Preliminary Design Review
24 Hours of Lemons

Senior Design I – Fall 2025

Client: Brad Stolz – Stolz Engineering

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December 10, 2025

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1. Executive Summary

The Colorado School of Mines 24 Hours of Lemons Team enters Fall 2025 with the objective of restoring and improving a previously campaigned Mazda Miata endurance racer for competition in Summer 2026 at High Plains Raceway. Building on lessons from the prior year, the 2025–2026 team is focused on achieving reliability, compliance, and enhanced vehicle performance through targeted efforts across major subsystems.

The Powertrain Subsystem Team is addressing previous reliability concerns by inspecting and repairing internal engine wear, implementing a higher-capacity radiator system with improved ducting, and redesigning the air intake and exhaust systems for greater efficiency. The addition of a new HEI ignition distributor eliminates prior tuning inconsistencies, providing a more consistent spark and modest power gains, while cost-saving measures such as omitting exhaust wrap balance performance improvements with budget constraints.

The Structures Subsystem Team is concentrating on reinforcement and safety. Efforts include replacing and strengthening the Miata's aluminum differential housing to mitigate prior failures, and fabricating a fully Lemons-compliant roll cage designed in-house using 3D scans for optimal driver ergonomics and safety.

The Electronics Subsystem Team is executing a major upgrade to the vehicle's data acquisition and driver interface. By implementing the OneGauge digital display system and integrating a comprehensive sensor network via a microcontroller, the team will provide real-time monitoring of vital parameters such as oil pressure, coolant temperature, and system voltage. This upgrade enhances both driver awareness and pit crew decision-making during long-duration racing events.

The Aerodynamics Subsystem Team is pursuing a combined active and passive aerodynamic strategy. A deployable Drag Reduction System (DRS) will complement static components such as splitters and diffusers, with all designs validated using CFD and wind tunnel testing. Together, these refinements will improve vehicle stability and cornering/top speed.

By the conclusion of the Fall 2025 semester, the team will deliver a complete design package including subsystem-specific analyses, manufacturable CAD models, and preliminary testing results. These outcomes will form the foundation for Spring 2026 integration and full vehicle assembly, ensuring a structurally sound, thermally stable, electronically advanced, and aerodynamically optimized race entry ready to compete safely and competitively in the upcoming season.

2. Scope of Work

The 24 Hours of Lemons Project at the Colorado School of Mines challenges senior design students to engineer a reliable and rule-compliant endurance race car for competition at High Plains Raceway while under an extremely tight budget.

The event's unique constraint, building a functional race car with a total vehicle cost under $500, forces teams to demonstrate creative engineering judgment and make every attempt to repair existing systems rather than replace them. The Mines team's entry, a heavily modified Mazda Miata, features a Ford 302 V8 engine swap and a range of custom-fabricated/off-the-shelf components that have evolved through multiple prior iterations.

Following the 2024–2025 campaign, the Miata sustained several critical failures during the race, including differential housing cracks, chronic overheating, and roll-cage non-compliance during technical inspection. The overarching problem statement for Fall 2025 is to restore and re-engineer the vehicle to a validated, build-ready design that eliminates prior mechanical and regulatory deficiencies while improving performance within Lemons competition and Mines Capstone constraints.

To achieve this, the team has divided the project into four major subsystem teams (Powertrain, Structures, Electronics, and Aerodynamics), each responsible for diagnosing the current post-race vehicle condition, developing targeted redesigns, and producing validated documentation for fabrication and testing in Spring 2026. This scope reflects both competition guidelines and client expectations from Brad Stolz (Stolz Engineering).

In preparing the design strategy, the team reviewed prior years' documentation, competitor solutions, and engineering standards applicable to motorsport applications. These include SCCA and Lemons roll-cage standards, ASTM E164 weld quality criteria, and established automotive materials and fatigue design principles for aluminum differential housings and chromoly steel safety structures. Patent and literature reviews of cooling system configurations, airflow management, and digital sensor integration informed subsystem concepts. This research ensures that the redesign process is evidence-based and grounded in proven engineering methodology.

The Fall 2025 scope encompasses all analytical and preparatory activities required to transition the Miata from its current post-race state to a fully validated, manufacturable configuration. Each subsystem is tasked with:

- Diagnosing and quantifying mechanical or electrical failures observed during the 2024 race season.
- Developing validated redesigns addressing performance, reliability, and compliance issues.
- Producing subsystem-specific FEA, CFD, and bench-level validation to confirm design viability.

- Compiling CAD packages, technical drawings, and documentation enabling fabrication in Spring 2026.

By December 2025, the team will deliver a comprehensive Preliminary Design Review (PDR) that integrates validated subsystem analyses, manufacturable models, and compliance verification. This deliverable will demonstrate that the vehicle is structurally sound, thermally stable, electronically reliable, and aerodynamically optimized—forming the foundation for a race-ready assembly in Spring 2026 and a competitive re-entry into the 24 Hours of Lemons Summer 2026 event.

2.1 Powertrain Subsystem - Subsystem Objectives

- Diagnose and repair internal engine wear and compression losses identified during inspection.
- Redesign the engine's cooling system, introducing higher-capacity heat exchangers and improved shrouding for sustained operation.
- Develop a revised intake system that increases efficiency while reducing complexity and mass.
- Develop a new exhaust header system to increase exhaust flow and efficiency while reducing complexity.
- Conduct performance validation through steady-state and transient thermal simulations, followed by bench testing.

2.2 Structures Subsystem - Subsystem Objectives

- Improve roll cage characteristics in driver ergonomics, safety, and 24 Hours of Lemons tech compliance.
- Inspect and develop a suitable solution for the failed differential housing.

2.3 Electronics Subsystem - Subsystem Objectives

- Fully test, characterize, and label the electrical harness.
- Assess the additional performance information needed for ensuring driver and vehicle safety and determine what sensors to add.
- Find a suitable display upgrade according to requirements found above.
- Assess the need for an upgrade to the ECU.

2.4 Aerodynamics Subsystem - Subsystem Objectives

- Finalize designs for a front splitter, rear spoiler, and radiator airflow ducting to improve pressure balance and cooling.
- Conduct CFD simulations to validate drag and downforce effects.
- Prepare manufacturable CAD geometry and validation data for integration in Spring 2026.

2.5 Fall 2025 Deliverables

- Fully validated CAD and design documentation for each subsystem.
- Subsystem-specific FEA/CFD analysis packages.

- Prototype or bench-level testing results (thermal, structural, electrical).
- Updated compliance documentation and mock tech inspection checklist.
- A comprehensive Preliminary Design Review (PDR) report integrating results across subsystems.

2.6 Constraints

- Expected Budget: Must not exceed total funding.
- Regulations: Must meet 24 Hours of Lemons and Mines Capstone Design safety and compliance standards.
- Timeline: All designs will be ready for review by December 10, 2025, to allow for transition to verification and validation in the Spring semester.

3. Design Requirements

The Design Requirements define measurable, verifiable targets that indicate successful design completion for Fall 2025. Each requirement corresponds with one or more Definitions of Done adopted by the team and reviewed by the client and faculty advisor.

3.1 System-Level Requirements

ID	Requirement	Verification Method
G-1	Vehicle systems should be capable of surviving subsystem specific race loadings for 24 hours.	FEA / Benchtop Testing
G-2	All designs shall meet all specifications set out by Lemon's Rulebook	Dimensional Check and Mock Inspection
G-3	Subsystem CAD models and analyses shall be completed and approved by the client prior to fabrication/purchase.	Client sign-off
G-4	All modifications shall remain within project budget	Final Budget Audit

3.2 Powertrain Requirements

ID	Requirement	Verification Method
P-1	Engine compression shall meet OEM tolerance range (~10% variation).	Leak-down and compression testing
P-2	Cooling system shall maintain fluid temperatures 225°F ± 10%	Coolant temperature sensor

P-3	Intake/exhaust redesign shall increase volumetric flow +10%.	Flow simulation and bench airflow test
P-4	Subsystem design documentation finalized for client approval.	Client sign-off

3.3 Structural Requirements

ID	Requirement	Verification Method
S-1	FOS Requirement: Differential – 2.5+ FOS Roll Cage Requirement - 3	FEA
S-2	Roll cage shall conform to SCCA/Lemons specification (1.5” DOM, 0.095” wall).	Dimensional check and mock inspection
S-3	All required modifications to securely mount differential to vehicle have been made.	FEA and Dimensional check
S-4	All welds and joints meet ASTM E164 visual inspection standards.	Fabrication review

3.4 Electronics Requirements

ID	Requirement	Verification Method
E-1	Wiring harness shall be fully pulled, labelled, and should be tested.	Documentation and potential test results
E-2	A list of all additional sensors shall be compiled, and a viable method of display shall be found.	Documentation
E-3	Potential ECU upgrade viability shall be assessed and decided upon.	Documentation and supporting information

3.5 Aerodynamics Requirements

ID	Requirement	Verification Method
A-1	The front splitter, rear diffusers, and rear wing shall induce 400 N of downforce on the rear axle at 60 mph while not increasing drag by more than 250 N at or below 100 mph	CFD aerodynamic validation
A-2	Cooling airflow efficiency through radiator ducting shall improve by atleast 15 % relative to baseline.	CFD thermal and pressure field analysis
A-3	All aerodynamic mounts shall be designed with a FoS of 2.5 based on estimated loading conditions	FEA structural analysis and static bench test

A-4	All aerodynamic components shall comply with Lemons' visibility, clearance, and safety regulations.	Dimensional inspection and rule check
A-5	Final aerodynamic design package, including CFD plots and manufacturable geometry, shall be approved prior to fabrication.	Client sign-off

4. Concept Exploration

4.1 Powertrain Subsystem

4.1.1 Headers

Option 1: keep the stock exhaust manifold

Currently, the Miata has the stock Ford exhaust manifold system that connects the engine to the exhaust. This stock manifold is made from cast iron, which is relatively durable and low-cost, but it leaves significant performance to be desired. The inherent problem with most exhaust manifolds is that, immediately after the exhaust exits the block, it takes a 90° turn, slowing the air significantly and reducing the exhaust flow rate. Since it's made of cast iron, it's heavy and retains heat, increasing the overall engine bay temperature [1]. Before the stock manifold can be reused, it will need to be checked to see if any warping has taken place, and if it has, some machining will be required to restore the original surface prior to use.

Advantages: Free

Disadvantages: Air flow restriction, weight, and efficiency

Figure 1: Stock Exhaust Manifold

Option 2: New Exhaust Headers

Some benefits to the set of new exhaust headers include improved exhaust flow, lighter weight material, reduced exhaust system pressure, increased horsepower, and less heat radiation in the engine bay [2]. The advantages are due to the material and geometry. The component achieves greater horsepower through the syphon effect, essentially "sucking" the exhaust out of the engine, allowing the motor to make power more efficiently [3]. The selected headers are made from stainless steel, weighing roughly 15-20 lbs (OEM equipment weighs approximately 35 lbs). This weight savings and improved exhaust flow due to the much shallower tube angles, shown in

Figure 2 below. This does come at the cost of an increased space requirement due to the exaggerated geometry. These headers range in price from $120 to $500 for a set, with a proposed set costing $160. The way they achieve greater horsepower is through the syphon effect, essentially "sucking" the exhaust out of the engine, allowing the motor to make power more efficiently [3].

Advantages: Increased horsepower, weight reduction, exhaust flow, reduced back pressure

Disadvantages: Price, space requirement.

Figure 2: Exhaust headers [2]

Option 3: 8 to 1 collector exhaust

An 8 to 1 collector exhaust takes all 8 exhaust pipes and feeds them all into 1 main exhaust pipe. The main advantage of this would be improved high RPM performance. By merging the eight primaries into a single main, it optimizes the scavenging effect, effectively "sucking" the exhaust out of the engine [4]. This reduces the back pressure at high RPM, allowing the engine to "breathe" better, achieving greater peak horsepower [5]. There is also a different sound that is produced that is arguably better, due to the simplified downstream flow path.

There are also some drawbacks to this as well. For example, an 8 to 1 collector is something that has to be handmade. So, it would either have to be done at a custom shop to make them or make custom ones. This is something that is outside the scope of the team's abilities. The actual 8 to 1 funnel ranges in cost from $200 to $900, and then roughly $1000 to $2000 to have a shop make the headers for it. Another drawback is that it can also lose mid-range torque due to the exhaust gas velocity slowing down through the collector, which uses the scavenging effect to diminish the lower RPM performance [6].

Advantages: Improved scavenging effect, increased horsepower, easier routing back-end exhaust, sounds better

Disadvantages: expensive, loss of lower RPM performance

Figure 3: 8 to 1 collector exhaust [7]

Table 1: Exhaust Design Matrix

Criteria	Weight	Keep the same Exhaust Manifold	Exhaust headers	8 to 1 collector
Cost	40%	5	3	1
Power Gain	40%	2	4	4.5
Reliability	20%	2	4	4
Total Score	100%	3.2	3.6	3
Final Ranking		3rd	1st	2nd

Conclusion

The goal for this subsystem was to find a solution that would increase engine power output as much as possible for as little as possible. Table 1, above, is the design Matrix for the exhaust system. It compares all three solutions, in a weighted ranking system designed to show what the best solution would be considering the cost, power gain, and reliability. Also, according to MotorDyne, the long tube headers tested increased horsepower by as much as 11% when tested on a dyno [10]. For this reason, the exhaust header was the solution that was chosen because they balanced a relatively low cost with usable benefits to help the performance of the car.

4.1.2 Air Intake System

Option 1: Utilizing last year's intake system

To save money and time, the team could utilize last year's design. However, this design would come with drawbacks. The current iteration of the intake is a modification of the short ram air intake with a headlight delete. While the intake has a large enough inner diameter where the engine gets proper flow, the intake is located in the engine bay and therefore collecting hot air directly from the engine and using it for combustion. This will drastically lower the efficiency of the engine because warm air is less dense than cold air. When the air is less dense, the engine will receive less oxygen, which will affect combustion [8]. Furthermore, the headlight delete does not optimize the air flow into the engine. Because there is not an air box trapping the air with the intake, most of the air is entering the engine bay and not the intake system. Last year's intake set up is shown in Figures 4 and 7.

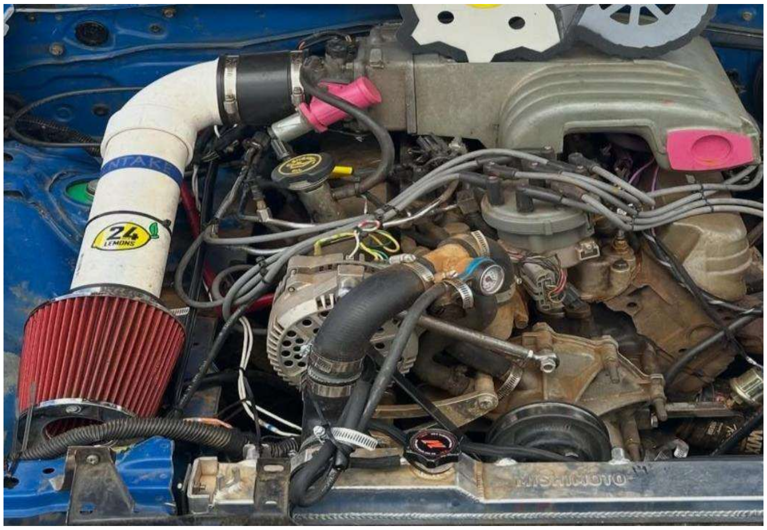


Figure 4: Current Intake System

Option 2: Cold Air Intake

Cold air intake utilizes longer intake tubes to draw cold air from outside the engine bay, normally from inside the bumper. This improves engine performance by delivering a higher volume of denser air. Cold air contains a higher concentration of oxygen molecules, which are important for combustion, and if the air is warm, this lower volume of oxygen can limit the vehicle's performance. Furthermore, a cold air intake uses longer and smoother tubes that reduce turbulence and increase flow, allowing the engine to breathe smoothly, thus causing a slight increase in horsepower.

Figure 5: Cold Air Intake on a 302 V8 Engine

Option 3: Headlight Air Intake system

A short ram air intake utilizes shorter tubing than the cold air intake but allows for more flow into the intake manifold and engine. The main drawback of a short ram air intake is that the air filter is in the engine bay, which causes an intake of warmer air as shown in Figure 5. However, with slight modification, the air flow of the current intake can be greatly improved. In Figure 6, the Miata has a short ram air intake that utilizes the headlight for air, but because of the lack of structure, air flows into the engine bay and causes a smaller pressure differential. This pressure differential then minimizes the amount of air flow entering the engine.

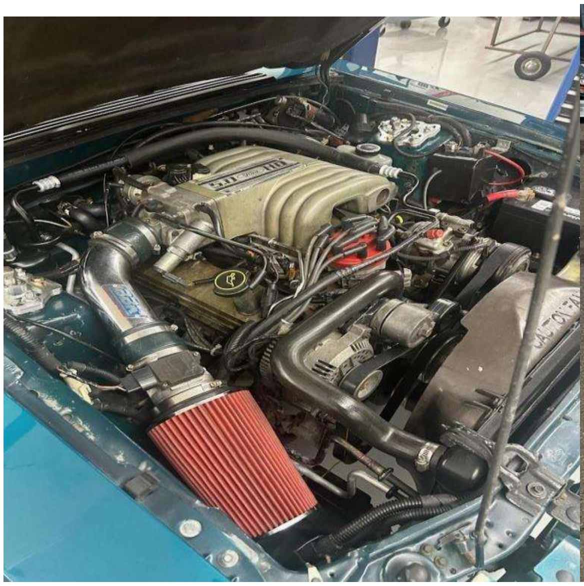


Figure 6: Example of a ram air intake

Figure 7: Intake system in context

To maximize the amount of air brought into the engine, a headlight intake will help create a structure that will help aerodynamically. Headlight intakes are opening around a vehicle's headlight housings that channel air flow into the short ram intake system [9]. A custom headlight assembly will be added to close the existing headlight housing holes, and designed holes will allow air to be channeled and inducted into the short ram intake system (Figure 8).

Figure 8: Headlight Intake Example [11]

Table 2: Intake System Design Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Current System	Cold Air Intake	Headlight Intake
Cost	40%	5	3	4
Performance	40%	2	5	4
Complexity	20%	5	3	4
Total Score	100%	3.8	3.8	4
Final Ranking		3rd	2nd	1st

Conclusion

While implementing a cold air intake system would maximize performance by drawing a large amount of air from outside the engine bay, there is too much complexity when it comes to fabrication. Because a cold air intake system doesn't exist to work with both the V8 and the Miata, the tubes will need to be fully designed and fabricated. In comparison, the headlight intake will also draw colder outside air for the engine but with a reduction in complexity for a minor loss in performance. Because last year's design with headlight intake can be utilized, it will drastically reduce the amount of complexity. The remaining complexity is designing and fabricating a cover that can mount to the headlight holes in the hood.

4.1.3 Distributor

Option 1: Stock Distributor

A cost-effective alternative would be to retain the stock distributor, despite its known tuning limitations and reduced precision compared to modern ignition systems. While this approach minimizes immediate expenses and simplifies installation, it may hinder fine-tuning capabilities and overall engine performance optimization in the long run.

Option 2: HEI Distributor

Another viable option would be to purchase an inexpensive HEI (High Energy Ignition) distributor. This upgrade would effectively eliminate the tuning inconsistencies associated with the stock ignition system while providing a more reliable and consistent spark. In addition to simplifying maintenance and setup, improved ignition efficiency could also yield a modest increase in horsepower and overall engine responsiveness. However, the stock system uses the distributor to communicate when to fire the fuel injectors. This means that there would be further work done in order to use an HEI Distributor.

Figure 9: HEI Distributor

Option 3: Coil Pack Swap

It may be possible to get rid of the distributor entirely and switch to a coil pack system. This would come at a pretty high cost though. The first option would be to purchase a conversion kit from MSD, but this would come at a price point of $2,000. Another option would be to try and incorporate a camshaft position sensor and a more modern coil pack system. The main drawback with this is that it is relatively unheard of with these older engines and would require many custom parts to need to be made. Another drawback would be that there would need to be a way for the ECU to communicate with the new sensor and then it would need to have highly accurate timing with the coil packs. Overall, this second option wouldn't be viable due to the high cost that would come from it, but it could still be a consideration.

Figure 10: MSD Coil Pack Swap Kit

Table 3: Distributor Decision Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Current System	HEI	Coil Pack Swap
Tunability	10%	3	1	5
Cost	40%	5	2	1
Performance	40%	2	5	4
Reliability	10%	3	4	4
Total Score	100%	3.4	3.3	2.9
Final Ranking		1st	2nd	3rd

Conclusion

Although a coil pack system would be highly advantageous for tuning and reliability of the ignition system, a coil pack swap would be far too costly given the current funding. The stock ignition system, despite having more tunability, was having tuning issues from the previous year. However, due to the complexity of trying to make an HEI distributor system work on this motor, the current system in the car will be the best route to go for the ignition system.

4.1.4 Cooling Sub-subsystem

The previous team encountered several issues with the cooling system during the race. The first issue was the absence and subsequent addition of a thermostat to their cooling system which negatively affected overall performance. The next issue involved the water pump, which was not circulating enough water due to the serpentine belt slipping on the water pump pulley. Another problem was insufficient airflow to the radiator which resulted in the bumper being removed. This left the radiator unprotected, and during the race it became damaged as a result of a racing incident.

Before making any major changes to the system, the first priorities should be to ensure that the radiator is properly protected, verifying that the water pump system functions properly, and installing a thermostat that is properly rated for the current configuration. To address the belt slippage, the team will add a tensioner or an idler pulley to the serpentine belt system to increase belt contact on the pulley and prevent slipping. To improve airflow and protection, the bumper will be reinstalled in collaboration with the aerodynamics team, and a ducting system will be added to direct air efficiently toward the radiator. Additionally, hood vents will be added onto the low pressure zone of the hood to enhance hot air extraction from the engine bay, thus improving overall cooling efficiency and maintaining stable operating temperature during the race.

Starting with the hood vents, the team could make their own and place them in the optimal locations, or the team could purchase pre-made vents for around $100 and install them. Vents could look like Figure 11 below.

Figure 11: Potential hood vent locations [11]

Regarding protecting the radiator and increasing airflow efficiency to the radiator, a bumper will be placed back on the front of the Miata. The aerodynamics team will be redesigning a front bumper to accommodate a splitter and included in this redesign will be a large duct to the radiator and 2 small ones for both front brakes. This upgrade could look like Figure 12 below and will be done in-house by the team.

Figure 12: Potential Ducting Locations [12]

To fix the slipping issues, the team would add a tensioner or an idler pulley to maintain a proper contact angle on the water pump, so the coolant system gets the flow it needs to properly cool the engine. Figure 13 is a diagram of what this could look like, although there is a high potential for change once the engine is put back together. Once it is back together, the team can determine both the proper component and the proper location to best ensure water pump performance.

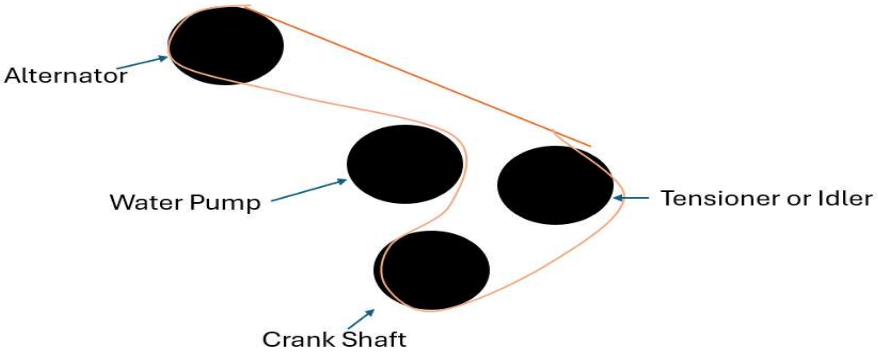


Figure 13: Diagram of a potential serpentine belt system

Option 1 – Keep the Same Cooling System

The most cost-effective solution for cooling would be to keep the same radiator with the previously discussed changes. Due to all the issues during the race, it is difficult to grasp if the radiator itself was insufficient for the car to perform properly. There is a chance that if the water pump functions to its capabilities, there is proper ducting, venting, and an adequate thermostat, then the radiator could properly cool the system. The current radiator is made by Mishimoto with total dimensions of around 27 by 18 by 2.55 inches. This setup is rated for the stock Miata system, which is around a 1.6-liter inline 4 engine. Comparing this to the 5.0-liter V8 currently in the Miata, it is evident that this radiator is not properly equipped to cool the system.

The upside of this radiator is that it takes no money away from the team's limited budget and allows money to be spent elsewhere. This radiator also fits perfectly into the engine bay with no modifications needed to accommodate its integration. A new radiator will be larger, requiring engine bay modifications and taking a significant portion of money out of the team's budget to implement. Keeping the same cooling system is not recommended due to its poor performance, but if the team runs into significant budget limitations, then this option will need to be considered more thoroughly.

Figure 14: Image of the Current Radiator [13]

Option 2 - Adding an Oil Cooler

An oil cooler is a simple way to upgrade the cooling system. This component will provide targeted cooling towards engine oil and can be placed in front of the radiator to ensure that it gets ample air to cool the oil. Due to the oil cooler focusing on oil, it would be ideal for racing applications where oil temperatures tend to reach high temperatures. It would cost around $400-$600 to implement, which would be similar to upgrading the radiator, and it would provide some extra cooling that the system needs. While most oil coolers would improve the car's cooling capacity, they likely would not provide as much support as a new radiator in a similar price range. The oil cooler would not require changes to the body, but it would require special mounts to align it with the radiator, and the team would have to acquire a thermostat and proper hoses to run the oil to the cooler and back to the engine.

Overall, this upgrade would help the performance of the cooling system and should be something for the team to consider. Due to the high price associated with this upgrade, it would likely be smarter for the team to go in a different direction because of the limited amount of funds available. If more funds became available, this would be an upgrade to consider in addition to more prevalent upgrades to the cooling system.

Figure 15: Potential Oil Cooler [14]

Option 3 – Upgraded Radiator

The third option is to upgrade the radiator itself. As discussed with option 1, the current radiator is rated for a Miata engine, which provides significantly less heat and performance than the Ford 302 engine that the car currently has. The choice here is to upgrade to a radiator that is rated to perform with a 5.0-liter V8. After some research, an ideal choice could be a Mishimoto with total dimensions of 29 x 19 x 2.55 inches. This radiator gives a larger frontal area, which allows for more air to flow through the radiator and thus enhances heat transfer through convection. A drawback to this upgrade is that adjustments to the frame would be needed to accommodate the 2 inches of extra length that this radiator has. It would also require custom mounts and likely a larger ducting system to take advantage of the larger frontal area. This upgrade would cost around $500-$600 and would be the costliest of the 3 options listed.

Although this upgrade requires body changes and a high upfront cost, it would be worth it as it would likely remove a significant portion of the cooling problems that occurred in the previous race. If it is determined that changes to the body cannot occur, then the team can pivot to other radiator dimensions that would better suit the car whilst providing similar performance. Regarding cost estimations of a pivot, there is a wide range of options from $300-$800. If funds are a major issue, then there is a chance that the team should consider other options with the cooling system but correcting these issues should be high on the priority list as effective cooling is essential to race performance, and as the results showed in last year's race, cooling problems severely limited overall vehicle performance.

Figure 16: Proposed Radiator Upgrade [15]

Design Matrix

The design matrix considers 3 main variables: cost, effectiveness, and reliability. Cost and effectiveness were rated the highest due to the team's limited budget and persistent cooling issues observed in the last race. Reliability is also a very important factor but was weighed less because a system could be considered reliable but if it does not meet the basic parameters needed to have effective cooling then the system will fail. The overall goal of the cooling system is to provide a cost and performance-effective solution that will give the team the best chance to have no cooling failures for a 24-hour race.

Table 5: Cooling System Design Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Keep the same radiator	Add an oil cooler	Upgrade the Radiator
Cost	40%	5	2	2
Effectiveness	40%	2	4	5
Reliability	20%	2	4	5
Total Score	100%	3.2	3.2	4
Final Ranking		3rd	2nd	1st

Conclusion

The design matrix recommends that the team upgrade the radiator to one that is properly rated for the engine. While this option is potentially the most expensive, it provides the best heat dissipation and gives the team the best chance for a reliable cooling system. This system also gives the team the best chance to meet requirement P-2 under powertrain requirements, which specifies that the coolant temp shall be less than 225°F with a 10° tolerance.

While this decision allows for the best performance, it also comes with design challenges like modifying the vehicle frame to allow the radiator to fit at the front of the engine bay. Another consideration for the team, if budget allows, would be to combine options 2 and 3 into a 4th option that would involve upgrading the radiator and implementing an oil cooler, which would enhance heat dissipation at a higher level than any 1 option could do by itself. Preliminary calculations determining how much heat the cooling system needs to dissipate can be found in the appendix under Cooling Calculations.

4.1.5 Shroud System

Option 1: Shroud Water Sprayer

Using a microcontroller, a cooling system that actively monitors the coolant temperature and then takes action to help cool the car when needed can be designed [16]. Some possible systems that could be implemented would be 1. A water/washer fluid reservoir that passively sprays water into the shroud. 2. An active aero splitter in front of the shroud to adjust how much air goes into the radiator, or provides downforce/aerodynamics when needed. 3. A warning light on the dash to warn the driver. 4. Active aerodynamic adjustment for brake ducts.

Option 2: Basic Shroud

To save money, a basic shroud could be fabricated out of sheet metal. This would direct air through the radiator, allowing for better cooling [17]. Without a shroud, air isn't directed through the radiator as well, causing a decrease in cooling.

Figure 17: Racecar Shroud [18]

Option 3: No Shroud

To save money, the possibility of not using a shroud will be considered. This would harm aerodynamic efficiency since a bigger opening for the radiator would be needed, along with overall performance, since this may not have to use the full potential of our engine power.

Table 5: Shroud Decision Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Shroud Water Sprayer	Shroud	No Shroud
Cost	50%	2	3	5
Effectiveness	50%	5	3	1
Total Score	100%	3.5	3	3
Final Ranking		1st	2nd	2nd

Conclusion

The current largest issue with the car is a lack of cooling. For this reason, it is not viable to continue using no shroud for the radiator [19]. Using a simple shroud would be a decently viable option for directing more air through the radiator, but this system could be further improved. For this reason, a shroud will be used along with a water sprayer, which will dispense water into the shroud whenever the car is sensed to be running too hot [20]. At the current time it is difficult to model a shroud for verification purposes, but a model will be constructed for testing as soon as a radiator is selected. A 3D model can be used to model the amount of air going through a shroud.

4.2 Structures Subsystem

4.2.1 Differential

Option 1: Repair and Bolster Original Differential

The original Miata differential housing, an aluminum alloy casting, experienced cracking along both differential mounting arms due to cyclic loading and stress concentrations from the V8 engine retrofit and harsh driving conditions. Rewelding and reinforcing existing housing represents a cost-effective path to restore functionality and improve structural rigidity while maintaining the existing driveline alignment.

This represents a low-cost path to restore function, but it must still satisfy the project's structural design requirements. Most importantly, achieving a minimum FoS of 2.5+ for the differential (S-1), ensuring the differential is securely mounted to the vehicle (S-3), and verifying that all welds/joints meet ASTM E164 visual inspection standards (S-4).

Welding repairs on aluminum castings present distinct challenges due to the material's inherent porosity, oxide formations, and residual stress concentrations. The Miata differential housing, likely cast from an A356-T6 aluminum alloy, is particularly sensitive to thermal cycles during repair. Fusion welding disrupts the original T6 temper, causing a significant loss in mechanical strength within the heat-affected zone (HAZ). For A356-T6 and like materials, yield strength typically decreases from around 230 MPa in the as-tempered condition to roughly 90–120 MPa post-weld if no post-weld heat treatment (PWHT) is applied [21]. PWHT is required in any attempt to restore original properties, though such treatments are rarely practical for assembled components. Should this path be pursued, TIG welding using ER4043 filler metal is widely recommended for repairing A356 castings, as its silicon-rich composition improves wetting behavior, mitigates hot cracking, and provides good compatibility with alloys of a similar makeup; however, it provides no guarantee of success [22].

Advantages: Low cost, retains factory tolerances, guaranteed direct fitment.

Disadvantages: Reduced fatigue life in the weld zone, thermal distortion risk, requires extremely skilled TIG welding.

Option 2: Replace Housing and Bolster Known Failure Point

An alternative approach is to acquire an undamaged, identical Miata differential housing and apply reinforcement modifications prior to vehicle installation. This method avoids the metallurgical drawbacks associated with welding a previously fractured casting and enables the design of optimized reinforcement before service.

In this approach, reinforcement can be achieved using TIG-welded gussets or bonded aluminum stiffening ribs in high-stress regions, such as the differential mount ears and carrier web. Finite element studies on similar aluminum automotive housings indicate that increasing the section thickness by 20% around stress risers improves fatigue life by more than 50% under cyclic torque loads [23].

Replacing the damaged housing with an undamaged 7-inch Miata housing and reinforcing known high-stress regions is the preferred “repair-and-improve” approach because it better supports the differential design criteria established in the requirements section. The reinforcement concept is intended to be engineered so the assembly can meet FoS 2.5 (S-1) while maintaining a secure mounting interface to the chassis (S-3) and ensuring reinforcement welds/joints are validated to ASTM E164 visual standards (S-4) prior to service.

Compared to rewelding the entire housing arm, reinforcing an intact casting provides better control of weld quality and geometry, as the component can be fixtured accurately and welded under more favorable conditions. The unbroken housing arm will preserve its T6 temper (with the exception of the HAZ and remelt volume). This allows for localized reinforcement without dramatic loss of strength in the base material. Furthermore, the dimensional accuracy of the mounting points remain uncompromised, simplifying driveline reinstallation and alignment.

This method also allows integration of lightweight design principles (e.g., applying reinforcements selectively where FEA identifies critical load paths). Reinforcements can be TIG-welded, and potentially even mechanically bonded using high-strength aluminum epoxies such as Hysol EA 9394 if FEA analysis shows it is suitable [24].

However, the free donated housing has not yet been received, so final, defensible FEA is not possible yet. Until the part is in-hand, the team cannot confirm the casting thickness distribution, nor can it validate weld quality (which directly affects local stiffness/strength assumptions and governs whether modeled load paths are realistic). Once received, the team will (1) measure critical section thicknesses, (2) inspect weld quality, and (3) run the final FEA used to verify compliance with S-1/S-3, with results presented at the CDR.

Advantages: Maintains material temper and geometry, high fatigue resistance, optimized reinforcement design.

Disadvantages: Requires sourcing new housing, increased upfront cost.

Option 3: Swap for Higher Power Differential (FORD 8.8)

Another option includes swapping the current differential with a Ford 8.8 differential, which is significantly stronger and capable of handling the power and torque provided by the V8 engine. This differential is known for its durability and has been used in a wide range of Ford vehicles, making it more widely available and relatively cheaper than other high-strength differential options [25].

This swap would create a higher cost than sticking with the stock Miata differential because it would require a new driveshaft, new axles, and new mounting hardware since the Ford 8.8 is larger than the Miata unit. Installation of the parts may also be more complex unless a conversion kit is purchased to make this process more streamlined. There are many known conversion kits that typically include mounting brackets, axles, and hubs. [26] This can also add to the overall price, but the price can also be reduced by either finding cheaper parts or even going to a junkyard to find the Ford parts needed.

Figure 18: Differential Mounting Kit

Another thing to note is the increased weight to the rear that the 8.8 differential would provide. The car is currently really front heavy, which negatively affects the handling. This added weight to the rear may improve the car's handling characteristics because a better weight distribution will increase stability while also reducing understeer by balancing the load across all tires instead of letting the front tires bear the brunt of the force when turning.

Additionally, the wide variety of available gear ratios that this differential provides is a major advantage to have. Since the 8.8 was used across multiple different Ford platforms, the gear sets are available in ratios from approximately 2.73-5.13:1. This range allows the gearing to be tailored precisely to the car's needs. [27] In an endurance race, a moderate ratio somewhere around 3.27 to 3.55 may provide a good balance between acceleration and top speed while also keeping engine RPM and heat manageable over long runs. Table 6 shows the design matrix for all three solutions

Advantages: Strength, durability, availability, gear ratio flexibility, added weight

Disadvantages: Cost, installation process

Table 6: Differential Design Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Fix Broken 7" Differential	Fortify New 7" Differential	Ford 8.8
Strength	40%	2	3	5
Cost	30%	5	5	1
Performance	20%	2	3	5
Complexity	10%	1	5	2
Total Score	100%	2.8	3.8	3.5
Final Ranking		3rd	1st	2nd

Conclusion

As seen in Table 6, Fortifying a 7" Differential ranks 1st (3.8), ahead of the Ford 8.8 (3.5, 2nd) and Fix Broken 7" (2.8, 3rd). This option best balances the weighted criteria (strength, cost, performance, complexity) while remaining consistent with the differential design requirements and the current integration plan, so it will be the baseline solution, with the Ford 8.8 kept as a backup if scope/budget expand.

The free housing has not yet been received, so accurate FEA cannot be completed for this PDR because the required inputs (as-built thickness measurements and weld quality/condition assessment) are currently unknown. These inspections and the final verification of FEA against the established differential criteria will be completed and documented at the Critical Design Review (CDR).

4.2.2 Roll Cage

The roll cage is the single most critical safety component of the vehicle, and its design is governed by strict regulations set forth by the 24 Hours of Lemons technical inspection. Failure to meet these requirements (which occurred with the previous iteration of the vehicle) necessitates a complete re-evaluation of the roll cage strategy. The primary design objectives are compliance with all technical regulations, ensuring a minimum Factor of Safety (FoS) of 3, and guaranteeing driver ergonomics are not compromised (specifically addressing interference with the clutch pedal).

Four distinct strategies were identified for the roll cage implementation, each presenting unique trade-offs concerning cost, labor, schedule, and safety assurance.

Option 1: Modify Existing Roll Cage

This option involves repairing, widening, and structurally reinforcing the current roll cage. While this is the most cost-effective path, it carries the highest risk. The existing cage nearly failed the technical inspection and was recommended by the officials to make serious modifications. The current cage also interferes with the driver's ability to operate the clutch comfortably and is not conducive to easy entry/exit, costing more time on the track. Furthermore, the structural integrity and Factor of Safety (FoS) of the current frame are unknown, requiring a time-consuming Finite Element Analysis (FEA) to ensure structural integrity with the modifications.

Figure 19: Modified Roll Cage

Option 2: Buy an off-the-shelf roll cage

The purchase of a prefabricated, bolt-in cage, such as the Rhodes Race Cars1 5/8" DOM 6-point design, offers guaranteed material quality. However, at an estimated cost of $700 before shipping, this option provides only a marginal safety improvement over the existing cage. Critically, these commercial designs often utilize floor-mounted connection points, which risk perpetuating the existing driver interference issues that violate design ergonomics. This cage is considered a special order item by the vendor and will result in long lead times.

Option 3. Buy a custom "overkill" cage

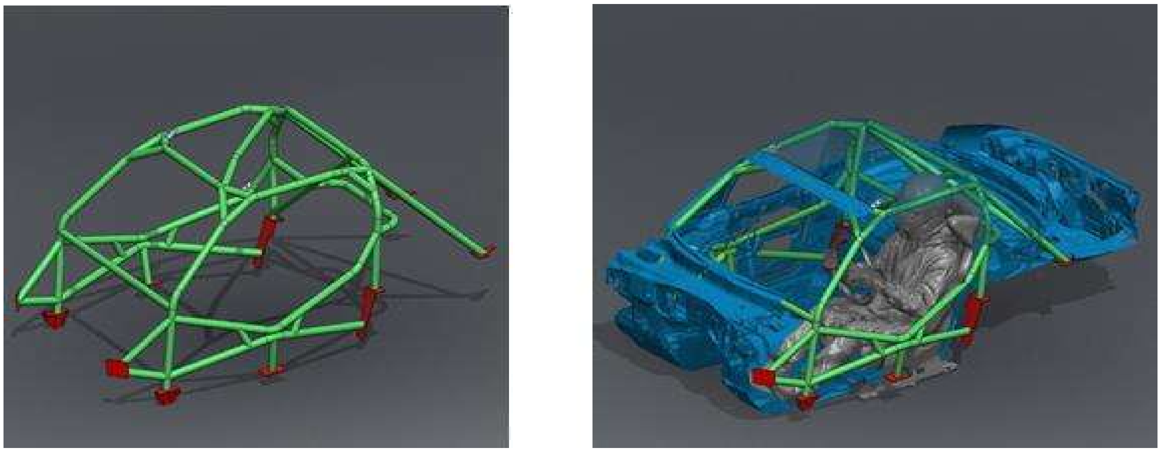


Figure 20: Overkill Roll Cage

This approach involves acquiring a high-end, pre-cut 10-point roll cage kit. The advantages include superior fitment and professional-grade design. However, the price point of approximately $2,100 is considered exorbitantly expensive and places excessive strain on the overall project budget. The fit and finish would result in the shortest installation time and would be relatively easy to meet the design factor of 3, as the cage has been professionally designed.

Option 4: Build a new roll cage

This option involves complete in-house design and fabrication of a new roll cage. While the previous team's DIY attempt failed, this team has secured 3D scans of the vehicle tub and access to specialized resources, mitigating the risk of poor fitment. This approach is the most time-intensive but allows the team to engineer a solution that explicitly meets all custom design criteria, including optimal driver fitment and structural integrity, well within the 3 FoS requirement. This ensures it will be overbuilt for safety and address all previous points of failure.

Table 7: Display Decision Matrix

Selection Criteria	Option 1 (Modify Existing)	Option 2 (Off-Shelf Purchase)	Option 3 (Custom Overkill)	Option 4 (Engineer & Build New)
Safety Assurance (FoS >=3)	2 (Unknown Risk)	3 (Adequate)	5 (Max Assurance)	4 (Engineered Assurance)
Ergonomics & Driver Fit	1 (Known Interference)	2 (Risk of Interference)	4 (High Quality)	5 (Custom Fit)
Regulatory Compliance	1 (Failed Points)	3 (Standard)	5 (Guaranteed)	5 (Design-Driven Compliance)
Cost	5 (Lowest Cost)	3 (Moderate Cost)	1 (Exorbitant Cost)	4 (Controllable Moderate Cost)
Schedule/Time Investment	3 (Rework Time)	2 (Shipping Delay)	4 (Low Time)	1 (Most Time-Intensive)
Weighted Score	40	50	76	79
Ranking	4th	3rd	2nd	1st

Conclusion

After solving the design matrix and discussing the options as a team, building a new roll cage from scratch was the best overall choice. Starting from the ground up will create a superior cage design and improve on the problems that exist in the current cage.

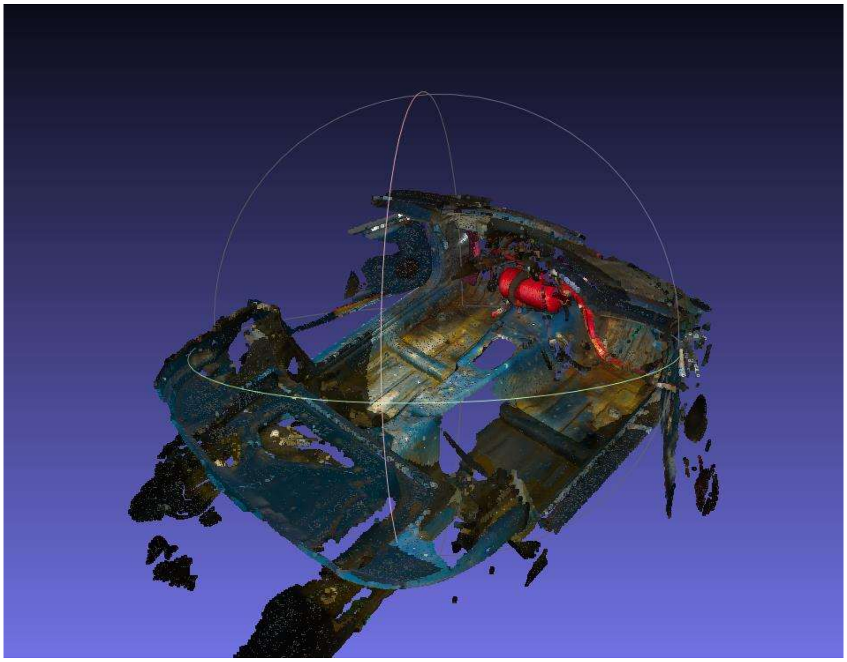


Figure 21: 3D scan of Miata Tub

In preparation for fabrication, the 3D scan is underway, and the required tubing has been purchased. The material consists of 100-feet of 1.5-inch mild steel DOM tubing with a 0.120-inch wall thickness, selected to meet Lemon's specifications. The next steps involve generating a SolidWorks model based on the 3D scan and performing Finite Element Analysis to verify that design will meet the minimum Factor of Safety of 3 while maintaining proper fitment within the vehicle. Once the design is validated, fabrication of the new roll cage will begin using the model as reference. This approach ensures that the final cage satisfies all safety, fitment, and regulatory requirements.

4.3 Electrical Subsystem

4.3.1 Display

The electrical system is paramount for monitoring important systems within the car's engine compartment, undercarriage, and exhaust. The current state of the Miata's displayed information is far from ideal, with only the engine RPM, oil pressure, and coolant temperature being displayed. After consulting previous drivers, the current team, and considering typical racecar gauge setups, the following list of gauges was compiled:

- Coolant pressure
- Exhaust temperature
- Fuel level
- Fuel pressure
- Voltage level
- Vehicle speed

These will be added in addition to the three essential gauges already implemented. The data points serve as crucial information for driver awareness regarding the operating conditions of the vehicle. This will require a new dash module that can display these values while the car is operating under extreme loading conditions. While it would be ideal to include all of these data values, further refinement to the sensor array selection will occur as the team delegates the remaining budget to where funds are most needed.

Option 1 – BTI 52mm Multi Integration OLED CAN Gauge

Figure 22: BTI Gauge

BTI's 52mm OLED CAN gauge is a preliminary choice for the solution of the dash issues. While small, the gauge could still display 4+ parameters on the panel at a time and could cycle through several pages where other, less important parameters could be held. This gauge was also more affordable at a price point of $350 compared to larger displays that easily surpassed the $500 reasonable budget limit. This gauge's small form factor also makes a mounting solution straightforward from a manufacturing standpoint. The gauge also communicates over a pure CAN network, in some ways significantly simplifying wiring by only requiring power, ground, and a two-wire CAN bus terminal.

While initially, this display may seem to be ideal for the project, several considerations were made regarding its compatibility with our existing wiring system as well as viewing convenience. The CAN network that this gauge communicates over is present in many modern-day vehicles that have updated ECU's with OBDII ports. Unfortunately, our ECU for the Foxbody engine is dated and uses an OBDI port. This is a big hurdle to surmount, both pricewise and complexity-wise, as this would either recruit the team to buy an aftermarket ECU and wiring harness that is compatible with the display or create our own CAN protocol. This is a highly involved task that would take a significant amount of time and troubleshooting, and while it may be a cheaper option on the front end, there are plenty of failure points that may cause the team to have to allocate more funds than necessary towards the implementation of the display solely. Size was also an issue, as a 52mm display is rather small. This wouldn't be conducive to quick readings, while racing and crunching many parameters onto the small display would make information even harder to read. This would then require the team to invest in another 52mm display, ultimately negating the cost benefit that this gauge posed [28].

Option 2 – RacePak IQ3 Display Dash

Figure 23: Racepack Dash

The RacePak IQ3 display is a powerful option for a digital dash. As a well-respected and utilized option in the motorsport world, the IQ3 would read sensor data over its proprietary V-Net sensor modules, or through its wide cross compatibility with aftermarket ECU's over an OBDII channel. There is also the option to buy this display as a logger, which utilizes a microSD writer to store information from the sensors it reads for later analysis; however, this option does come at a higher price point. The form factor of this display affords the driver a much clearer view into the car's information, and while it is a somewhat irregular shape, it would not pose a huge design challenge to manufacture a mounting bracket. This gauge also provides the user with a customizable layout, allowing freedom to relocate and redefine what information the display actually presents.

While this display is appealing to the more affluent racing teams, it has a steep price point at around $750. If the team were to use the compatible V-Net sensors, the price would only climb from there, landing well over +$1000, as the technology is proprietary. If the *compatible* aftermarket ECU route was chosen for delivering sensor data to the display, new sensors would still need to be purchased along with the pricey ECU, resulting in a similar price constraint. Designing our own CAN network would pose an even greater challenge than with BTI's gauge, as configurations of the displays Datalink II software would need to be made. Without using the V-Net modules, using any type of homemade network would be severely limiting and again call for a vast portion of the team's time being dedicated to troubleshooting the CAN network. [29]

Option 3 – OneGuage Display Kit Builder

Figure 24: OneGuage Display

OneGauge's Display Kit Builder is centered around a *highly* customizable 7" or 10" touchscreen LED display and central hub. Regardless of the display size, the gauge can accept a vast number of inputs from sensors, making it the most versatile in data acquisition. After customizing the proper kit for the team's use case, the price climbs to ~$750, but this figure includes all the necessary sensors that the team desires, making its price point very competitive. As seen in the picture, housing for the display can be bought, which the team will forego, but it proves that the design for housing the dash lacks complexity and advanced manufacturing. A huge benefit to this system is that it can read information directly from sensors without needing to route through an ECU or custom-made CAN network. The display is also highly customizable, similar to RacePak's IQ3 display option, giving a large scope of freedom for the team to decide which information will be available to the driver. A logging option is also available at a step up in price.

OneGauge's Display Kit is a "best of all worlds" option for the team's needs. The customizability of the display is paramount for driver knowledge of the car's performance, the ability to hardwire sensors directly into the display eliminated the need for pricey aftermarket ECU's or overly complex self-made CAN networks, the larger display ensures a high level of readability for driver convenience, and the cost effective balance between the display and the sensors ensures that the team won't break the bank when accounting for all the information that is deemed necessary to probe. The team has also achieved sponsorship for this dash, along with the desired auxiliary sensors that the team wanted for extra telemetry, completely eliminating the monetary restraint on this subsystem. One drawback, like RacePak's design, is the increase in price when choosing the data logging option. The data logging was not included in the sponsorship mentioned above, meaning if data logging is chosen, a custom solution using a microcontroller would be required [30].

Table 8: Display Decision Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	BTI 52mm Gauge	RacePak IQ3	OneGauge Digital
Cost	30%	3	2	5
Display Density	20%	2	4	5
Customizability	25%	2	3	4
Programming Complexity	25%	2	3	4
Total Score	100%	2.3	2.9	4.5
Final Ranking		3rd	2nd	1st

Conclusion

The decision matrix of table 8 was used to determine the path the team will take. The BTI 52mm gauges and the RacePak IQ3 are both very expensive options, and each have issues. The BTI gauges lack the required display density, and the RacePak is even more expensive. Both also require a full OBD II upgrade, massively increasing their complexity. The OneGauge Kit Builder provides the best display density and customizability while not requiring an OBD II upgrade. In addition, the cost is covered by the sponsorship, freeing up money from the very tight budget.

4.3.2 Microcontroller

To display all the desired information, sensors must be installed at critical points in the car's subsystems and be connected to a microcontroller for interfacing. This data, once formatted properly, serves as a baseline of the car's, and its underlying subsystems', performance. This allows the team to implement small changes in each subsystem to increase the car's performance and safety, while keeping the driver well-informed during the race.

In order for the data to be useful for the driver, it needs to be updated frequently. While the car does not currently use the CAN protocol, CAN 2.0 is the standard for most automotive applications and will be used as a baseline. Can 2.0 has a maximum baud rate of 500kbit/s, with typical message sizes of 8 bytes (64 bits) . With 9 total desired gauges, there will be 72 bytes required to update the displayed information. This means that the maximum possible refresh rate of information is roughly 868 Hz. With code requirements and the human brain's ability to process information taken into account, a minimum refresh rate of 200 Hz is required.

Option 1 – Arduino Mega 2560

The Arduino Mega 2560 (Mega 2560) is a microcontroller and development board package for a relatively cheap price. Arduinos are known for their wide range of applications, ease of programming, and easy implementation. The Mega 2560 is no different, offering the largest package available for an Arduino, shown in Figure 25 below.

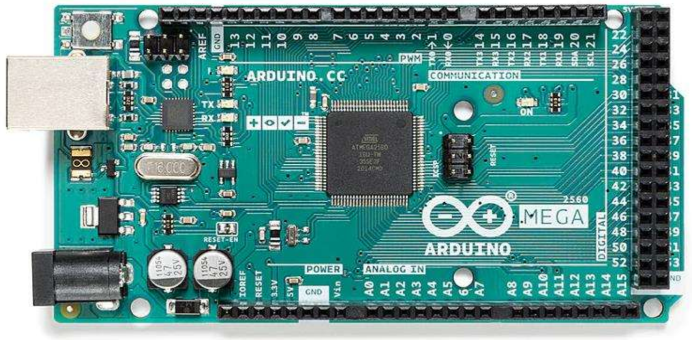


Figure 25: Arduino Mega 2560 Package

The Mega 2560 has 54 pins total, 16 of which support analog inputs [31]. This number is important because most automotive sensors are analog, thus requiring an Analog to Digital Converter (ADC) to be read. 16 pins is enough to include all desired sensors, with a 10-bit ADC providing adequate fidelity. The input voltage for these analog pins is up to 5 Volts, which is the standard for automotive sensors, meaning they could be connected directly with no modification [31].

The input voltage for the board is 7-12 Volts, meaning the 12 Volts of the battery could be tapped and connected directly, allowing for additional simplicity in the car's wiring [31]. Cost-wise, the Mega 2560 is roughly $61, providing a baseline for the cost metric [31]. The big issue with the Mega 2560 is its relatively low clock speed of just 16MHz [31]. With this clock speed and the magnitude of data acquisitions, writing, configuration, and sending that need to be performed, it would be easy for the processor to lag behind the moment, causing outdated information to be displayed. This could be detrimental to the driver, as some data may arrive too late to be considered before an error. With this clock rate, the 200 Hz refresh rate specification is unlikely to be met.

Option 2 – Teensy 4.1

The Teensy 4.1 (T 4.1) is a microcontroller and development board package strongly related to Arduino, going so far as to use the same Integrated Development Environment (IDE) with only one plugin. They can be used in a wide range of applications, much like Arduinos, with the same ease of software development. The T 4.1 is the most robust current model offered by Teensy, shown in Figure 26 below.

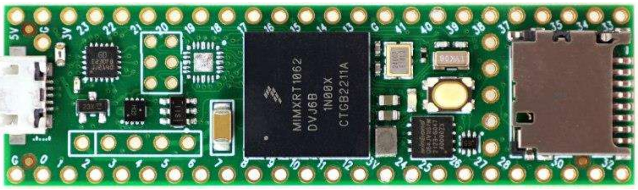


Figure 26: The Teensy 4.1 Package

The T 4.1 has 55 pins total, 18 of which support analog inputs [32]. This is 2 pins more than the Mega 2560, however these 2 extra pins would not be utilized as the desired sensors can be supported without them [32]. The ADC used defaults to the standard 10-bit ADC, with the ability to switch to a 12 bit ADC [32]. The extra two bits could prove useful by increasing resolution, but would also increase the effect of noise. The input voltage for these pins is 3.3 Volts, meaning that the sensor signals would require an additional step-down section before being readable by the controller [32]. This would decrease the fidelity of the sensor signal, and complicate the acquisition.

The input voltage of the T 4.1 is 5 Volts, requiring an external voltage regulator for the board to function [32]. This would complicate the wiring of the vehicle, but could provide greater customizability and isolation when compared to the on-board voltage regulator of the Mega 2560. Cost-wise, the T 4.1 package that would be used is roughly $30 [32]. This is half the cost of the Mega 2560, providing a much better price point. The greatest advantage of the T 4.1 is the clock speed of 600 MHz [32]. This is much faster than the Mega 2560 and would be able to keep up with vehicle performance with no issues or concerns. The 200 Hz refresh rate could easily be met with this clock speed.

Option 3 – OneGauge Kit Builder (Microcontroller)

The OneGauge Kit Builder (OKB), discussed above, would massively simplify the role of the microcontroller. Because it would take sensor inputs directly, processing the data itself, there would be no need to have a microcontroller acting as the interface. Without this requirement, no microcontroller would be needed, and if one were to be added, it could be exclusively used to log the data transmitted or driver telemetry. Should this idea be continued with, the Mega 2560 is likely to be chosen as the clock speed is less important.

The OKB would be able to take the 5 Volt sensor signals directly, not requiring any additional circuitry to work. The OKB supports a variable range of refresh rates, with 200 Hz within the given range, meaning the refresh rate requirement would be met. Cost-wise, the OKB is by far the most expensive option for a microcontroller; however, the cost includes all of the needed sensors and the display, drastically lowering the microcontroller-specific cost. Due to a recently secured sponsorship with OneGauge, the OKB was provided at no cost to the team. This entirely removes the cost constraint for this option.

Table 9: Microcontroller Decision Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Arduino Mega	Teensy 4.1	OneGauge Digital
Programming Complexity	40%	2.5	2.5	5
Clock Speed	25%	2	5	4
Analog Input Voltage	20%	5	2	5
Cost	15%	3	4	5
Total Score	100%	2.95	3.25	4.8
Final Ranking		3rd	2nd	1st

Conclusion

The decision matrix in Table 9 was used to determine the path the team will take. The Mega 2560 and T 4.1 require an incredibly complex custom network to function properly. They are comparatively cheap, however the clock speed of the Mega 2560 could cause serious issues, and the T 4.1's measurements would lose fidelity compared to alternative options. The OKB will have no issues when it comes to clock speed or fidelity and will not require a custom network to work. The biggest issue, cost, was completely removed due to the sponsorship, making the OKB ideal for the team's needs.

4.3.4 ECU

The Engine Control Unit (ECU) is the brain of the Miata's powertrain, responsible for managing all critical engine functions. From precisely controlling the air-fuel mixture and ignition timing to monitoring engine RPM, having a properly functioning ECU is paramount for a safe and reliable vehicle. In our project, the ECU that is currently being used allows the vehicle to function at a low level of reliability and adjustability given different loading scenarios, due to the ignition timing coming from a speed density basis. This poses issues when tuning the engine to specific performance conditions. Finding an alternative that allows for more variable fuel timing can greatly increase performance metrics of the vehicle, as well as provide a much more efficient drivetrain overall.

Option 1 – Stock ECU (DA1/DB1 or similar)

Figure 27: Current ECU of the Miata

With the current ECU setup that the Miata is running, there is a very limited amount of adjustability that is afforded to the team. This is in part due to how the ECU is programmed to send fuel to the engine. The stock ECU (historically manufactured as the DA1 or DB1) runs on a speed density program. This program has a unique, and now outdated, method of measuring how much air the engine is intaking given a certain load. The methodology for the measurement relies on two sensors, a Manifold Absolute Pressure (MAP) sensor, and a Profile Ignition Pickup (PIP) sensor embedded within the distributor which reads the engine RPM. These values, along with the temperature of the intake air, are interpolated over a volumetric efficiency graph, which allows the ECU to determine at what amount of air coming into the engine and the correlated amount of fuel that should be sent to injectors.

Thus, the issue is posed; what happens when certain modifications are made to engine components, ie. The air intake? Without a proper re-tune, which can surpass hundreds of dollars in cost, the ECU does not have the proper Volumetric Efficiency table for the engine setup. This can cause bad idling, running rich or lean under certain conditions, and a serve as a massive hit towards fuel economy, which is paramount for excelling in an endurance race. While this ECU does perform its job, keeping the car running, it is far below the standard the team would need to attain a high level of competitiveness in the race. One positive side to this ECU, considering budget constraints, is it will sufficiently run the car for no extra cost, allowing more funds to be allocated to subsystems that have parts *needing* to be replaced.

Option 2 – A9L/P ECU Upgrade

Figure 28: A9L ECU

The A9L/P ECUs are the “next generation” of ECU that Ford deployed in the Mustang. This ECU had some changes to how it ran the vehicle, but most notably was the switch from a speed density system to a mass air flow (MAF) system. While performing the same task as the MAP and PIP sensors, the MAF sensor eliminated the need to have both sensors working in conjunction and instead used a hot-wire sensor. This system works by supplying a current through a wire located inside the intake manifold where cold air would cross over the wire and cool it down. The ECU would be able to measure how much current was needed at a given point in time to maintain a certain temperature in the wire, and that would correspond to the mass of air entering into the engine. The MAF transfer function is the tool the ECU uses to relate the current supplied to the mass of the air entering the engine, which subsequently tells the ECU how much fuel to provide during *any* loading scenario.

This ECU upgrade would boost the performance of the car due to the MAF system directly measuring the actual air mass entering the cylinder, rather than estimating it, allowing the car to automatically adapt to changes in volumetric efficiency. This would prevent the conditions of bad idling, running too rich or too lean, and reducing concerns about the vehicle’s fuel efficiency. This would also eliminate the need to get a costly re-tune for any engine-side component changes the team makes to the vehicle. The initial drawback of this upgrade would be the cost of procurement; however, the savings the team would incur far outweigh the principal investment. Another potential issue would be the conversion of a MAP/PIP sensor setup to a MAF setup, which is possible, but could take valuable time away from rewiring the vehicle if any conversion bottlenecks arise. Finally, the biggest issue to overcome would be the operating condition that the ECU comes in. Since this specific ECU is not manufactured by Ford any longer, the best place to find one is from Ebay, where is it uncertain whether there will be internal electronic issues.

Option 3 - MegaSquirt MSPNP2 Gen 2

Figure 29: MegaSquirt MSPNP2 Gen 2 Ford 86-93 Foxbody Mustang 5.0

The MegaSquirt MSPNP2 (MegaSquirt) is a third-party ECU meant to be an upgrade to the stock ECU. It is a more reliable version with additional features, while sticking with the same MAP configuration of the stock option. It has pre-loaded tuning settings, but more importantly allows the ECU to be connected to a laptop. This allows for real-time data to be obtained, vastly improving the tuning experience. A wide variety of data is viewable, and there is a great number of customizable engine configurations, meaning the ECU is designed for modifications.

This ECU upgrade has the potential to greatly improve the car's performance, though doing so would require a full engine tune. While not all of the features of the MegaSquirt would be used, the flexibility in engine configurations it provides means that a good match is very obtainable. One of the largest issues with this ECU is that it is not plug-and-play compatible with the current engine. The MegaSquirt, by default, only supports the 1986 to 1988 Ford Thunderbird engines. The current engine being worked on is a 1993 Ford Thunderbird. This means that additional special-order jumper connections would be required to make the engine run at all. The cost of this option is also a large detriment to its feasibility. Since the MegaSquirt is a brand new part, the ECU alone retails for $900, not including the additional sensors, connectors, and jumpers required to make this configuration work. This means it will work reliably, but the mint price tag is much higher than previous options. After factoring in the cost of the added components, the price rises to roughly $1500. With the already limited budget of the team, this is unlikely to be obtainable.

Table 10: ECU Decision Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Stock ECU	A9L upgrade	MegaSquirt MSPNP2
Reliability	25%	4	3	5
Implementation Effort	20%	5	3	2
Tuning Flexibility	30%	1	5	4
Cost	25%	5	3	1
Total Score	100%	3.55	3.6	3.1
Final Ranking		2nd	1st	3rd

Conclusion

The decision matrix in Table 10 was used to determine the path the team will take. The stock ECU is guaranteed to work and is already fully implemented but will underperform when compared to the rest of the options. The MegaSquirt would provide a great deal of flexibility to the team, a boon which is particularly valuable when the engine's state is still undetermined. The cost and extra effort required for implementation seriously hinders the MegaSquirt, however. The A9L upgrade provides the greatest increase to performance at a decent price point. The MAP to MAF conversion is a potential source of error, and that is if the purchased ECU works fully. Despite the issues, the A9L proves to be the best solution due mostly to its necessary performance increase.

4.3.5 Wiring Harness

After the PDR presentation and receiving feedback for future progress, the team has incorporated actionable items into this subsystem report. For the electrical subsystem, this will include baseline testing of the important sensors, repair standards, and expectations for classifying the electrical system as working.

The wiring harness is integral to the functioning of the Miata. It is the vessel system for all the important driver information, controls the timing of the engine, and operates many critical components. After the previous race of the car, the harness was left in poor condition. Examples of the condition are in figures 30, 31, and 32 below.

Figure 30: An image of the wiring harness in the empty hood.

Figure 31: An image of a torn connection.

Figure 32: An image of a melted wire sheathing.

The damage done to the harness is substantial and could easily cause catastrophic issues during operation through unintentionally grounding or electrifying components which should remain electrically isolated. To meet the expectation of running the car for 24 hours, the wiring harness will need to be repaired and bolstered to avoid causing issues. A simple resistance check will be conducted on the wiring harness once it is pulled from the chassis. 10-gauge copper wire is used for a majority of the wires in the harness, with a maximum length of 2 meters. At this thickness and length, the resistance of the wire is .007 Ohm [33]. The number of wires with resistance is above this value will be noted as a benchmark, and the offending wires will be repaired or replaced with new wire. The test will be conducted again after repairing the harness, ensuring that the repairs were implemented correctly.

The engine had previously run hot enough to fully melt through the insulation of wires near the engine. This is seen in figure 32 above. This has the potential to cause the same issues discussed above. To remedy this, once the wiring harness is fully pulled, it will be thoroughly inspected for melted sections. Any sections will be noted, replaced, and reinforced with heat shielding. To prevent any possible melting issues that did not occur previously, any wire (not including spark plug feeds) within one inch of the main engine block will also be reinforced. The heat shielding chosen (Insultherm Ultraflex) to reinforce the harness is made of braided E-type glass. This material can operate up to 1,202 degrees F [34] and is electrically insulative [35]. The maximum heat is far above the previous highest engine temperature, ensuring that any wire will be protected. Because the shielding is electrically insulating, no accidental shorts will be introduced.

To ensure that the engine can run at a stoichiometrically balanced air-fuel ratio, 14.7:1, benchtop testing must be conducted on all the relevant sensors in the wiring harness [36]. This will aid in determining if the ECU is receiving reliable data from the sensors, which would otherwise be a compounding factor in subpar engine performance. The persistent failure points in this age of engine and sensor array are as follows: ACT & ECT sensors, the MAP sensor & O2 sensors. These sensors all play a critical role in maintaining the reliability of the car as well as efficiency via ensuring the vehicle runs as intended without overheating and burning the proper amount of fuel to optimize fuel efficiency. The ACT & ECT sensors provide temperature data of the air coming into the engine and the coolant running through the engine, respectively. The MAP sensor is responsible for reading intake manifold absolute pressure, which serves as the ECU's primary reference for engine load and air volume calculations. The O2 sensor works as a feedback system that measures the presence of oxygen in the exhaust gases relative to the external air and helps in adjusting the air fuel ratio as well [37].

The procedures for benchtop testing these components are as follows:

- ACT & ECT Sensors [37]
    - As both sensors are thermistors, their respective positive & negative leads will be attached to a multimeter and resistance across each will be read
    - The sensors will be subjected to room temperature (~74 degrees Fahrenheit) with an expected resistance of 35k – 40k Ohms
    - The sensors will be subjected to cold air/ice water (~32 degrees Fahrenheit or below) with an expected resistance of 58k – 60k Ohms or more depending on the final temperature of the air/water
        - If the sensor does not increase resistance, it will be deemed dead
        - This should be sufficient to see if the sensors work as intended, but for a full spectrum test, hot conditions will be used as well
    - The sensors will be subjected to hot air/heated water (~100 degrees Fahrenheit) with an expected resistance of 20k – 22k Ohms or less depending on the final temperature of the air/water
        - If the sensor does not decrease resistance, it will be deemed dead
- MAP Sensor [37]
    - The sensor must be powered, so it will be rigged to a 5V power source with the multimeter positive lead attached to the signal pin, and the negative lead attached to the ground pin along with the 5V ground
    - The ambient pressure in Denver will produce a signal from the sensor around 150Hz
        - If the reading does not move from 0Hz, the sensor will be deemed dead
    - A hand pump will be attached to the nipple of the sensor and pumped to approximately 20 inHg with the expected signal of ~105Hz
        - If the reading stays at150Hz, the sensor will be deemed dead.
- O2 Sensors [37]
    - The sensor will be clamped in a vice grip to ensure a secure mounting spot for testing
        - The vice should not clamp onto the threads or body, only the hex nut of the sensor to reduce damage
    - The signal wire and ground wire will be attached to the multimeter positive and negative wire respectively, ignoring the two remaining heating wires
    - A propane torch will be used to heat up the tip of the sensor so that it may begin producing a signal.
    - The tip of sensor will be heated for ~30 seconds to extract a voltage reading

        - If after heating there is no change in voltage reading or the voltage reading never surpassed 0.5V, the sensor will be deemed dead
    - The heat will then be removed from the sensor, and the following voltage drop will be recorded
        - If the sensor takes over 5 seconds to begin dropping its signal or never drops from above its peak voltage reading, the sensor will be deemed dead

4.4 Aerodynamics Subsystem

4.4.1 Body Kits

Option 1: Stock & Current Miata aero packages

The 1997 Mazda Miata comes with the classic lightweight body, well-known and loved. Given its popularity as a project car/racer, many studies have been done to quantify the aerodynamics of the car using Computational Fluid Dynamics (CFD) Analysis and experimental model testing. According to a computational and experimental study by the Hancha Group [38], the stock Mazda Miata MX-5 has a lift and drag coefficient of 0.27 and 0.36, respectively. It is worth noting that the lift coefficient is positive, which means the car's stock aerodynamics cause it to have a smaller ground force for tire friction. Instead of using downforce to gain traction, the MX-5 creates lift, so the primary goal of the aerodynamics subsystem is to optimize the overall downforce of the car while gaining relatively small drag, if at all. Now, there are different aerodynamic packages the team can install on the Miata, so they are listed below.

Option 2: Flat Underbody Panels & Roof

The 24 Hours of Lemons team's Miata is not exactly stock. Many changes have been made to get the car started, and many cause an increase in turbulence and drag. For example, the Ford V8 engine is not available on the stock car that most aerodynamic studies are based on. This can change the fluid flow inside the car. Since the car does not have any outlets for air on the hood, any air cooling the engine exits through the bottom, creating more lift even with a front lip spoiler. An addition to consider for the car is an underbody panel designed to manage airflow. By controlling the fluid moving inside the car, the air can be routed over the top of the car. Although this will increase drag, the lower air pressure under the car would cause a suction force down, aligning with our goal to optimize downforce. Additionally, the aerodynamics subsystem can work with the cooling subsystem to transfer heat effectively from the engine to the surroundings instead of accumulating hot and turbulent air.

Additionally, the previous team working on this car removed the roof, but according to this study by the University of Ontario Institute of Technology [39], top-down tests showed a 0.1 drag coefficient reduction at higher speeds compared to the top-up design.

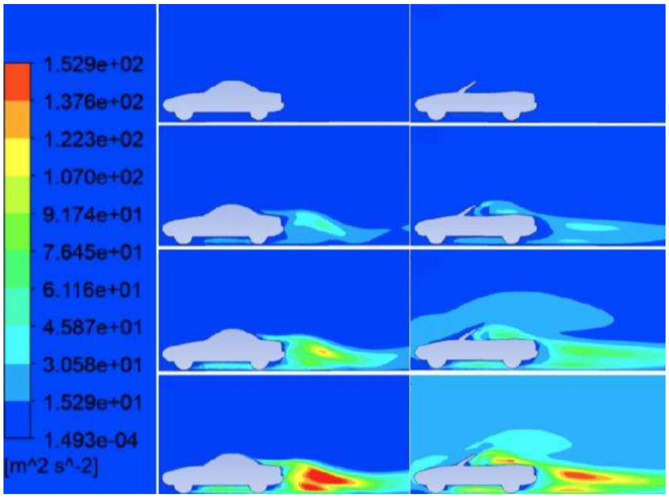


Figure 33: Turbulence kinetic energy field at 50, 100, 150, and 200 km/hr [39]

The figure above shows the impact of adding the roof. At higher speeds, the top-down Miata experiences a concentration of turbulent air in the passenger compartment, which creates unnecessary drag. Whereas airflow is laminar in the top-up model, with a higher turbulence concentration behind the car. Given that this is a racecar that needs to allow the driver to exit the car quickly, the windows were removed to facilitate this. This significantly limits the improvements that can be made to the drag caused by the open top.

4.4.2 Active Aerodynamic Components

Initial CFD was performed to prove a basic aerodynamic package with a wing, splitter, and diffuser could be used to reach the subsystem goal, the results of which can be seen in figures 34 and 35.

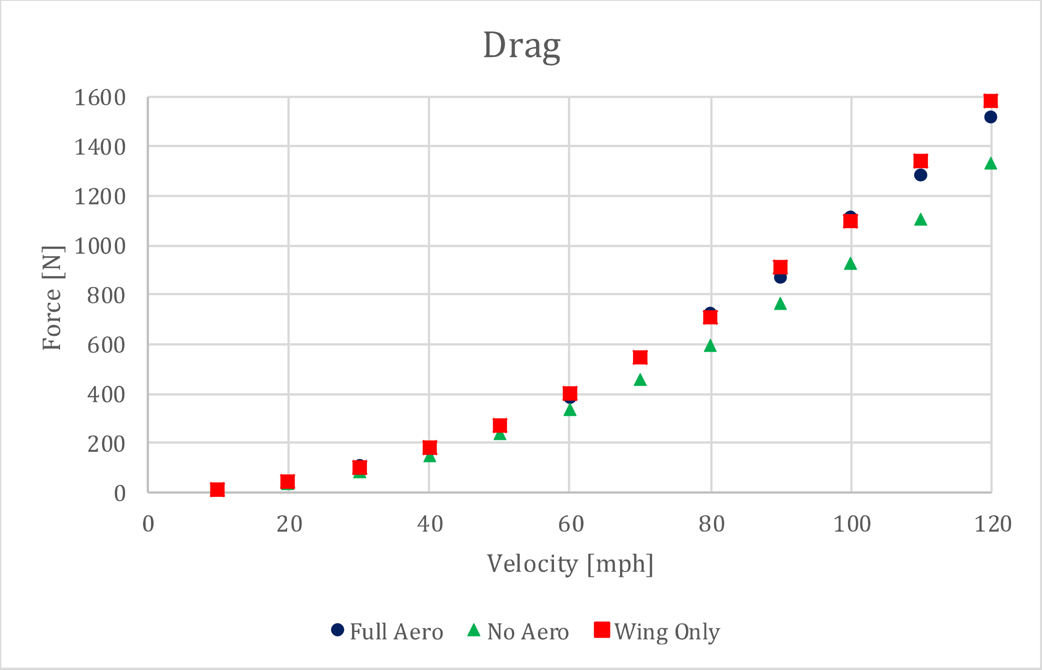


Figure 34: Initial CFD drag data

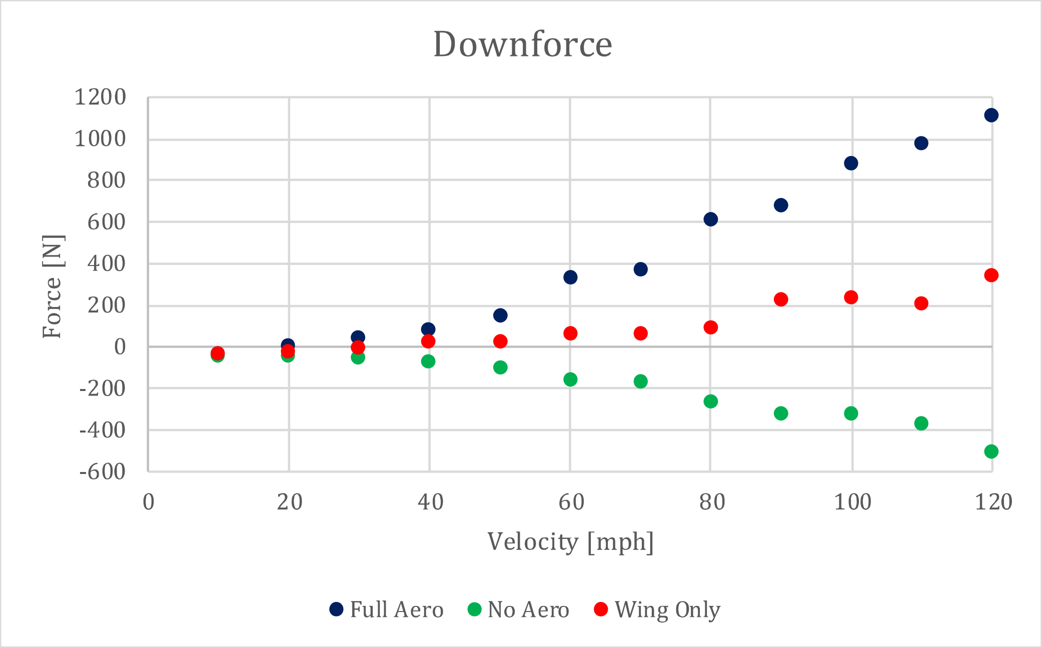


Figure 35: Initial CFD downforce data

With this initial data the subsystem goals are not yet reached, this could be done with optimization of the system or with use of active components to alter when maximum downforce and minimum drag is achieve. This is a technique often used in high performance vehicles and in racing series when permitted. The performance potential is possible, but the benefits may not outweigh cost and risk of failure.

Option 1: Rear wing DRS

The Drag Reduction System (DRS) is best suited for a wing with a large frontal area, creating high amounts of downforce in exchange for increased drag. This system would have two states: closed, with maximum downforce and drag, and open, with reduced drag and downforce. The wing would remain in the closed position until the driver manually switches the system to open. It is conceivable to automate this system using accelerometers, brake position sensors, or GPS. Since the assumption for this system is a large difference in downforce between the open and closed states, it is likely best to leave the system manual to not put the driver in a position where they expect downforce when they don't have it. To the same effect, this system should also include a fail-safe where the system enters the closed state whenever the driver operates the brake pedal in the event that they fail to close the flap themselves, entering a braking zone.

The actuation for this system can come from four main systems. One option is hydraulics, similar to the mechanism used in Formula 1 cars [40]. Hydraulics can provide fast and high-powered actuation, but require hydraulic lines, pumps, and actuators. These components can be expensive and could create more points of failure. A second option is pneumatic control; pneumatic systems are initially cheaper than hydraulic systems and offer many of the same advantages. The main disadvantage of pneumatics is the energy required to operate the system and keep the air compressed [41]. The third option is electronic control using linear actuators. Cheaper and easier to control when compared to hydraulics and pneumatics; the disadvantages are speed of operation and power. The final option is mechanical control with a cable. This could attach to either an electronic motor or a lever that the driver can operate. This is the least complex option, but it is low in power and speed of operation.

Option 2: Rear wing to airbrake

Actuating the rear wing to act as an airbrake is similar to the DRS option but is more versatile with different wing shapes. This system operates in 2-3 positions: neutral, balancing drag and downforce; braking, with a negative angle of attack to maximize drag and downforce; and top speed, with a zero to positive angle of attack to minimize drag near top speed. This system increases in complexity compared to DRS, as it is not operated by drivers. This system must be able to change state under appropriate conditions. Brake position sensors could be used to detect when to change to the braking position, and GPS could be used to detect speed and change to the top speed position. This requires the addition of an electronic controller and would need to be calibrated.

An alternate option to actuating the wing is to use the trunk as an airbrake. Though unconventional, the open position of the Miata's trunk visually appears to be an effective airbrake; this would need to be confirmed with either simulations or experimental testing. Using the trunk as an airbrake creates two potential roadblocks. One is protecting the components within the trunk after the lid opens. This could be solved by fabricating a second lid that sits under the stock trunk lid. The other issue is actuation. Given the size and potential forces acting on the open truck, the actuation system may require significant power to operate effectively. This would likely increase cost as hydraulics or pneumatics may be the only feasible options. This may negate the cost savings from fabricating a simpler rear wing.

This system may require the actuation assembly to withstand a portion of the forces applied to the wing; this may increase cost compared to the DRS system. Despite the cost difference, the other advantages and disadvantages of different actuation methods remain similar to the DRS system. The cable control method is likely not feasible as three different positions are desired. This could be done with servo or stepper motors; however, these could also just be placed on the wing to achieve a similar effect.

Option 3: Fully actuated wing

This system operates similarly to option 2, but with a full range of wing positions. The wing must actuate on multiple axis allowing actuation of pitch and roll. This is the most complex system as it requires taking multiple inputs from the vehicle to determine the most advantageous position for the wing, Table 11.

Table 11: Wing position inputs

Driver Inputs	External Sensors
Accelerator pedal position	GPS (velocity)
Brake pedal position	Accelerometers (longitudinal & lateral)
Steering input	Force feedback from wing

This sensor package allows the system to choose both the optimal angle of attack for the wing and the optimal roll angle, changing the downforce applied to each rear wheel, allowing for better cornering performance. This system can also be calibrated for different drivers depending on driving style or personal preferences. This is the most expensive system, requiring a larger sensor package and independent operation for the actuation components on either side of the wing. It also requires a more advanced controller to properly analyze the sensor data.

The physical actuation requirements are similar to option 2, though the hydraulics and pneumatics now require multiple pumps or controllers, increasing cost. This system has the highest potential for performance benefits, but also has the most failure points, the highest cost, and the highest complexity.

Option 4: Active splitters and diffusers

As splitters and diffusers operate close to the ground, adding moving components can be risky, as curbs and track debris could lead to damage and decreases in performance. Despite the risk, the ability to change the airflow around these components could lead to substantial performance upgrades. The goal of active splitters and diffusers is to change the airflow to decrease drag in straight sections of track. This can be done by actuating vents along the front splitter to change the path of airflow, allowing more air under the vehicle, into the engine bay [42], or over the hood. Slats can be actuated along the rear diffuser to change the direction of air behind the vehicle, altering the pressure and decreasing the drag force, figure 36.

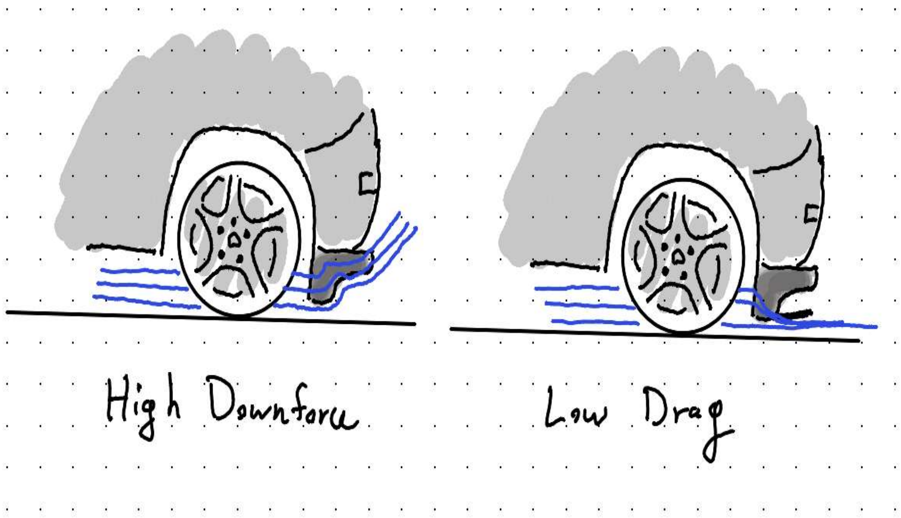


Figure 36 : Active rear diffuser positions

Option 5: Active engine bay ducts

The intake ducts for both the engine and radiator are areas of drag. While these components require airflow to operate, the amount of air required can vary during operation. This means it's possible to actuate these ducts to decrease drag. For this system to be effective, both the radiator and engine sensors must send data to another controller to operate the ducts. This system is risky as a failure may result in either the engine or radiator no longer receiving the necessary airflow, increasing the risk of the engine overheating. This system also requires the engine and radiator to operate without maximum airflow, and the feasibility of this in an endurance setting is unknown. The reduction in drag from this system may also be minute compared with other options, making the addition of this system likely to be a stretch goal.

Option 6: Airbrakes along the bodywork

In addition to the standard controlled aerodynamic surfaces along the car, airbrakes can be placed along the body of the car. These must be active components, as these components are designed to increase drag for better braking performance. These could be placed along the side of the car, along the hood, or on the roof if one is added. It is important to consider driver visibility if placed along the hood. These would be activated with the brakes and require similar consideration in actuation as the active rear wing. A major downside is that for every airbrake added, another actuator must be installed, adding cost and complexity [43].

Without time prohibitive CFD analysis or testing, the effectiveness of these active aerodynamic components cannot be determined quantitatively. Any addition of active aerodynamics to the Miata will be designed and tested in parallel with the design of the static components. This will allow for the design of an effective aerodynamic package independent of the addition of active components. Adding complexity and cost without measurable performance increases is not desirable.

Table 12: Body Kits / Active Aero Decision Matrix

		Rankings (Scale: 1-5)					
Criteria	**Weight**	**DRS**	**Wing to airbrake**	**Fully actuated wing**	**Active splitters & diffusers**	**Active engine bay ducts**	**Airbrakes along bodywork**
Performance potential	0.3	3	4	5	3	3	2
Cost	0.25	3	2	1	2	2	3
Complexity	0.25	5	3	1	3	3	4
Risk of failure	0.2	4	3	2	1	4	4
Total Score	1	3.7	3.05	2.4	2.35	2.95	3.15
Final Rank		1st	3rd	6th	5th	4th	2nd

Conclusion

Based on this analysis, the best options are the DRS system or using airbrakes along the bodywork. As the DRS is the simplest and most cost effective, it makes the most sense to implement. Analysis is still required to find the most optimal wing positions for max downforce and minimum drag; the next steps are CFD and experimental testing.

4.4.3 Splitters & Diffusers

Adding a splitter and diffuser to the Miata's aerodynamic package acts to reduce front-end lift, increase overall downforce, and improve the airflow through the radiator and brakes. These passive aerodynamic components could serve to provide a more stable car at high speeds while also aiding in cooling the car and providing better downforce. The design process focuses on balancing the aerodynamic benefits with feasibility, rule compliance, and cost.

Option 1: Splitter Only

Adding a splitter to the vehicle would function to add a horizontal extension beneath the front bumper. This would work to separate the high-pressure air flowing over the car from the low-pressure air flowing below the car. A splitter allows the car to better separate the high-pressure air from the low-pressure air by preventing air from flowing under the chassis. This would reduce front-end lift and direct more air into areas that need to prioritize air flow, such as the radiator intake and brake ducts. In adding a splitter, the team would need to look for a discounted Miata splitter or, more likely, design a low-cost splitter that fits the Lemons' rules. To be effective, proper mounting would need to be added, and the team would need to run CFD simulations to determine how beneficial a splitter would be, as well as how the splitter would need to extend beyond the bumper to balance downforce gains with ground clearance. Additionally, the splitter's height will need to be adjustable, similar to how a rear wing has angle adjustment. With the ability to adjust height on the splitter, tuning the splitter would be simple and effective [44]. Finally, a splitter will force more air flow through the radiator, which, although helpful in cooling the car, will need to be evacuated upwards instead of through the floor of the car. For this reason, louvers or a hole in the hood may be necessary to consider as well. The splitter will require a mounting bracket and adjustable height setting to optimize performance. It can be fabricated using high-grade plywood, ensuring the part will be low-cost and durable. The shape and angle of the splitter will be determined using CFD analysis, ensuring the optimal angle is used to get an optimal low pressure under the car while producing front-end downforce.

Figure 37: Miata Splitter Kit [45]

Option 2: Diffuser Only

A rear diffuser would act to accelerate the underbody airflow and then expand it at the rear of the vehicle. This effectively reduces the pressure under the chassis and creates more downforce [46]. Additionally, a diffuser would help to keep the vehicle cool by evacuating hot air from the engine bay. To implement this, the team will likely need to construct a diffuser and test to see what the optimal expansion angle is. The team will also investigate whether the aerodynamic and thermal benefits of the diffuser are significant enough to warrant adding the diffuser. The diffuser will be constructed using sheet aluminum or fiberglass panels and will be attached to the rear subframe. Despite the splitter being made of plywood, the diffuser will require vertical fences. These vertical fences will need to be rigid and thin, which would be harder, if not impossible to feasibly achieve with plywood. The optimal expansion angle will be determined using a CFD analysis to maximize downforce while avoiding flow separation.

Figure 38: Miata Rear Diffuser Kit [47]

Option 3: Splitter and Diffuser Combination

Combining both a front splitter and rear diffuser would give the team the greatest aerodynamic effects. This would allow the car to be more efficient than before by balancing downforce generation between the front and rear of the car. While the splitter reduces front lift, it also acts to keep the air on the bottom of the car more uniform and lower pressure. This makes the overall efficiency of the diffuser more effective, allowing the diffuser to manage the flow, keeping the low pressure under the car while accelerating the flow at the rear of the car, allowing for more rear downforce. Both components will be optimized together through CFD to ensure the splitter works most effectively to make low pressure under the car, while the diffuser acts to keep that low pressure and effectively accelerate it once it reaches the back of the car.

Additionally, basic calculations have been done to calculate an estimate for the load the mounting of the splitter will need to be able to uphold. With the calculated figures (Appendix 9.2.3), the team will need to ensure that all mounting points are secure, and a frame will be added to the splitter to distribute the force created by the splitter onto a larger area, ensuring that the splitter is sturdy and will withstand the large forces it will face when used.

Table 13: Splitter/Diffuser Decision Matrix

		Rankings (Scale: 1-5)		
Criteria	Weight	Splitter Only	Diffuser Only	Splitter + Diffuser
Downforce	30%	3	4	5
Cooling	20%	4	3	5
Compliance	15%	5	5	5
Complexity	15%	4	3	4
Drag Impact	10%	4	3	4
Cost	10%	4	4	3
Total Score	100%	3.85	3.7	4.55
Final Ranking		2nd	3rd	1st

Table 13: Splitter/Diffuser Decision Matrix

As seen in Table 13, using a combination of a splitter and diffuser would be most beneficial, considering all the decided criteria. This option will allow for the most aerodynamic effects, as well as being cost effective and improving cooling capabilities.

Conclusion

After feedback from the PDR presentation, the team has decided to prioritize working on subsystems such as cooling and powertrain. While development of aerodynamic components will continue, the aerodynamic components will only be implemented once the team gets the car fully functional. The only exception to this is the development of the splitter and air dam. The splitter and air dam directly affect the cooling system and have the potential to benefit by directing air flow into the radiator and cooling the brakes.

5. Concept Critique

The Universal Design Scorecard, summarized in Table 15, was applied to evaluate how the redesigned Miata endurance racecar supports safe, driver intuitive, and reliable operation for all potential drivers. The scorecard highlights key human-factor considerations, information clarity, hazard mitigation, driver and crew ergonomics, and driver error reduction which are especially critical in a demanding endurance race environment.

Decisions such as adopting the sponsored OneGauge display, redesigning the roll cage to improve driver fitment, and implementing high-impact aerodynamic upgrades were central to enhancing vehicle performance and safety. However, certain considerations—such as accommodations for left- or right-handed operation or the use of assistive devices—were not incorporated. These elements were deemed less relevant within the specific context of motorsport applications and therefore were not prioritized in the design.

The selected design solutions enhance the overall driver experience, improve vehicle performance, and reduce operational risk. These outcomes reflect a strong alignment with universal design principles and reinforce the validity of the team's design direction as the project progresses into the next phase of development.

Table 15: Universal Design Scorecard

Category	**Criteria Met**	**Justification**
Equitable Use	3/4	Improved driver fitment, universal access to telemetry, consistent safety features for all drivers.
Flexibility in Use	3/4	Multiple actuation methods evaluated, displays adaptable, systems adjustable to driver needs.
Simple & Intuitive Use	4/4	Consolidated display reduces complexity; warnings and organized information improve usability.
Perceptible Information	3/3	High-contrast digital dash, multiple modes of feedback, clear differentiation of elements.
Tolerance for Error	4/4	DRS fail-safe behavior, cooling warnings, simplified wiring, safer roll cage geometry.
Low Physical Effort	3/4	Improved ergonomics, reasonable operating force, reduced strain through clearer layout.
Size & Space for Use	3/4	Better cockpit layout, improved line of sight, increased usability for varying driver sizes.

6. Lifecycle Analysis

Scope, Boundary, and Assumptions

Boundary: A "cradle-to-grave" assessment of the team's modifications (powertrain cooling/intake/exhaust updates, structural reinforcement and roll cage work, electronics/telemetry upgrades, and aerodynamic components), rather than a full vehicle LCA.

Method: Qualitative screening LCA (hot-spot identification) based on likely dominant drivers (material mass, welding/fabrication intensity, replacement frequency, and operational durability).

Functional goal: Enable a safe, rule-compliant vehicle capable of surviving a 24-hour endurance event with minimized unplanned part replacement and reduced rework across the build–race–repair cycle.

Data limitations: Vendor-specific embodied-energy and emissions factors were not available at PDR. Therefore, results are expressed as design implications and mitigation actions rather than quantified CO2.

Lifecycle Stages and Design Implications

The vehicle's effective life cycle is iterative: components are designed, fabricated, raced, inspected, repaired, and reused in successive seasons. For this project, the primary lifecycle objective is to reduce failure-driven replacements during the use phase while maximizing reuse of existing assets under Lemons budget constraints.

Lifecycle stage	Primary impacts / risks	Design approach / mitigation
Material sourcing & reuse	Embodied impact of new parts; lead times; budget pressure that drives suboptimal substitutions.	Refurbish existing components where safe, replace only when necessary (favor reinforced stock-geometry solutions), and maintain a parts provenance log for budget and traceability.
Manufacturing & fabrication	Energy and consumables from welding/cutting; scrap rates from rework; quality variation leading to premature failures.	Design for manufacturability with clear drawings/fixturing and weld/joint criteria, validated CAD/FEA/CFD before fabrication, and standardized fasteners/joint geometries to reduce rework.
Assembly & integration	Integration rework (fitment conflicts, wiring faults)	Implement modular interfaces with standard brackets and

	increases material waste and schedule risk.	clearances, labeled harnesses, early mock inspections/dimensional checks, and controlled sensor pinouts/connectors.
Use phase (24-hour endurance race)	Dominant lifecycle “hot spot”: failures drive emergency repairs, spares consumption, downtime, and potential safety risk.	Design for reliability with thermal margin (cooling/airflow), fatigue-resistant structures (diff mounts, cage joints), and robust electricals (strain relief, sealed connectors, fusing), with measurable thresholds that trigger pit actions before damage.
Maintenance & repair cycle	Wear parts and consumables; repeated disassembly can induce secondary damage; uncontrolled repairs can degrade compliance.	Plan preventive maintenance with race-hour-based inspections, a standardized post-session checklist, and components designed for rapid service (tool access, removable panels, modular harnesses).
End-of-life / offseason transition	Disposal and replacement cost; loss of institutional knowledge; “one-off” parts become unusable for future teams.	Design for reuse and handoff by documenting as-built CAD, wiring, calibrations, and spares; using repair-friendly materials (steel for reweldable structures); and locally reinforcing aluminum castings to limit heat-affected damage and preserve fitment.

Identified Hot Spots and Priorities

1) Reliability-driven replacements during the use phase are expected to dominate both cost and environmental burden. Cooling failures, differential cracking, and electrical faults are “high-leverage” issues because a single failure can force multiple downstream replacements (radiator, hoses, fluids, wiring, sensors) and create collateral damage.
2) Fabrication quality is a secondary hot spot. Rework and scrap from poor fitment or inconsistent weld quality increase material consumption and extend schedule risk.

3) Knowledge transfer is a lifecycle risk unique to multi-year student teams. Missing documentation effectively shortens service life by forcing redesign and repurchase.

7. Project Plan

The following project schedule (Table 14) outlines the sprint-based implementation plan. Each sprint spans approximately two weeks, with buffer periods included for fabrication, testing, and integration.

Table 14: Project Plan

Sprint / Phase	Dates	Major Activities	Primary Subsystems / Leads	Deliverables & Milestones
Sprint 7 – System Re-Initialization & Bay Prep	Jan 6 – Jan 17	Re-establish workspace, finalize BOM, vendor confirmations, safety re-approval.	All Subsystems	Updated BOM, workstation layout, subsystem task breakdowns.
Sprint 8 – Differential & Roll Cage Fabrication Start	Jan 20 – Feb 2	Begin fabrication of differential reinforcement and roll cage fit-up, finalize cooling system design.	Structures	Initial weld inspection and fitment report, cooling mount drawings approved.
Sprint 9 – Cooling System Installation & Powertrain Integration	Feb 3 – Feb 16	Install new radiator and ducting, integrate intake/exhaust, update wiring, mounts.	Powertrain & Electronics	System pressure test and validation log, subsystem sign-off sheets (P-1 to P-4).
Sprint 10 – Electronics and Display Fabrication	Feb 17 – Mar 2	Assemble One Gauge display kit, wire harness labeling, microcontroller bench tests.	Electronics	Electrical validation report (E-1 to E-3), circuit schematic revision 2.0.
Sprint 11 – Aerodynamics	Mar 3 – Mar 16	Fabricate splitter and diffuser, conduct CFD cross-	Aerodynamics	CFD plots vs baseline, mount FoS validation (S-1 & A-3).

Component Fabrication		checks, integrate cooling ducts.		
Sprint 12 – Subsystem Integration & Vehicle Assembly	Mar 17 – Mar 30	Install differential, cooling system, electronics, and aero components.	All Subsystem Leads	Full vehicle integration review, approved test plan.
Sprint 13 – Testing & Validation	Mar 31 – Apr 13	Perform static and dynamic tests, validate sensor data logging.	All Subsystems + Client Review	Validation package (FEA/CFD/test data), mock safety inspection pass.
Sprint 14 – Refinement and Final Integration	Apr 14 – Apr 25	Implement design revisions, polish aero, finalize paint, and presentation materials.	All Subsystems	Final assembly complete; showcase materials finalized.
Capstone Design Showcase / Handoff	Apr 28 – May 2	Conduct mock tech inspection, demo run, and final report submission.	Team Leads + Client	Final Design Report delivered and vehicle ready for race testing.

The Gantt Chart that was created for the team to follow will be in an accelerated format, with the goal for the team's progress begin to adhere to the Gantt Chart schedule. This accelerated timeline allows for some time cushioning in the event of a major setback or an accumulation of smaller delays. This schedule omits any class centered deliverables as it will act as a highly detailed project goal sheet. Sprint Reviews will be conducted on the same basis as SD1 .

24 Hours of Lemons'
Gantt Chart

8. Budget

The team budget is structured to maximize performance and follow all competition rules for safety. As of this report, the team has a budget of around $4000 to use. The main portion of this budget will go towards the structural subsystem since that team redesigning and building both the roll cage and the differential. Without a roll cage that passes tech inspection, the team cannot race, and without a working differential, the car will not drive. From there, funds will be directed to areas of need, with the electrical, powertrain, and cooling subsystems demanding the most improvement. If the cooling system is not adequately upgraded, then the team could experience similar results to last year, with recurring cooling problems keeping the car off track. The electrical budget will be $600 even with the newly acquired parts that amount to around $800. This will allow the team ample room to make more improvements on a system in need of major upgrades. Most of the powertrain budget will go to rebuilding the engine with the remainder going towards other work that the team would like to accomplish. Finally, the team will have an emergency or miscellaneous expenditure fund of $650. This should be used as a last resort for items that the team did not originally plan for. The total budget breakdown is visualized below in Table 15.

Table 15: Project Budget Breakdown

Subsystem	**Budget**
Aerodynamics	$400
Cooling	$500
Electrical	$600
Powertrain	$600
Structural	$1,200
Emergency/Miscellaneous	$650

Breaking down the budget from a standpoint of funding, the team has received $2000 from the school as a baseline for the project. On top of this, the team has started fundraising through the Mines Alumni foundation which has netted close to $2000. The team has also been trying to acquire corporate sponsorships with some value already being shown in the free electrical equipment the team will be receiving. To continue raising the project budget, the team will continue reaching out to the community through social media, and to companies that the team looks to acquire parts from, along with the foundation fundraising.

Overall, the expectation is that this budget will evolve as more funding appears and client/subsystem needs are determined. All expenses will be tracked and reported, with communication between system leads and the CFO (chief financial officer) being essential to team success and clarity. Regular reviews will be conducted to adjust funding and strategy as needed.

9. Appendix

9.1 Powertrain

9.1.1 Cooling Calculations

Bare bones model estimating the minimum and ideal amount of heat dissipation needed to satisfy the engine. This model also includes the core dimensions for all 3 options and preliminary estimates for passage flow and outdoor conditions.

%Estimates the total heat rejection required for a cooling system based on engine horsepower

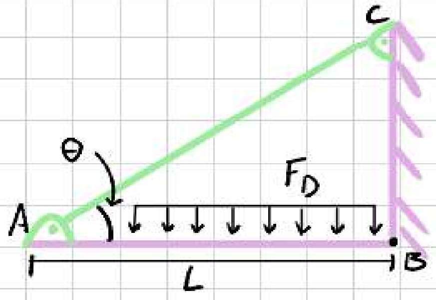
```
% 1. Inputs and Constants
HP_mech = 225; % Given Horsepower (HP)
C_factor = 1.3; % Cooling Factor: 30% bump over minimum heat dissipation
HP_to_BTUhr = 2544.43; % Conversion constant: 1 HP = 2544.43 BTU/hr

% 2: Convert the mechanical power (HP) into a heat rate (BTU/hr).
P_mech_BTUhr = HP_mech * HP_to_BTUhr;

% 3: Apply the Cooling Factor to find the required heat rejection (Q).
Q_BTUhr = P_mech_BTUhr * C_factor;

% 4. Display Results
fprintf('--- Engine Cooling Requirement Estimation ---\n');
fprintf('Mechanical Power (HP):              %.2f HP\n', HP_mech);
fprintf('Cooling Factor (C_factor):          %.2f\n', C_factor);
fprintf('Equivalent Power (Heat):            %.0f BTU/hr\n', P_mech_BTUhr);
fprintf('------------------------------------------\n');
fprintf('Required Radiator Heat Rejection (Q):  %.0f BTU/hr\n', P_mech_BTUhr);
fprintf('Ideal Radiator Heat Rejection (Q):  %.0f BTU/hr\n', Q_BTUhr);

% Set up options:
%     A: larger radiator
%     B: smaller radiator (DPI 1140 like geometry)
%     C: smaller radiator + separate oil cooler
```

```
%Estimating Conditions

T_air_in_F     = 75;        % ambient air degF

V_air_mph      = 40;        % vehicle speed (mph) used for external convective h

Coolant_flow_GPM = 18;      % coolant volumetric flow (GPM)

Oil_flow_GPM     = 6;       % oil volumetric flow (GPM)


% Radiator / core modeling assumptions (modifiable)

fin_efficiency = 0.85;      % overall fin efficiency (assumed)

k_mat = 180;                % W/m.K (aluminum)

FPI = 16;                   % fins per inch (typical performance core)

tube_wall_thickness = 0.0005;% m (assumed thin wall)


% Tube / passage geometry (typical flat tube approximations)

%Check these Values

W_tube_c_mm = 16;

H_tube_c_mm = 2;

P_vertical_c_mm = 10;

W_tube_o_mm = 6;

H_tube_o_mm = 2;

P_vertical_o_mm = 4;


% Core definitions: [L_in, H_in, tube_thickness_in, n_rows, 'Fluid', 'Name']

CoreDefinitions = {

   24.45, 16.85, 2.05, 3, 'Coolant', 'Option A (Large Radiator)';

   12.60, 25.12, 2.05, 3, 'Coolant', 'Option B (Small Radiator DPI1140)';
```

```
    % Option C: small radiator + oil cooler
    12.60, 25.12, 2.05, 3, 'Coolant', 'Option C (Small Radiator DPI1140)';
    11.00, 5.43,  1.97, 19,'Oil',     'Option C (Oil Cooler)';
};

%Unit Conversions
in_to_m = 0.0254;
mm_to_m = 1e-3;
GPM_to_m3s = 6.30902e-5;   % 1 GPM = 6.30902e-5 m^3/s
mph_to_ms = 0.44704;
```

9.2 Aerodynamics

9.2.3 Splitter & Diffuser Calculations



Splitter Load

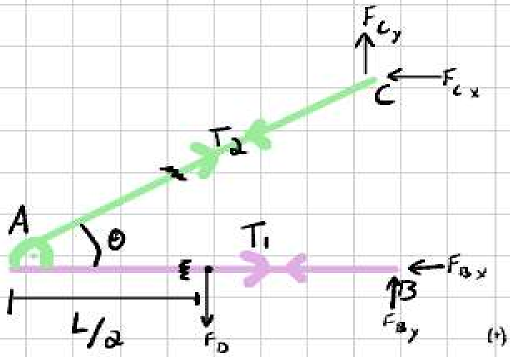
$$(+)\circlearrowleft \sum M_B = 0 = F_D(L/2) - T_2 L \sin\theta$$

$$\therefore \boxed{T_2 = \frac{F_D}{2\sin\theta}}$$

$$(+)\uparrow \sum F_{x(A)} = 0 = T_1 + T_2\cos\theta$$

$$\therefore T_1 = -T_2\cos\theta$$

$$\boxed{T_1 = -\frac{F_D}{2\tan\theta}}$$



$$F_{C_x} + F_{B_x} = 0\ ,\quad F_{B_x} + T_1 = 0 \Rightarrow F_{B_x} = -T_1$$

$$\therefore \boxed{F_{B_x} = \frac{F_D}{2\tan\theta}} \ \& \ \boxed{F_{C_x} = -\frac{F_D}{2\tan\theta}}$$

$$F_{C_y} = T_2\sin\theta = \frac{F_D}{2\cancel{\sin\theta}}\cancel{\sin\theta} = \boxed{F_D/2 = F_{C_y}}$$

$$(+)\uparrow \sum F_y = 0 = -F_D + F_{C_y} + F_{B_y}$$

$$F_D = (F_D/2) + F_{B_y} \Rightarrow \boxed{F_{B_y} = F_D/2}$$

Assume 90 Kg (198 lbs) load (F_D) & $\theta \approx 55°$

$$T_1 = -\frac{F_D}{2\tan\theta} = -\frac{(90)(9.81)}{2\tan(55)} = -309N$$

$$T_2 = \frac{F_D}{2\sin\theta} = \frac{(90)(9.81)}{2\sin(55)} = 539N$$

$$F_{B_x} = \frac{F_D}{2\tan\theta} = \frac{(90)(9.81)}{2\tan(55)} = 309N$$

$$F_{B_y} = \frac{F_D}{2} = \frac{(90)(9.81)}{2} = 441.5N$$

$$F_{C_x} = -\frac{F_D}{2\tan\theta} = -\frac{(90)(9.81)}{2\tan(55)} = -309N$$

$$F_{C_y} = \frac{F_D}{2} = \frac{(90)(9.81)}{2} = 441.5N$$

$T_1 = 309N$ (Tension)
$T_2 = 539N$ (compression)
$F_{B_x} = 309N$
$F_{B_y} = 441.5N$
$F_{C_x} = 309N$
$F_{C_y} = 441.5N$

9.3 Budget

Rough bill of materials for the entire project. Will be updated as more information becomes available and the scope becomes clear.

Table A1. Bill of Materials

Quantity	Item	Total Price (estimate)
	Powertrain	
1	Main Bearing	$72.30
1	Rod Bearing	$158.42
1	Piston Ring Set	$95.69
2	Head Bolt St	$48.52
1	Full Gasket Set	$99.90
1	Lube	$8.99
2	Ultra Black	$24.98
1	DNJ Engine Component	$29.67
	Cooling	
	Sheet Metal	$0 (stock already in bay)
1	Radiator	$200-$600
	Radiator Hoses	$100
1-2	Brake Hose	$50
	Structural	
1	Differential Housing	$0
	Bushings	$0
	Seals	$0
5	Cold Rolled Round Tube 1020 DOM 1.500 X 0.120 (20 ft)	$598.51
	Electrical	$100
2	½" Insultherm - 5 ft	$20.00
1	OneGuage Display	$0
1	A9L	$40
	A9L Capacitors	
1	MAP to MAF conversion	
	Aerodynamics	
1	Plywood	$250
4	Sheet metal	$0 (stock already in bay)
4	Splitter Support rods	$100
1	Snowboard	$0
	Assorted mounting bolts	$50-$100

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