

Design and Fabrication of a Carbon Fiber Rear Wing for the NB Mazda Miata

Aerodynamic, Structural, and Manufacturing Validation of a Student-Built Composite System

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Project Summary

This project presents the design and fabrication of a custom carbon fiber rear wing for the NB Mazda Miata to evaluate whether student-accessible composite manufacturing methods can produce a wing that's competitive with premium aftermarket offerings in aerodynamic performance, structural capacity, mass, and cost.

Performance targets were established by benchmarking three common configurations of industry standard Nine Lives Racing (NLR) Miata wings at 100 mph and 10° angle of attack. CFD analysis, strain-based structural evaluation, and full composite manufacturing were used to design and validate the final product.

At the primary benchmark condition of 100 mph, the custom built wing produces 220 lb of downforce with a downforce-to-drag ratio of 10.43. The fully assembled wing with all components weighs 6.88 lb, approximately 50–70% lighter than comparable aftermarket wings. Structural analysis shows a margin of safety of 1.266 under an ultimate load case of 1,450 lb, with a theoretical failure load exceeding 3,200 lb.

The entire wing was manufactured using 3D-printed molds, vacuum bagging, and forged carbon fiber methods in a university and small-shop environment with limited tooling and machinery. Total production cost remained below \$1,101, reducible to \$535 when shared tooling is available.

A direct comparison to benchmark aftermarket wings is shown below.

Metric	Custom Wing	NLR Base	NLR Mid	NLR High
Downforce	220 lb	199 lb	241 lb	309 lb
Downforce / Drag	10.43	9.95	11.92	12.96
Mass	6.88 lb	14–15 lb	19–23 lb	16–19 lb
Cost	\$1101 (\$535)	\$995	\$1,789	\$3,804

These results demonstrate that a student-manufactured composite wing can match or exceed the performance of mid to high-end aftermarket options, while also dramatically reducing mass and cost.

Introduction and Project Motivation

The Mazda Miata is extremely popular in motorsports competitions like autocross, time attack, and track-days due to its advanced handling and large aftermarket support. However, as driving speeds increase above roughly 70 mph, the NB Miata generates lift over both axles[1]. This decreases grip and worsens drive quality.

Rear wings and front splitters are common solutions for addressing this problem, but high-performance aftermarket options for the Miata include many tradeoffs. Entry-level wings, while affordable, create little downforce, are excessively heavy, have limited adjustability, and use subpar mounting solutions. On the other hand, higher end wings improve on most of these features, but frequently exceed \$1,000 in just base configurations. Pricing for performance oriented wings can reach \$3,800+ as more desirable materials, more sophisticated endplates, or special mounting solutions are fitted.

This gap between affordability and performance motivated the central question of the project: can a custom, student-designed rear wing offer a lower mass, a lower production cost, and match or exceed the performance of premium aftermarket Miata wings? This project was approached with the intent of physically manufacturing a component capable of real-world competitive performance.

Aftermarket Options & Benchmarking

To keep realistic performance and cost expectations, the custom wing was benchmarked against commercially available NB Miata wings. Rather than designing a wing separately, the project intended to compete directly with existing offerings that are already validated and competitive in the commercial space.

Aftermarket Miata Wing Options

Aftermarket Miata wings generally fall into two categories:

- **Entry-Level Wings**
Entry-level wings prioritize low prices. They are affordable, but simple and heavy.
- **Performance-Oriented Wings**
Higher end wings offer heavy adjustability, more efficient aero profiles and components, and stronger, more reliable mounting systems. However, these benefits usually come

with heavy tradeoffs. For example, performance oriented wings are often restricting and significantly expensive, due to their engineered carbon fiber elements or mounting styles.

Only a small number of manufacturers sell Miata oriented wings specifically within the performance category. Of this group, only several options feature well-developed geometries and integral motorsports features.

Selection of Benchmark Manufacturer

Among available options, Nine Lives Racing (NLR) wings are widely popular and often considered a benchmark for Miata aerodynamic performance. NLR wings can be found on many Miatas at most motorsports events. These wings are known for their structural rigidity, adjustability, and tailored airfoil shape.

Before starting this project, purchasing an NLR wing was strongly considered for the Miata used in this study. However, the cost for even the most basic wing configuration touched almost \$1,000, raising the question of whether a custom designed and built option could offer the same performance and function at a reduced price. Thus, the NLR wing builds were selected as a reference for benchmarking.

Limitations of Published Aerodynamic Data

A limitation in evaluating aftermarket aerodynamic parts is the lack of published and publicly available manufacturer performance data. While NLR does publish downforce data for one sample wing build, it doesn't release detailed CFD results, force coefficients, or testing conditions for their wings. Thus, to make direct comparisons, supplementary methods were utilized.

Benchmark performance estimates were calculated using a combination of the following:

- Manufacturer-published specifications
- Reported component weights
- General aerodynamic principles
- Published motorsport aero references and patterns

While this introduces uncertainty, it follows the same constraints faced by engineers and consumers when evaluating performance components.

Selected Benchmark Configurations

Nine Lives Racing offers several customization options, including airfoil materials, mounting style, and more. To create realistic comparisons, three commonly configured builds were selected, each with different traits:

- **Base Configuration**
Aluminum wing element with basic endplates and bottom-mounted pylons.
- **Mid-Level Configuration**
Aluminum wing element with advanced endplates and swan-neck mounting.
- **High-End (“Exotic”) Configuration**
Carbon fiber wing element with CFD optimized endplates and swan-neck mounting.

These configurations span NLR’s product offerings and represent increasing levels of aerodynamic performance, complexity, and cost.

Benchmarking Assumptions

To maintain consistency across all benchmark cases, the following conditions were applied:

- Vehicle speed: 100 mph
- Angle of attack: 10°
- Air density: 1.196 kg/m³

This speed and angle of attack reflect realistic track driving conditions and a semi-aggressive wing setup. This aligns with typical peak aerodynamic efficiency ranges for motorsports wings.

Reference Data and Assumptions

Performance estimates were influenced by the following statistics from NLR directly and from supplementary sources:

- Base aluminum wing mass (64 in span with mounts and endplates): 14.6 lb [2]
- Carbon fiber element mass reduction: approximately 4 lb
- Aluminum wing chord: 9.5 in [2]
- Carbon wing chord: 12 in (≈28% increase in planform area) [2]
- Maximum lift-to-drag ratio for aluminum airfoil: approximately 15.2:1 [2]
- Swan-neck mounting effect: 6–10% increase in downforce with approximately 1% drag increase [3]
- Advanced endplate effects [2][4]:
 - ~10% increase in downforce for standard advanced plates
 - ~10% increase in downforce with 7–7.5% reduction in drag for CFD-optimized plates

These statistics were applied to relevant NLR builds to determine total mass, downforce, aerodynamic efficiency, and more key benchmarking metrics. Additionally, build prices were also calculated using the NLR website. Both datasets are pictured in figures 1 and 2 below.

Category	Weight	Downforce (lbs)	Drag (lbs)	Downforce to Drag Ratio
Bare Bones Budget	14-15lbs (estimated)	199 (per 9livesracing.com)	20	9.95
Mid level	19-23lbs (estimated)	~240.79 (+21%)	~20.2 lbs (+1%)	11.92
Exotic	16-19.5lbs (estimated)	~308.45 lbs (+55%)	~23.8 lbs (+19%)	12.96

Figure 1: benchmark performance data for NLR wing builds showing key values.

Category	Wing material	Mounting Type	Endplates	Gurney flap?	Coating	Price
Bare Bones Budget	Aluminum (\$995.00)	Bottom mount (+\$0.00)	Basic (+\$0.00)	No (+\$0.00)	No (+\$0.00)	\$995.00
Mid level	Aluminum (\$995.00)	Swan Mount (+\$518.22)	MEGGA (+\$192.46)	1/4" (+\$34.99)	Vinyl (+\$49.00)	\$1,789.67
Exotic	Carbon Fiber (\$2,865.51)	Swan Mount (+\$518.22)	CFD V2(+\$233.28)	1/2" (+\$58.32)	Powdercoat (+\$129.00)	\$3,804.33

Figure 2: benchmark pricing data for NLR wing builds showing key build prices.

Benchmark Performance Envelope

Using the assumptions described above and data from NLR, estimated performance at 100 mph for the three benchmark configurations is summarized below:

- **Base Configuration:**
 - Downforce: 199 lb
 - Downforce-to-drag ratio: 9.95
 - Mass: ~14–15 lb
- **Mid-Level Configuration:**
 - Downforce: ~241 lb
 - Downforce-to-drag ratio: 11.92
 - Mass: ~19–23 lb
- **High-End Configuration:**
 - Downforce: ~309 lb
 - Downforce-to-drag ratio: 12.96
 - Mass: ~16–19.5 lb

Benchmark Pricing Envelope

Using the NLR wing configurator on the NLR website, the total price for each benchmark wing build was calculated:

- Base Configuration: \$995.00
- Mid-Level Configuration: \$1,789.67
- High-End Configuration: \$3,804.33

These values represent realistic benchmarks for the wing project. If it offered similar performance at a lower price, or increased performance at a similar price, the project could be considered successful. In other words, these benchmarks presented clear numerical goals for the project.

Project Objectives & Success Evaluation

To keep design and manufacturing decisions focused, a set of project objectives was defined at the start. These objectives were formed by limitations of currently available aftermarket solutions, motorsports requirements, and practical constraints for the user.

Rather than focusing on one metric like downforce or cost, the project aimed to find a balance between aerodynamic efficiency, structural rigidity, mass, cost, and practicality. Success was evaluated against benchmarks consistent with commercially available wing offerings described above, rather than theoretical performance targets.

Primary Objectives

The primary objectives of this project included:

1. **Aerodynamic Performance**
Design a rear wing capable of generating equal or greater downforce than comparable aftermarket wings.
2. **Aerodynamic Efficiency**
Achieve a downforce-to-drag ratio that meets or exceeds that of commercially available aftermarket wings at similar speeds and setups.
3. **Mass Reduction**
Deliver a lower total mass than aluminum and carbon fiber aftermarket alternatives through optimized geometry, material selection, and structural design.
4. **Cost Competitiveness**
Maintain a total build cost lower than premium carbon fiber aftermarket wings, all while remaining achievable using student-accessible tools and manufacturing processes.

Secondary Objectives

In addition to performance oriented goals, several secondary objectives were also considered in the design and build phases:

- **Adjustability:** Enable tuning of wing angle and endplate geometry to accommodate different driving conditions and vehicle setups.
- **Structural Integrity:** Maintain sufficient stiffness and strength to safely operate at all realistic aerodynamic loads with conservative safety margins.
- **Usability:** Keep the trunk accessible and avoid potential long term damage associated with trunk-mounted wings [5].
- **Aesthetics:** Achieve a visually aggressive, motorsports inspired appearance, matching modern racing trends and exotic designs.

Success Evaluation

Because some of these goals interfere with one another, project success was defined as achieving at least 2 of the primary 4 goals. This allowed for meaningful comparison and evaluation without requiring the custom wing to outperform in every category. These objectives provide a consistent framework for evaluating design decisions and overall performance. Additionally, they serve as the basis for project conclusions presented in later sections.

Design Requirements & Constraints

Based on the project's objectives and the benchmarking analysis defined above, several design requirements were established before CAD design started. These requirements kept the final wing design competitive, while remaining within limitations of the Miata platform, limitations of a student's tool accessibility, and limitations of affordable pricing. This kept the project grounded and realistic, while still being competitive against proven leaders.

Aerodynamic Requirements

To compete meaningfully with existing performance oriented Miata wings, the following requirements were chosen:

- **Single element wing build:**
A single element rear wing design was chosen to limit complexity, reduce mass, and reduce build costs.
- **Competitive downforce at realistic speeds:**
The wing was required to generate downforce comparable to or exceeding baseline aftermarket configurations at 100 mph, a realistic operating condition for track use.
- **High aerodynamic efficiency:**
Rather than chasing outright downforce numbers at the expense of excess drag, aerodynamic efficiency was a key requirement.
- **Adjustability:**
The wing geometry needed to support angle-of-attack adjustment to accommodate different track conditions and car setups.

Geometric Constraints

The physical size and shape of the NB Miata created several constraints:

- **Wing span:**
The maximum practical wing span was limited by the vehicle's overall width. A span of 64-inches was selected to maximize aerodynamic effectiveness while maintaining a 1" clearance relative to the bodywork.
- **Chord length:**
Chord length was constrained by aerodynamic considerations and proportionality relative to the vehicle. A chord near 9.5-inches aligned with proven NLR designs and influenced airfoil selection.
- **Endplate size and orientation:**
Endplates were required to be large enough to reduce drag and aesthetically consistent with the rest of the wing.

Mounting and Structural Constraints

Mounting strategy was a key component of the wing design, and received special, pre-design attention.

- **Chassis mounted load path:**
The wing was required to mount directly to the vehicle chassis via the trunk rain sills, eliminating reliance on the trunk lid and minimizing structural deflection under load, allowing for more competitive performance.
- **Preserved trunk access:**
The mounting design was carefully chosen to preserve access to the car's trunk lid. This constraint directly influenced the pylon-wing interface geometry.

- **Structural robustness:**
All mounting components were required to safely withstand maximum aerodynamic loads derived from CFD analysis with conservative safety margins.

Manufacturing Constraints

The design was required to be manufacturable using tools and processes accessible within CU Boulder or a casual garage environment:

- **Composite construction:**
Carbon fiber was selected as the primary structural material to minimize mass while enabling complex geometry and offering consistency with modern motorsport materials.
- **Tooling limitations:**
Molds were required to be producible via 3D printing, avoiding complex metal tooling or autoclave curing.
- **Material efficiency:**
Laminate thickness and internal structures were chosen to optimize strength-to-weight ratios and maintain manufacturability.

Cost Constraints

To remain competitive with premium aftermarket options, total project cost was constrained by the following criteria:

- **Target cost:**
The complete wing assembly was required to remain below the cost of premium carbon fiber aftermarket wings.
- **Replicability:**
The design needed to be reproducible at reduced cost when shared resources such as 3D printers or vacuum pumps are available.

Role of These Constraints in the Design Process

These requirements were fixed reference points throughout the design process. If a design or an iteration failed to meet these constraints, it was reproduced, resulting in a complete final design that satisfied as many goals as possible.

Wing Geometry & Aerodynamic Design

Airfoil Selection

The wing features a motorsports-oriented airfoil based on the Benzing 123–125 family of profiles. This airfoil style is widely popular within the motorsports community due to its strong balance of big downforce numbers and aerodynamic efficiency[6].

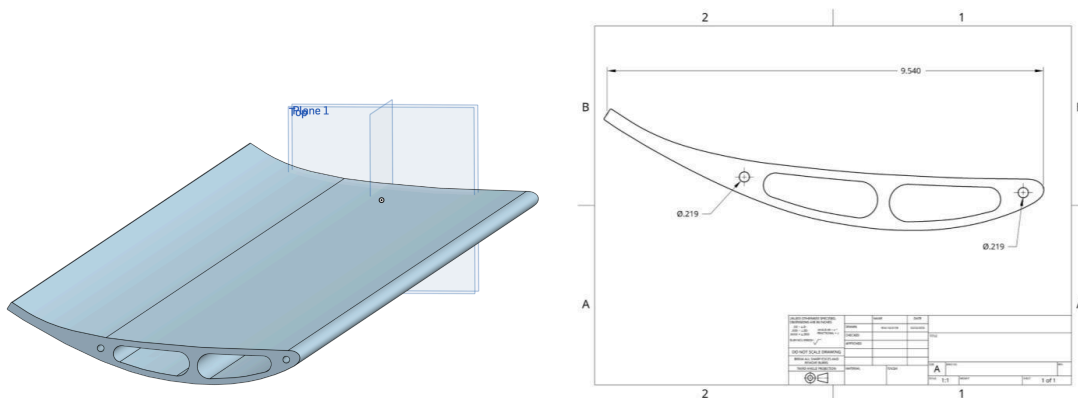
A Benzing 123–125 series airfoil was selected to match proven motorsport performance while avoiding airfoil development.

Wing Geometry

The wing's geometry was selected to closely match dimensions that have demonstrated success on the NB Miata platform:

- Span: 64-inches
- Chord: 9.54-inches

The full wing body geometry is shown in figures 3 and 4 below.



Figures 3 & 4: Wing body side-view drawing showing chord size (right) and wing body render showing chord and width (left)

Mounting Configuration

Swan-neck mounts were used to avoid flow disturbance on the pressure surface and improve aerodynamic efficiency.[3].

The pylons were designed to be low profile and sleek, consistent with modern sports cars and motorsports designs. Pylon design and renders are shown below in figures 5-7. Many aftermarket pylons use bottom-mounted geometries that disturb sensitive flow areas and increase visual bulk, like in figure 8 below.

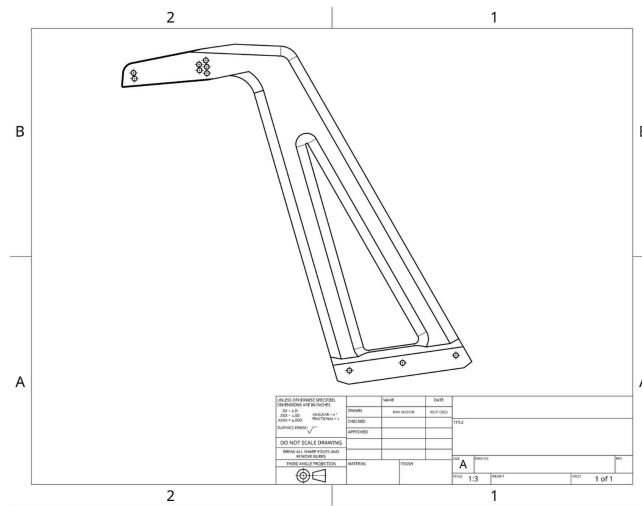
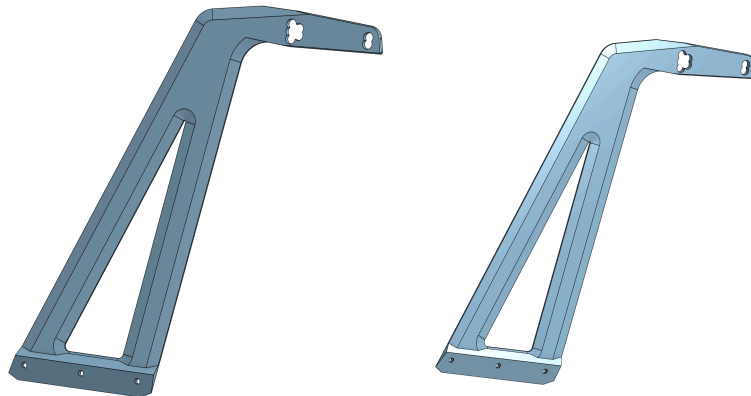


Figure 5: Wing pylon drawing displaying overall design and proportions



Figures 6 & 7: Pylon renderings displaying sharp chamfers, sleek curves, and modern design.



Figures 8 & 9: Outdated and bulky NLR wing pylon (left) and 992 Porsche 911 GT3RS swan neck wing, displaying modern, cutting-edge, trendy pylons (right)[2].

Chassis Interface and Vehicle Usability

Unlike many aftermarket Miata wings that mount directly to the car's trunk lid, this wing mounts directly to the car's chassis, through the trunk rain sills, between the trunk lid and quarter panels. This mounting strategy provides a direct load path into the car's chassis, hides mounting hardware under the trunk lid, and gives the wing a factory-engineered appearance. Overall, this improves aesthetics, strengthens the car-wing connection, and prevents long-term wear on body panels and seals[5]. A mounted wing render is presented below in figure 10.



Figure 10: Rendering of custom wing mounted on Miata, displaying direct chassis mounting. 3D vehicle model courtesy of antoineallardchoquette via Sketchfab.

Chassis mounted Miata wings often share a drawback: reduced trunk access. To avoid this, the pylon-wing interface was designed with removable front pin hardware. This allows the wing assembly to pivot downward with the removal of both front pins, allowing for adequate trunk access, as pictured in figure 11. This feature was developed specifically to preserve daily usability.



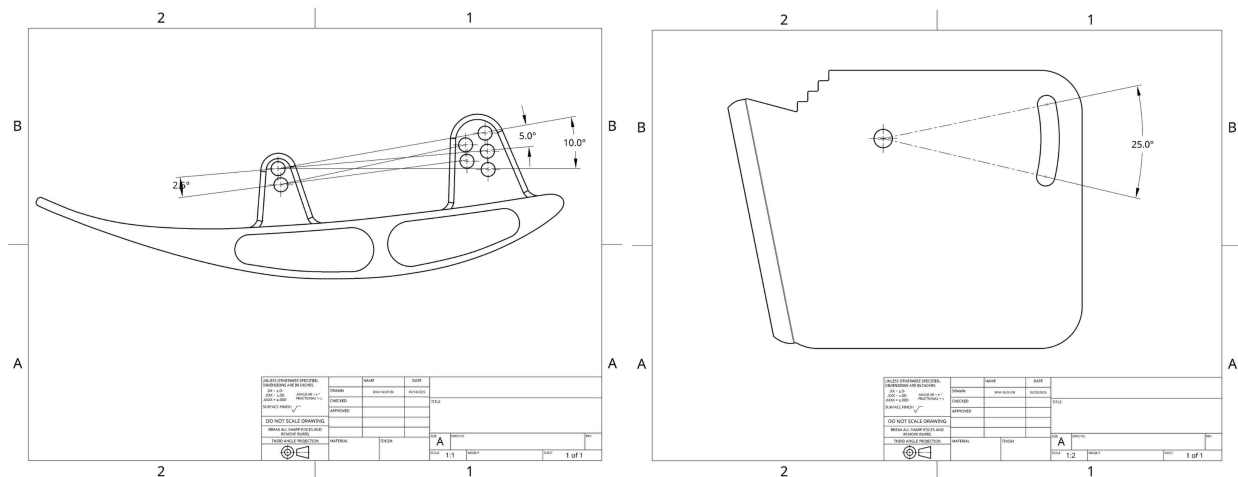
Figure 11: Full rendering with wing folded down, showing increased clearance and trunk access. 3D vehicle model courtesy of antoineallardchoquette via Sketchfab.

Adjustability Features

Adjustability was incorporated to allow tuning for different operating conditions and driver preferences:

- **Wing angle adjustment:**
Multiple mounting holes allow a total of 12.5 degrees of angle-of-attack adjustment in 2.5-degree increments, all while using a low profile dual-hump mounting design.
- **Endplate adjustment:**
Slotted endplate mounting holes allow for up to 25-degrees of endplate adjustment, for precise aero configurations.

These features, shown below in figures 12 and 13, allow the aerodynamic balance of the vehicle to be tuned without redesigning or remanufacturing components.



Figures 12 & 13: Aluminum internal mounting rib drawing and wing endplate drawing, both displaying mounting designs with adjustment.

Design Integration

Pre-manufacturing, all components were designed in CAD and meshed to ensure proper integration. Interfaces are shown below in figure 14. Special design attention was paid to load paths and interface geometry to ensure a strong final product.

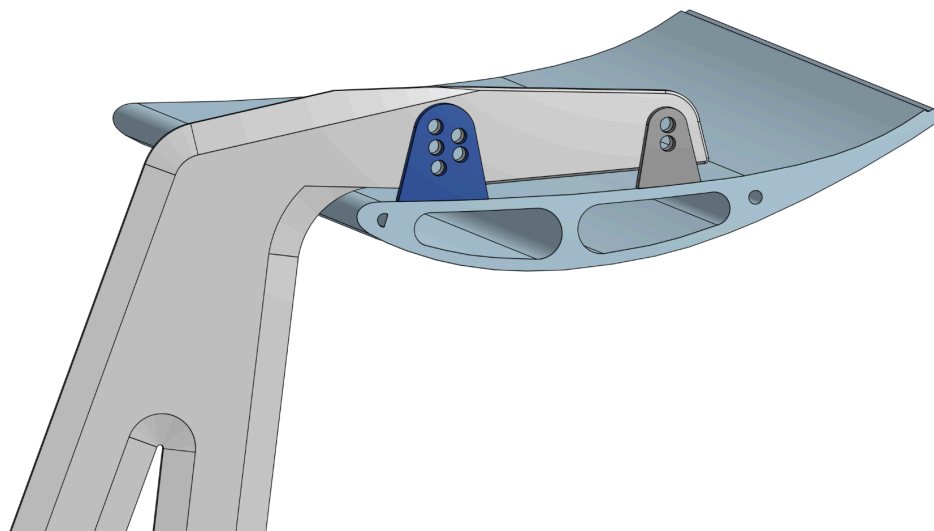


Figure 14: Wing pylon-body interface, displaying proper component integration.

CFD Analysis & Aerodynamic Results

Computational Fluid Dynamics (CFD) software was used to evaluate the aerodynamic performance of the wing geometry and to simulate load cases for later structural analysis. CFD was used to generate consistent comparative performance and load data.

CFD Setup and Assumptions

All simulations were completed in SimScale with steady-state incompressible flow assumptions. The wing was analyzed in isolation, rather than as part of the full vehicle model to reduce computational costs.

Key simulation parameters included:

- Freestream velocity:
 - 45 m/s (approximately 100 mph) for benchmarking.
 - 65 m/s (approximately 145 mph) for high-speed load evaluation.
- Air density:
 - 1.196 kg/m³, selected to represent realistic ambient conditions at elevated temperatures.
- Angle of attack:
 - 10 degrees for primary benchmarking, consistent with typical operating ranges for motorsports rear wings and NLR's testing.

Boundary conditions and domain sizing were chosen to maximize volume while maintaining appropriate and economical processing costs. A consistent meshing approach was used across all simulations.

Aerodynamic Performance at 100 mph

At the primary benchmark condition of 100 mph and 10 degrees angle of attack, the wing produced the following results:

- Downforce: 220.42 lb
- Drag: 21.13 lb
- Downforce-to-drag ratio: 10.43

These values exceed most baseline aftermarket configurations while remaining competitive with higher-end wing builds, particularly when accounting for mass and cost. These results indicate that the airfoil and endplate geometries achieve efficient downforce without excessive drag. CFD screencaptures and calculations are shown below in figures 15-19.

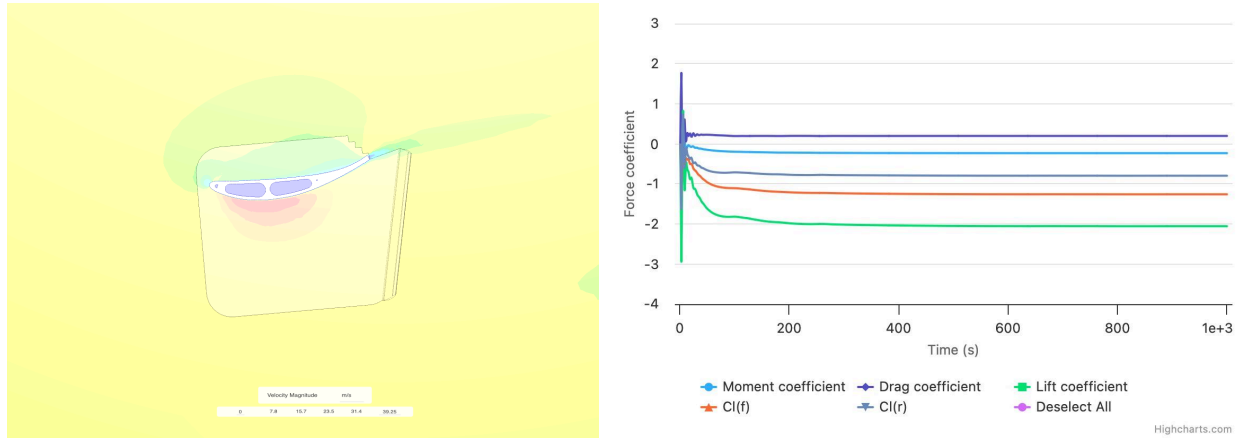


Figure 15 & 16: Simscale velocity simulation capture (left) and force coefficient plot, showing important 100 mph metrics (right).

Downforce (Lift):

$$F_L = \frac{1}{2} \rho V^2 A_{reference} C_L$$

Here,

ρ = Air density (1.196KG/m³)

V = Test velocity = 45.00m/s

$A_{reference}$ = Wing reference area = chord · width
 $= 9.54 \cdot 64.00 = 610.56in^2 = 0.394m^2$

C_L = Lift force coefficient (from simscale simulation) = - 2.055

$$F_L = \frac{1}{2} (1.196)(45.00)^2 (0.394)(- 2.055) = - 980.47N = - 220.42lbs$$

Drag:

$$F_D = \frac{1}{2} \rho V^2 A_{reference} C_D$$

Here,

ρ = Air density (1.196KG/m³)

V = Test velocity = 45.00m/s

$A_{reference}$ = Wing reference area = chord · width
 $= 9.54 \cdot 64.00 = 610.56in^2 = 0.394m^2$

C_D = Drag force coefficient (from simscale simulation) = 0.197

$$F_D = \frac{1}{2} (1.196)(45.00)^2 (0.394)(0.197) = 93.99N = 21.13lbs$$

Figures 17 & 18: Downforce and drag calculations using measured Simscale values at 100 mph

Downforce to drag ratio:

$$\frac{DF}{D} = \frac{220.42lbs}{21.13lbs} = 10.43$$

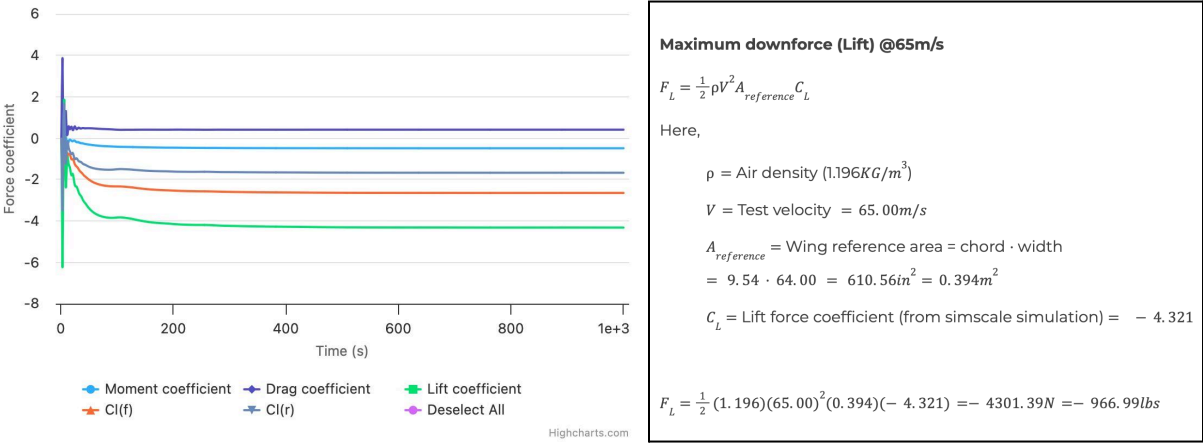
Figure 19: Downforce to drag ratio calculation using downforce and drag values determined above.

High-Speed Load Case

To determine maximum use loads, an additional CFD case was run at approximately 145 mph, representing the upper bound of the Miata’s track speed, and thus the wing’s environment. At this condition, the wing generated:

- Downforce: 967 lb

This case was used as the maximum expected load for later structural assessments. Calculations and captures are shown below in figures 20 & 21. To account for manufacturing and simulation uncertainties, a safety factor of 1.5 was applied to calculate the wing’s ultimate load of approximately 1,450 lb.



Figures 20 & 21: Post 145 mph simulation coefficients graph (left) and load calculation using measured Simscale values at 145 mph (right)

Comparison to Benchmark Envelope

When evaluated within the benchmark envelope established earlier, the custom wing:

- Produces greater downforce than baseline NLR configuration at 100 mph
- Achieves competitive aerodynamic efficiency relative to mid and high-end configurations
- Does so at a substantially lower mass and comparable or lower cost

These results demonstrate that the aerodynamic design meets or exceeds the primary performance objectives defined at the start of the project.

Structural Design & Load Analysis

Structural analysis was conducted for the wing mounting system to ensure it could withstand any realistic load encountered during operation. Structural performance was evaluated using strain, the appropriate failure metric for composite laminates.

Load Cases

Two main load cases were pulled from CFD testing:

- **Normal operating condition:**
100 mph, consistent with typical track use
- **Maximum operating condition:**
Approximately 145 mph, representing a realistic upper bound on vehicle speed

At 145 mph, the wing generates approximately 967 lb of downforce, calculated in figure 21. This value was selected as the maximum expected aerodynamic load during operation. To account for simulation and construction uncertainties and inconsistencies, a safety factor of 1.5 was applied, resulting in an ultimate design load of roughly 1,450 lb.

Because the wing is supported by two pylons, all structural analyses were performed assuming each pylon carries 50% of the total aerodynamic load.

Structural Architecture

The structural entire system consists of the following components and materials:

- **Wing body:**
A quad-layer 2x2 twill carbon fiber shell bonded around internal XPS foam and aluminum ribs.

- **Internal ribs:**
CNC-machined 6061 aluminum ribs located at the wing edges and pylon interfaces, creating load transfer points.
- **Pylons:**
Forged carbon fiber pylons with integrated aluminum inserts at all bolted interfaces.
- **Galvanic corrosion prevention:**
Resin beads and precise bond gaps were used at all aluminum to carbon interfaces to prevent direct material contact and halt galvanic corrosion.

These architectural choices were made to maintain a stiff, continuous load path from the wing body to the car's chassis.

Strain-Based Evaluation

Structural performance was evaluated using strain, which is a more appropriate failure metric for composite materials than stress. Typical allowable strain limits for motorsports oriented carbon fiber laminates range from approximately 0.8% to 1.5%, depending on fiber orientation, resin type, and layup quality[7].

For this analysis, a very conservative allowable strain limit of 0.8% was used.

Structural Analysis Results

Strain simulations were performed on the pylon geometry under both normal, maximum, and ultimate load conditions.

- At 100 mph (normal load):
 - Peak strain: 0.235%
- At 145 mph (maximum expected load):
 - Peak strain: 0.353%
- At ultimate load (1.5× safety factor):
 - Strain values scaled linearly

All measured strains were well below the conservative allowable limit of 0.8%, proving that the pylons operate far from material failure, even in extreme conditions. Strain simulation captures and calculations can be found in figures 21-24 below.

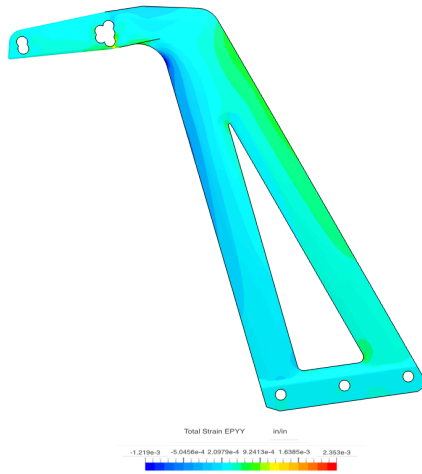
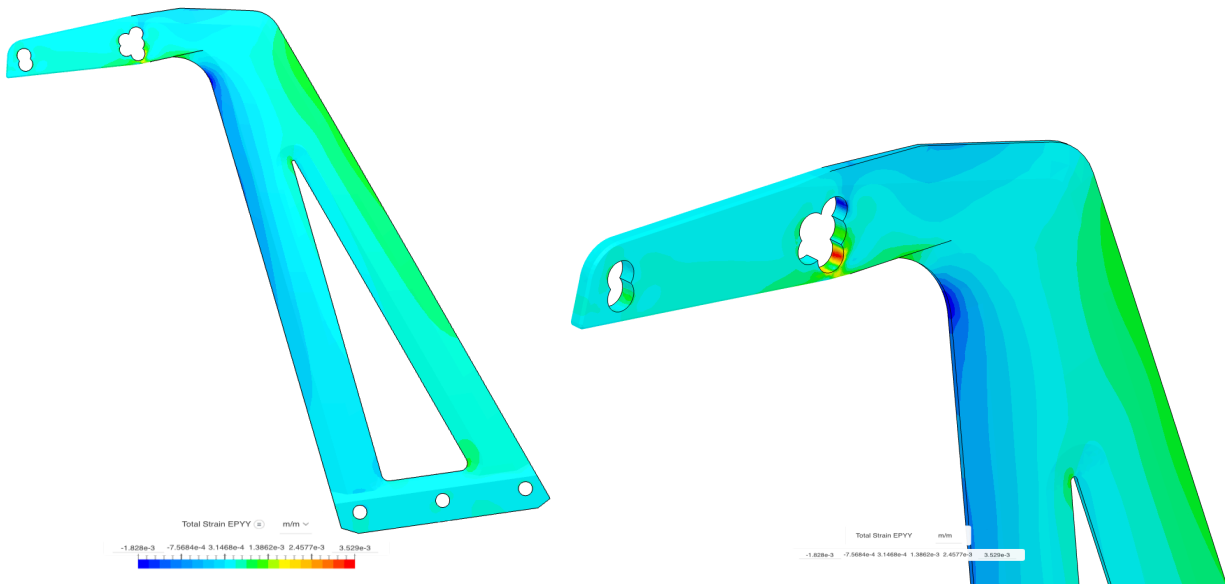


Figure 21: Strain analysis at normal load, showing a peak strain of 0.236%.



Figures 22 & 23: Strain analysis at maximum expected load, showing a peak strain of 0.353% (left) and close detail of maximum load strain analysis, displaying regions with peak positive and negative strain (right).

Strain

Run 1:

$$2.353 \cdot 10^{-3} \frac{m}{m} = 0.2353\%$$

Run 2 Expected:

$$(2.353 \cdot 10^{-3})(1.5) = 3.530 \cdot 10^{-3} \frac{m}{m} = 0.3530\%$$

Run 2 Actual:

$$3.530 \cdot 10^{-3} \frac{m}{m} = 0.3530\%$$

Figure 24: Strain conversions for run 1 (normal load) and run 2 (maximum load) depicting a linear growth.

Margin of Safety and Failure Mode

Using the strain results from the ultimate load, the margin of safety was calculated to be 1.266, shown below in figure 25, indicating a structurally conservative and safe design.

Margin of Safety

$$MS = \frac{\epsilon_{allow}}{(\text{strain})} - 1 = \frac{(0.008)}{(3.530 \cdot 10^{-3})} - 1 = 1.266 \rightarrow \text{Very safe}$$

Figure 25: Margin of safety calculation showing a very large safety margin of over 100%

By linearly increasing load until a strain of 0.8% was reached, a failure mode for the wing was determined. Each pylon could sustain approximately 1,640 lb of load before reaching the allowable limit, for a combined total load of over 3,280 lb. This exceeds the weight of the entire vehicle, and far exceeds any loads the wing could realistically generate. The maximum load calculation is shown below, in figure 26.

Maximum Load

$$L_{hit} = (\text{working load}) \cdot \frac{\epsilon_{allowable}}{\epsilon_{working}} = (2150) \cdot \frac{(0.008)}{(2.353 \cdot 10^{-3})} = 7309.8N = 1643.3lb$$

Figure 26: Calculation for the wing’s maximum load, with a result of over 1643 lb per pylon.

Design Confidence Conclusions

The structural analysis confirms that the wing system operates within excessively safe load ranges. This provides confidence in static strength and durability under repeated, drawn-out loading cycles consistent with heavy track use and extreme driving.

Materials Selection & Manufacturing Process

Materials and manufacturing methods were selected to ensure a balance between aerodynamic performance, structural integrity, mass reduction and cost minimization. Manufacturing methods were selected to be achievable with university and small-shop tooling.

Material Selection

Carbon fiber was selected as the primary structural material for the wing assembly due to its high stiffness and strength-to-weight ratio and motorsports-heavy heritage.

- **Wing body:**
The main wing structure uses a quad-layer 2x2 twill carbon fiber shell. This weave was selected for its balance of flexibility, availability, and structural performance. The shell is bonded around XPS foam ribs and internal aluminum ribs to form an ultra lightweight sandwich structure.
- **Pylons and endplates:**
Pylons and endplates were manufactured using chopped carbon tow in a forged carbon fiber process. This allowed for complex geometries while retaining relatively simple, multi-piece molds. This results in a strong part with minimal manufacturing tradeoffs.

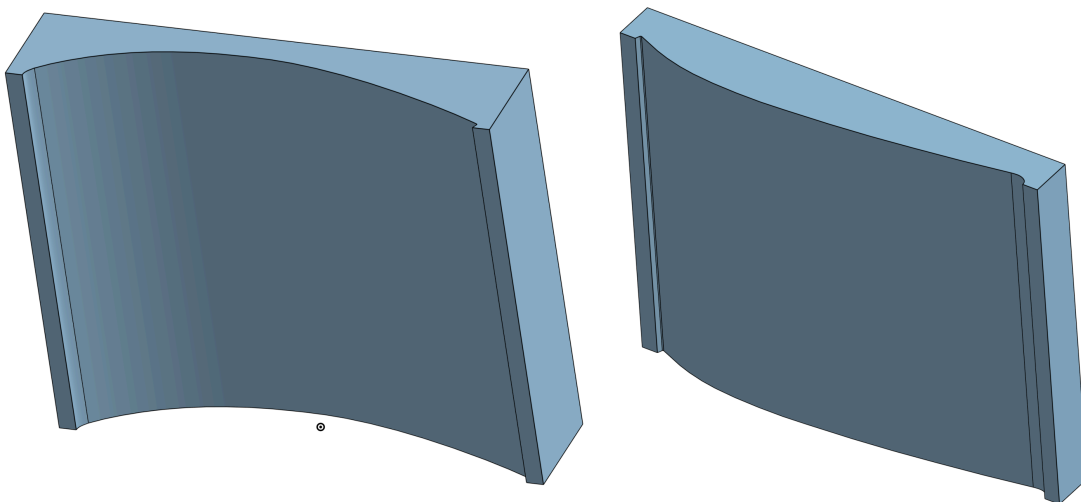
- **Internal structure and inserts:**
CNC-machined 6061 aluminum was used for all internal ribs and bonded inserts due to its machinability and accessibility.

Tooling and Molds

To minimize cost and increase iteration and production ease, all molds were 3D printed.

- **Wing body mold:**
Due to printer size limitations, the wing mold was printed in multiple 8.5” sections and bonded together using JB Weld epoxy adhesive. After assembly, the mold’s surface was finished and prepared using sandpaper, PVA, and mold release for an optimal final surface finish and mold release.
- **Pylon and endplate molds:**
Male and female molds were designed and printed for forged carbon components. These molds were designed to be bolted and bonded together, and compressed using clamps. This allowed for easy part removal and controlled compression.

This mold approach avoided the need for CNC-machined molds or more complex composite manufacturing practices like autoclave or prepreg, all while remaining precise within the project’s goals. 3D printed upper and lower wing mold sections are shown below in figures 27, 28, and 29. 3D printed male and female pylon and endplate drawings and mold assemblies are also shown below in figures 29-38.



Figures 26 & 27: Lower and upper main wing body mold renders - 8.5” sections

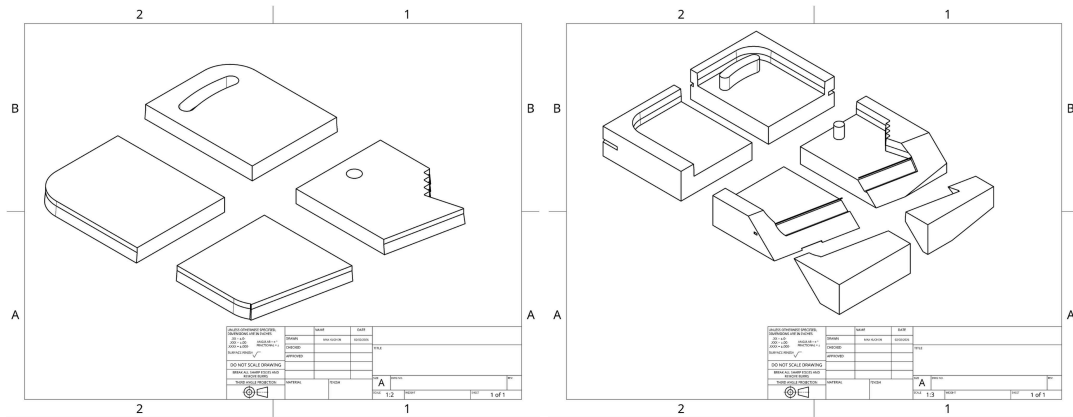


Figure 32: Complete male (left) and female (right) endplate mold assembly drawings.

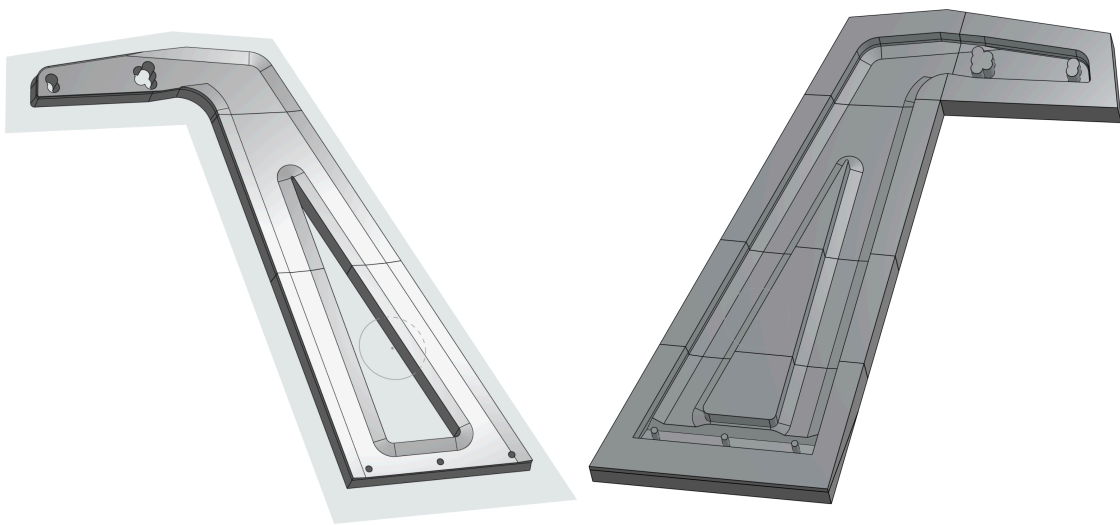
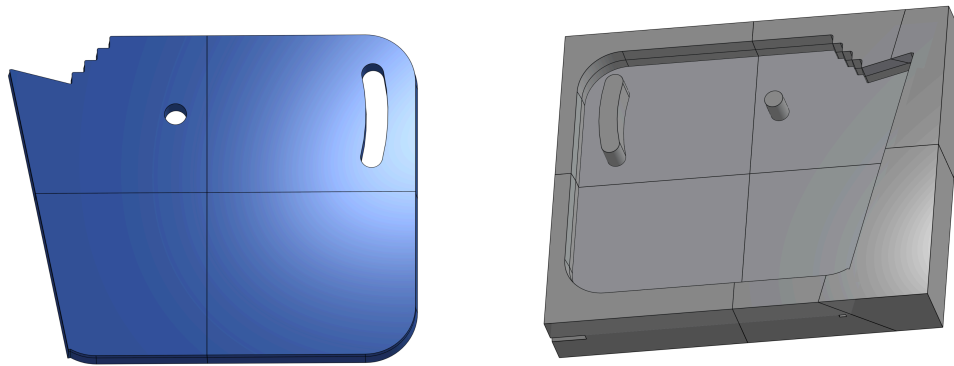


Figure 33 & 34: CAD render showing complete male (left) and female (right) pylon mold assemblies.



Figures 35 & 36: CAD render showing complete male (left) and female (right) endplate mold assemblies.



Figures 37 & 38: Completed 3D printed male endplate mold assembly (left) and completed 3D printed female and male pylon mold assemblies (right).

Wing Body Manufacturing Process

The wing body was manufactured in two stages: top shell and bottom shell manufacturing.

Carbon fiber fabric was laid into the prepared upper mold with carefully controlled resin application, targeting a fiber-to-resin ratio of 60/40 by volume. A vacuum bag was sealed onto the mold, and a vacuum was pulled, removing air bubbles, and ensuring even resin distribution. Vacuum bagging produced uniform laminate thickness and surface finish.

After curing, the top shell was removed from the mold and bonded to internal structure components, consisting of:

- Four CNC-machined aluminum ribs (one at each wing edge and one at each pylon interface)
- Three XPS foam core sections bonded between ribs

All carbon-aluminum interfaces were bonded using 3M DP420. Resin beads were added to prevent direct material contact, mitigating any possible future galvanic corrosion.

Once the internal components were bonded to the top shell, the bottom shell was aligned and bonded to this assembly, completing the wing body. Machined ribs are pictured below in figures 39 and 40.



Figures 39 & 40: Freshly machined 6061 aluminum internal mounting and finished and tapped edge ribs.

Forged Carbon Component Manufacturing

Pylons and endplates were manufactured following a forged carbon fiber process. Female molds were 3D printed, prepared with mold release spray, and bolted together. Chopped ½” carbon tow and epoxy resin were mixed to a target ratio of approximately 40% fiber and 60% resin by volume and loaded into the female mold cavity. The male mold was then installed and the assembly was clamped using vises and C-clamps to apply even and consistent compression during curing. Excess resin was evacuated in this process.

After curing, mold pieces were unbolted and pried apart. Forged carbon components were removed from the molds and finished. Aluminum inserts were bonded into all bolt interfaces using DP420 and resin beads to distribute loads and prevent localized composite damage.

All composite components were sanded and finished with two coats of a UV-resistant 2K clear coat to protect against degradation and environmental wear.

Manufacturing Tradeoffs

While more advanced composite methods may have resulted in a lighter or stiffer final product, these processes were avoided to maintain accessibility and economical control. Redundant and proven manufacturing and bonding strategies were utilized to avoid any variability.

Overall, the selected materials and manufacturing methods provided a realistic balance between performance, reliability, and replicability.

Mass & Cost Analysis

A primary goal of this project was to produce an industry competitive wing that produced meaningful aerodynamic performance without the mass and costs that come with aftermarket setups. To evaluate this, the final wing design was assessed with a focus on total mass and total build cost. These values were compared directly to benchmark aftermarket options.

Mass Breakdown

The completed wing assembly has a total mass of 6.88 lb, including all components and hardware. The breakdown for this value is shown below in figure 41.

Desc.	Volume	Material	Density	Weight	
Aluminum					
Wing Body					
Inner rib (x2)	3.095008 in ³	6061 Aluminum	2.70 g/cm ³	9.660 oz	
Outer rib (x2)	2.854085 in ³	6061 Aluminum	2.70 g/cm ³	8.908 o	
Pylon Inserts					
Pylon bottom inserts (x6)	0.10221 in ³	6061 Aluminum	2.70 g/cm ³	0.957 oz	
Pylon front inserts (x2)	0.04252 in ³	6061 Aluminum	2.70 g/cm ³	0.133 oz	
Pylon rear inserts (x2)	0.101241 in ³	6061 Aluminum	2.70 g/cm ³	0.316 oz	
Endplate Inserts					
endplate slot insert (x2)	0.172862 in ³	6061 Aluminum	2.70 g/cm ³	0.540 oz	
endplate insert (x2)	0.040803 in ³	6061 Aluminum	2.70 g/cm ³	0.127 oz	
Carbon Fiber					
lower wing body		Carbon fiber Shell		11.8275oz	
Upper wing body		Carbon fiber Shell		11.2575oz	
Pylon (x2)	15.624 in ³	Carbon fiber	1450 kg/m ³	26.188 oz	
Endplate (x2)	21.401 in ³	Carbon fiber	1450 kg/m ³	35.872 oz	
Hardware (all 316 stainless steel)					
Endplate-wing mounting bolt: 1/4"-20 x 1" hex countersunk (x4)	0.04524 in ³	316 stainless steel		0.836 oz	
Wing-pylon rear mounting bolt: 1/4"-20 x 7/8" hex button head (x2)	0.05459 in ³	316 stainless steel		0.506 oz	
Wing-pylon rear mounting nut: 1/4"-20 nylon insert locknut (x2)	0.01854 in ³	316 stainless steel		0.172 oz	
Wing-pylon front mounting clevis pin: 1/4" x 7/16" clevis pin (x2)	0.02684 in ³	316 stainless steel		0.248 oz	
Pylon-chassis mounting bolt: 1/4"-20 x 1 1/4" hex button head (x6)	0.0695 in ³	316 stainless steel		1.926 oz	
Pylon-chassis mounting nut: 1/4"-20 nylon insert locknut (x6)	0.01854 in ³	316 stainless steel		0.516 oz	
Other					
Interior foam (XPS)	4.62201 in ³	XPS	35 kg/m ³	0.0935 oz	
			Total	110.08 oz	6.88 lb

Figure 41: Complete mass breakdown of wing, including densities and volume of components where applicable.

This represents a substantially lower mass than commercially available Miata wings, which typically weigh between 14 and 23 lb depending on configuration, as shown in figure 1 above. These mass savings can be attributed to two key design decisions:

- Extensive use of carbon fiber in the wing body, pylons, and endplates
- Skeletonized pylon geometry that removes non-load-bearing material

Relative to the benchmark configurations established earlier, which all feature aluminum pylons and endplates with solid geometries, the custom wing weighs approximately 29-48% as much as comparable aftermarket offerings. This reduction in mass presents several benefits, including lower overall vehicle mass, and thus improved vehicle responsiveness.

Cost Breakdown

The total cost to design and fabricate the wing was \$1,100.77. This figure includes:

- Carbon fiber fabric and chopped tow
- Epoxy resins and adhesives
- Aluminum stock for ribs and inserts
- 3D printing filament for molds
- Consumables such as vacuum bagging materials
- Purchase of a new vacuum pump

Total cost exceeds entry-level aluminum wings but remains far below premium carbon fiber alternatives, which can exceed \$3,800. A complete production cost breakdown is presented below in figure 42.

Item	Cost
Mold Materials	
Male / Female wing body mold (5'334in ³) @30% infill	\$183.23
Pylon mold female (both sides) (2*199.4in ³) @60% infill	\$87.55
Pylon mold male (both sides) (57.0in ³) @60%infill	\$12.51
End plate mold female (both sides) (2*273.2in ³) @60%infill	\$119.84
End plate mold male (both sides) (2*80.2in ³) @60%infill	\$35.20
Wing Internals	
Internal rib metals (1.5" x 10" x 12" & 1" x 5" x 12" 6061 Aluminum bar)	\$129.07
	\$33.50
Inset metals (3/16" x 5" x 12" 6061 Aluminum bar)	\$13.54
Carbon and Resin	
Wing Body: 2x2 twill, 50" wide (\$44.50x4 yards)	\$178.00
Wing body: 0.314 gal 635 thin epoxy	\$30.62
Wing Pylons: 215g carbon toe	\$11.61
Wing pylons: 0.0429 gal 635 thin epoxy	\$4.18
End plates: 294.58g carbon toe	\$15.91
0.0588gal 635 thin epoxy	\$5.73
Hardware (all 316 stainless steel)	
Endplate-wing mounting bolt: 1/4" x 1" countersunk (\$0.483x4)	\$1.93
Wing-pylon rear mounting bolt: 1/4"-20 x 7/8" hex button head (\$0.4516x2)	\$0.90
Wing-pylon rear mounting nut: 1/4"-20 nylon insert locknut (\$0.1706x2)	\$0.34
Wing-pylon front mounting clevis pin: 1/4" x 7/16" clevis pin (\$2.70x2)	\$5.40
Pylon-chassis mounting bolt: 1/4" x 1 1/4" hex button head (\$0.3148x6)	\$1.89
Pylon-chassis mounting nut: 1/4"-20 nylon insert locknut (\$0.1706x6)	\$1.02
Other Equipment	
Aluminum Vacuum Bag Connector	\$32.50
PITTSBURGH 2.5 CFM Vacuum Pump	\$94.99
Finish	
2K clearcoat	\$28.70
Consumables	
Breather cloth	\$15.00
Peel ply	\$10.00
Vacuum bagging film	\$20.00
Vacuum bagging sealant tape	\$7.60
mixing cups	\$10.00
foam brushes	\$10.00
Total (everything included)	\$1,100.77
Total (molds and vacuum equipment already accessible)	\$534.95

Figure 42: Complete wing production cost breakdown showing a final production cost of \$1,100.77, with a possible reduced production cost of \$534.95.

Cost Reduction Opportunities

A large portion of this pricing comes from the purchase or construction of one-time tools like vacuum pumps and molds. The total build price can be substantially reduced if tools are already accessible.

If a vacuum pump is borrowed or reused and 3D printing resources are provided at no cost (which is common in academic environments like CU Boulder), the estimated build cost drops to approximately \$534.95. Under these conditions, the custom wing becomes:

- Approximately 48% cheaper than the least expensive benchmark aftermarket wing
- Over 70% cheaper than premium carbon fiber configurations

This demonstrates that the wing is cost-efficient, and manufacturable in academic environments.

Value Comparison to Aftermarket Options

When evaluated entirely, the custom wing offers a unique and powerful value relative to aftermarket solutions:

- Comparable or greater downforce than baseline aftermarket configurations
- Competitive aerodynamic efficiency
- Less than half the mass of most alternatives
- Significantly lower cost than premium carbon fiber wings

These results show that the mass and cost objectives defined at the start of the project were successfully met, without sacrificing performance or structural integrity.

Results & Discussion

This project's results are evaluated relative to the objectives developed earlier. Rather than treating performance metrics in isolation, this discussion considers the system as a whole, consolidating aerodynamic performance, structural capability, mass, cost, and usability.

Aerodynamic Performance

At the primary benchmark of 100 mph at 10 degrees angle of attack, the custom wing produces approximately 220 lb of downforce, with a downforce to drag ratio of 10.43. This exceeds the

performance of baseline aftermarket configurations and falls within the performance envelope of much more advanced and expensive offerings, as displayed in figure 1.

Although higher-end aftermarket wing builds are capable of producing greater downforce, this typically comes at the expense of increased system mass and much higher cost. In contrast, the custom wing offers a competitive aerodynamic efficiency, which when normalized by mass and cost, compares favorably to all benchmark configurations.

Structural Performance

Structural analysis confirms that the wing mounting system is governed by aerodynamic performance, not structural limitations. Peak strains under normal, maximum, and extreme operating conditions remain well below even conservative allowable motorsports composite limits.

At the maximum expected operating speed of approximately 145 mph, the pylons experience peak strains of only 0.353%, corresponding to a margin of safety of 1.266 under ultimate loading, as shown in figures 22-25. Scaled failure loads exceed 3,200 lb for the wing system, well beyond any realistic aerodynamic force the wing could generate.

These results display that the structural design provides substantial excess capacity, maintaining durability and long-term reliability, a key for performance-focused motorsports components.

Mass Reduction

With a total system mass of 6.88 lb, the custom wing weighs less than half of most aftermarket alternatives, and as little as one third of some more complex configurations. This mass reduction was achieved through strategic composite use and removal of unnecessary material.

Reducing mass at the rear of the vehicle increases handling response. These changes are particularly beneficial for a lightweight car like the Miata, where small changes can have a noticeable driving impact.

Cost Effectiveness

Although the total build cost of \$1,101 slightly exceeds the price of the most basic aluminum aftermarket wings, the materials, performance, and features of the custom wing align more closely with premium carbon fiber products that cost several-fold more.

Additionally, if shared fabrication and production resources are available, the effective project cost drops to approximately \$535, placing the custom wing well below even the most affordable performance-oriented aftermarket options, despite offering greater performance. This demonstrates that advanced aerodynamic motorsports components can be produced cost effectively with the right tooling and manufacturing decisions.

Tradeoffs and Limitations

As with any engineering project, some tradeoffs were made. A single-element design limits maximum achievable downforce relative to dual or multi-element wings. A single-element design was used to meet mass and cost targets. Additionally, CFD simulations were conducted with the wing in isolation, rather than as a part of the full vehicle model, which introduces uncertainty in absolute performance values. However, it is important to note that this is a common practice in wing evaluation.

Despite these limitations, the consistent benchmarking goals and conservative assumptions used throughout the project provide confidence in the performance comparisons and overall conclusions.

Evaluation Against Objectives

Based on the results presented, the project successfully met all primary objectives:

- **Aerodynamic performance:** Met or exceeded baseline aftermarket benchmarks
- **Aerodynamic efficiency:** Competitive DF/D ratio within the benchmark range
- **Mass reduction:** Much lower mass than all benchmark configurations
- **Cost competitiveness:** Lower cost than premium carbon fiber alternatives

Additionally, all secondary project objectives were also met:

- **Adjustability:** Offers competitive angle-of-attack and endplate adjustment
- **Structural Integrity:** Maintains sufficient stiffness and strength to safely operate at all realistic aerodynamic loads with conservative safety margins
- **Usability:** Trunk remains accessible and potential long term damage associated with trunk-mounted wings is avoided
- **Aesthetics:** Exotic materials and modern design achieves a visually aggressive, motorsports-inspired appearance, matching modern racing trends and exotic designs.

Considering that all primary and secondary objectives were met, despite a project goal of meeting only 2 primary objectives, the project can be considered a success.

Current Status & Future Work

At the time of writing, the project is approaching completion, with almost all components fabricated and finished. Remaining work is focused on final fabrication, assembly, and real-world validation.

Current Status

- **Wing body:**
Fully fabricated and bonded, including carbon fiber shells, internal foam core, and aluminum ribs.
- **Pylons and endplates:**
Endplate manufacturing in progress using chopped carbon tow and 3D printed molds. Aluminum insert install and final surface finishing pending.
- **Mounting hardware:**
Purchased, awaiting install and mounting.
- **Simulation and analysis:**
Aerodynamic performance and structural capacity validated through CFD and finite element analysis.

Planned Future Work

Several steps remain to fully validate the design:

- **On-car installation and testing:**
Install the completed wing on the vehicle and evaluate real life fitment, adjustability, and structural performance.
- **Performance validation:**
Conduct on car, track oriented testing to assess handling, rear grip, and driver feedback across different wing and endplate settings.
- **Composite coupon testing:**
Manufacture and destructively test composite coupons to better understand laminate strength, stiffness, and failure behavior of different weaves and builds, and optimize future projects.

These steps would provide a higher level of confidence in absolute aerodynamic performance and further push the project from simulation to real-world results.

Conclusion

This project demonstrates that student-accessible composite manufacturing can produce a rear wing competitive with premium aftermarket offerings in aerodynamic performance, structural capacity, mass,

and cost. CFD-driven load estimation, strain-based composite evaluation, and practical manufacturing methods were combined into a complete functional system.

The resulting wing delivers competitive downforce and aerodynamic efficiency while achieving a substantial reduction in system mass and total cost relative to commercially available alternatives. Structural analysis confirmed that the mounting system performs safely with excess capacity, ensuring final product durability. Importantly, these results were achieved using manufacturing processes and tools available in a university or small workshop environment.

Aerodynamics, rigidity, materials, manufacturing, cost, and usability were all treated as connected design variables, rather than isolated problems. The final product is a balanced solution that is competitive in every category.

Overall, this project displays end-to-end ownership of a complex engineering system, from initial idea, through benchmarking and design, to iteration and development, to fabrication and validation planning. This presents a project level consistent with the work of professional motorsports and composite engineering teams.

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