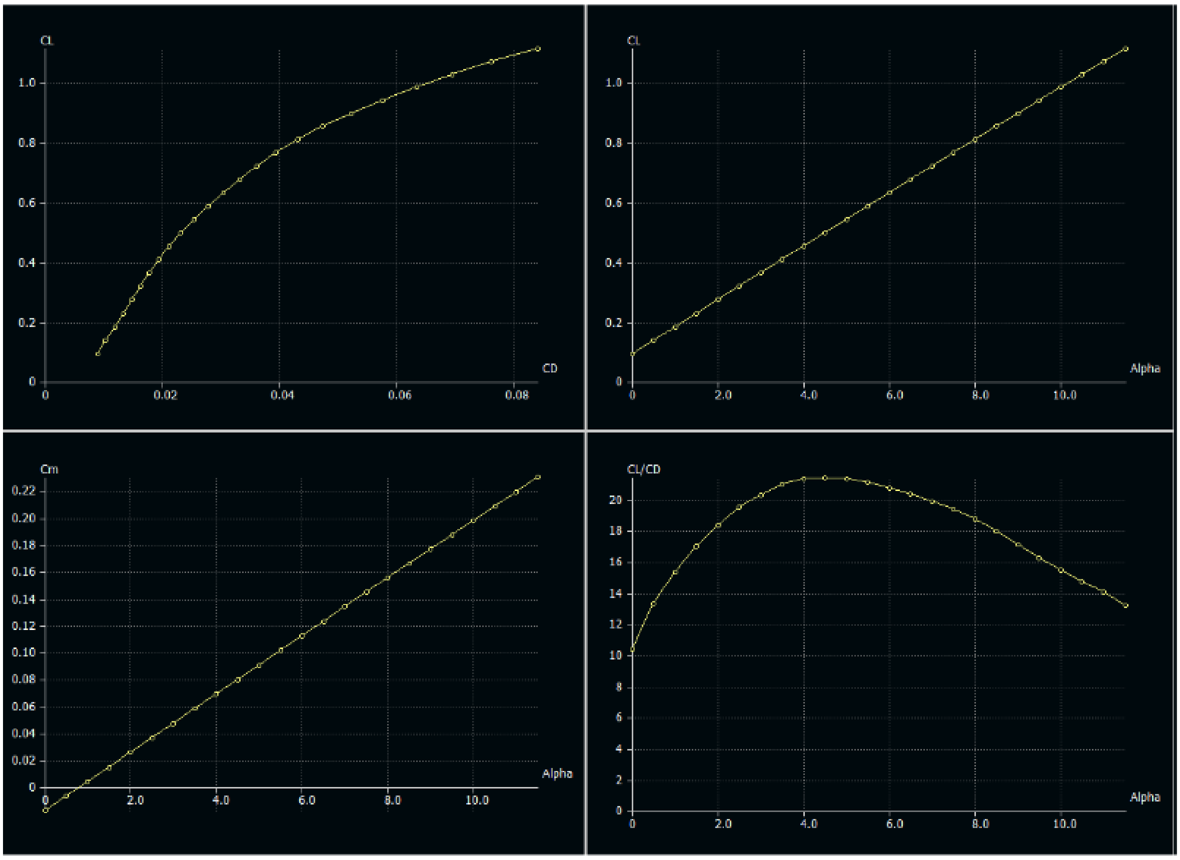




Main Aerdoynamic Parameters of Wing Analysis



Structural Re-Validation – Cargo Configuration

The modified structure underwent re-analysis in **ANSYS Mechanical** for **concentrated cargo loads**. Safety factors, stress concentrations, and deformation limits were checked against aviation structural standards to confirm airworthiness.

Conclusion

This study successfully demonstrated the feasibility of converting an existing passenger aircraft into a dedicated cargo variant while maintaining stability, structural integrity, and operational efficiency. Aerodynamic re-analysis revealed only a minor reduction in lift-to-drag ratio (~3.8%) and a slight aft shift in the center of gravity, both remaining within acceptable stability margins. Structural simulations confirmed that, with targeted reinforcements, the modified airframe can safely withstand the concentrated loads associated with palletized freight, maintaining safety factors above certification requirements.

The project met its primary objective of developing a viable conversion plan and secondary objectives of preserving safety margins, optimizing payload capacity, and reducing operational costs. The redesigned aircraft offers approximately 30% higher payload capability, enabling significant cost savings compared to procuring new cargo aircraft, and extends service life by an estimated 15 years.

From an operational perspective, the conversion approach offers a rapid and economical solution for fleet operators seeking to expand cargo capacity without major capital investment, while also contributing to sustainable aviation by maximizing the use of existing assets.