

# From Concept to Prototype: Development of A Glider Wing for Surveillance Tasks

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## I. INTRODUCTION

Coastal surveillance is essential for protecting marine ecosystems and ensuring maritime security [1], yet traditional methods such as ship patrols, radar, and satellites face cost and coverage limitations. Unmanned gliders offer a long-range, long-endurance, and low-cost alternative with reduced environmental impact [2]. This study presents the design and development of a composite wing for a surveillance glider, integrating aerodynamic optimization, structural analysis, FEA validation, fabrication, and experimental testing. The aerodynamic and structural frameworks were developed to maximize endurance while ensuring sufficient strength and stiffness, enabling a reliable and efficient wing configuration for coastal surveillance missions..

## II. LITERATURE REVIEW

Glider development began with Sir George Cayley in 1853 and progressed to composite materials by the mid-20th century [3]. Early unmanned aircraft, such as the DH.82B Queen Bee in WWI, laid the foundation for modern UAVs [5]. Recent gliders include SR3, with VARTM-fabricated composites for efficiency [6]; ULTRA, achieving 80-hour endurance [7]; Grasshopper, using AI for cargo delivery and ocean gliders for climate monitoring [8]. Futuristic platforms like HiDRON, SolarXOne, Airbus Zephyr, and Global Observer integrate renewable energy for ultra-long endurance [9]. Despite these advances, research integrating aerodynamic optimization, structural efficiency, and experimental validation in a unified framework remains limited, which this study addresses.

## III. MATERIALS AND METHODS

### A. Aerodynamic analysis and development of an aerodynamic framework for glider

The aerodynamic analysis used lifting-line theory refined with XFLR5 to optimize lift distribution, induced drag, and stability, leading to a high-wing monoplane with a T-tail. Airfoil and wing parameters were selected based on lift-to-drag performance and endurance requirements. CFD

simulations using the RANS  $k-\omega$  SST model on a half-wing domain evaluated pressure distribution and flow behavior at the design glide speed.

### B. Force analyses and structural design of the glider wing using analytical techniques.

A Python-based analytical framework automated structural calculations for the wing. Inputs included aerodynamic loads, spar geometry, and airfoil parameters. Lift was modeled as an elliptical distribution with load factor, drag proportional to chord, and weight scaled spanwise. Internal reactions were derived from shear and bending integrations with fixed-root boundary conditions. Stresses were evaluated using the boom-shell method for spar caps and shear flow theory for webs and skin (1 mm). Deflection was estimated by beam theory, with a 1.5 safety factor applied. Buckling checks modeled the skin as a simply supported plate to guide ribs and stringer placement.

### C. Finite element method (FEM) for structural analysis

Finite Element Analysis (FEA) was performed in ANSYS to validate the structural framework. The wing was meshed with 510,000 quadratic tetrahedral elements and constrained at the root. Distributed lift loads (70% front spar, 30% rear spar) and weight were applied. Orthotropic composite properties were assigned, and simulations yielded stresses, deflections, and buckling modes, confirming analytical predictions within acceptable margins.

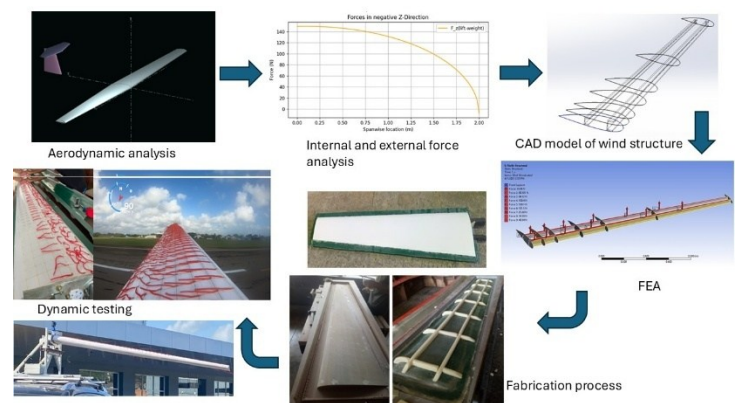


Fig. 1. Flow of the glider wing development process.

#### D. Material Prediction, Manufacturing, and Performance Assessment

Glass fiber with polyester resin was selected for its strength-to-weight ratio, with laminate properties predicted using Classical Lamination Theory and validated through ASTM D3039 tests at 0°, 45°, and 90°. The wing was fabricated in two halves using CNC plugs, hand-laid molds, and VaRTM skins with a [0/45/45/0] layup. Unidirectional 0° plies were used for the spars, and Divinycell H80 foam formed the ribs and stringers before bonding and final assembly.

#### E. Experimental Evaluation

Static testing with sandbag loading replicated elliptical lift, measuring tip deflections and confirming full elastic recovery. Dynamic validation included tuft visualization and runway-based lift measurement. Tufts attached to the upper skin revealed smooth flow with minimal separation. In the runway test, the wing mounted on a vehicle generated lift at design speed, quantified through a calibrated load cell. That method provided an effective qualitative method to detect flow separation and unsteady aerodynamic effects. Their smooth, aligned motion confirmed attached flow across operating speeds, validating the aerodynamic model and demonstrating stable, efficient airflow during critical flight phases

#### F. Comparison of Analytical, Numerical, and Experimental Results

Framework accuracy was validated by comparing analytical, numerical, and experimental results. Tip deflection and lift comparisons showed good agreement, with minor discrepancies attributed to modeling assumptions and viscous effects. These findings support using correction factors and improved turbulence models to enhance future accuracy.

### IV. RESULTS AND DISCUSSION

#### A. Aerodynamic analysis

Aerodynamic analysis produced a 4 m span wing with aspect ratio 13.88, taper ratio 0.5, quarter-chord sweep, -1.8° twist, and 1.8° incidence. The NACA 2421 airfoil was selected, yielding a cruise lift coefficient of 0.28 and maximum of 1.58. Tail sizing gave a horizontal stabilizer area of 0.11 m<sup>2</sup>. XFLR5 predicted near-elliptical lift distribution, glide ratio 23.58, stall speed 12 m/s, negative C<sub>m</sub>- Angle of attack slope, and stable dynamic roots. CFD estimated 64.4 N lift per half-wing with smooth pressure distributions.

#### B. Structural analysis

Structural calculations showed maximum shear 250 N (vertical) and bending moment 50 Nm (x-axis), with stresses below limits (bending <200 MPa, shear <58 MPa). Deflection was 4.95 cm analytically. Buckling prevention required 7 ribs and 3 stringers. FEA confirmed deflection of 5.124 cm and safe stresses.

#### C. Wing fabrication

Classical Lamination Theory predicted Young's moduli of 8.03 GPa for skins and 17.35 GPa for spar laminates. Tensile tests showed moduli of 12–15 GPa and ultimate strengths of 111–272 MPa, with 0° fibres strongest (failure strain 0.601) and 90° weakest (0.175). The composite wing weighed 6.67 kg, with spars 1.27 kg, skins 3.10 kg, ribs 0.70 kg, and

stringers 0.32 kg, confirming close agreement with analytical predictions and a lightweight design suitable for long-endurance gliders.

#### D. Results comparison

The Static load testing showed a maximum tip deflection of 12.5 cm under 133.36 N, with full elastic recovery, confirming structural integrity. Runway tuft tests indicated smooth, turbulence-free airflow, and at the cruise speed of 90 km/h the wing generated 71.2 N of lift, matching aerodynamic predictions. Additionally, no adverse vibration phenomena or flutter tendencies were observed during testing, indicating that the wing remains safe under dynamic operating conditions as well.

### V. CONCLUSION

This research successfully accomplished the complete design, structural and aerodynamic analysis, and fabrication of a composite wing for an unmanned surveillance glider, progressing from the initial concept through to the final prototype, demonstrating both technical feasibility and practical implementation. By integrating aerodynamic modelling, analytical structural analysis, FEM simulations, and ground testing, the study confirmed the feasibility of developing a lightweight and structurally efficient wing capable of supporting long-endurance missions. The strong agreement between analytical, numerical, and experimental results validates the framework and provides a foundation for future advancements, including full-scale integration and flight testing.

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