SAE Aero Design East 2025
Design Report

March 16, 2025

The University of British Columbia

UBC AeroDesign

Team 316 - Micro Class

Team Captains:

Simba Hu, Thenushaa Balasingam

Design Team Members:

Alanna Lu, Ayden Nguyen, Benjamin Chen, Benjamin Liu, Colten Rockford, Elijah Stewart, Evan Comba, Gabriel Lee, Josh Marwaha, Julia Shaw, Justin Yoon, Kevin Wang, Melody Leung, Michelle Nguyen, Nathan Ngai, Nic Chu, Rycel Luis Martos, Vansh Sharma

Statement of Compliance

APPENDIX A - STATEMENT OF COMPLIANCE

Certification of Qualification

Team Name	UBC AeroDesign Micro	Team Number	316
School	University of British Columbia		
Faculty Advisor	Sheldon Green		
Faculty Advisor's Email	sheldon.green@ubc.ca		

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 **2025** 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.

Sheldon G	March 10. 2025
Signature of Faculty Advisor	Date
Therushaa B	March 08th, 2025
Signature of Team Captain	Date

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1. Executive Summary

This report discusses the University of British Columbia AeroDesign (UBCAD)'s Micro Class (MCRC) competition aircraft, *Barbie*, for the 2024-2025 SAE Aero Design East Micro Class Competition. The team's objective this year is to bring a robust aircraft to competition, ensuring all systems are properly integrated and takeoff performance is validated. *Barbie* features a square fuselage with a high wing and conventional tail, mounted on a tricycle landing gear configuration. *Barbie* is designed to have a maximum takeoff weight (MTOW) of 6.0lb with a 40 in wingspan, and carry 3.0 lb of payload. With 6 payload configurations, *Barbie* is robust, reliable, and can achieve a maximum estimated score of 12.9 per flight round, which our team believes will allow us to place top three in the competition. The following sections describe the design, manufacturing, and testing UBCAD conducted to prepare *Barbie* for competition.

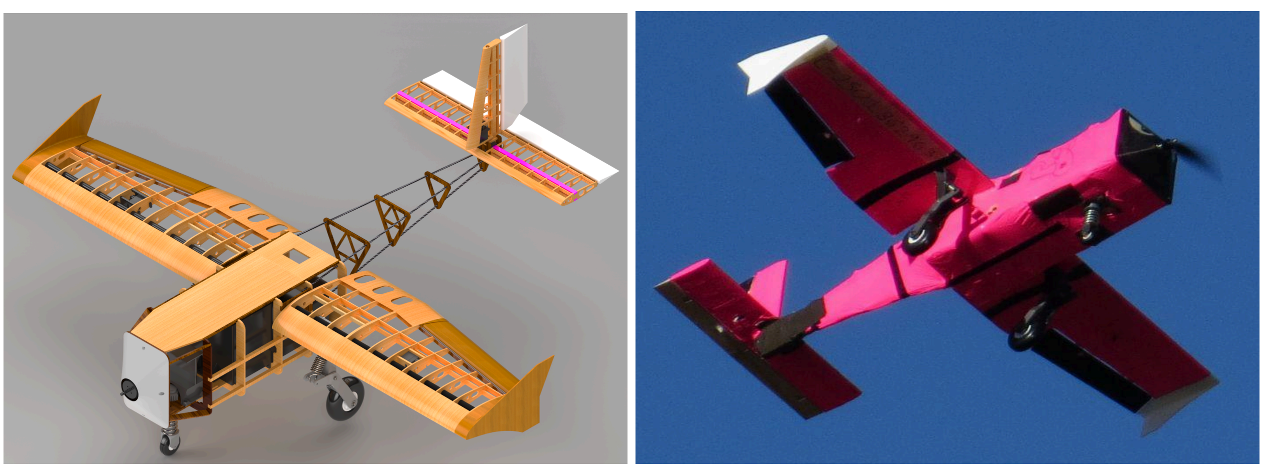

Figure 1.1.1: (left) Render of *Barbie* **(right)** *Barbie* in Flight

2. List of Symbols and Acronyms

α, AoA	Angle of Attack
AR	Aspect Ratio
C	Chord
C_D	Combined Aircraft Drag Coefficient
$C_{D,max}$	Maximum Combined Aircraft Drag Coefficient
$C_{D,min}$	Component Drag
C_{HT}	Tail Volume Coefficient for Horizontal Tail
C_l	Lift Coefficient for 2D Section Profile
C_L	Lift Coefficient for Finite Aspect Ratio Wing
$C_{L\alpha}$	Slope of Lift vs. Angle of Attack Curve for Finite Aspect Ratio Wing
$C_{L,max}$	Lift Coefficient at Maximum Angle of Attack for Finite Aspect Ratio Wing
C_M	Moment Coefficient
CF	Carbon Fibre
C_{VT}	Tail Volume Coefficient for Vertical Tail
HT	Horizontal Tail
MAC	Mean Aerodynamic Chord
MCRC	Micro Class
MLG	Main Landing Gear
MTOW	Maximum Takeoff Weight
NP	Neutral Point
NLG	Nose Landing Gear
PWT	Parkinson Wind Tunnel
PLA	Polylactic Acid
Re	Reynolds Number
SM	Static Margin
TO	Takeoff
T/W	Thrust-to-Weight Ratio
UBCAD	UBC AeroDesign
VLM2	Ring Vortex Lattice Method
VT	Vertical Tail
W	Weight
W_E	Empty Weight
WBS	Work Breakdown Structure
WDM	Weighted Decision Matrix
x_{CG}	Longitudinal Centre of Gravity Location
x_{NP}	Longitudinal Location of Neutral Point
λ	Taper Ratio

3. Referenced Documents & Specifications

[1] Raymer, D.P. (2018). Aircraft Design: A Conceptual Approach (6th ed.). American Institute of Aeronautics and Astronautics.

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[3] Selig, M. (n.d.). UIUC Airfoil Coordinates Database. University of Illinois at Urbana-Champaign. Retrieved June 15, 2024, from https://m-selig.ae.illinois.edu/ads/coord_database.html

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4. Project Management

The 2024-25 UBCAD MCRC team is composed of nineteen members assigned to Airfoils, Fuselage/Landing Gear, and Propulsions subteams. Each subsystem is managed by subteam leads, who are responsible for guiding members and ensuring work completion.

4.1 Systems Engineering Management Plan and Work Breakdown Structure

UBCAD developed a Systems Engineering Management Plan (SEMP) to create a framework for all activities done by the team. A Work Breakdown Structure (WBS) was developed to break down tasks into deliverables to provide an overview of all subteam activities. The two combined gives the MCRC team a detailed view of project maturity and ensures all deliverable completion.

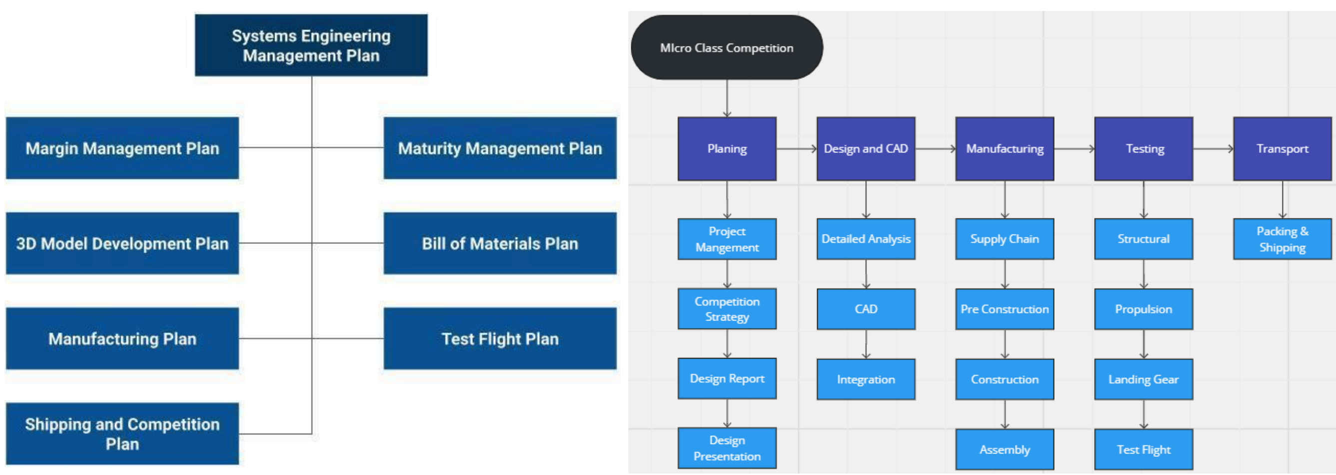


Figure 4.1.1: (left) SEMP Breakdown **(right)** WBS Categories

4.2 Schedule & Project Risk

UBCAD created a Gantt Chart (Figure 4.2.1) to plan our design progress. In the summer, the MCRC team initiated the preliminary design phase, where an initial timeline was created and modified as the design matured. To ensure a well-tested competition aircraft, the timeline was planned around three test flights; one before the design report, one before the technical presentation, and one at the competition airfield. The initial test flight was scheduled and completed on January 25th, 2025, providing valuable design feedback for our first iteration.

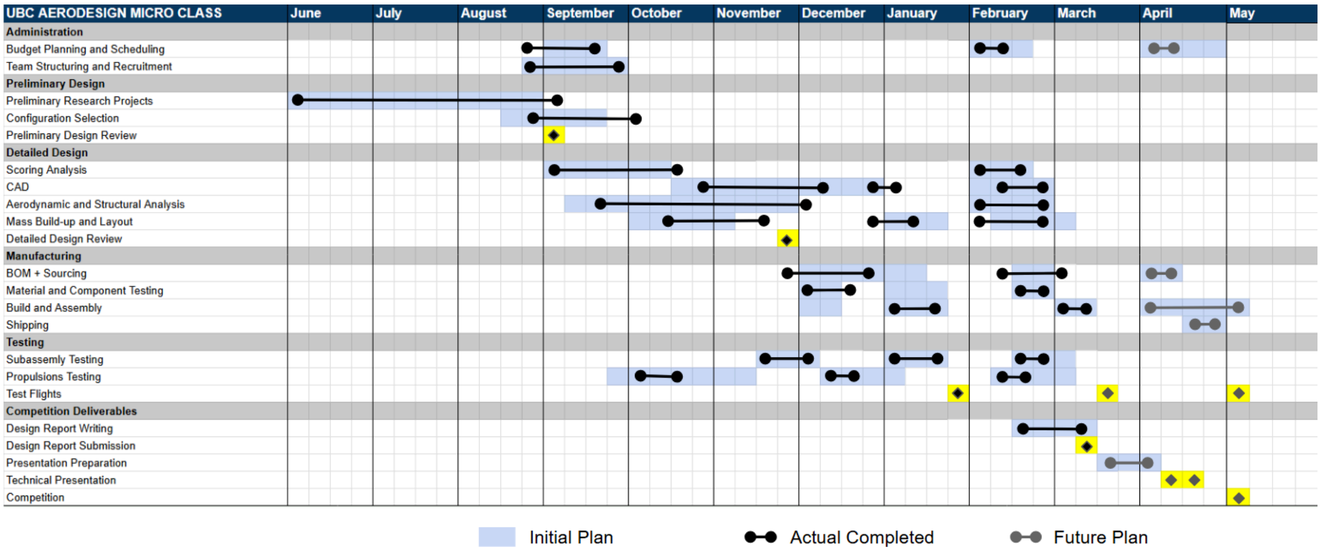


Figure 4.2.1: High-Level Gantt Chart, Showing Planned, Completed, and Future Timelines

A second test flight is planned for March 22nd, 2025 to allow the MCRC team to complete flight rounds mimicking the competition scenario. Planning three test flights meant strict manufacturing and integration deadlines. To reduce risk, the MCRC team opted for several familiar and safer design decisions, which has allowed us to meet deadlines.

5. Design Layout & Trade Studies

5.1 Derivation of Requirements

The MCRC aircraft's mission is to takeoff within the 100 ft runway limit, turn and cruise, and land safely within 200 ft. After landing, water must be released from the payload container in one minute. The aircraft design objectives are summarized in Table 5.1.1.

Table 5.1.1: Summary of Aircraft Design Objectives

Scoring Requirements	SAE Requirements	Flight Plan Constraints
Minimize Wingspan & Empty Weight Minimize Takeoff Distance Maximize Liquid Payload Weight	Maximum 450W Power Draw 67 fluid ounces payload container	Must takeoff within 100 ft Must land within 200 ft

To fulfill the design objectives, UBCAD developed a mission profile to extract competition and aerodynamic requirements (Figure 5.1.1) and a flight envelope for structural requirements (Section 7). A scoring equation sensitivity analysis led to a Maximum Takeoff Weight (MTOW) of 6.0 lb, carrying 3.0 lb of liquid payload allowing for a competitive design. Initially, the empty weight (W_E) was set to be 3.5 lb and the payload weight was 2.5 lb. The W_E was reduced down to 3.0 lb while the payload weight was increased to 3.0lb as initial test flight results gave confidence to *Barbie's* takeoff (TO) performance. Scoring analysis assumed a 25 ft runway TO, as a 10 ft ground-roll was deemed unfeasible based on the constraint analysis performed in section 5.2

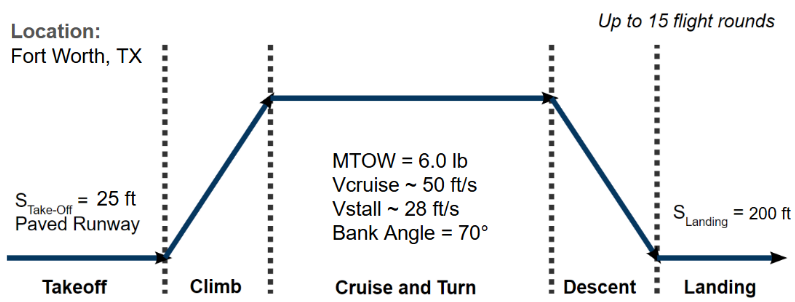


Figure 5.1.1: *Barbie's* Mission Profile Diagram

An aspect ratio (AR) of 5 was selected to minimize the wingspan with high lift, verified with preliminary XFLR5 finite wing analysis. A load factor of 3 was decided based on Raymer's chart of common load factor for transport aircraft [1].

5.2 Scoring Analysis

A sensitivity analysis on the scoring equation was performed by varying one parameter while holding others constant, allowing UBCAD to prioritize design parameters that most significantly impact score as shown in Figure 5.2.1.

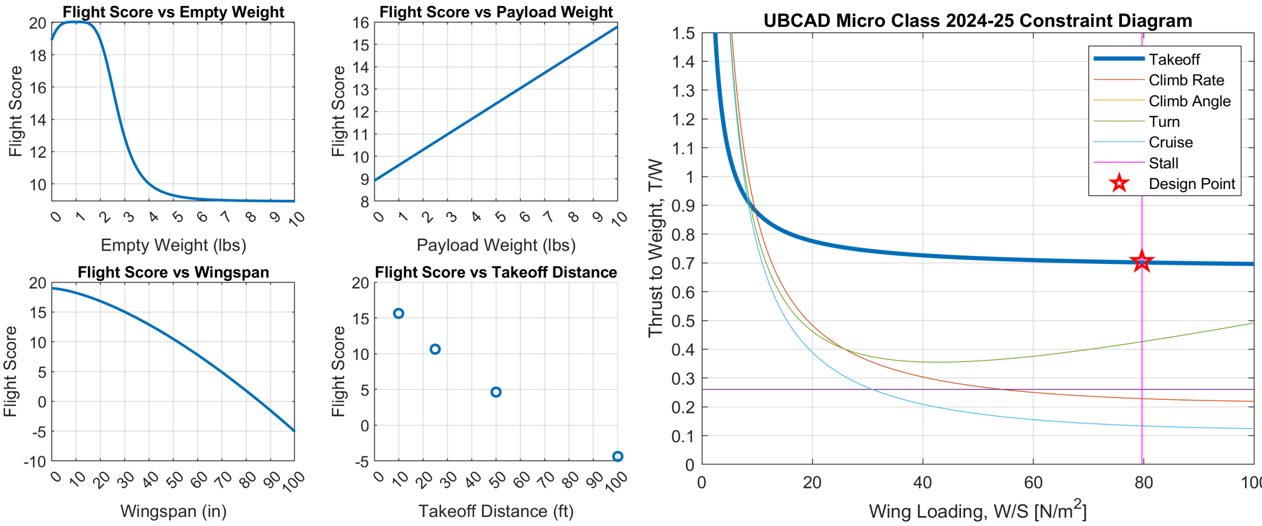


Figure 5.2.1: (left) Sensitivity Analysis on Scoring Equation & **(right)** Constraint Diagram for *Barbie*

Following the sensitivity analysis, TO performance and W_E were prioritized in the design. The TO bonus, the largest contributor to the flight score, made a 25 ft TO crucial. Decreasing W_E from the initial 3.5 lb to 3.0 lb also significantly increased the score. High-level aircraft parameters were determined and optimized with Gudmundsson's constraint diagram theory [2], creating a constraint diagram (Figure 5.2.1 (right)) to constrain the aircraft design space. Preliminary lift values from XFLR5 indicated a wingspan of 40 in was necessary for sufficient lift in TO. The constraint diagram marks a red star at the design flight case, where all flight conditions are met. TO was identified as the most demanding flight regime, requiring a 0.7 T/W based on the rudimentary analysis. A detailed TO analysis (Section 8.2) confirmed that with our design, *Barbie* would score 12.9 points per flight round by taking off within 25 ft.

5.3 Configuration Selection and Trade Studies

UBCAD considered five aspects for *Barbie's* configuration (Table 5.3.1), integrating them into five concepts.

All concepts utilize a bulkhead and stringer fuselage type for structural integrity.

Table 5.3.1: Summary of Configurations Considered for Concept Generation

Design Element	Traditional Single	Traditional Twin	Bi-Wing Single Prop Traditional	Narrowbody Single	Inverted V Double Rod Push-Pull
Wing Placement	High	High	High	High	High
Wing Arrangement	Monoplane	Monoplane	Biplane	Monoplane	Monoplane
Tail Shape	Conventional tail	Conventional tail	Conventional tail	Conventional tail	V- tail
Motor Configuration	Single Tractor	Twin, Wing-Mounted	Single Tractor	Single Tractor	Push Pull
Tail Attachment	Single Boom	Single Boom	Single Rod	Single Boom	Twin Rod

To compare the initial concepts, UBCAD performed a scoring analysis with a Weighted Decision Matrix (WDM) based on the criteria outlined in Table 5.3.2. Weightings for the WDM were defined by their judged relative importance to the aircraft design's objectives, and from previous years' experiences. Specifically, the performance of the previous year's aircraft led UBCAD to place an emphasis on stability and ease of analysis. From UBCAD's analysis, the traditional single configuration scored highest, minimizing the design risk and maximizing stability and control.

Table 5.3.2: Weighted Decision Matrix Weightings

Manufacturability	Aerodynamic Efficiency	Ease of Integration	Ease of Payload Removal	Empty Weight	Stability and Control	Design Risk
4%	23%	13%	5%	18%	20%	17%

For the tail configuration, UBCAD performed an XFLR5 Ring Vortex Lattice Method (VLM2) analysis to assess downwash effects on the tail, evaluating wing downwash angles across α from -14° to 13.5°. The analysis indicated that positive α's are most likely to impact the tail (Figure 5.3.1). Trigonometric calculations using the downwash angle and tail arm confirmed the tail remains free of wing downwash effects across all α's during flight.

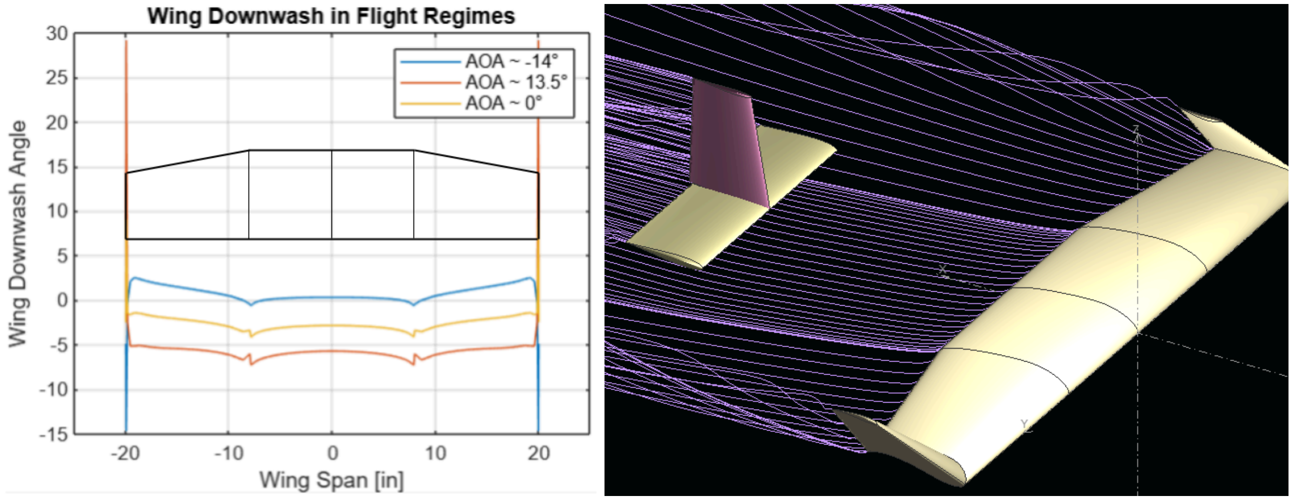
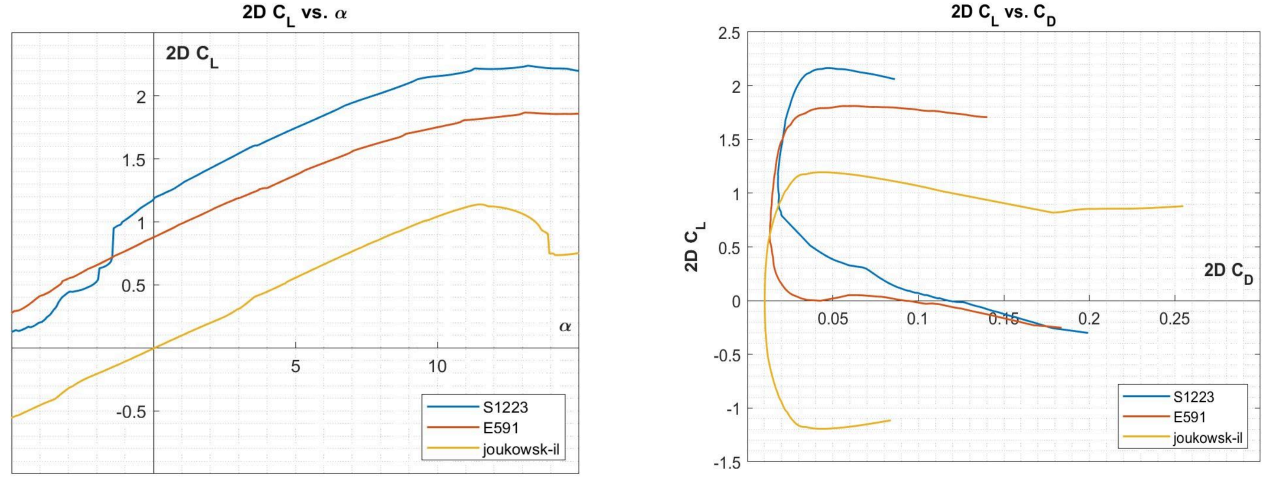


Figure 5.3.1: (left) Wing Downwash with Varying AOA's & **(right)** XFLR5 Flow Stream Visualization at 0° AOA

6. Design Sizing and Optimization

6.1 Airfoil Selection

UBCAD considered fifteen airfoils from the University of Illinois Urbana-Champaign airfoil database [3], comparing them with a WDM that prioritized high C_L, C_L/C_D, and strong stall characteristics, averaged over -5° to 10° AoA. These values were analyzed in XFLR5's XFOIL using Lifting Line Theory (LLT) at a fixed freestream speed of 50 ft/s. The S1223 was chosen as the wing root for its high C_L (1.764) and C_L/C_D (46.6), while the E591, with a higher critical α, was selected for the wingtips to improve stall behaviour. For the empennage, symmetrical airfoils with high $dC_L/d\alpha$ were prioritized for responsiveness in elevator deflection. The Joukowsk-il was selected for



the vertical tail (VT) and horizontal tail (HT). Figure 6.1.1 shows the airfoils' aerodynamic properties.

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

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

6.2 Wing Sizing

Wing sizing was conducted to optimize *Barbie*'s AR. As outlined in the constraint diagram and scoring equation in Section 5.2, UBCAD constrained the wingspan to 40 in, with an AR of 5. These values were determined to reduce the risk of LLT low AR assumption inaccuracies and provide ease of manufacturing.

6.3 Wing Planform Design

UBCAD developed a 3D finite wing with a root chord of 8.649 in and a tip chord of 6.486 in by optimizing for values of C_L=0.871, C_D=0.0947, and C_M=-0.427 using an XFLR5 LLT analysis. The tip-to-root taper was fixed to optimize the taper location spanwise. This location was then fixed to optimize the taper. UBCAD did not incorporate geometric twists, sweeps, or other features that contribute minimally to subsonic flight [4]. The XFLR5 analysis agrees with confirmatory methods described in [5, 6], however our wind tunnel tests resulted in lower lift values due to interface friction between the wing and the bottom of the wind tunnel (Figure 6.3.1).

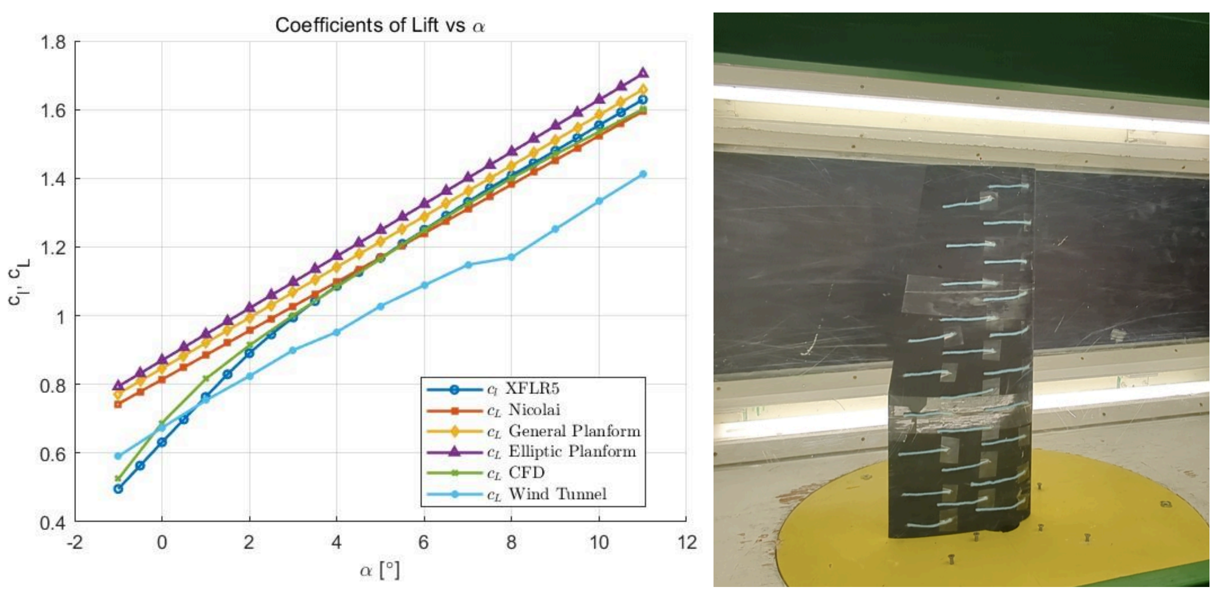


Figure 6.3.1: (left) XFLR5 LLT vs. 3D Finite Wing Correction C_L Predictions & **(right)** Wind Tunnel Testing

6.4 Tail Sizing

A conventional empennage configuration was chosen. UBCAD set values for the wing and frustum geometry based on the target score of 12.9, then iterated volume coefficients and tail AR to optimize its layout. The aim was to produce a stable tail with predictable flight characteristics, ensuring confidence in pitch and yaw authority. VT and HT volume coefficient values were adopted from Gudmundsson's textbook [2], specifically referencing an agricultural aircraft for their relevance to the design requirements: short landing and TO ability, optimized low-speed flight performance, and maneuverability with liquid payloads. Values for tail arm and empennage sizing (Table 6.4.1) were calculated iteratively from XFLR5 simulations and using equations from [2]. From test flight feedback, the angle of incidence was removed from the HT as it affected cruise and TO stability.

Table 6.4.1: *Barbie* Tail Sizing

Parameters	**Value**	**Parameter**	**Value**
VStab AR	1.50	Vertical Tail area	32.16 in^2
HStab AR	3.00	Horizontal Tail Area	15.53 in
Vstab Volume Coeff.	0.04	Vertical Tail Span	6.94 in
HStab Volume Coeff.	0.50	Average Horizontal Tail Chord	5.18 in
Wing reference span	40 in	Average Vertical Tail Chord	4.63 in
Wing Geometric Chord	8 in	Length of Tail	19.5 in
Radius of tail boom at Wing	2.5 in		
Radius of tail boom at Tail	0.5 in		

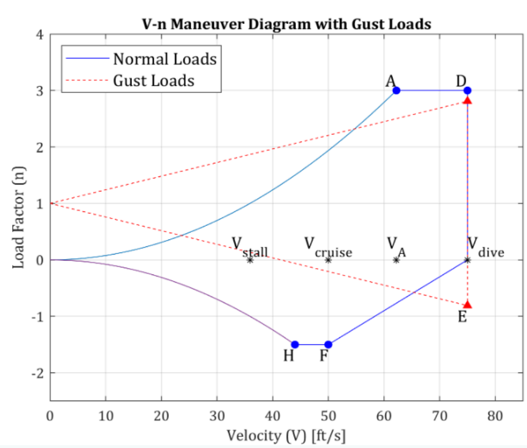
The tail section thickness at the quarter chord provides clearance at the optimal TO angle of attack (AoA) while maximizing space for the tail section structure, further explored in Section 8.8. With the wingspan constrained to 40 in and the wing geometric chord constrained to 8 in (Table 6.5.1), the tail length was calculated to be 19.5 in using formula 11-56 from Gudmundsson's text on p. 513 [2].

6.5 Subassembly Sizing and Interfaces

Barbie's main sizing constraint is the minimum payload volume. UBCAD constructed a rigid payload with internal baffles to prevent sloshing. To remove the payload, the aircraft's bulkheads create an open-top hatch. Because of logistical constraints, *Barbie* is designed to be transported in four pieces: the fuselage with the spar permanently attached, the wings, the nose landing gear (NLG), and the main landing gear (MLG). The engine compartment's horizontal taper is constrained by the NLG's gearbox. The tail section is tapered vertically for maximum ground clearance during takeoff. Tapering begins 4.8 in behind the wings to provide space for the payload container and electronics.

7. Loads Derivation

The limit loads for *Barbie's* various flight conditions were analyzed, and gust loads using historical averaged gust wind velocities at Fort Worth, Texas [7] were considered. *Barbie* was designed to handle loads of dive speeds up to 150% of the cruise speed, and design load factors of +3 and -1.5 were used to design the aircraft structures following the V-n diagram shown in Figure 7.1.1 based on methods presented in [8]. The averaged gust wind speed and Barbie's flight velocities are shown in Table 7.1.1 below.



Parameters	Velocity (ft/s)
Positive V_{stall}	28.0
V_{cruise}	50.0
V_A	62.2
V_{dive}	75.0
Gust Wind Speed	15.0

Figure 7.1.1: (left) V-n Diagram for *Barbie* with Normal t LoadsGus & **(right)** Flight Envelope Velocity Table

8. Analysis & System Testing

8.1 Drag Analysis

UBCAD conducted a drag polar analysis (Figure 8.1.1) to validate drag estimates made in preliminary design and airfoil selection. *Barbie*'s $C_{D,min}$ was calculated with the skin friction of all major components through the component drag buildup method [2], as shown in Table 8.1.1. To model *Barbie*'s drag polar, UBCAD calculated the induced drag factor based on an LLT XFLR5 analysis, with an Oswald efficiency factor of 0.901 calculated from Raymer's estimation formula [1]. The viscous factor, K'', was determined by plotting a linear fit between C_D and the curve $(CL - CL_{min})^2$ with 3D airfoil data, as per Nicolai's method [5]. The resulting drag polar confirms our aircraft's excellent drag characteristics, with an optimal glide ratio of around 10.

Component	$C_{D(min)}$
Fuselage	0.0130
Wing	0.0085
Horizontal stabilizer	0.0019
Vertical stabilizer	0.0011
Landing gear	0.0113
Total	**0.0358**

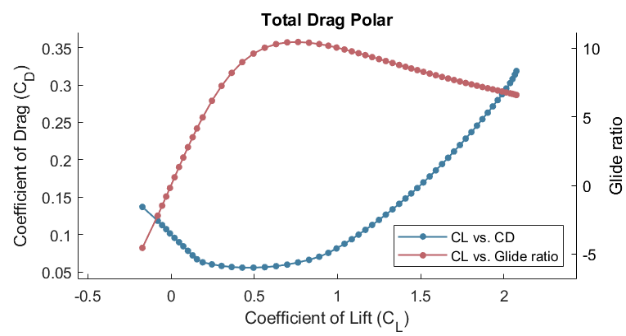


Table 8.1.1: (left) C_{Dmin} from Different Plane Components & **Figure 8.1.1: (right)** Total Drag Polar

8.2 Runway/Takeoff Performance

Takeoff is a crucial constraint in the scoring equation and constraint diagram. To ensure *Barbie* can takeoff within 25 ft, UBCAD developed a takeoff simulator [8]. TO distance vs thrust required was plotted (Figure 8.2.1), assuming a ground friction coefficient of 0.04 for hard turf [2]. The analysis determined that 3.4 lb of thrust is needed for a 25 ft takeoff, with a 1.25 FoS to account for uncertainties.

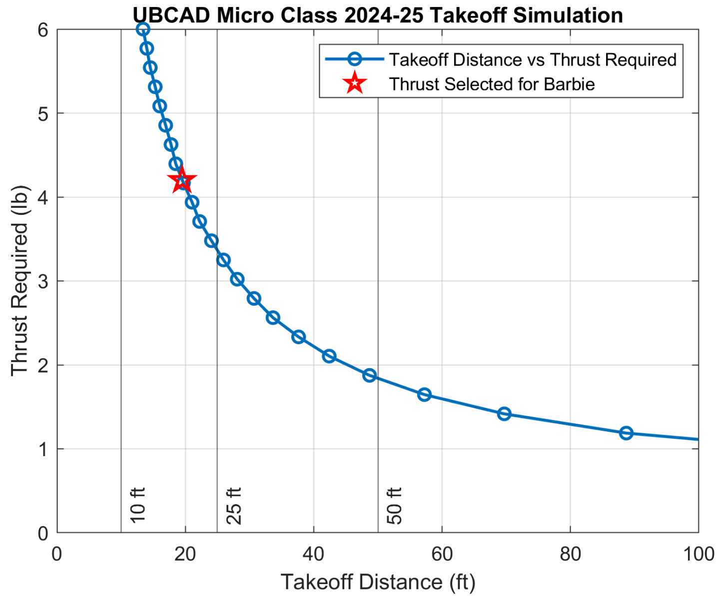


Figure 8.2.1: Thrust Required vs Takeoff Distance

Using the lift and drag data derived in Section 6.3 and 8.1, along with thrust values obtained from dynamic testing in Section 8.6, the ground roll, transition, and climb-out performance was calculated(Figure 8.2.2), where the 2D equations of motion were solved through numerical integration. A climb angle of 8° and 8 ft obstacle height was assumed for this analysis.

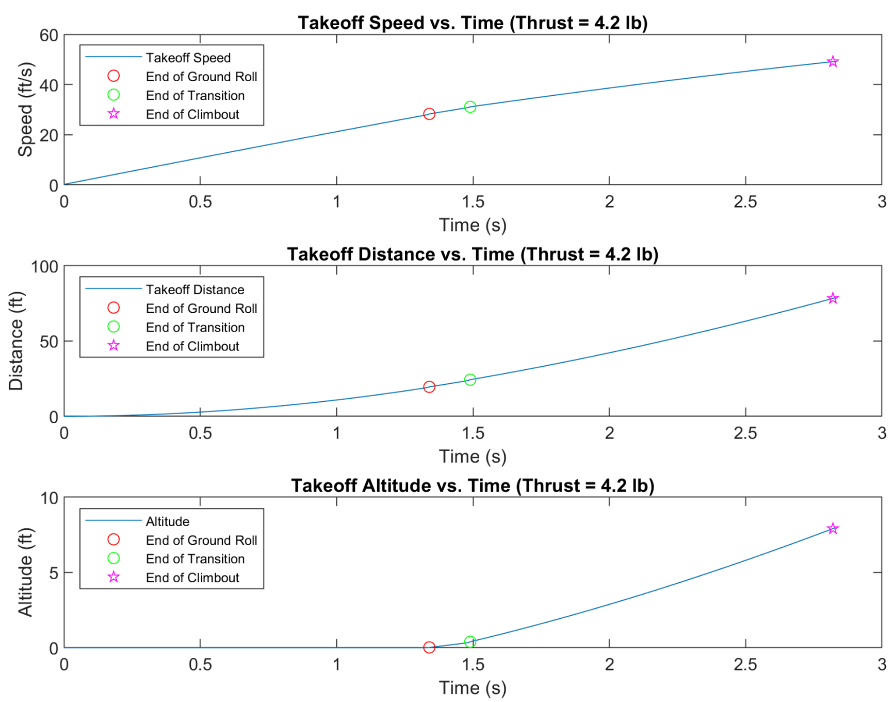


Figure 8.2.2: Takeoff Speed, Distance, and Altitude vs Time with Ground Roll, Transition, and Climb-Out

Barbie can take-off comfortably in <25 ft in 1 second, and is able to climb out of the way of any 8 ft obstacle within 3 seconds.

8.3 Control Surface Sizing

Given the maximum deflection angle and performance parameters derived using Sadraey's critical value method [4] in MATLAB, the aircraft's control to lifting surface ratios were set to meet performance requirements, shown in Table 8.3.1, ensuring maneuverability.

Table 8.3.1: Control Surface Sizing

Control Surface	Control-to-Lifting Surface Chord Ratio	Maximum Deflection Angle	Performance Parameter	Projected Performance
Ailerons	25%	20°	Banking time to 30°	~ 1.3 s
Elevators	36%	20°	Takeoff angular acceleration	$20°/s^2$
Rudder	27%	30°	Cross-wind speed for deflection angle < 30°	Cross-wind < 9.57 mph

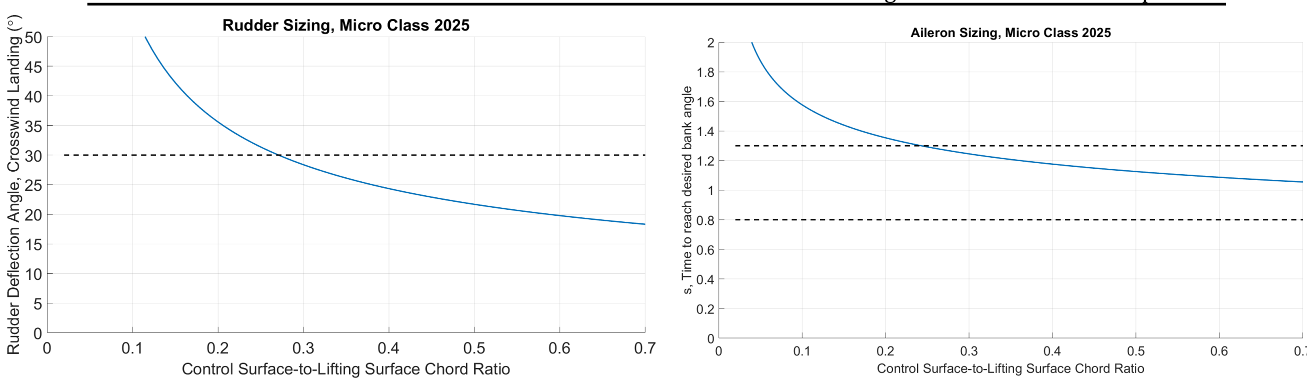


Figure 8.3.1: (left) Rudder Deflection Angle vs. Control Surface to Lifting Surface Chord Ratio & **(right)** Time to Reach Desired Bank Angle vs. Control Surface to Lifting Surface Chord Ratio.

8.4 Roll Stability Improvement

In addition to induced drag reduction, UBCAD considered winglets to increase roll stability. An Ansys Fluent CFD study was conducted to compare roll stability with features such as wingtips, dihedrals, and increased wingspan, using the CFD parameters validated in Section 6.3. This was done to determine potential roll stability improvements to our 36 in wing from 2024. A steady state crosswind was simulated at roll AoA between -16° and 16°. This analysis demonstrated that a wingspan of 40 in and using winglet fences increased *Barbie*'s stable roll AoA range in heavy crosswinds by over 70% (Figure 8.4.1). This range was determined by examining the angle where C_M becomes negative: 9.4° for the initial control and 16° with stability features.

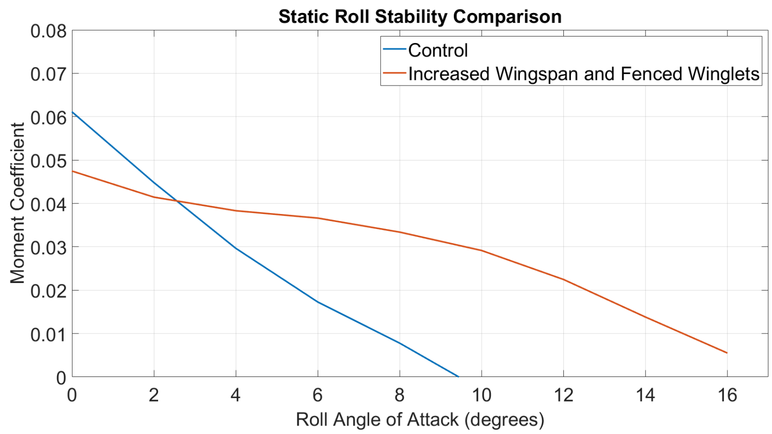


Figure 8.4.1: Roll Stability Compared Between a 36 in Wing Without Winglets and 40 in Wing with Winglets

8.5 Servo Sizing

To select servos, UBCAD determined the torque needed to deflect each control surface ±30° at 30 ft/s. Using XFLR5, pressure was calculated along the chord, then multiplied by discretized areas and hinged moment arms to find torques. Scaling by the 0.591 in the control horn arm and a FoS of 5 for gusts, UBCAD obtained the required torques. A servo calculator [9] yielded larger results, indicating a larger FoS. UBCAD then selected the smallest servos meeting these criteria.

Table 8.5.1: Servo Sizing Results

Control Surface	Hinge Torque (oz-in)	Servo Torque (oz-in)	Website Torque (oz-in)	Servo (Torque in oz-in)
Aileron	0.10	0.87	1.6	MG90S (25)
Elevator	0.11	0.95	1.4	MG90S (25)
Rudder	0.02	0.16	0.3	FS90 (21)

8.6 Propulsion Performance & Testing

Given the power constraint of 450 W with a design goal of short takeoff and heavy payloads, UBCAD focused on maximum low-speed thrust for takeoff, while keeping total propulsion system weight below 30% of the MTOW. Equation (15-53) from Gudmundsson [2] was used to relate physical parameters such as propeller pitch, diameter, speed, and motor power, to their expected performance. UBCAD respected design constraints such as motor KV ratings, motor current limits, and propeller speed limits and determined that a motor of ~1000 KV paired with a 10-12 in propeller with a pitch of ~6 in would result in optimal performance. Static thrust was chosen as a baseline due to low-speed performance emphasis.

Motor + Propeller	Open-Air Thrust (lb)
AT2814 11x5.5	4.3
AT2814 11x7	4.2
AT2321 11x5.5	4.2
AT2321 11x7	3.8
AT2321 10x6	4.2
AT2321 11x4.7	4.1
AT2321 10x7	4.0
AT2321 9x6	3.6
AT2317 10x6	2.9
AT2317 9x4.5	3.4

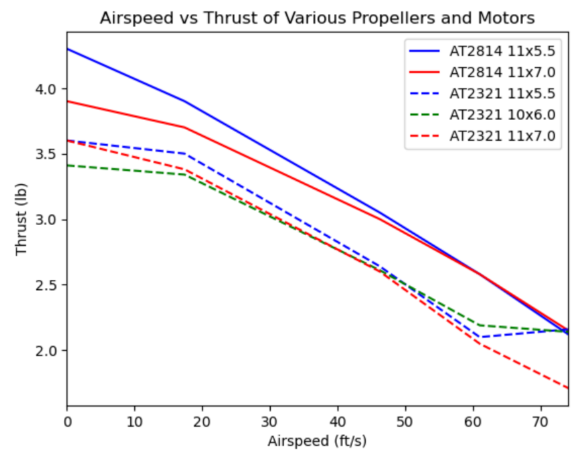


Figure 8.6.1: (left) Static Thrust & **(right)** Dynamic Thrust

Using static thrust tests, a set of top-performing motors and propellers were advanced to dynamic thrust tests. The static thrust performed in the wind tunnel may differ from the tested static thrust due to circulation inside the wind tunnel. All thrust tests were performed with a fully charged 2000 mAh 4S battery and a 450 W power limiter at 100% throttle. The AT2814 900 KV with a 11 x 5.5 inch propeller had high thrusts across most speeds. The AT2814 setup is heavier than the AT2321 setup, but the ~20% thrust increase was favoured for a short takeoff.

8.7 Wing Spar Sizing & Testing

UBCAD chose a hollow CF tube wing spar placed at the aerodynamic center [10] to support the flight forces acting on the wing. As bending from lift is the primary flight loading mode, UBCAD used XFLR5's LLT to determine the bending moment (Figure 8.7.1, left), then stresses throughout the wing. The optimal spar dimensions were then determined with a FoS of 1.5. UBCAD used the same processes for the empennage spars, but with a greater focus on manufacturability, therefore opting for composite I-beams with balsa webbings and basswood spar caps.

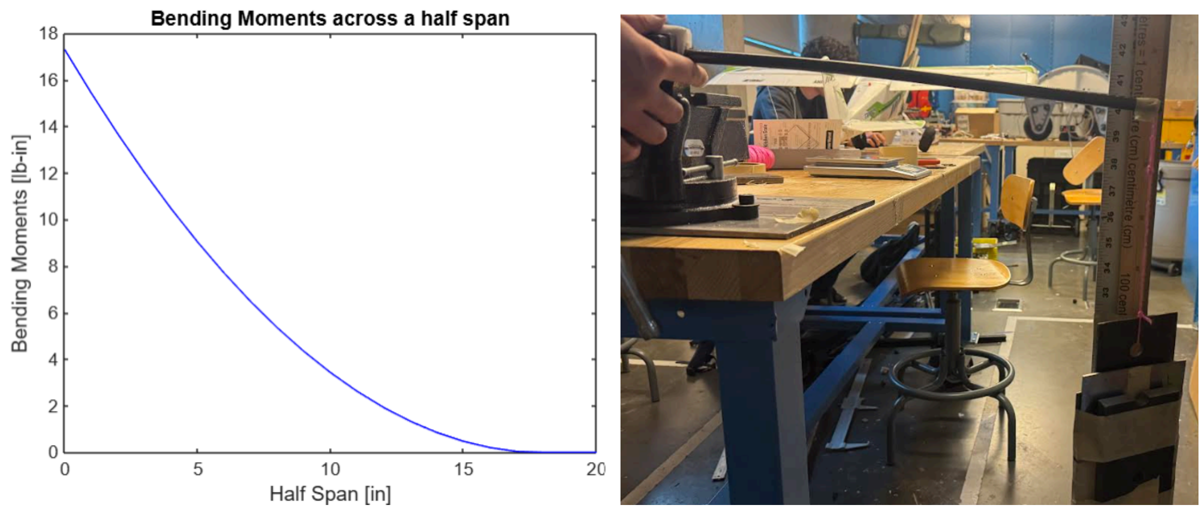


Figure 8.7.1: (left) Bending Moments Acting Across a Half Span & **(right)** Spar Cantilever Test with 2.2 Load Factor

UBCAD verified the spar's strength through a cantilever test, simulating a wing bending scenario while constrained at the fuselage (Figure 8.7.1, right). The weights applied to the cantilever's free end were up to a 2.2 load factor, and displayed moderate deflections with no signs of fracture.

8.8 Fuselage Sizing & Testing

In line with UBCAD's focuses on design safety and completeness, a bulkhead and longeron structural configuration was chosen so the system is easier to model and manufacture. UBCAD elected to use a filleted square bulkhead cross-section to improve manufacturing quality. A fuselage length of 32 in was chosen based on several iterations of aircraft layout and tail sizing. Bending and shear moment diagrams (Figure 8.8.1) were drawn from expected forces during level flight, landing.

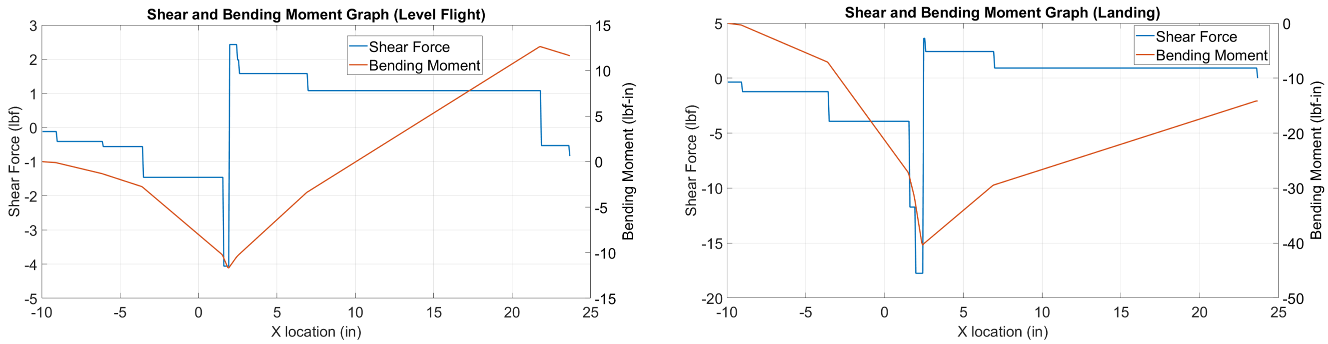


Figure 8.8.1: Shear and Bending Moment Graphs Under **(left)** Level Flight Conditions & **(right)** Landing Conditions

Under a maximum bending moment of -37.5 lb·ft, *Barbie* experiences a maximum tensile stress of 115.0 psi under a load factor of 3. UBCAD optimized the placement of panels, longerons, and bulkheads based on a bending moment and shear diagram to achieve a FoS of 4.8.

UBCAD conducted physical testing on the payload compartment to validate the analyses. The bending test (Figure 8.8.2, left) consisted of a 10 lb load and yielded a 5 FoS. The torsion test (Figure 8.8.2, middle) consisted of 5 lb loads applied to each end of the attached rod and yielded a 5 FoS with a 25° fracture angle.

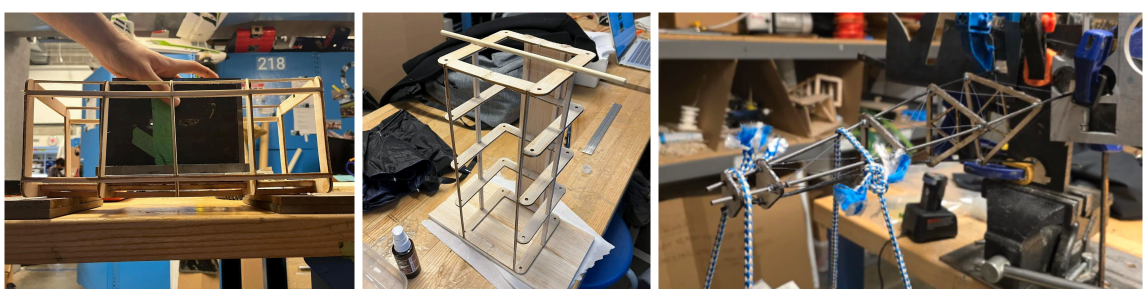


Figure 8.8.2: (left) Payload Compartment Bending Test, **(middle)** Torsion Test & **(right)** Tail Bending Test

The tail length was set at 19.5 in from the wing's mean geometric quarter-chord to the quarter-chord of the HT and VT (Section 6.4). To reduce dependency on the inconsistent grain direction of wood in a long protruded structure, UBCAD used carbon longerons and ply bulkheads for the tail section. Kevlar strings were used as bracing wires for frame rigidity due to its high tensile strength and lightweight properties. A triangular cross-sectional design was chosen to maximize the cross-sectional area while minimizing material usage.

UBCAD conducted physical testing on the tail section to evaluate its weight, maximum bending strength, maximum torque, and FoS. The tail section has a total weight of 0.076 lbs and is designed to withstand bending moments up to 85.5 lbs-in and torque up to 0.203 lbs-in during in flight conditions. The root of the tail section was clamped to simulate a cantilever (Figure 8.8.2, right). The tail section withstood torques up to 1.43 lbs-in and a bending moment of 361 lbs-in before failure, resulting in a FoS of 4.2.

8.9 Landing Gear Sizing

UBCAD designed *Barbie*'s landing gear for safety and reliability, using a tricycle configuration to maximize stability during takeoff and landing. Our analyses, based on the conditions defined by Chapter 9 of Sadraey [4], yielded a base of 10.25 in and a track of 11 in for a ~6.5 in centre of gravity (CG) height. The MLG was designed to fully absorb expected energies defined by FARs §23.723-23.727 and §23.473 [11], given an approximate 80% static load. Trial and analysis led to a levered extension-spring design (Figure 8.9.1, right) mounted by bolts to the spar. UBCAD validated landing gear safety by conducting dynamic drop tests on a prototype airframe. Using the aforementioned FAR standards, the prototype was dropped from a height of 7 in with a 5 lb total weight and proved capable of absorbing landing energies.

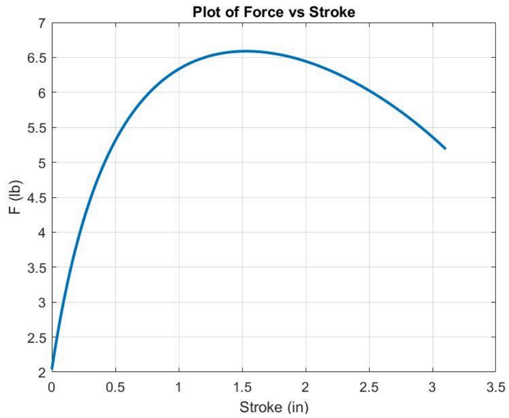


Figure 8.9.1: (left) MLG Force Vs. Stroke Plot & **(right)** Landing Gear Dynamic Drop Test on Prototype Aircraft

The NLG features a telescopic design to isolate spring compression from gear and servo movement. Custom 3D-printed gears were utilized to convert servo movement into NLG rotation as they provide great strength and reliability.

8.10 Layout - Mass Properties and balance

Barbie's layout was designed to maintain safe margins for both CG and static margin (SM) given any payload loading conditions. By estimating and refining component weights and mean weight positions, relative layout positions were iterated to provide acceptable margins in CG and SM calculated by conventional methods [12]. The payload is centered near the empty CG, thus only minorly affecting CG or SM during loading. This provides greater flight consistency between configurations, and makes water movement within the payload more predictable. To minimize this sloshing, the payload uses a rigid structure encompassing vertical and horizontal baffles. The payload container was customized using various indents, to meet volume requirements while ensuring integration with fuselage components. The payload is bolted down for sufficient constraint within the fuselage.

Table 8.10.1: Calculated Neutral Point and Center of Gravity for All Loading Configurations of *Barbie*

Payload Loading/Parameters	**0% 0 lb**	**20% 0.60 lb**	**40% 1.20 lb**	**60% 1.8 lb**	**80% 2.4 lb**	**100% 3.0 lb**
Center of Gravity	20.05	20.04	20.04	20.03	20.03	20.03

(% MAC):						
Neutral Point *(% MAC):*	31.4 for all					
Neutral Point Position *(in aft of leading edge):*	2.51 for all					
Center of Gravity Position *(in aft of leading edge):*	1.60	1.60	1.60	1.60	1.60	1.60

Following a test flight where the aircraft was initially nose-heavy (an empty CG at ~0% MAC), the layout was modified to place the CG in a more typical range (Table 8.10.1) while preserving SM. UBCAD shortened the nose and rearranged electronics to place the CG further back at 20% MAC.

8.11 Static & Dynamic Stability

UBCAD verified *Barbie*'s static and dynamic stability using XFLR5. A VLM2 analysis for all lifting surfaces produced C_M versus α data (Figure 8.11.1, left), indicating *Barbie*'s static stability throughout all flight stages. In particular, C_M is consistently positive for negative α values under all loading conditions, and all conditions have a x_{CG}/MAC of below 65% where the C_M slope is consistently negative, fulfilling all static stability criteria [2].

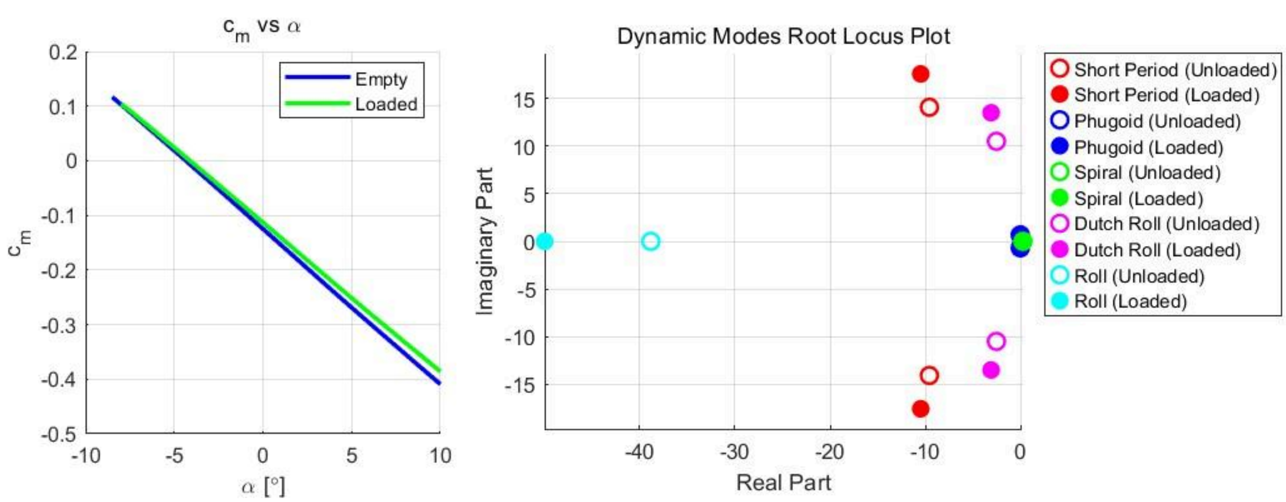


Figure 8.11.1: (left) Static Stability Curve & **(right)** Root Locus Plot of All Dynamic Modes

A root locus plot generated using XFLR5's eigenmode analysis at critical flight conditions (Figure 8.11.1, right) indicates the spiral mode is stable enough to be corrected by pilot aileron input, and all other modes are stable (Table 8.11.1) The analysis assumes that mass and inertial properties are dynamically dominating and neglects fuselage geometry. Characteristic stability values were compared to the relative "Class 1", "Category B flight phase", and "Level 1 flying qualities" as defined in [13].

Table 8.11.1: Characteristic Dynamic Stability Value Benchmarks

Mode	Characteristic Requirements	Unloaded	Loaded
Short Period	$0.3 < \zeta < 2.0$	$\zeta = 0.563$	$\zeta = 0.513$
Phugoid	$\zeta > 0.04$	$\zeta = 0.093$	$\zeta = 0.203$
Spiral	t2 > 20 sec	t2 = 3.226 sec	t2 = 4.029 sec
Dutch Roll	$\zeta > 0.08$ $\omega_N > 0.4$ rad/sec $\zeta^*\omega_N > 0.15$ rad/sec	$\zeta = 0.237$ $\omega_N = 1.672$ rad/sec $\zeta^*\omega_N = 0.369$ rad/sec	$\zeta = 0.225$ $\omega_N = 2.149$ rad/sec $\zeta^*\omega_N = 0.484$ rad/sec
Roll	$\tau < 1.4$ sec	τ =0.026 sec	$\tau = 0.020$ sec

8.12 Test Flights

On January 25th, 2025, UBCAD test flew *Barbie* six times to validate takeoff, cruise, and landing performance. Despite the airfield's bumpy long-grass surface, *Barbie* successfully took off with incrementally increasing gross weights. During validation trials, the aircraft took off at 4.2 lbs within 25 ft, while for a flight at 5.9 lbs roughly 80 ft of grass runway were used. Given the high resistance of a grass runway compared to a paved strip, this result gives UBCAD confidence in *Barbie*'s ability to meet takeoff performance goals during competition. Throughout testing, *Barbie* cruised without difficulty and displayed good stability, demonstrated by a prompt recovery from an accidental incipient spin. At the end of each successful flight, *Barbie* conducted controlled landings where the landing gear withstood the impact forces.

Figure 8.12.1: (left) *Barbie* On Final Approach & **(right)** The Team Inspecting *Barbie*'s NLG

9. Manufacturing

9.1 Materials

UBCAD used the material selection chart shown in Figure 9.1.1, selecting woods for practical beam bending performance. Balsa was mostly used due to its high specific strength, and plywood was used in areas requiring greater absolute strength. Basswood was used in empennage spar caps to improve compressive strength and stiffness, while still being suitably light. The wings used CF spars, with higher stress scaling volume to practical levels. Spreadsheet calculations based primarily on bending stress determined longeron materials, using plywood as needed to achieve desired FoS. In the landing gear, CF-reinforced PETG filament was used for load-bearing components due to its excellent specific strength, stiffness, and ductility, while ABS was used for gears and the NLG sleeves to enhance manufacturing precision and reduce friction.

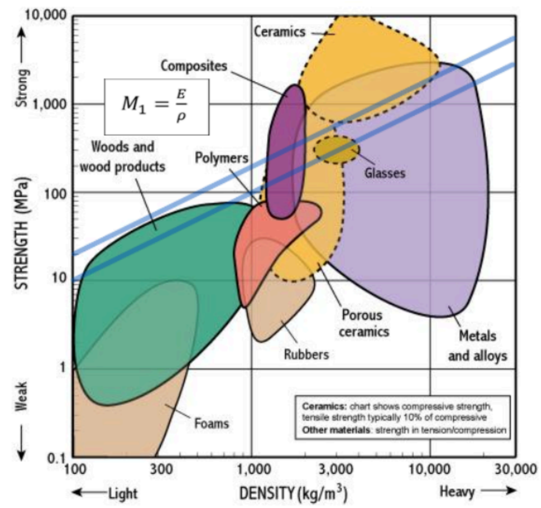


Figure 9.1.1: Material Selection Chart [14], with Material Index for Beam Bending

9.2 Methods, Techniques and Tools

Barbie's design conforms to the principles of design for manufacturing and assembly and utilizes various materials. Most structures are precision laser-cut balsa and plywood, while the landing gears are 3D printed, and carbon rods reinforce the tail. Components are mainly joined with cyanoacrylate glue, with sparing use of bolts for weight reduction. Balsa leading edge sheeting is pressed and soaked into 3D printed molds to precisely match the airfoil profile. *Barbie* is wrapped in Monokote to streamline the profile, provide strength, and reduce skin friction drag. During construction, section weights are taken and compared against CAD estimates to validate weight-related assumptions.

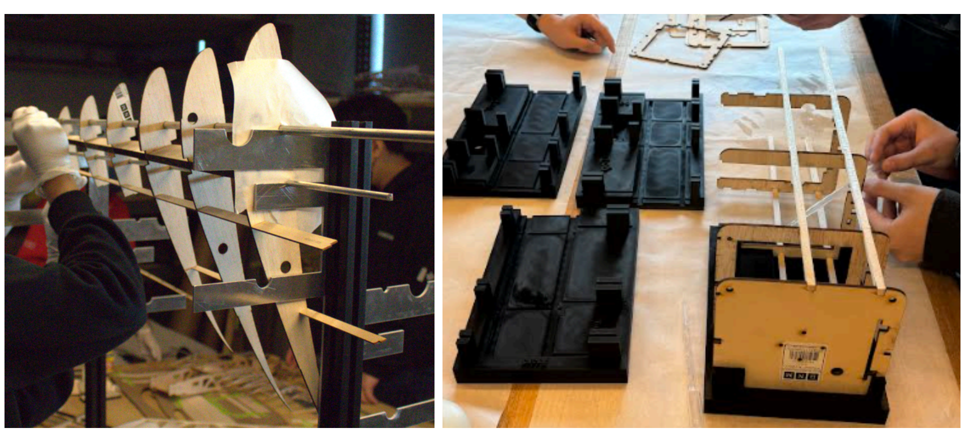


Figure 9.2.1: (left) Wing Manufacturing Using a Custom Alignment Jig & **(right)** Fuselage Manufacturing Using a Custom Jig

10. Conclusion

Barbie was designed within the framework of a Model-Based Systems Engineering approach that maximized the aircraft's achievable score. Parameters including empty weight, payload weight, wingspan, and T/W ratio were derived and balanced from this approach, leading to an aircraft with a 6.0 lb MTOW, 3 lb payload, 40 in wingspan, and expected flight score of 12.9 points per round. To achieve the goal of building a robust aircraft, UBCAD rigorously validated and iterated on critical systems and components, building off knowledge from previous years. UBCAD's efforts in this regard led to a first test flight which vastly surpassed any test flight from recent years in its success, and in the amount of insight it provided. UBCAD is confident that through the extensive validation that has gone into the design of *Barbie*, she will rank as a high-performing contestant in the coming SAE Aero Design East competition.