

# SAE Aero Design East 2026 Design Report

Feb 1, 2026



## The University of British Columbia

UBC AeroDesign

Team 302 - Micro Class

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## Statement of Compliance

### APPENDIX A - STATEMENT OF COMPLIANCE

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#### Certification of Qualification

|                         |                                       |             |            |
|-------------------------|---------------------------------------|-------------|------------|
| Team Name               | <u>UBC AeroDesign Micro</u>           | Team Number | <u>302</u> |
| School                  | <u>University of British Columbia</u> |             |            |
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#### Statement of Compliance

As faculty Adviser:

SG (Initial) I certify that the registered team members are enrolled in collegiate courses.

SG (Initial) I certify that this team has designed and constructed the radio-controlled aircraft in the past nine (9) months with the intention to use this aircraft in the 2026 SAE Aero Design competition, without direct assistance from professional engineers, R/C model experts, and/or related professionals.

SG (Initial) I certify that this year's Design Report has original content written by members of this year's team.

SG (Initial) I certify that all reused content has been properly referenced and is in compliance with the University's plagiarism and reuse policies.

SG (Initial) I certify that the team shall use the Requirements Check & Safety and Airworthiness Inspection checklists to inspect their aircraft before arrival at Technical Inspection and that the team shall submit the completed checklists, signed by the Faculty Advisor or Team Captain, to the inspectors before Technical Inspection begins.



Signature of Faculty Advisor

January 15, 2026

Date



Signature of Team Captain

1/15/2026

Date

# Table of Contents

|                                                                    |           |
|--------------------------------------------------------------------|-----------|
| <b>Statement of Compliance</b>                                     | <b>2</b>  |
| <b>Table of Contents</b>                                           | <b>3</b>  |
| <b>List of Figures</b>                                             | <b>4</b>  |
| <b>List of Tables</b>                                              | <b>4</b>  |
| <b>1. Executive Summary</b>                                        | <b>5</b>  |
| <b>2. List of Symbols and Acronyms</b>                             | <b>6</b>  |
| <b>3. Referenced Documents &amp; Specifications</b>                | <b>7</b>  |
| <b>4. Project Management</b>                                       | <b>8</b>  |
| 4.1 Work Breakdown Structure & Systems Engineering Management Plan | 8         |
| 4.2 Schedule & Risk                                                | 8         |
| <b>5. Design Layout &amp; Trade Studies</b>                        | <b>10</b> |
| 5.1 Derivation of Requirements                                     | 10        |
| 5.2 Configuration Selection & Trade Studies                        | 11        |
| 5.3 Planform Sizing & Scoring Analysis                             | 12        |
| <b>6. Design Sizing &amp; Optimization</b>                         | <b>13</b> |
| 6.1 Airfoil Selection                                              | 13        |
| 6.2 Planform Refinement                                            | 14        |
| 6.3 Winglet Optimization                                           | 14        |
| 6.4 Tail Sizing and Tapering                                       | 15        |
| 6.5 Subassembly Integration                                        | 16        |
| <b>7. Analysis &amp; System Testing</b>                            | <b>16</b> |
| 7.1 Loads Derivation                                               | 16        |
| 7.2 Drag Analysis                                                  | 17        |
| 7.3 Planform Validation                                            | 17        |
| 7.4 Control Surface Sizing                                         | 18        |
| 7.5 Layout – Mass Properties and Balance                           | 19        |
| 7.6 Stability Analysis                                             | 20        |
| 7.7 Propulsion Performance & Testing                               | 21        |
| 7.8 Launch Performance                                             | 22        |
| 7.9 Servo Sizing                                                   | 23        |
| 7.10 Wing Structural Sizing & Testing                              | 23        |
| 7.11 Fuselage Structural Sizing & Testing                          | 24        |
| 7.12 Landing Gear Sizing & Testing                                 | 26        |
| 7.13 Test Flights                                                  | 27        |
| <b>8. Manufacturing</b>                                            | <b>28</b> |
| 8.1 Materials                                                      | 28        |
| 8.2 Methods, Techniques & Tools                                    | 29        |
| <b>9. Conclusion</b>                                               | <b>29</b> |
| <b>10. 2D Drawing</b>                                              | <b>30</b> |
| <b>TDS: Aircraft Performance Prediction</b>                        | <b>31</b> |

## List of Figures

**Figure 1.1.1:** Render of *Toothless*

**Figure 4.1.1: (left)** Systems Engineering Management Plan & **(right)** Work Breakdown Structure

**Figure 4.2.1:** Project Gantt Chart

**Figure 5.1.1:** Micro Class Mission Profile

**Figure 5.3.1: (left)** Initial Planform Optimization & **(right)** Scoring Equation Sensitivity Analysis

**Figure 5.3.2:** Scoring Constraint Heatmap, 2.5 lbs Empty Weight

**Figure 6.1.1: (left)** XFLR5 2D Lift vs. AOA for Airfoils & **(right)** XFLR5 2D Lift vs. Drag for Airfoils

**Figure 7.1.1:** V-n Diagram

**Figure 7.2.1:** Drag Polar Curve and Glide Ratio vs.  $C_L$

**Figure 7.3.1: (left)** Wind tunnel testing & **(right)** Finite Wing 3D CL estimates from  $-1.5^\circ$  to  $11^\circ$  AOA

**Figure 7.4.1: (left)** Rudder Deflection Angle vs. Chord Ratio & **(right)** Time to Achieve  $30^\circ$  Bank Angle vs. Chord Ratio

**Figure 7.5.1: (left)** Assembled Payload & **(right)** Payload Fitment in Fuselage

**Figure 7.6.1: (left)** Longitudinal Static Stability & **(right)** Root Locus Plot of All Dynamic Modes

**Figure 7.7.1: (left)** Thrust vs Airspeed Data & **(right)** Dynamic Thrust Testing Setup

**Figure 7.8.1:** Simulated Takeoff Plots

**Figure 7.10.1: (left)** Bending Moments Acting Across a Half Span & **(right)** Wing Structure Loading Test

**Figure 7.11.1: (left)** Bending Moments and Shear Force Diagram at Landing & **(right)** Level Flight Case

**Figure 7.11.2: (left)** Fuselage Main Compartment Bending Test & **(right)** Torsion Test

**Figure 7.11.3: (left)** Shear Force and Bending Moment Graph of Tail Mounts & **(right)** Weighted Bending Test Setup

**Figure 7.12.2: (left)** MLG Stress Simulation & **(right)** Drop Test on Prototype Aircraft

**Figure 8.1.1:** Material Selection Chart

**Figure 8.2.1: (left)** Two Main Jig Bodies & **(right)** The Main Jigs & Spacers Used for Fuselage Assembly

## List of Tables

**Table 4.2.1:** Top Risks in Risk Register

**Table 5.1.1:** UBCAD Mission Objectives

**Table 5.2.1:** Summary of Configurations Considered for Concept Generation

**Table 5.2.2:** Weighted Decision Matrix Weights for Concept Generation

**Table 6.1.1:** Selected Airfoils

**Table 6.3.1:** Winglet Optimization Results

**Table 6.4.1:** Toothless Tail Sizing

**Table 7.1.1:** V-n diagram Resultant Airspeeds

**Table 7.2.1:** Parasitic Drag per Component

**Table 7.4.1:** Control Surface Sizing

**Table 7.5.1:** Calculated Neutral Point and Center of Gravity for All Loading Configurations of *Toothless*

**Table 7.6.1:** Stability Criteria Benchmarks

**Table 7.9.1:** Servo Sizing Results



## 1. Executive Summary

This year, UBC AeroDesign (UBCAD) Micro Class is delivering *Toothless*, an optimized, robust, and competitive blended-wing-body (BWB) aircraft. This report will detail the design process and methods applied by Micro Class (MCRC) alongside the decisions made in the development of this year's design. Continuing from last year's success with *Barbie*, UBCAD is aiming to increase the total flight score to 60 points by accepting higher risk in design, offset by diligent analysis, testing, and application of accumulated experience. *Toothless* employs a conventional tail design, tricycle landing gear, and a fully blended lifting body with a  $10^\circ$  static inclination angle. With a maximum takeoff weight (MTOW) of 4.2 lbs, a payload weight of 1.7 lbs, a 30 in wingspan, and a validated 5 lbs of thrust, *Toothless* performs under tight optimization constraints while maintaining sub-10 ft takeoffs (TO). Critically, this report describes in detail how *Toothless* will achieve a predicted 60-point total flight score, and how each level of system design was developed to make a competition-ready, top-three scoring aircraft.



**Figure 1.1.1:** Render of *Toothless*

## 2. List of Symbols and Acronyms

|                         |                                                     |
|-------------------------|-----------------------------------------------------|
| AoA, $\alpha$           | Angle of Attack                                     |
| $\alpha_{\text{stall}}$ | Stall Angle of Attack                               |
| ABS                     | Acrylonitrile Butadiene Styrene                     |
| AHP                     | Analytical Hierarchy Process                        |
| AR                      | Aspect Ratio                                        |
| $\beta$                 | Sideslip Angle                                      |
| BWB                     | Blended Wing Body                                   |
| CG                      | Center of Gravity                                   |
| $C_D$                   | Coefficient of Drag                                 |
| $C_{D, \text{min}}$     | Minimum Coefficient of Drag, Parasitic Drag         |
| CF                      | Carbon Fiber                                        |
| CFD                     | Computational Fluid Dynamics                        |
| $C_L$                   | Coefficient of Lift                                 |
| $C_m$                   | Coefficient of Pitching Moment                      |
| $C_{m, \alpha}$         | Derivative of $C_m$ , with Respect to $\alpha$      |
| $C_{m, q}$              | Derivative of $C_m$ , with Respect to Pitching Rate |
| $C_n$                   | Coefficient of Yawing Moment                        |
| $C_{n, \beta}$          | Derivative of $C_n$ , with Respect to $\beta$       |
| $C_{n, r}$              | Derivative of $C_n$ , with Respect to Sideslip Rate |
| $\Delta L$              | Net Lift Improvement                                |
| ESC                     | Electronic Speed Controller                         |
| FDM                     | Fused Deposition Modeling                           |
| FEA                     | Finite Element Analysis                             |
| FoS                     | Factor of Safety                                    |
| HT                      | Horizontal Tail                                     |
| Kv                      | Motor Velocity per Voltage Constant                 |
| LLT                     | Lifting-Line Theory                                 |
| MAC                     | Mean Aerodynamic Chord                              |
| MCRC                    | Micro Class                                         |
| MLG                     | Main Landing Gear                                   |
| MTOW                    | Maximum Takeoff Weight                              |
| NLG                     | Nose Landing Gear                                   |
| PETG                    | Polyethylene Terephthalate Glycol                   |
| PMF                     | Payload Mass Fraction                               |
| Re                      | Reynolds Number                                     |
| SEMP                    | Systems Engineering Management Plan                 |
| TO                      | Takeoff                                             |
| TPU                     | Thermoplastic Polyurethane                          |
| TWR                     | Thrust-to-Weight Ratio                              |
| $t_2$                   | Time to Double Bank Angle                           |
| UBCAD                   | UBC AeroDesign                                      |
| UIUC                    | University of Illinois Urbana-Champaign             |
| V                       | Velocity                                            |
| $V_A$                   | Maneuver Velocity                                   |
| $V_{\text{cruise}}$     | Cruise Velocity                                     |
| $V_{\text{dive}}$       | Dive Velocity                                       |
| V-n                     | Load Factor vs. Velocity                            |
| $V_{\text{stall}}$      | Stall Velocity                                      |
| VLMM2                   | Vortex Lattice Method 2                             |
| VT                      | Vertical Tail                                       |
| WBS                     | Work Breakdown Structure                            |
| $W_E$                   | Empty Weight                                        |
| WDM                     | Weighted Decision Matrix                            |
| $W_P$                   | Payload Weight                                      |
| $\zeta$                 | Damping Ratio                                       |

### 3. Referenced Documents & Specifications

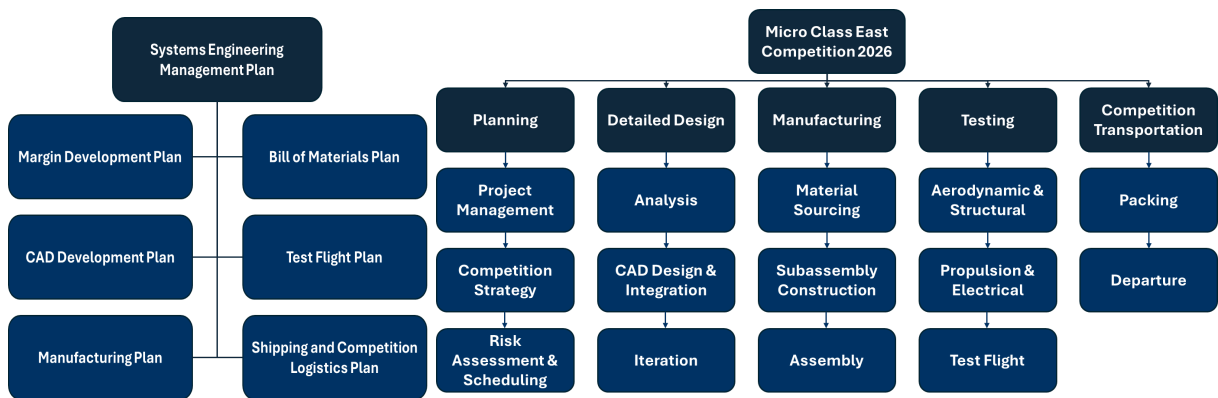
- [1] M. H. Sadraey, Aircraft Design - A Systems Engineering Approach. Chichester: John Wiley & Sons, 2013.
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[https://m-selig.ae.illinois.edu/ads/coord\\_database.html](https://m-selig.ae.illinois.edu/ads/coord_database.html)
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[http://www-materials.eng.cam.ac.uk/mpsite/interactive\\_charts/](http://www-materials.eng.cam.ac.uk/mpsite/interactive_charts/)

## 4. Project Management

Through the 2025-2026 year, UBCAD MCRC was structured under Fuselage/Landing Gear and Airfoils subteams for mechanical tasks, while electrical and propulsion responsibilities were split across subteams. UBCAD MCRC is composed of 14 members including four subteam leads, two for each subteam, who lead and mentor the others. Funding is received through university support and fundraised donations through sponsorships, totaling a \$4,400 CAD budget for all material purchases, with additional funding allocated to competition and logistical costs.

### 4.1 Work Breakdown Structure & Systems Engineering Management Plan

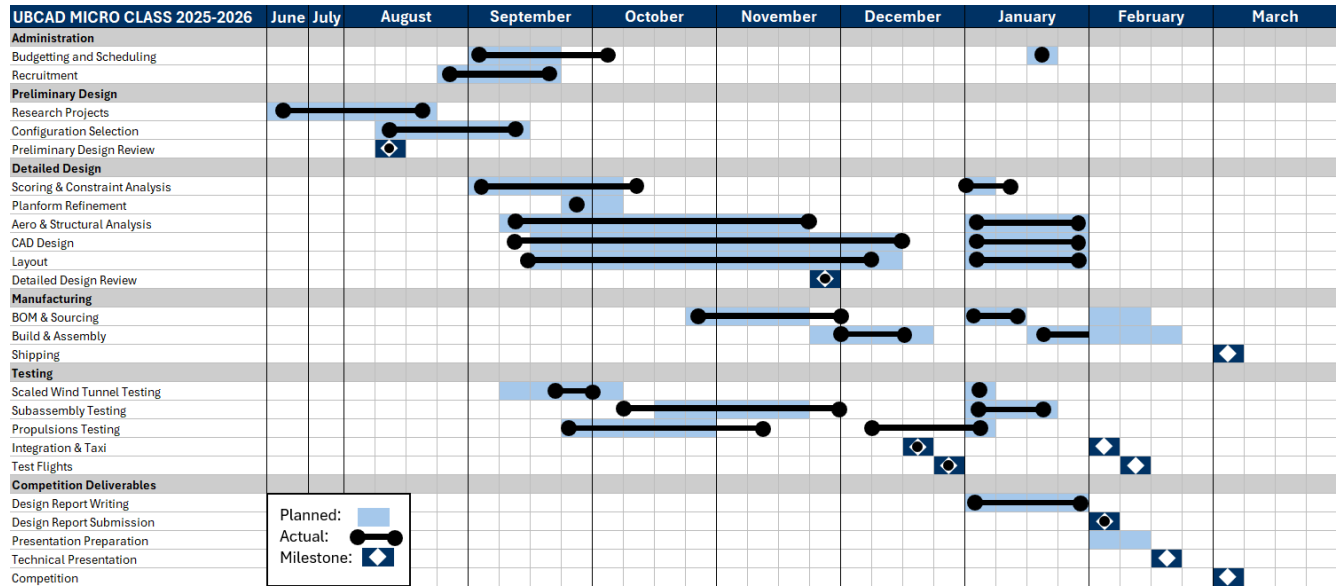
To track necessary work and ensure all technical and supporting aspects are accounted for, UBCAD developed a work breakdown structure (WBS) and systems engineering management plan (SEMP), as both shown in Figure 4.1.1.



**Figure 4.1.1: (left) Systems Engineering Management Plan & (right) Work Breakdown Structure**

### 4.2 Schedule & Risk

A high-level schedule for the project was developed as a Gantt chart shown in Figure 4.2.1. The project was divided into three phases: preliminary design over the summer, followed by detailed design, and finally competition. Preliminary design included focused research projects, while detailed design includes development and testing of the new design.



**Figure 4.2.1: Project Gantt Chart**

Optimization studies conducted during the preliminary design phase indicated that to remain competitive, UBCAD would need to adopt a higher performing, higher risk design compared to the previous aircraft. Managing and addressing this risk over a rapid design cycle would be critical to the team's success, and was accomplished through a risk register (Tab. 4.2.1) that organized risks and ranked them by a product score of likelihood and severity. The risk register was updated throughout the project, and many risks were identified based on prior experience.

**Table 4.2.1: Top Risks in Risk Register**

| Description                                       | Likelihood | Severity | Risk Score | Mitigation Actions                                                             |
|---------------------------------------------------|------------|----------|------------|--------------------------------------------------------------------------------|
| Weather delays test flights                       | 5          | 4        | 20         | Early planning, ensuring aircraft ready for open weather windows               |
| Analysis methods inaccurate for BWB               | 2.5        | 5        | 12         | Diversification of CFD methods; wind tunnel testing                            |
| CG misplacement                                   | 3          | 4        | 12         | Flight testing at different CG positions; diligent communication of weights    |
| Propeller torque effects compromise TO stability  | 3          | 4        | 12         | Use of stabilizing flight controller; ample aileron sizing; torque measurement |
| Propeller slipstream effects compromise stability | 2.5        | 4        | 10         | Margin in aileron and elevator sizing                                          |

Additional time was scheduled for higher risk tasks, and system testing was universally emphasized. Test flights are critical milestones for validating analyses, ensuring competition readiness, and de-risking the design.

## 5. Design Layout & Trade Studies

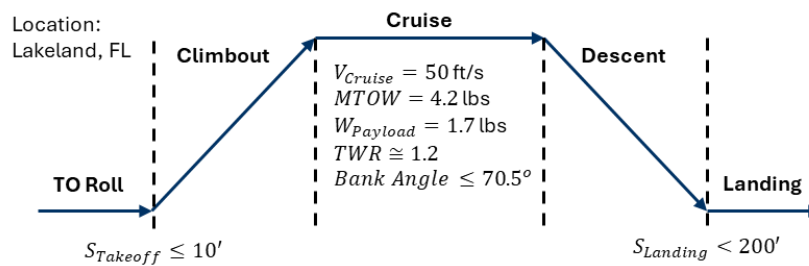
### 5.1 Derivation of Requirements

UBCAD's mission as defined by the 2025-2026 ruleset is to safely complete a single circuit flight and unload any carried liquid water payload after landing. SAE requirements, flight profile constraints, scoring criteria, and internal requirements are outlined in Table 5.1.1.

**Table 5.1.1: UBCAD Mission Objectives**

| SAE Requirements                       | Mission Constraints    | Scoring Criteria          | Internal Goals                          |
|----------------------------------------|------------------------|---------------------------|-----------------------------------------|
| 67 fluid ounce payload volume          |                        | Minimize wingspan         | Exceed previous aircraft                |
| 450 W power limit                      | Take off within 100 ft | Minimize takeoff distance | <i>Barbie's</i> flight score of 42      |
| Separate flight and avionics batteries | Land within 200 ft     | Maximize payload weight   | Complete three successful flight rounds |
|                                        |                        | Minimize empty weight     |                                         |

The above criteria alongside the experiences of the previous year from a similar ruleset allowed UBCAD to develop a competitive mission profile which emphasizes a sub-10 ft TO with a high fraction of payload weight. Figure 5.1.1 summarizes the mission profile and design parameters.



**Figure 5.1.1: Micro Class Mission Profile**

Planform parameters were determined (Sec. 5.3) resulting in the selection of a 30 in wingspan, 2.2 aspect ratio (AR) BWB design. A common maximum load factor of 3 was selected from Sadraey's [1] guidelines on typical load factors for general aviation and transport aircraft.

## 5.2 Configuration Selection & Trade Studies

UBCAD strategically selected a BWB design to maximize overall lifting area within the scoring equation's wingspan penalty. *Toothless's* fuselage airfoil was the determining factor in the feasibility and manufacturability of all other design elements. UBCAD selected GOE625 for its aerodynamic performance (Sec. 6.1) and deep camber, with maximum thickness at 30% mean aerodynamic chord (MAC), supporting payload and electronics integration. The resulting five BWB configurations considered for *Toothless* (Tab. 5.2.1) were compared using a Weighted Decision Matrix (WDM) scoring analysis.

**Table 5.2.1:** Summary of Configurations Considered for Concept Generation

| Design Element      | Conventional Tail w/ Boom | Conventional Tail w/ Rod | Inverted U-Tail w/ Rods ( Twin Motors) | V-Tail w/ Rods | Inverted U-Tail w/ Rods |
|---------------------|---------------------------|--------------------------|----------------------------------------|----------------|-------------------------|
| Wing Arrangement    | Monoplane                 | Monoplane                | Monoplane                              | Monoplane      | Monoplane               |
| Tail Shape          | Conventional Tail         | Conventional Tail        | Inverted U-Tail                        | V-Tail         | Inverted U-Tail         |
| Motor Configuration | Single Tractor            | Single Tractor           | Twin, Wing-Mounted                     | Single Tractor | Single Tractor          |
| Tail Attachment     | Single Boom               | Single Rod               | Twin Rod                               | Twin Rod       | Twin Rod                |

UBCAD selected the BWB with a conventional tail and single tail rod for ease of manufacturing and conventional controllability. The scoring criteria and relative importance of each criterion, which were determined using an Analytic Hierarchy Process (AHP), are outlined in Table 5.2.2.

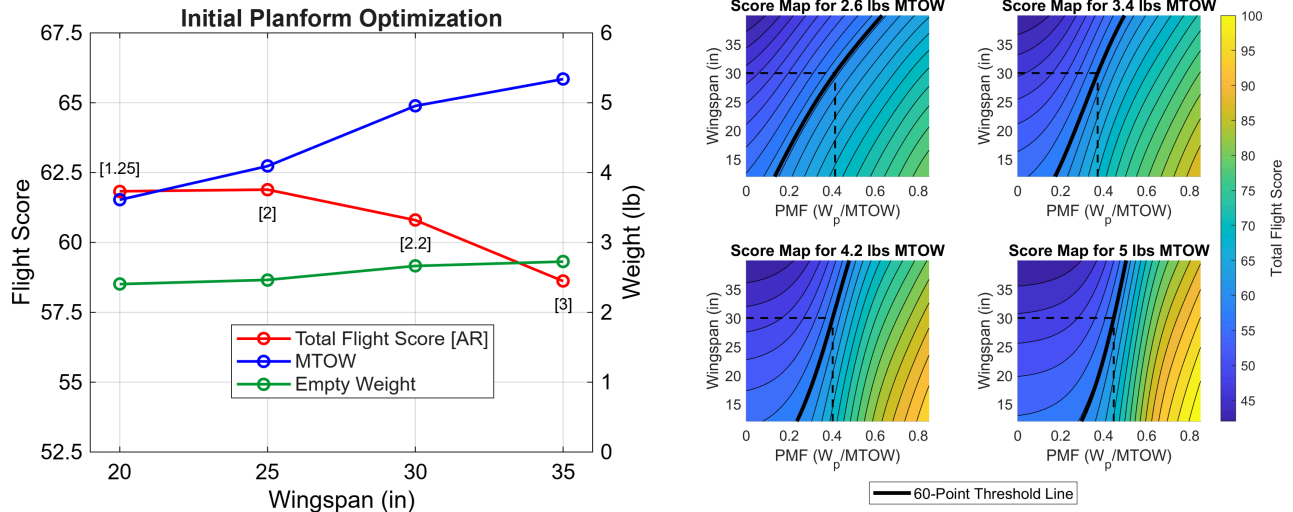
**Table 5.2.2:** Weighted Decision Matrix Weights for Concept Generation

| Manufacturability | Aerodynamic Efficiency | Ease of Integration | Ease of Payload Integration | Empty Weight | Stability and Control | Design Risk |
|-------------------|------------------------|---------------------|-----------------------------|--------------|-----------------------|-------------|
| 16%               | 12%                    | 13%                 | 14%                         | 15%          | 18%                   | 12%         |

UBCAD utilized 2024-2025 test flight and competition performance data to aid configuration selection. Additionally, UBCAD preferred the single carbon fiber (CF) tail rod chosen for its low weight. Inverted U-tail and V-tail configurations were screened out due to tail-rod manufacturing constraints, and reduced control authority for the vertical tail (VT).

### 5.3 Planform Sizing & Scoring Analysis

UBCAD applied an integrated process to select top-level constraints to achieve desired 60-point scoring with *Toothless*. To initially size its planform, TO performance of various wingspans and ARs were sampled, with fixed-BWB fuselage geometry and variable tapered wings. MTOW estimates for an assumed 10 ft TO were made with XFLR5 VLM2  $C_L$  simulations at a static inclination of  $10^\circ$ , with an averaged thrust dynamics model. Previous UBCAD aircraft weights were extrapolated by wingspan and AR to estimate empty weights. From each AR sampling, best score estimates were found, shown in Figure 5.3.1.



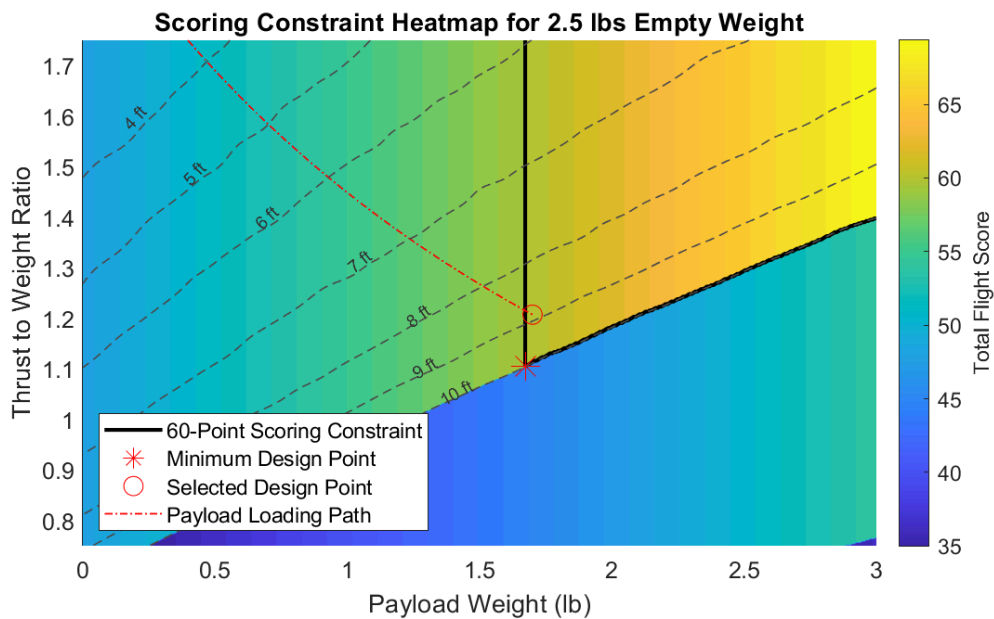
**Figure 5.3.1: (left) Initial Planform Optimization & (right) Scoring Equation Sensitivity Analysis**

A scoring sensitivity analysis (Fig. 5.3.1) was conducted to size a suitable MTOW, wherein empty weight ( $W_E$ ) and payload weight ( $W_p$ ) were combined into the payload mass fraction (PMF), with an assumed 10 ft TO that maximizes scoring. Selection of MTOW=4.2 lbs,  $W_E$ =2.5 lbs, and  $W_p$ =1.7 lbs permitted a low PMF with sufficient margins for subsystem weight uncertainties.

Following sensitivity analysis, takeoff simulation and Gudmundsson's style of constraint analysis [2] were combined to determine complete top-level requirements that ensure a sub-10 ft TO. Using a simulator detailed in Section 7.8, the TO distance constraint was proven to be



determinative of design requirements, unlike climb, cruise, and stall constraints. From planform sizing, a wing of span = 30 in and  $AR \approx 2.2$  was selected, balancing low-wingspan scoring gains against lateral stability losses. Wind and air density were considered from historical data in early March [3] near Lakeland, FL to select the mean minimum required thrust-to-weight ratio (TWR) of 1.14. While illustrating combined constraints, the method used to generate Figure 5.3.2 can also predict scoring in zero-wind conditions (Sec. 7.8).



**Figure 5.3.2:** Scoring Constraint Heatmap, 2.5 lbs Empty Weight

## 6. Design Sizing & Optimization

### 6.1 Airfoil Selection

UBCAD considered 33 airfoils from the UIUC airfoil database [4] for the wings, fuselage, and tail, through XFLR5's XFOIL. WDMs were used for each selection, with weights determined using an AHP. Considering the increased stability risk inherent to BWB designs, additional emphasis was placed on pitch stability, gradual stalls, and manufacturability.

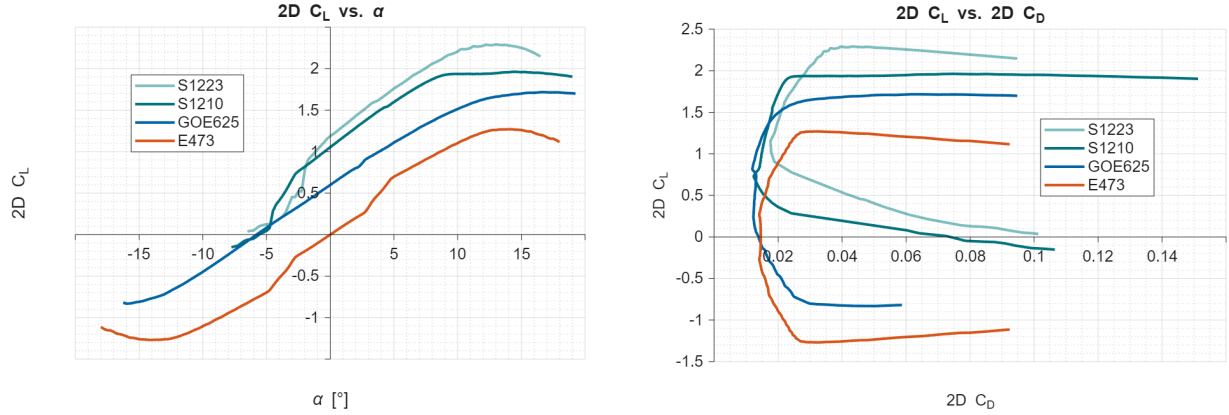
For the fuselage and wing, high maximum and average  $C_L$  values were favoured for  $\alpha \in [-3^\circ, 10^\circ]$ . The fuselage required airfoil sections that accommodated electronics and payload (Sec. 5.2), and

wing tips favoured higher  $\alpha_{\text{stall}}$ . In the empennage, high  $dC_L / d\alpha$  for  $\alpha \in [-10^\circ, 10^\circ]$  was prioritized.

The resulting airfoil selections are shown in Table 6.1.1 and compared in Figure 6.1.1.

**Table 6.1.1: Selected Airfoils**

| Lifting surface region                        | Fuselage       | Wing root  | Wing tip   | Empennage  |
|-----------------------------------------------|----------------|------------|------------|------------|
| Selected airfoil                              | Goettingen 625 | Selig 1223 | Selig 1210 | Eppler 473 |
| Analysis Reynolds number ( $\times 10^{-3}$ ) | 500            | 200        | 200        | 200        |



**Figure 6.1.1: (left) XFLR5 2D Lift vs. AOA for Airfoils & (right) XFLR5 2D Lift vs. Drag for Airfoils**

## 6.2 Planform Refinement

UBCAD refined *Toothless*'s planform to maximize  $C_L$ , using XFLR5's VLM2 simulations, with validation described in Section 7.3. Geometric constraints included a rear-aligned taper to move the wings' lift aft of the fuselage, and geometric twist to delay stall at the ailerons. First, taper location was refined, then the wingtip chord. Both processes yielded optima at their boundaries, with a minimum inboard taper position enforced to maintain fuselage volume and a minimum tip chord enforced to maintain  $Re > 100k$  in TO.

## 6.3 Winglet Optimization

To minimize lift loss from vortices, UBCAD optimized winglet fence geometry. Ansys Fluent was used to simulate various configurations'  $C_L$  values with a no-winglet control, with  $\Delta L$  defined as the lift increase at given conditions, adjusted to account for the weight of the winglets. Foamboard

was selected for winglet construction for its low weight and suitable strength. Table 6.3.1 outlines the results of the best-performing simulated winglet configuration.

**Table 6.3.1: Winglet Optimization Results**

| Parameter        | Control ( $\alpha=0^\circ$ , 50ft/s) | Winglets ( $\alpha=0^\circ$ , 50ft/s) | Control ( $\alpha=9^\circ$ , 34ft/s) | Winglets ( $\alpha=9^\circ$ , 34ft/s) |
|------------------|--------------------------------------|---------------------------------------|--------------------------------------|---------------------------------------|
| $C_L$            | 0.41977                              | 0.45803                               | 0.80586                              | 0.84373                               |
| $\Delta L$ (lbf) | 0                                    | 0.15286                               | 0                                    | 0.06602                               |

#### 6.4 Tail Sizing & Tapering

Working from the selected conventional tail configuration (Sec. 5.2), UBCAD iteratively minimized tail volume coefficients, with constraints on static stability (Sec. 7.6), CG position, and lifting surfaces' ARs (Tab. 6.4.1). Simultaneously, tail lifting surfaces were elevated relative to the fuselage to increase tail efficiency, lowering the required horizontal tail (HT) coefficient. For redundancy, combinations of lifting areas, tail arms, and HT incidences were sampled, minimally affecting optimal coefficients. After the general-requirements optimization, a larger VT coefficient was sized to mitigate adverse yaw from propeller-induced roll at TO.

**Table 6.4.1: Toothless Tail Sizing**

| HT Parameter  | Value    | VT Parameter  | Value    | Parameter             | Value                 |
|---------------|----------|---------------|----------|-----------------------|-----------------------|
| Volume coeff. | 0.5      | Volume coeff. | 0.065    | Tail vertical offset  | +5 in                 |
| AR            | 3        | AR            | 1.5      | Reference span, wing  | 30 in                 |
| Span          | 18.97 in | Span          | 7.746 in | Reference chord, wing | 14.23 in              |
| MAC           | 6.969 in | MAC           | 5.230 in | Reference area, wing  | 415.3 in <sup>2</sup> |
| Arm           | 21.97 in | Arm           | 20.03 in |                       |                       |
| Incidence     | -5 deg   | Root chord    | 5.770 in |                       |                       |

A CF tube was selected for the tail rod, with guy wires connected from the VT to the wings to resist torsion. Next, the total weight from lifting surfaces, the tail rod, and servo wire were formulated as a function of longitudinal tail position, from which the tail weight was minimized and tail lifting area fixed. The VT was then iteratively tapered to maximize  $dC_L/d\alpha$ , while the HT negligibly improved, so a rectangular HT planform was selected for manufacturability.

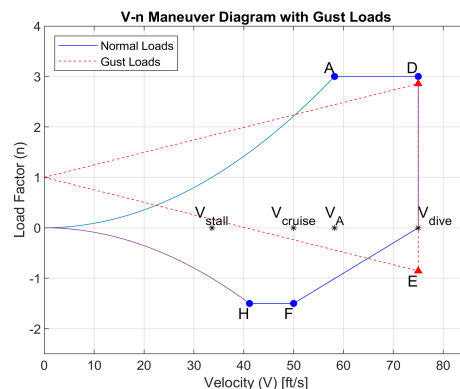
## 6.5 Subassembly Integration

*Toothless's* subassembly sizing was predominantly constrained by rib spacing and payload integration. UBCAD designed a non-structural, flexible payload within the fuselage compartment, constrained by plywood ribs and panels. Further, the motor mount and front compartment tapering were constrained by the nose landing gear (NLG) gearbox. For transportation, *Toothless* will be shipped in six sections: the fuselage, the spar, the wings, the NLG, the main landing gear (MLG), and the tail.

## 7. Analysis & System Testing

### 7.1 Loads Derivation

*Toothless's* overall load limits were analyzed with consideration for Lakeland, FL historic gust speeds [3] and the various phases of flight. Conventional design loads were chosen at +3G and -1.5G resulting in the generation of a V-n diagram, shown in Figure 7.1.1, using a maximum dive speed of 150% the cruise speed.



| Parameter                    | Velocity (ft/s) |
|------------------------------|-----------------|
| Power-off $V_{\text{stall}}$ | 33.6            |
| $V_{\text{cruise}}$          | 50              |
| $V_A$                        | 58.2            |
| $V_{\text{dive}}$            | 75              |
| Gust speed                   | 20              |

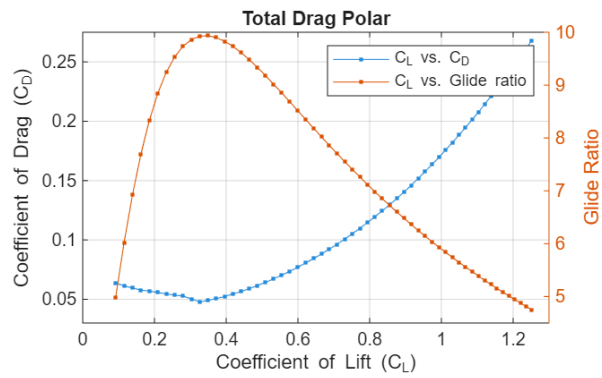
**Figure 7.1.1: V-n Diagram & Table 7.1.1: V-n Diagram Resultant Airspeeds**

V-n analysis was based on the methods outlined in Roskam [5], and the loading conditions defined by it informed the design of the main structures to ensure safety and integrity.

## 7.2 Drag Analysis

UBCAD conducted a polar drag calculation to validate preliminary design estimates. Using the component buildup method [6], parasitic drag ( $C_{D,min}$ ) for each major component was found, as shown in Figure 7.2.1, with a combined  $C_{D,min} = 0.0266$ . UBCAD modelled the induced drag curve using VLM2 on XFLR5, with  $AR = 2.167$  and an Oswald Efficiency Factor of 0.706 [1]. The resulting polar in Figure 7.2.1 shows the aircraft has a maximum  $C_L = 1.25$ , suitable for short-field TO, and a glide ratio of 10 for cruise performance.

| Component    | $C_{D,min}$    |
|--------------|----------------|
| Wing         | 0.00272        |
| Fuselage     | 0.02055        |
| Empennage    | 0.00322        |
| Landing gear | 0.000624       |
| <b>Total</b> | <b>0.02656</b> |

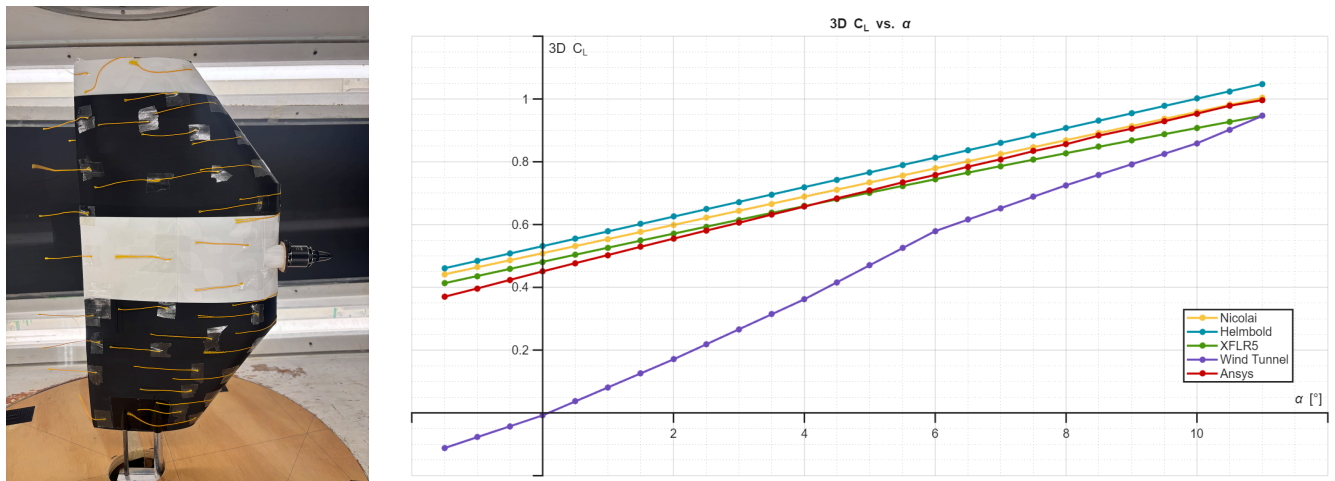


**Table 7.2.1:** Parasitic Drag per Component & **Figure 7.2.1:** Drag Polar Curve and Glide Ratio vs.  $C_L$

## 7.3 Planform Validation

UBCAD validated XFLR5 VLM2 analyses from Planform Sizing (Sec. 5.3) and Refinement (Sec. 6.2) with analytical, numerical, and empirical methods. Analytical methods extrapolated  $C_L$  from  $\alpha$  ( $C_L = 0$ ) with  $dC_L / d\alpha$  values estimated using methods for low ARs and idealized geometries [7, 8]. The Nicolai [9] method was included solely as a consistency check and is not used for quantitative performance prediction given its known limitations at lower ARs. Using  $C_L$  polars from XFLR5 XFOIL analyses, an aggregate 2D  $C_L$  slope used for all analytical validation methods was calculated with a chord-weighted spanwise integration of the planforms' airfoils. Additionally, Ansys Fluent CFD simulations supported analytical and XFLR5 LLT predictions.

To further validate these results, UBCAD performed wind tunnel testing in the UBC Parkinson Wind Tunnel to investigate  $dC_L/d\alpha$ , and  $C_L/C_D$  for  $\alpha \in [-8^\circ, 20^\circ]$  for comparison with analytical and numerical estimates. Discrepancies between numerical and wind-tunnel results are attributed primarily to uncertainties in the setup, including observed model flexing and geometric inconsistency under load. As the results exhibit greater agreement at higher AoAs, which is the primary region of concern for TO, deviations at lower AoAs are not especially concerning.



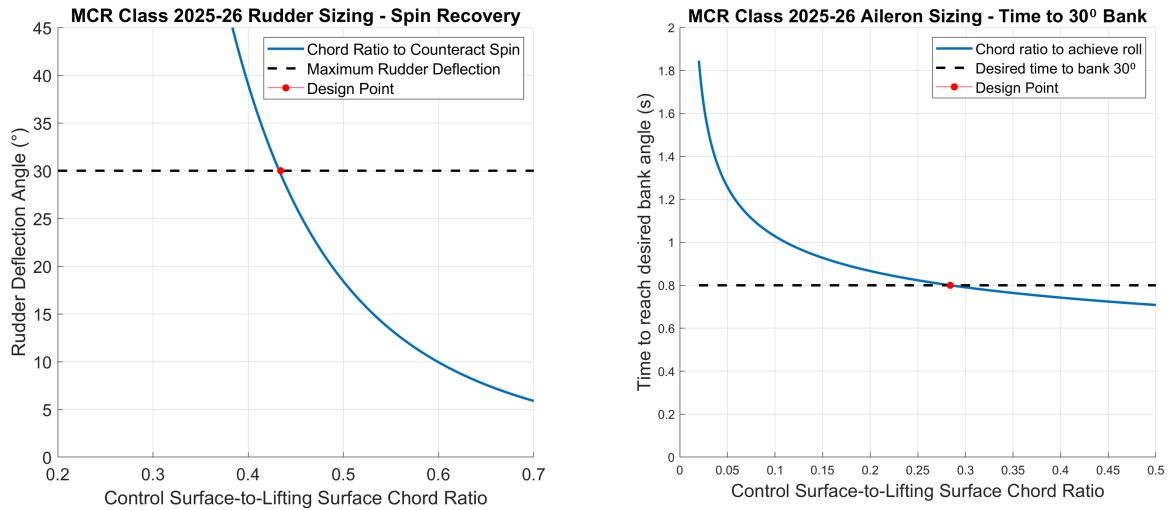
**Figure 7.3.1: (left) Wind tunnel testing & (right) Finite Wing 3D  $C_L$  estimates from  $-1.5^\circ$  to  $11^\circ$  AOA**

## 7.4 Control Surface Sizing

Implementing methods found in Sadraey [1], using MATLAB, UBCAD sized *Toothless's* control surfaces to meet performance requirements outlined in Table 7.4.1.

**Table 7.4.1: Control Surface Sizing**

| Control Surface | Identified Control-to-Lifting Surface Chord Ratio | Maximum Deflection Angle | Performance Parameter        | Projected Performance  |
|-----------------|---------------------------------------------------|--------------------------|------------------------------|------------------------|
| Ailerons        | 28%                                               | $20^\circ$               | Banking time to $30^\circ$   | 0.8 s                  |
| Elevator        | 20%                                               | $25^\circ$               | Takeoff angular acceleration | $20^\circ/s^2$         |
| Rudder          | 43%                                               | $30^\circ$               | Spin Recovery                | < 3s, at $270^\circ/s$ |



**Figure 7.4.1: (left) Rudder Deflection Angle vs. Chord Ratio & (right) Time to Achieve 30° Bank Angle vs. Chord Ratio**

## 7.5 Layout – Mass Properties & Balance

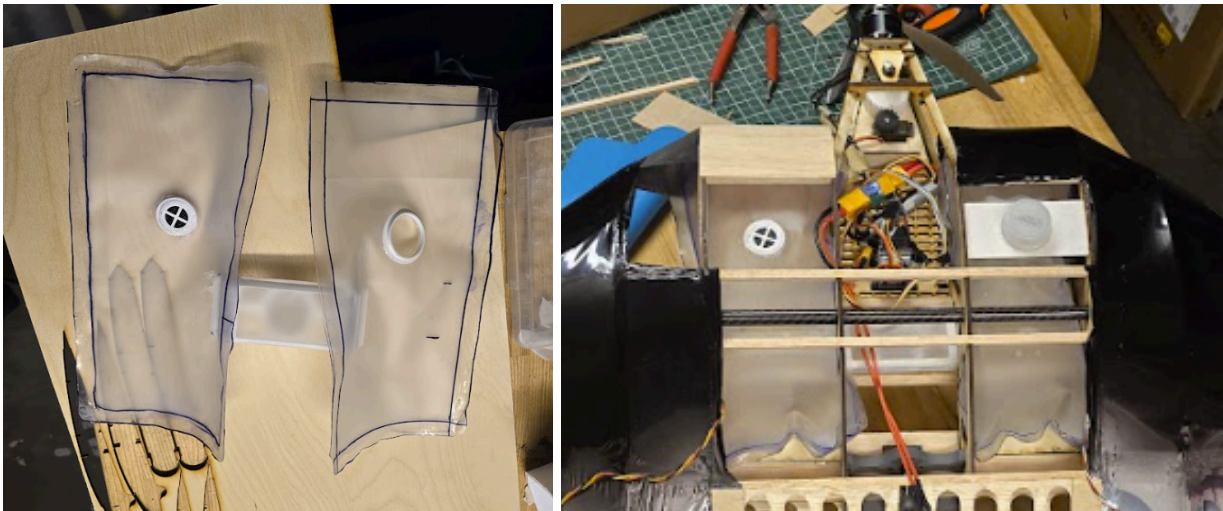
*Toothless's* layout was designed with safe CG and static margin (SM) location margins for unloaded and loaded flight, as flexible electronic placement can counteract CG changes. UBCAD used subassembly weights and estimated positioning from physical prototypes to construct an analytical moment balance [10] to refine designs and subassembly positioning. To minimize the CG margins due to payload sloshing, foam walls were installed aft of the flexible payload bag to constrict the volume. To mitigate CG shifts due to water sloshing within the payload compartment, baffles were installed in the midsection of the fuselage to restrict lateral flow.

**Table 7.5.1:** Calculated Neutral Point and Center of Gravity for All Loading Configurations of *Toothless*

| Payload Loading/Parameters                                     | 0%<br>0 lb   | 25%<br>0.425 lb | 50%<br>0.850 lb | 75%<br>1.275 lb | 100%<br>1.70 lb |
|----------------------------------------------------------------|--------------|-----------------|-----------------|-----------------|-----------------|
| Center of Gravity<br>(% MAC):                                  | 24.05        | 22.76           | 21.81           | 21.09           | 20.52           |
| Neutral Point<br>(% MAC):                                      | 43.4 for all |                 |                 |                 |                 |
| Neutral Point Position<br>(in aft of leading edge of MAC):     | 7.95         |                 |                 |                 |                 |
| Center of Gravity Position<br>(in aft of leading edge of MAC): | 3.42         | 3.24            | 3.10            | 3.00            | 2.85            |

The CG position of ~20% MAC with an MTOW of 4.2 lbs was validated with test flight data.

The payload is designed to meet the minimum volume requirement of 67 fluid ounces of liquid water at max capacity while keeping the same relative CG as the fuselage. The payload is laterally continuous with greater volume allocation in outboard fuselage regions, maintaining symmetry while providing space for electrical components inboard. With baffles built into its midsection, the payload has an average full drainage time of 13 seconds from testing.

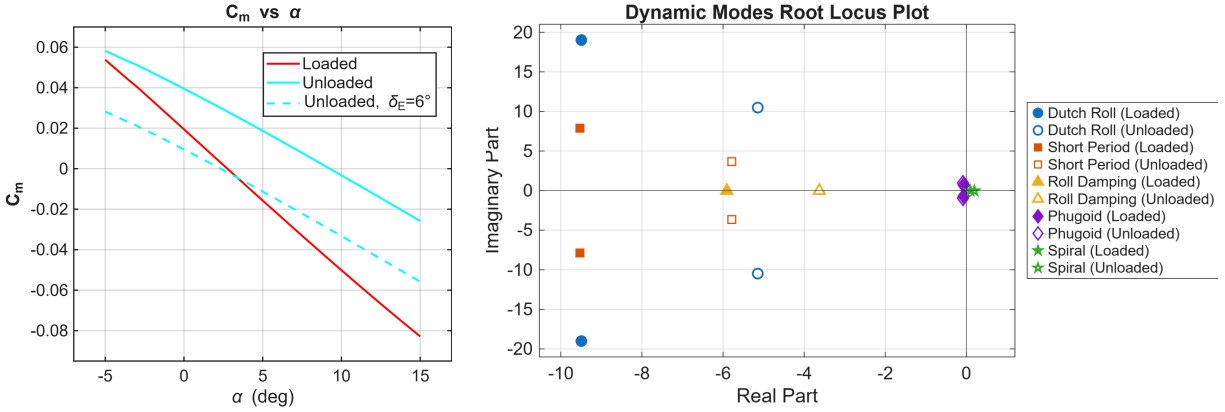


**Figure 7.5.1: (left) Assembled Payload & (right) Payload Fitment in Fuselage**

## 7.6 Stability Analysis

UBCAD verified *Toothless*'s static and dynamic stability with XFLR5 VLM2 simulations and eigenmode analyses, in loaded and unloaded cases. In both, the  $C_m$  vs.  $\alpha$  curves (Fig. 7.6.1) exhibit consistent longitudinal stability. While the unloaded  $C_{m,\alpha}$  (Tab. 7.6.1) falls outside requirements defined in Sadraey [1], the loaded case meets all static stability requirements, fulfilling the fully-loaded mission profile. When flying unloaded, a noticeable trim  $\alpha$  shift is corrected with a  $+6^\circ$  elevator deflection, indicating sufficient longitudinal control authority in all operating conditions. Further, strong directional stability ( $C_{n,\beta}$ ,  $C_{n,r}$ ) was confirmed, countering adverse yaw at TO.





**Figure 7.6.1: (left) Longitudinal Static Stability & (right) Root Locus Plot of All Dynamic Modes**

Dynamic modes, visualized in Figure 7.6.1 and quantified in Table 7.6.1, indicate the spiral mode is stable enough to be countered by aileron input. All other dynamic modes are stable and satisfy requirements per [11] in both loading cases.

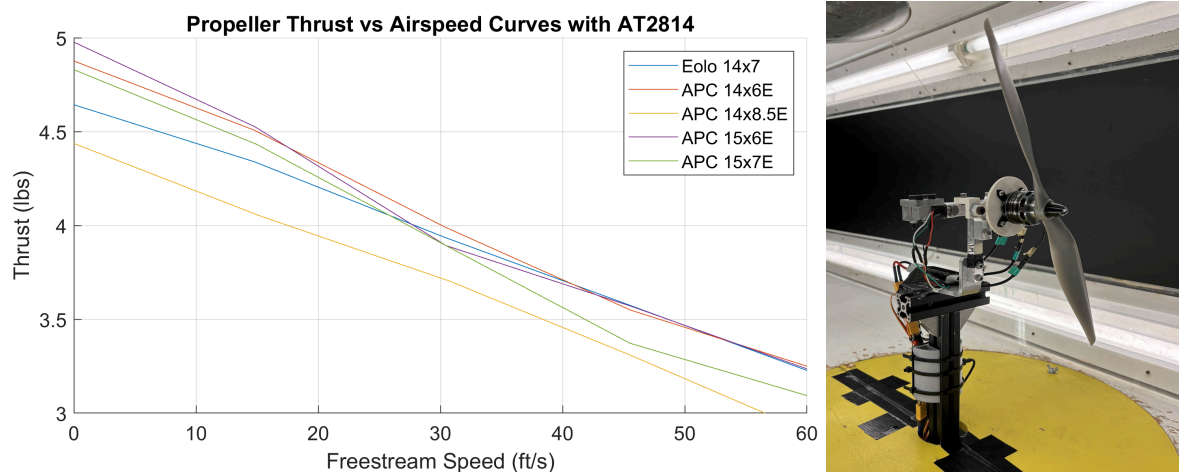
**Table 7.6.1: Stability Criteria Benchmarks**

| Criterion                          | $C_{m,\alpha} \text{ (rad}^{-1}\text{)}_1$ | $C_{m,q} \text{ (rad}^{-1}\text{)}_1$ | $C_{n,\beta} \text{ (rad}^{-1}\text{)}_1$ | $C_{n,r} \text{ (rad}^{-1}\text{)}_1$ | Dutch Roll $\zeta_2$ | Spiral $t_2 \text{ (s)}_2$ |
|------------------------------------|--------------------------------------------|---------------------------------------|-------------------------------------------|---------------------------------------|----------------------|----------------------------|
| <b>Characteristic Requirements</b> | $-1.5 < C_{m,\alpha} < -0.3$               | $-40 < C_{m,q} < -5$                  | $C_{n,\beta} > 0.05$                      | $C_{n,r} < -0.1$                      | $\zeta > 0.08$       | $t_2 > 8$                  |
| <b>Value (Loaded)</b>              | -0.3901                                    | -5.349                                | 1.125                                     | -1.974                                | 0.447                | 7.244                      |
| <b>Value (Unloaded)</b>            | -0.2446                                    | -4.918                                | 1.058                                     | -1.746                                | 0.441                | 3.543                      |

1: Per Sadraey [1, Tab. 6.3], 2: Per MIL-F-8785C [11, pp. 96-99, Class 1, Flight Phases B & C, Level 2]

## 7.7 Propulsion Performance & Testing

Thrust requirements set out in Section 5.3 defined the base requirements for *Toothless's* propulsion system. To maximize the specific thrust-to-weight ratio of the propulsion setup considering the 450 W power limit, larger diameter propellers in the 14-15 in region were investigated in combination with a low (800-1000) Kv motor. The resulting additional requirements in length and weight of the landing gear for propeller clearance were acceptable against the significant thrust improvement gained through the use of larger propellers. The T-Motor AT2814 KV900 motor was selected for its excellent torque for its weight. Various propellers were dynamically tested on a thrust stand, as shown in Figure 7.7.1, and the APC 14x6E was selected to best balance thrust, weight, and ground clearance requirements.

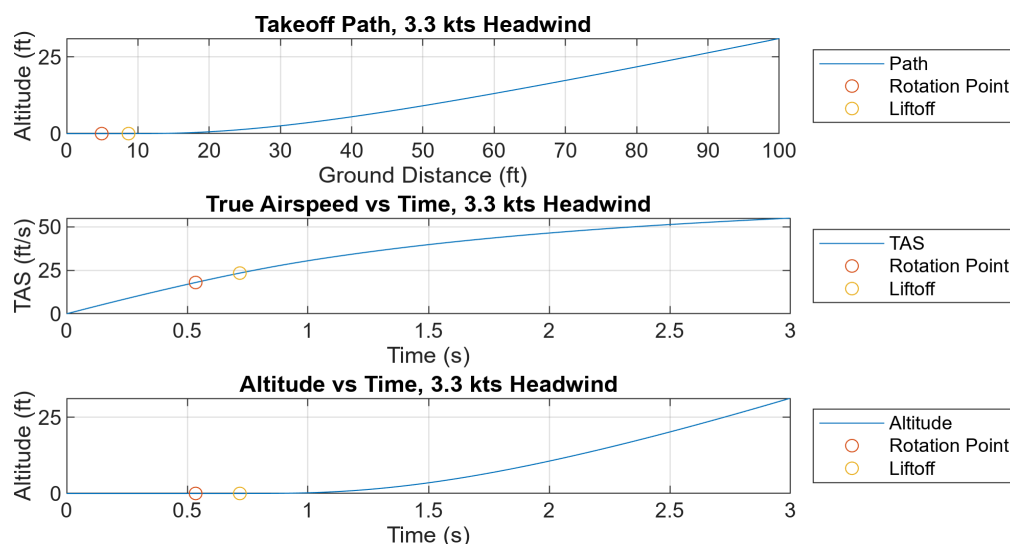


**Figure 7.7.1: (left) Thrust vs Airspeed Data & (right) Dynamic Thrust Testing Setup**

For the duration of the TO burst, the APC 14x6E and AT2814 combination produces 5 lbs of thrust. This setup, paired with a 1050 mAh battery and ultralight ESC, offers an overall aircraft TWR = 1.2 with an ample 3.5-minute estimated flight time.

## 7.8 Launch Performance

UBCAD applied a TO simulator to predict launch performance. The simulator uses lift and drag polars, weight, thrust, wind, air density, and static inclination to provide a simulated launch. An explicit Euler iterative scheme is applied to the 2D equations of motion, including TO rotation. The predicted TO path is shown in Figure 7.8.1, displaying ample obstacle-clearing ability.



**Figure 7.8.1: Simulated Takeoff Plots**

For the purposes of this analysis, the simulated aircraft pitches up to 15° from the horizon and maintains this in the climb with an expected 3.3 kt headwind. Launch performance, and therefore the ability to take off under 10 ft, was analyzed statistically from historical wind data [3] between 2022 and 2025 in early March near Lakeland. 60% of relevant hourly-averaged data points meet or exceed the minimum required headwind of 2.25 kts to achieve 60 total flight points. In the case of zero wind, the maximum attainable score is 56 total points. Based on achievable scoring at the lower 20th-percentile headwind, there is an 80% likelihood of scoring at least 57 total points, including TO distance safety margin, at competition. Further flight testing will enable model refinement from ground friction coefficients and the initiation point of rotation on takeoff.

## 7.9 Servo Sizing

UBCAD aimed to reduce aircraft weight by selecting lightweight servos. To support changes in historical analytical methods, UBCAD used both a conservative wind loading estimation of an angled surface and a moment analysis about the hinge using XFLR5. The control surfaces were set to maximum deflection angles (Sec. 7.4), and servos were selected to achieve a factor of safety (FoS) of at least 1.5, based on the highest torque demands from the ailerons.

**Table 7.9.1:** Servo Sizing Results

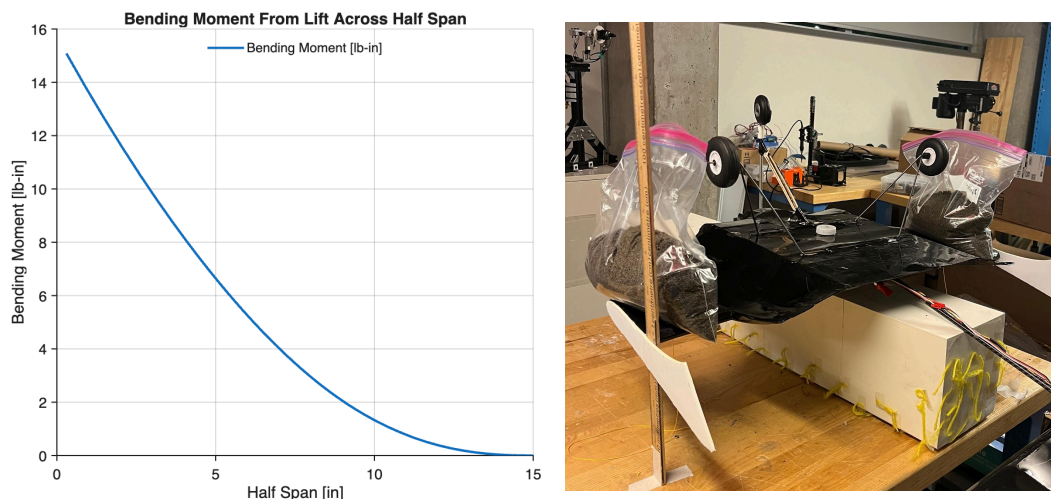
| Control Surface | Wind Pressure Moment [oz · in] | XFLR5 Moment [oz · in] | Servo Torque [oz · in] | Factor of Safety (FoS) |
|-----------------|--------------------------------|------------------------|------------------------|------------------------|
| Aileron         | 4.614                          | 1.173                  | 8.055                  | 1.746                  |
| Elevator        | 2.562                          | 0.142                  | 8.055                  | 3.144                  |
| Rudder          | 2.750                          | 0.921                  | 8.055                  | 2.928                  |

## 7.10 Wing Structural Sizing & Testing

Using XFLR5 LLT methods, the bending moment from lift at cruise (Fig. 7.10.1) was used to dimension a CF tube spar at FoS = 4.2, accounting for possible shock loading. In the tail, thin, twinned CF tube spars were sized for minimal weight. Next, to optimize longitudinal structures, UBCAD parametrically analyzed stress and deformation across all lifting surfaces' skins. Minimum

rib spacings were determined, at four ribs per outer wing section and the VT, and eight for the HT, minimizing structural weight while sufficiently supporting the skin. Analyses were performed using a coupled CFD-FEA study in Ansys Workbench, and verified with physical test models.

The wing was physically tested under static loading (Fig. 7.10.1), sustaining a tip loading of  $5.7 \times \text{MTOW}$  with moderate elastic deformation and no signs of fracture. Results indicate that the wings' structures increased the FoS beyond the intended  $\text{FoS} \geq 4$  for the spar alone, leading to increased rib lightening in design iteration.



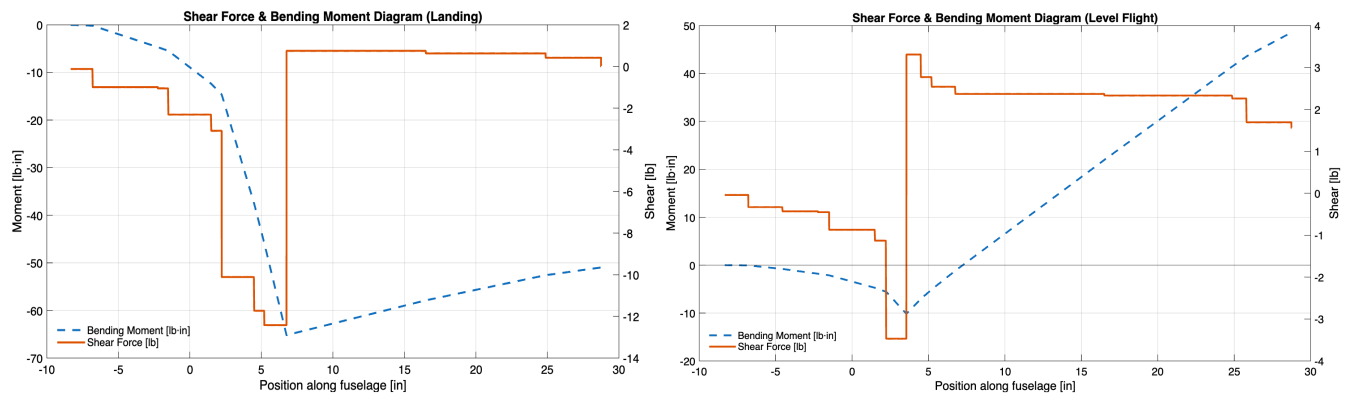
**Figure 7.10.1: (left) Bending Moments Acting Across a Half Span & (right) Wing Structure Loading Test**

### 7.11 Fuselage Structural Sizing & Testing

UBCAD optimized the lifting fuselage for weight, aerodynamic stability, and structural strength, with constraints of a 16 in chord and a 11.5 in width, resulting from payload, airfoil, and outboard wing (Sec. 6.2) geometry. Optimization resulted in using four plywood ribs, with space between the center ribs allocated for electronics and the tail mount. Additionally, stiffeners were used to improve torsional strength, with fracture observed at a  $19^\circ$  twist angle.

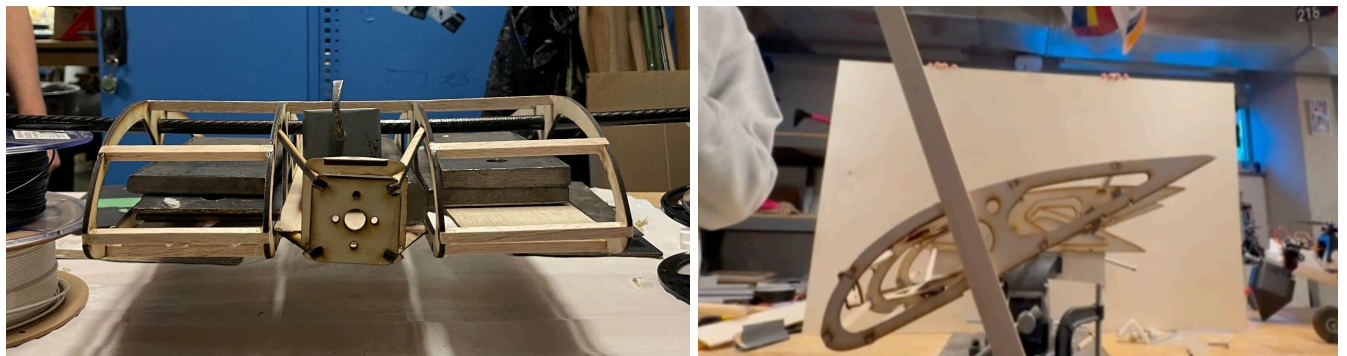
Structural bending and shear loading were evaluated through moment diagrams generated for level flight and landing load cases. Analytical results demonstrate that *Toothless* experiences a

maximum bending moment of 64.5 lb-in, under a landing load factor of three. Stiffener locations were optimized using bending and shear moment results to obtain a FoS = 1.4 against yielding.



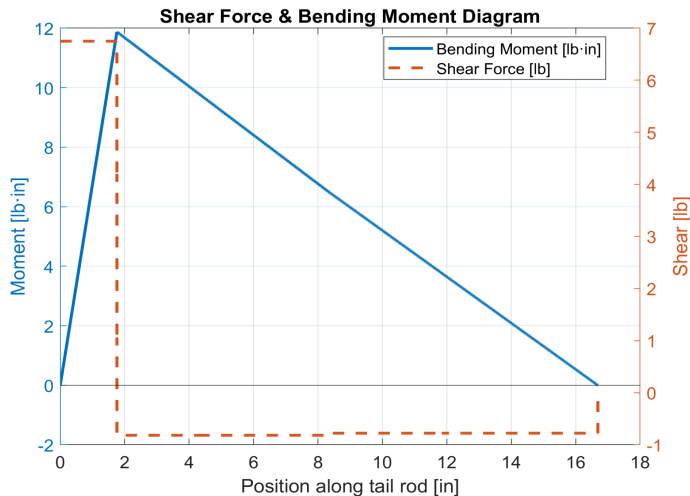
**Figure 7.11.1: (left) Bending Moments and Shear Force Diagram at Landing & (right) Level Flight Case**

Physical testing was performed on the fuselage compartment to verify the analytical results, including a bending test in which the fuselage sustained an 18 lb applied load, corresponding to a FoS = 1.47 against fracture on landing.



**Figure 7.11.2: (left) Fuselage Main Compartment Bending Test & (right) Torsion Test**

Tail mounts were designed to maximize strength, while minimizing weight and deflections of aerodynamic surfaces. CF-reinforced PETG was selected to 3D print the mounts for its superior elastic modulus and tensile strength compared to plain PETG. Rather than using a single tail mount, *Toothless* uses two lightweight, longitudinally spaced mounts to eliminate moments at the rib interfaces, yielding a 10.8% bending stress reduction, from 6560 psi to 5882 psi.



**Figure 7.11.3: (left) Shear Force and Bending Moment Graph of Tail Mounts & (right) Weighted Bending Test Setup**

The tail mounts were physically tested in a cantilever bending test, mimicking the mounted position. Weights were added at the end of the tail rod until failure, revealing a FoS = 2.8.

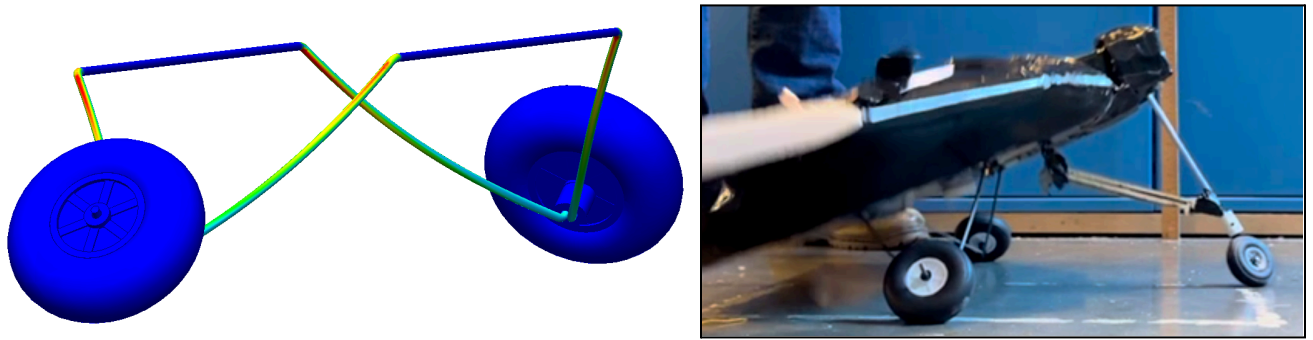
To integrate distinct fuselage and wing airfoil geometries, UBCAD designed a transition region to preserve aerodynamic performance while ensuring structural integrity. To minimize weight, the main body was constructed using 1/16 in balsa wood panels, while critical contour regions in the leading and trailing edge were reinforced by 3D printed components. From testing, panels were optimized to be 1 in wide and separated with 4 in gaps.

## 7.12 Landing Gear Sizing & Testing

UBCAD selected a tricycle landing gear configuration with a static AOA of  $10^\circ$  for maximum stability on takeoff. UBCAD's landing gear analysis was performed with Gudmundsson's methods [2], resulting in a wheel base and track of 10 in and 14 in, respectively.

UBCAD selected a steel music wire spring design for the MLG and a rigid CF strut with music wire for the NLG, optimizing for low weight and high impact-absorption, relative to other options.





**Figure 7.12.2: (left) MLG Stress Simulation & (right) Drop Test on Prototype Aircraft**

MLG and NLG designs were validated through FEA and dynamic testing. Following FAR standards [12], a prototype aircraft weighing 8 lbs was successfully dropped from a height of 7 in, proving the aircraft's ability to withstand worst-case landing conditions.

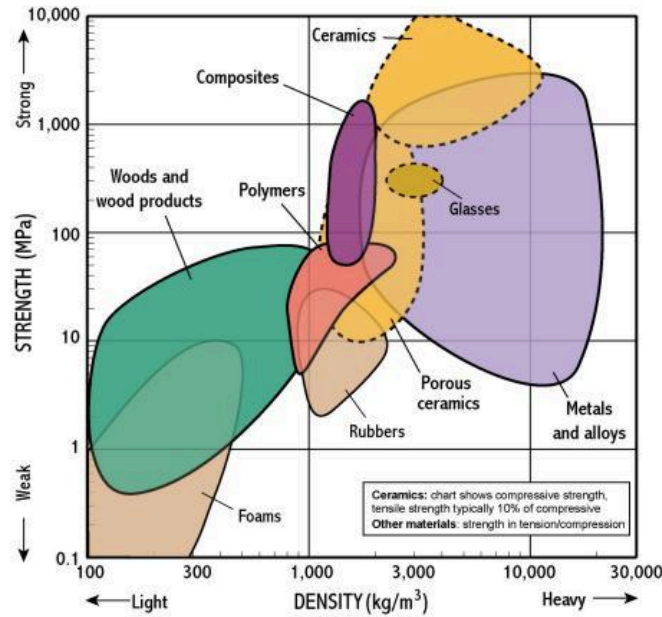
### 7.13 Test Flights

UBCAD places paramount importance on test flights for the insight and validation they provide. On December 28th, 2025, *Toothless* Mk I completed three successful flights from a grass strip and demonstrated excellent stability and cruise characteristics without gyro-stabilization. *Toothless* Mk I required ballasting to achieve a controllable CG, informing the Mk II allowable envelope and CG positioning. The Mk II aircraft, to be flown on February 8th, will address Mk I's shortcomings and be tested for TO distance and payload carrying ability in flight. Mk II will be flown repeatedly at varied weights to record TO distances on a rough turf field, enabling use of the ground friction coefficient to adjust the TO simulator for refined estimates on asphalt at competition.

## 8. Manufacturing

### 8.1 Materials

UBCAD used a material selection chart [13] to select materials with an optimal strength to weight ratio to maximize competition scoring. Balsa served as the primary construction material due to its low cost, simple manufacturability via laser cutting, and high specific strength.



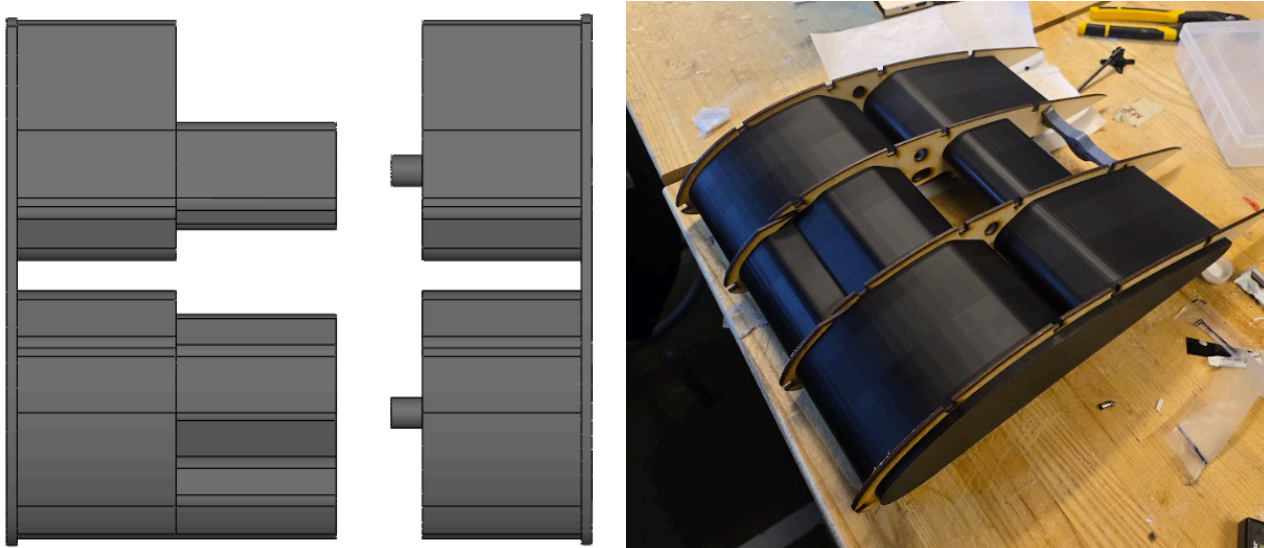
**Figure 8.1.1:** Material Selection Chart [13]

Laser-cut plywood was used in high stress areas, such as fuselage ribs and the front compartment, for its high absolute strength. By strategically isolating dense materials to primary load bearing regions, UBCAD minimized *Toothless's* empty weight, maximizing payload capacity. TPU sheets were used for the payload walls for its strength and ease of manufacturing, while its midsection, baffles, and air release valve were manufactured with FDM-printed ABS for its low density. CF was chosen for the wing spar and NLG for its excellent specific strength, while foamboard was used for the winglets and elevator to further optimize weight.

## 8.2 Methods, Techniques & Tools

UBCAD utilizes jigs for precise and efficient construction of all subassemblies. The jig for the fuselage used the lightening holes in the ribs to constrain them during construction. It was designed in eight parts: two main jig bodies and six spacers. The two main jigs constrain the panels from rotating about the plane's pitch axis, and the six spacers slide onto the main jig bodies and prevent the ribs from sliding along its pitch axis during the assembly process.





**Figure 8.2.1: (left) Two Main Jig Bodies & (right) The Main Jigs & Spacers Used for Fuselage Assembly**

The implementation of this jig during fuselage assembly, where the jig is constraining and spacing out the ribs before longerons are installed, is depicted in Figure 8.2.1.

## 9. Conclusion

UBCAD's third-ever Micro Class aircraft is a competitive design ready to achieve a top-three score. With a 4.2 lb MTOW, 1.2 TWR, and 30 in wingspan, *Toothless's* design represents the culmination of UBCAD's learned experiences and improved methods, reaching for a 60-point total flight score. In-depth analysis, rigorous validation, purposeful iteration, and thorough de-risking efforts applied both broadly and upon focused systems were essential to the delivery of UBCAD MCRC's most ambitious aircraft to date. UBCAD is confident *Toothless* will perform among the top aircraft at the 2026 SAE Aero Design East competition.

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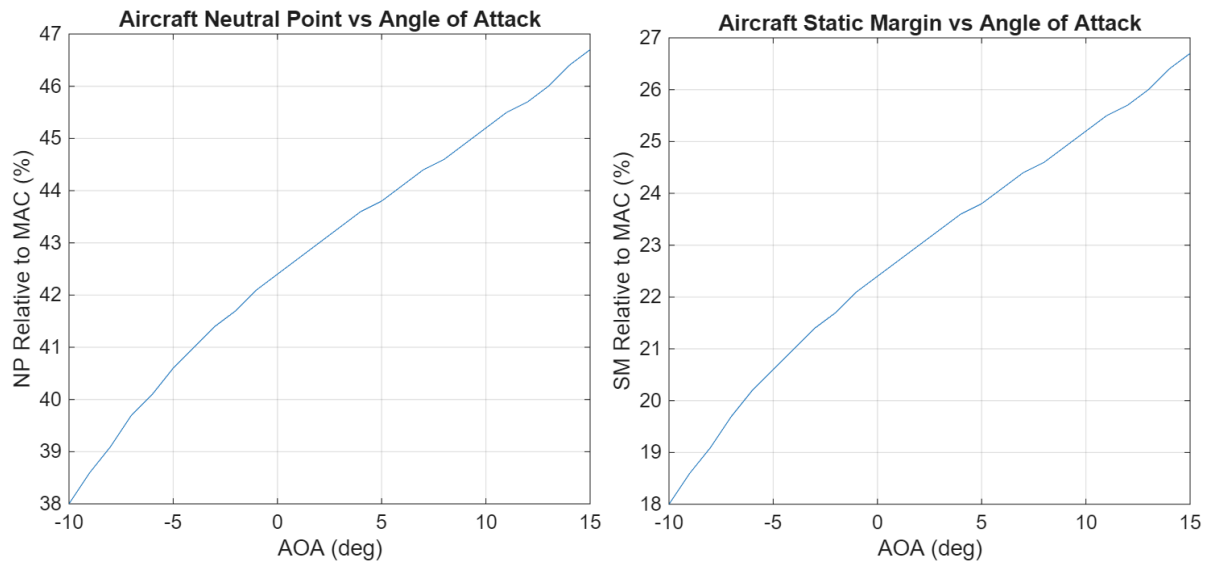
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## TDS: Aircraft Performance Prediction

UBC AeroDesign, University of British Columbia, Team: 302

To mitigate CG and NP shifts while in flight, *Toothless* was designed to restrict payload water movement with strategic rib and adjustable physical constraints for each loading configuration. The physical constraints mitigate water movement by compressing the empty volume. Figure 1 demonstrates the changing AOA's minimal impact on the neutral point and center of gravity location relative to the datum (leading edge of MAC) during expected flight conditions. As *Toothless* has an expected  $10^\circ$  AOA on takeoff and a  $3.4^\circ$  trim AOA during flight, Figure 1 indicates maximum location movement of 0.28 in (2% MAC) for the NP and SM, predicting aircraft stability in expected flying conditions.



**Figure 1: (left) Neutral Point Position from the Leading Edge & (right) Static Margin as a Function of Angle of Attack**