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Formula SAE: Final Design Report

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Executive Summary

The primary objectives of this year's senior design team were to deliver a fully functional FSAE race car that would be competition-ready by June 2021. Prior to this year, the chassis had been fully constructed, the suspension had been fully installed, and the engine had been fully mounted into the car. In addition, our team's objectives are to complete the subsystems of the car which includes the following: body panels, engine wiring, electronic control unit (ECU) hardware and software, cockpit, brakes, steering, and wheels.

This year, the team finished many sectors on the car such as the headrest, body panels, brakes, internal wiring, ECU wiring, the seat, and wheel alignment. Along with finishing the subsystems, this year's team was also tasked with designing and manufacturing the car body that would fulfill all of the FSAE guidelines and requirements. This includes maintaining driver visibility, offering adequate protection to subsystems, and being clear and free from interacting with other moving components of the car. In the Fall semester in 2020, the team designed CAD models of the body in Fusion360 and selected fiberglass as the material of choice based on multiple criteria. In the spring semester of 2021, the team fully manufactured and mounted the fiberglass body panels onto the car. This year's FSAE team has not completed the vinyl wrap and due to the failure of some electronic components, the car is not currently running.

The mechanical issues that arose this year were all resolved, however the main difficulties were with the electrical subsystems. Future teams will need to troubleshoot the relay systems to ensure adequate voltage is reaching all engine and ECU components. Seeing as the relay systems have not been in use in over four years, it may be necessary to order some new electronic systems. Similarly, the team feels that it is important that each team fully understands the importance of the tuning process. The team recommends that each future team use TunerStudio to tune the car to their specifications. As of May 1, 2021, the ECU communication with the software needs to be improved, and needs to be returned to include upgrades to the daughter board. The team has already placed an order for these components and plans on installing them in an attempt for one last engine test. If the team does not successfully complete this last test, future teams should look to the ECU and engine relay systems.

1. Introduction

In 2016, Trinity University Motorsports (TUMS) and the senior design team started Trinity's path to compete in Formula SAE, an international collegiate competition organized by the Society of Automotive Engineers. Students are offered the opportunity of designing and manufacturing an open wheel Formula-style car and competing in both static and dynamic events. Formula SAE has evolved from a domestic event in the U.S. to an international competition throughout the world being held by countries in Europe and Asia.

The design and development of this car is an ongoing project over the last four consecutive years since Trinity University's initiation into FSAE in 2016, with each of the four teams having made considerable progress towards delivering a fully functional car. Prior to this year, the chassis had been fully constructed, the suspension had been fully installed, and the engine had been fully mounted into the car. Based on meetings with the Project Sponsor and FSAE requirements, the Trinity University FSAE team has acknowledged the following constraints on the final design.

- The car must be completed within the initial budget of $10,841. This budget may change if sponsors or donors invest money into the project.
- Restrictions due to COVID-19 such as remote learning and social distancing.

In the 2020 Formula SAE rules there are General Regulations (GR) that include Good Engineering Practices and Rules of Conduct. These regulations are provided to give engineering teams an expectation and an efficient transition into the environment of the competition. Depending on the subsystem of the design, there are a set of standards to follow to ensure the safety of the drivers and sustainability of the racetrack. This year's team worked on the powertrain and the body, therefore sections T.5 and T.7 will be guides for the design process. Other than the competition rules, standards from ASME, ASTM and SAE will also be beneficial. Some standards may also be found in the Vehicle requirements section V of the Appendix.

The objective for the project as detailed in the Preliminary Design Report was to deliver a fully functional Formula-One style car by the end of the Spring semester in May of 2021. The car should have good functionality in terms of similarities to how other cars are accessed along with a simple user interface in order to monitor the race car during travel. This will be achieved through the integration of the available and unavailable subsystems along with an interface for the user to interact with the vehicle. Even though there was significant progress made on the car this year and all of the subsystems have been completed, the team has not yet managed to have the car in a drivable state. There will still be tests performed leading up to the design presentation. Other than the ultimate goal of producing a working car, the main design premise of this year's team was to build body panels for the race car. This process, from researching material and body styles, constructing different body panel designs, running weight, modal, and aerodynamic analysis, fabricating the body molds in the CSI MakerSpace, fiberglassing the panels at an off-campus facility, and attaching the final product to the chassis, took the entire year. The team collaborated on and decided on the optimal choice of body panel structure.

Subsystems that needed to be finished or improved included the following: engine wiring, electronic control unit (ECU) hardware and software, cockpit, brakes, and wheels. The areas of the engine that needed to be wired includes the start switch, relays (such as the load control relay, fan motor relay, the gear motor relays, and the starter relay) and the fuse box. These components were stripped from the original snowmobile body frame and left in the garage. Once our team identified which components are needed, the components were reassembled by the team using a soldering iron, heat shrink wrap, a heat gun, and electrical tape. By using the signal system circuit diagram given in the 2007 Phazer manual, the team was able to construct the vehicle relay systems needed to run the car [1]. The ECU motherboard pin connections needed to be connected to the wiring harness onto which the engine components are attached and the software needed to be uploaded and tuned. The motherboard itself had several transistors and other components attached which needed to be resoldered to ensure clean connections. The Megasquirt website provided the instructions and framework to upload the SQL format code onto the chip as well as the general guideline for using the TunerStudio tuning software in correlation with a JimStim engine stimulator.

The cockpit needed a new seat (one that was less rigid and would be formed to the body of the driver for maximum comfort and safety), a headrest, an FSAE regulated harness, and a new display for important information. This display gives the driver the current RPM, lap time, fuel consumption, oil pressure and temperature, and GPS tracking. Although last year's team had constructed a speedometer displayed on an LCD screen, the team decided it would be worth purchasing a more advanced system that would improve the driver's ability to operate the vehicle.

The brake system used by the previous team had to be assessed after it was determined that the brake adaptors were too small. This resulted in the brake calipers slipping out of the wheel mounts. Similarly, the wheels and tires were too small and the front brake calipers were getting caught on the rims.

The following sections will detail the entire body panel process from start to finish. Similarly, explanation of all subsystems, how they were constructed, and how they are integrated together within the car will be discussed.

2. Overview of the Final Design

2.1 Body panels

When creating and designing the different body panel designs, the team had to comply with the FSAE 2020 guidelines for the aerodynamics of the vehicle. For the bodywork of the vehicle, the guidelines state:

- T.7.1.1 There may be no openings through the bodywork into the driver compartment from the front of the vehicle back to the roll bar main hoop or firewall other than that required for the cockpit opening. Minimal openings around the front suspension components are allowed.
- T.7.1.2 All forward facing edges on the bodywork that could impact people, including the nose, must have forward facing radii of at least 38 mm. This minimum radius must extend to at least 45° relative to the forward direction, along the top, sides and bottom of all affected edges.

Along with the guidelines, the team conducted aerodynamics research and the comparison between the different designs in terms of the different types of fluid forces. The team had to take into consideration the weight distribution, drag force, down force, lift force, attachability and the ease of construction for the different designs. The team eventually created 6 different designs, each having a similar overall shape and exterior but differ in multiple aspects. Some designs would have a slight change in position and orientation of the nose cone, others would differ in the curve and sizes of the side body panels.

After serious consideration with the aerodynamics and overall aesthetics of each body panel design, the team ended up picking set 6, which the team will go into more detail in the design selection section below.

2.1.1 Material Selection

The team conducted a decision matrix at the beginning of the year to decide which material would be best fitted for the body panels of the vehicle given our current situation and budget. With a total of 7 different possible material choices, the choices were fiberglass, thermoplastic, papier-mâché, aluminum, carbon fiber, titanium, and plexiglass. The team researched and compared each different material with each other in different categories, then ranked them and gave them a corresponding score for each section. The different categories that were being evaluated were the strength of material, the cost of material per weight, the overall weight of the material, the different environmental effects of using each material, the safety of each material, the ease of construction of each material, and the marketability and aesthetics of the type of material (See matrix below).

	Fiberglass	Thermoplastic (Kydex)	Paper-mache	Aluminum (3003)	Carbon fiber	Titanium	Plexiglass	***Winner***
Strength	8.5	4	2	6	9	7.5	5	Carbon Fiber
Cost	8	6	10	8	6	4	8	Paper-mache
Weight	6	10	7	4	5	1	8	Thermoplastic
Environmental Effects	9	4	8	8	9	9	8	Tie
Safety	9	9	1	8	7	8	6	Tie
Easy Manufacture / Construction	7	7	5	8	3	5	6	Aluminum
Aesthetics / Marketability	8.5	6	2	9	10	9	5	Carbon Fiber
Total Score	56	46	35	51	49	43.5	46	**Fiberglass**

Figure 1. Material choice matrix

Strength: The strength of the materials was based on the material stress-strain relationship and careful observation of the elastic limit, yield strength, ultimate strength, fracture point of each material, and strength to weight ratio. Carbon fiber was ranked the strongest material. Carbon fiber does not have a yield strength, will not deform below its ultimate tensile strength, has high strength to weight ratio, and has a tensile strength upwards of 7.5 GPa. However, it did not receive a perfect score due to its tendency to fail suddenly and catastrophically. Coming in second place was fiberglass. Fiberglass is not as rigid as carbon fiber but it has greater durability and flexibility. Third in the ranking was Titanium. With a yield stress of 850 MPa, Titanium is malleable and can be bent into shape. Titanium can be very strong when used in a dense form, however in sheet metal form it will lose strength. The fourth ranked material was Aluminum 3003. This is a moderately strong aluminum alloy with good workability and a tensile strength of 186 MPa. Ranking as the fifth strongest material is Kydex. Kydex is a type of Kevlar material with high impact strength and a tensile strength of 42 MPa. Last in the ranking was papier mâché. Seeing as the FSAE race is a timed circuit race that has limited collisions, papier mâché was our team’s backup consideration. However, papier mâché does not offer adequate protection to the driver due to its brittle nature and ability to change shape with a small amount of applied force.

Cost: The cost was evaluated by finding the specific type of the material that the team would use and pricing based on surface area. Different materials would require different amounts of the material, due to the varying strengths of the materials. This was taken into consideration when evaluating the price of the material. The cost of manufacturing with the material was also considered here. This leads to the low score of materials such as carbon fiber, since many of the supplies used for manufacturing it are expensive and non-reusable.

Weight: The weight was calculated based on the surface area required and thickness the team expected of each material. The highest values in the chart being the materials expected to weigh the least. The low rating of titanium comes from the need for a fairly thick sheet to maintain rigidity of large panels, resulting in a relatively high weight.

Environmental Effects: Each material considered has excellent corrosion resistance, and each of them with the exception of the Kydex thermoplastic has excellent thermal resistance to extreme temperatures. For this reason, this criterion was not heavily considered when choosing between these materials.

Safety: Of these materials, papier mâché is the only one that completely fails in terms of safety in a collision since it has very low strength and is not robust at all. The rest of these materials would only deform and not shatter in the event of a crash. Additionally, this car would not be competing in any wheel-to-wheel races where collisions with other drivers would be possible, and will only be compete on an open track where collisions with a wall are less likely. The safety concern for each of these materials involve the manufacturing process. All have the capability to cause irritation with exposure to the skin. Fiberglass and carbon fiber involve irritating fibers, as well as epoxy resin that can be very toxic and should be applied while wearing a respirator. Machining, welding, and cutting aluminum can produce aluminum oxide, which is toxic. Titanium is also very dangerous during machining; inhaling the titanium dust is extremely toxic and could even be fatal.

Plexiglass could have small cracks and scratches that propagate rapidly, and it can even melt during machining. Overall, although each material comes with its own risks during manufacturing, they each have relatively the same level of safety risks and should be used with caution. Thus, the material safety was not a significant factor in selecting the material.

Ease of Manufacture: Of the seven different materials, our team made the decision to work with fiberglass while taking ease of manufacture into consideration. Our team realized early on that rigid metals such as titanium are difficult to cut, weld, and machine. In fact, titanium is commonly used as the material to cut other metals with and provide no room for error if mistakes are made. Free form materials such as epoxy resin, fiberglass, thermoplastic, and papier mâché require high precision or special facilities to construct properly. Considering that body panels take a long time to manufacture, locating such facilities and creating solid molds may cause great difficulty. Aluminum is a softer metal that can be machined with higher ease. Our team knows of locations and can order respirators to enforce safety. Therefore, our team decided that aluminum, when relatively compared to the other materials, is the easiest material to manufacture.

Aesthetics/Marketability: For this category, each material was judged and based on their aesthetics and looks, and how that could impact the attractiveness of the vehicle itself from an outside perspective. Between the lower ranking materials, papier-mâché ended up being the lowest score given the fact that a vehicle with papier-mâché body panels is not very practical and can look very cheap and damageable from the outside. Between the higher-ranking materials, fiberglass, aluminum, carbon fiber and titanium were all relatively close in their appearances and attractiveness. The team ended up giving carbon fiber the highest score due to the natural aesthetics of the material's body and how our body panels would look the best if they were made out of that material. However, the team still were very pleased with how the body panels would have turned out if they were any of the other higher-ranking materials in terms of aesthetics and marketability.

2.1.2 Design Selection

Weight Analysis:

Prioritizing aerodynamic performance, the following 6 CAD models shown in Figure 2 were created in Fusion360. The designs vary in nose width, nose length, and angle of attack from the top surface. The final design was selected using weight analysis, aerodynamic analysis, and modal analysis, where these designs were analyzed through a simulation that evaluated the design's aerodynamic performance, structural characteristics, their natural frequencies and mode shapes, and their marketability.

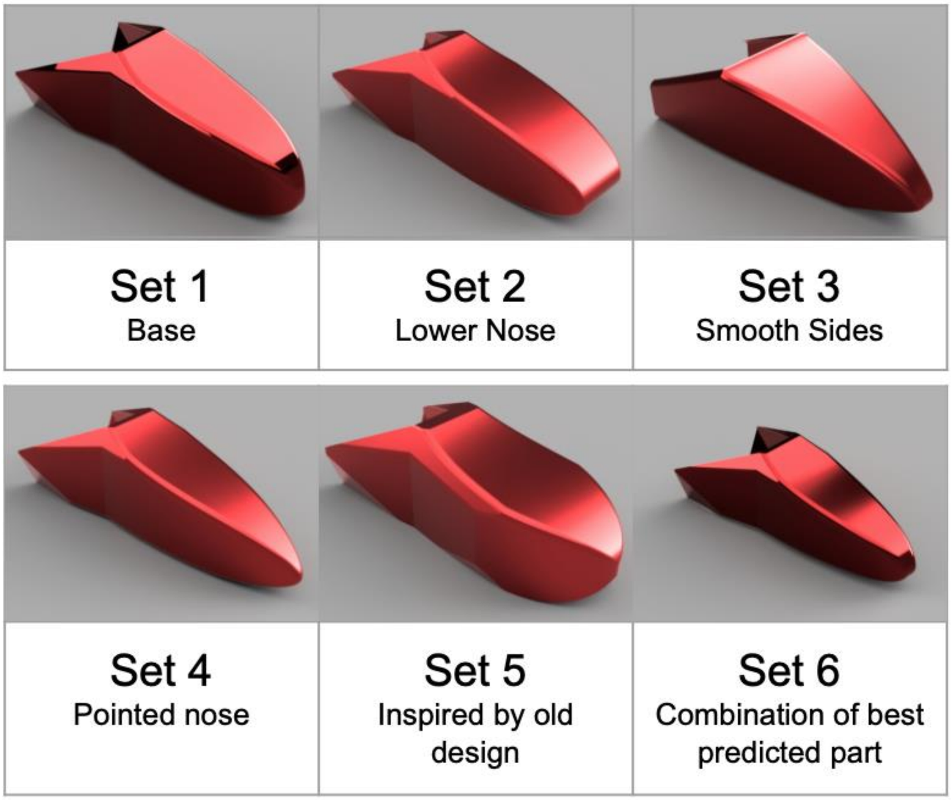


Figure 2. Fusion360 design models

The purpose of the weight analysis is to determine which body design will add the least amount of to the car, and which will provide the best weight distribution. Using a built-in feature in Fusion360 to calculate the volume and surface area of the design material, set 6 was determined to be the lightest design out of the six. This also means it would be the cheapest to manufacture since it would require less material. To measure the weight and the center of gravity of the car, scales were placed under each tire. The total gross weight of the car was estimated to be approximately 1014.3 lbs., with approximately 51.3% of the weight on the front tires. In order to maximize the grip of the tires, it is ideal to have a weight distribution near 50%. Thus, it would be better for our body panels to have their center of gravity as far back as possible. Table 1 shows the weight analysis of the six designs. While Set 4 would yield the lowest center of gravity, the difference of approximately 0.3 inches to that of Set 6 was essentially negligible. The center of gravity of Set 6 was the second closest to the middle of the car, only about 0.5 more than that of Set 3. The weight advantage of Set 6 seemed to mitigate the losses that it has in its other categories, and thus the team believes that Set 6 is the best choice in so far as its effects on the weight and weight distribution of the car goes.

Table 1. Weight analysis of different body panel designs

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	best	% difference to worst
Volume (in^3)	566.049	601.951	584.786	564.594	575.75	533.199	Set 6	12.89%
CG (lower) (in)	14.189	14.795	13.881	15.043	13.686	14.77	Set 4	9.02%
CG (forward)(in)	14.958	15.853	12.004	13.585	12.95	12.573	Set 3	32.06%
S Area (in^2)	9088.694	9674.71	9390.576	9076.69	9254.198	8580.875	Set 6	12.75%

2.1.3 Manufacturing

In order to build the body panels out of fiberglass, the team machined 5 interior molds out of rigid foam insulation (top, 2 sides, and 2 halves of the nose cone). Since the Computer Numerical Control (CNC) can only machine out a piece 2 inches tall, the molds had to be machine in sections and then glued together. Figure 3 shows the initial process of the CNC machining the foam insulation. Once all of the pieces were glued together, the cracks and crevices were filled in with spackling paste and then sanded down to ensure a smooth and flush surface. Bondo is commonly used in body work for commercial vehicles, but was not applicable here because it chemically reacted with the foam, causing it to deteriorate. Bondo is also much more difficult to sand than the spackling paste once it hardens. The final step in preparing the molds for the application of the fiberglass involved painting all of the surfaces with at least 3 layers of water-based paint. This was done so that the epoxy resin that seals the fiberglass will not react with the mold surface. This entire fabrication process took around 2 months to complete. Figure 4 details the molds completed and ready to be fiberglassed.

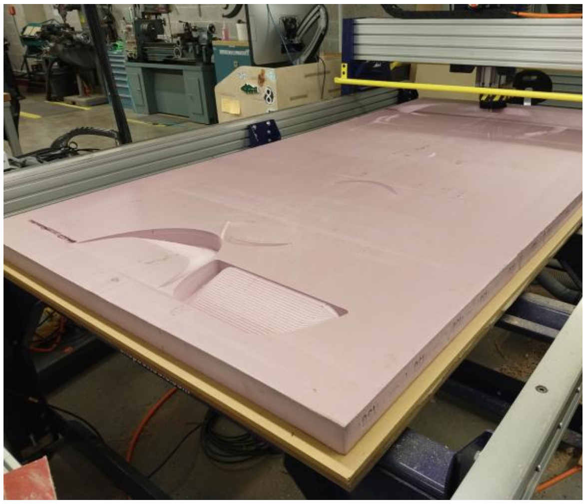


Figure 3. First stages of CNC machining the foam mold pieces that will be glued together

Figure 4. The molds after being assembled, sanded, painted, and ready to be fiberglassed

The fiberglass application process involves covering the mold surface with a layer of fiberglass chop strand mat. The strand mat was then precisely cut to align with the bottom edges of the mold and coated in epoxy resin mixed with a hardening activator. To produce a more permanent and durable mold surface, a single layer of fiberglass was applied with the resin on the painted surface. The layer of fiberglass was then sanded, given two coats of primer and three coats of wax. PVA solution used to remove the finished part from the mold works much better on the fiberglass mold surface than the painted surface. The 3-layer fiberglass body panels were fabricated one at a time with the epoxy resin. The fabrication of the fiberglass panels took about 3 weeks to complete.

When working with fiberglass, it is always important to wear a 3M P100 mask that protects against the organic vapors from the resin and the minute fiberglass particles during sanding and cutting. Likewise, it is crucial to perform the fiberglassing in a well-ventilated facility. For this reason, the team was not able to fiberglass in the CSI Makerspace. Luckily, the team was graciously allowed to perform the fiberglassing at Mammoth Architectural, a millwork shop in San Antonio. This facility had industrial sized mechanical ventilation fans that provided proper aeration. From applying the release agent, to resin application, and finally cutting and shaping the body panels, the entire fiberglassing process took place at this facility. Figure 5 below shows the right-side body mold after being fiberglassed and applied with the release agent. The release agent is applied so that the fiberglass panels, when dried, will be easily removable from the molds. Figure 6 shows team members wearing proper M3 respirators and sanding one of the dried single layer fiberglass body panel molds.

Figure 5. Right side body panel mold with initial fiberglass layer

Figure 6. Sanding of top body panel mold after a fiberglass application

After the body panels had been sanded, they were detached from the body panel molds (shown in Figure 7) and brought back to campus and marked up for cuts. It was crucial that these cuts be accurate because the panels needed to be fitted over the shock absorbers and A-arms. The cuts also had to be small enough to minimize the turbulent air and the ability for debris to enter the cockpit. Once the cuts were made, the body panels were coated in a final coating of primer, as shown in Figure 8. The completed body panels were then brought back to campus to be installed on the chassis of the car.

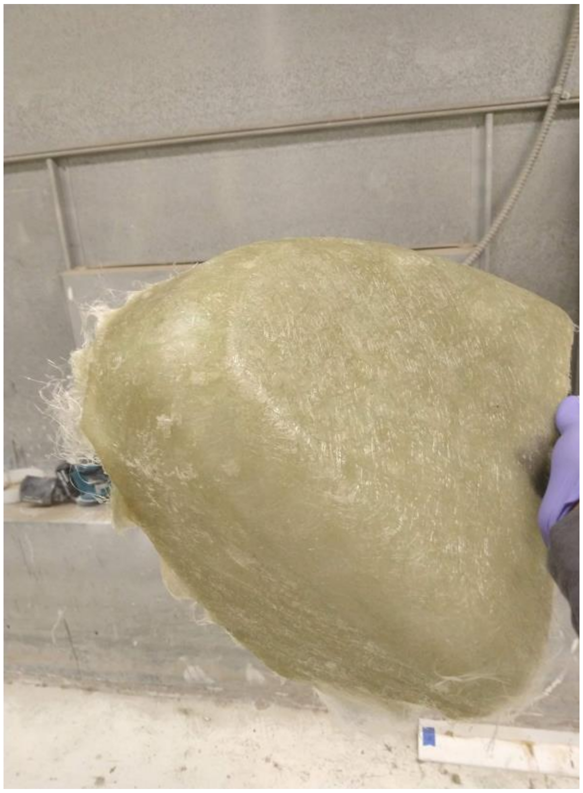


Figure 7. Nose panel after being detached from the mold

Figure 8. The finished right-side panel, cut, primed, and ready to be put on the car

With a total of four body panels (right and left side, nose cone, and top/hood) the team had to engineer a way of mounting the body panels onto the car. The panels needed to be attached in a way in which they did not interfere with the shock absorber, the vision of the driver, the tires, or the wheel mounts. With the use of the 3D printer, it was decided to make mounts that could be secured around the chassis and then connected to the body panel. The panels were brought back to Mammoth Architectural one last time to make specific cuts to avoid interference with the shock absorbers etc. Afterwards, the panels were secured and attached to the chassis as shown in Figure 9.

Figure 9. Completed body panels attached to the car chassis

2.1.4 Mounts

When designing the mounts to attach the body panels to the chassis of the vehicle, the team had to consider the mounting strength and the size for each body panel position. In addition, the most important aspect was the locations of the mounts to prevent the body panels from vibrating at both high and low frequencies.

The team came up with a few prototype designs that were 3-D printed using the Ultimaker but were too long in length that they would not fit properly between the body panels and the chassis of the car. Although the dimensions of the flat plates were valid, the length of the overall mount was not and the team had to come up with new designs on the spot. After numerous possible mount designs, the team designed a bridge mount due to their simple yet structural design. As can be seen in Figure 10 and Figure 11, the mount designs were then 3-D printed using the Ultimaker to attach them to the chassis of the car.

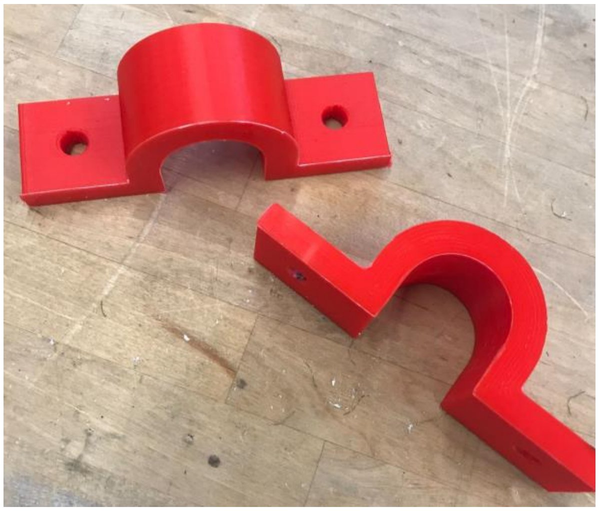


Figure 10. 3-D body panel mounts

Figure 11. 3-D printed body panel mounts securing body panels to chassis

The design of the mounts was specific to the diameter of the chassis of the vehicle, which happened to be exactly 1 inch all around. The length and width of the mount flat platforms were estimated to be the correct size in order to ensure stability as well as strength when fitting in the screws and washers.

In order to determine the exact positions of the mounts, the team used the Fusion 360 application, where the team ran a modal analysis test to see the possible deformation of the body panels and the corresponding natural frequencies. The test allowed us to determine the exact points which needed a securing mount to prevent the body panels from deforming during the race (See picture below). With a total of 6 mounts connecting the side and top panels, the lower parts of each panel would be secure from deformation.

2.2 Electronic Control Unit

The purpose of the engine control unit (ECU) is to relay the engine sensor outputs to the vehicle operator. The ECU can be tested before vehicle installation with the use of a JimStim 1.5v MegaSquirt Stimulator and EFI Analytics TunerStudio software. Along with tuning, the JimStim can be used to determine if there are any short circuits in the circuitry. Once ready for tuning, the JimStim and TunerStudio software can be manipulated to maximize engine output by safely configuring the engine spark, timing the fuel injectors, and accounting for any missing teeth in the crankshaft. Along with many other engine components, the ECU provides information from the manifold air temperature sensor (MAT) installed on the ECU motherboard, oxygen/lambda sensor (O2), coolant temperature sensor (CLT), throttle position sensor (TPS sensor), fuel injection system, spark relay, fuel pump, and tachometer. Once the ECU has been constructed, uploaded with code, and sufficiently tuned, it is ready for installation into the racecar. The wiring harness, garnering the engine wires, can be plugged into the ECU and secured on the floorboard of the chassis.

2.2.1 Engine Control Wiring

The car's wiring connections are detailed in the 2007 Yamaha Phazer snowmobile manual [1]. Components including but not limited to the knock sensor and the headlights in addition to the headlight fuses were omitted from the final wiring orientation as they are not relevant parts of the car. Figure 12 illustrates how the wires from the engine connect to the wiring harness which plugs into the ECU. This diagram differs from the relay and fuse box diagram given in section 5.1.4 of the Appendix.

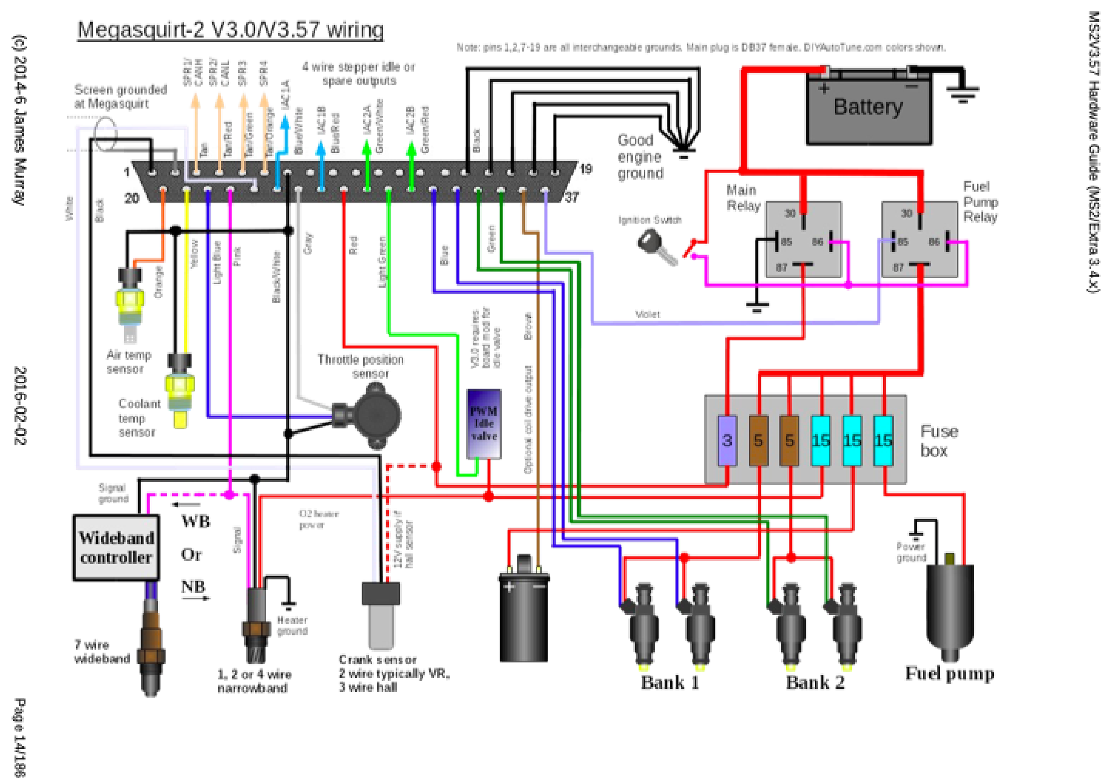


Figure 12. MegaSquirt II wiring diagram

2.2.2 MegaSquirt

The MegaSquirt is a line of aftermarket engine control units that can be used with many different engines ranging from 1 to 16 cylinders. The model used on our car is the MegaSquirt II (MS2) and can be purchased as pre-built or in an assembly kit. Our MS2 was purchased in an assembly kit and was already constructed before the 2020-2021 team began work on the car. Figure 13 shows the diagram the team used as an ECU component diagram.

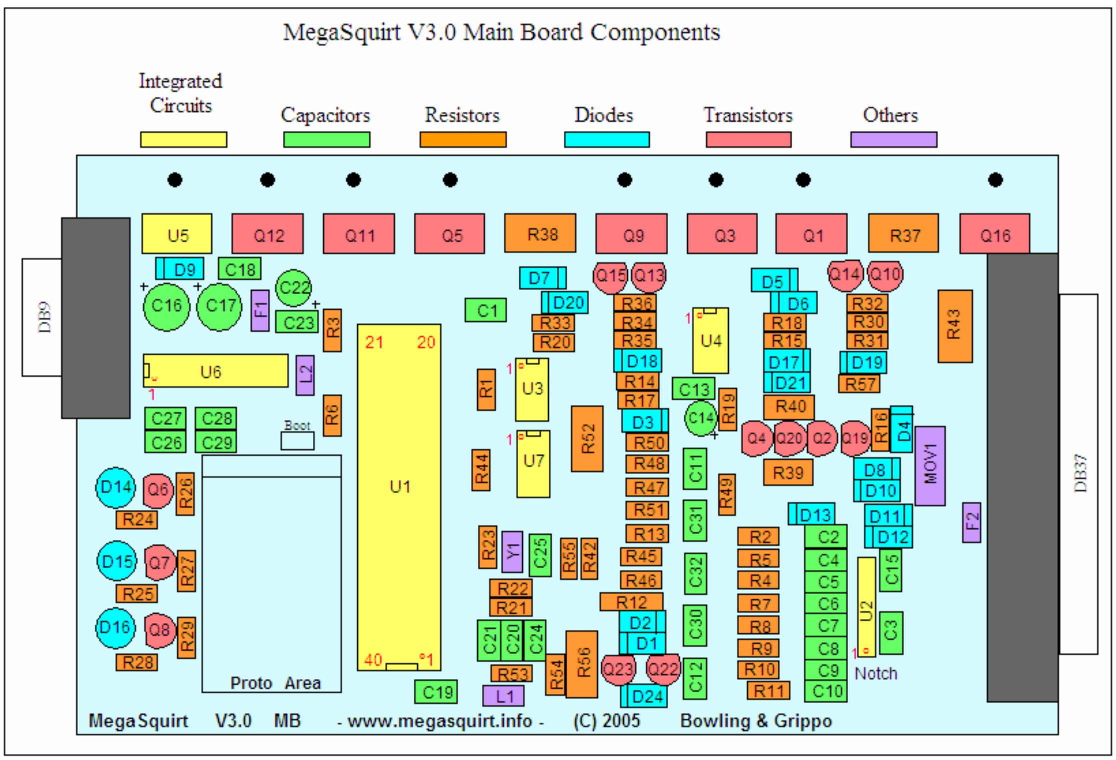


Figure 13. Main Board Components for MegaSquirt II version 3.0

One of the many benefits of the MS2 is the ability to make customizations for specific engines. In order to convert the MegaSquirt into a MegaSquirt II, the MS2 daughter card must be installed on the motherboard. This replaces the 68HC908 MegaSquirt I processor. The MS2 card is installed at position U1 in Figure 13. This new processor will increase speed and functionality of the tuning process. The ignition system for the 2007 Yamaha Phazer engine is a high output coil plug ignition system with dual sparks. In order to configure the spark coil ignition system for this engine, several modifications had to be configured on the MS2 motherboard. To configure the dual spark ignition, two Bosch BIP373 transistors needed to be installed (one for each spark). After the adjustments had been made, the code was uploaded to the ECU. The code is in Assembly Language programming and care must be taken to upload the correct code in the proper order. By exactly following the code installation instructions on the MegaManual, the code will behave correctly during tuning. The code used for our ECU is the MegaSquirt II - extra and is intended for use in engines with multiple spark configurations.

2.2.3 EFI TunerStudio

EFI TunerStudio is a tuning software that allows you to fully set up and tune any MegaSquirt controller. Paired with the JimStim, TunerStudio allows the user to test RPM, throttle position, pulse width, coolant temperature, ignition advance, fuel load, exhaust gas oxygen, and lost sync counter. The JimStim is a circuit board that connects to the ECU. The JimStim has several black dials that allow for adjustments to be made on the TunerStudio software in areas such as engine performance, fuel injection rate, throttle rate, etc. After the code is downloaded onto the ECU, the JimStim is able to adjust the simulation parameters to give our team a precise illustration of how the car will behave in real life.

All of this information is presented in a dashboard type setting shown in Figure 14. Once the ECU has been successfully tuned with the JimStim, the JimStim is removed and the wiring harness will be attached. Once the engine is started, fuel adjustments can be made. This is where the car will be tuned to either run lean (smaller amount of fuel injected to achieve greater fuel efficiency) or rich (larger amount of fuel to run at a faster RPM). The engine parameters must be properly set on the TunerStudio software. This is done Figure 15, showing the Engine and Sequential Settings. Here, the required fuel rate can be input and calculated, the injector specifications determined, and engineer parameters set.

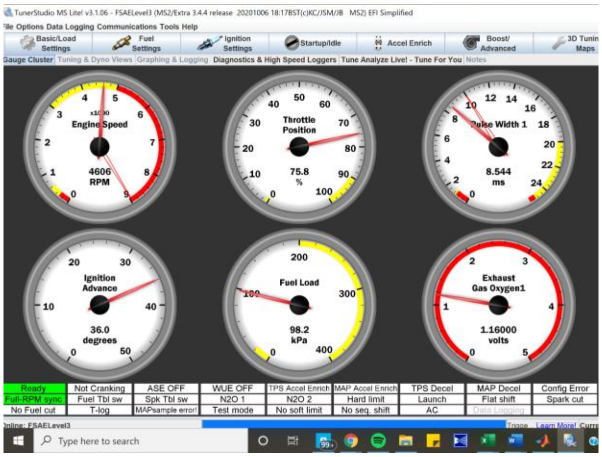


Figure 14. TunerStudio Gauge Cluster dashboard

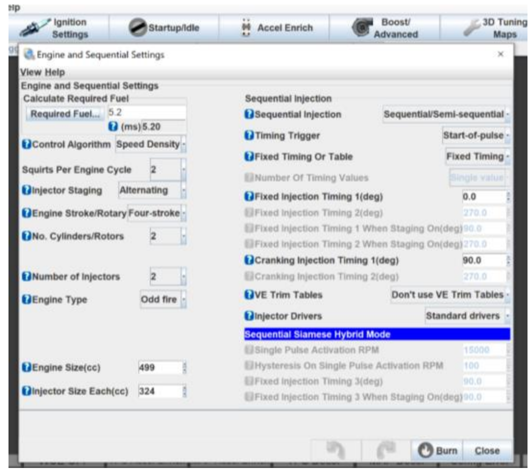


Figure 15. Engine and Sequential Settings in TunerStudio

2.3 Cockpit

Adjustments were made to the vehicle to complete the cockpit while following the guidelines set in place in the Formula SAE rulebook. With the progress made by previous groups the vehicle design meets FSAE rule T.3.3.1 by having the lowest point of the driver's seat no lower than the bottom surface of the lower frame rails. When seated in a normal driving position, the driver has a field of vision of 100° to either side, as required in section V.2.2. A 6-point harness was installed in accordance with sections T.2.2 through T.2.7. A headrest, shown in Figure 16 and Figure 17 was also installed within the cockpit. The design was produced to follow the requirements set in section T.2.8 and it was tested prior to mounting within the vehicle.

Figure 16. The 3-D printed headrest is composed of three parts with the interface being secured using aircraft grade epoxy

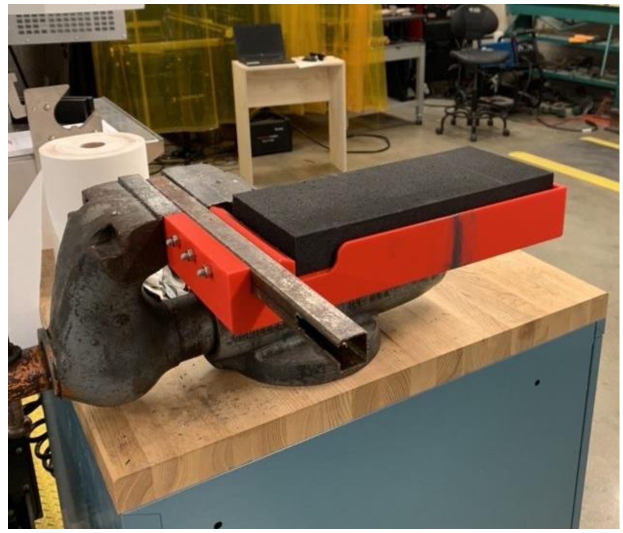


Figure 17. Completed headrest with head cushion installed for driver comfort and safety standards

The headrest successfully withstood the minimum required force of 900 newtons in the rearward horizontal direction and 300 newtons in the sideward horizontal direction. A creaform bead seat kit was purchased, molded, and prepped for installation in order to provide a comfortable and beneficial seating position to the driver. For the purpose of providing the driver with car performance information, an Aim Solo was purchased and a mount for it was crafted for the vehicle. This device provides the driver with current speed, lap times, GPS tracking, and a variety of other minor information intended for improving driving performance. The team also purchased a new Sabelt seat harness needed to meet the standards set by the 2021 FSAE Rulebook. Mounts for the harness designed through a modification of the alignment mounts. More can be found on the seat harness, creaform bead seat, and Aim Solo, and in section 5.4 - 5.6 in the Appendix.

<u>2.4 Brakes</u>

The brake adaptors are intended to hold the brake calipers to the uprights in order to stop the wheels. The previous brake adaptors were too small to place in the car and the alternatives did not fit with the wheels on it. The front and rear adaptors have been manufactured and are installed.

In addition, the brakes leaked due to the previous team's negligence which required our team to rework the brake lines, fitting new hardware and rerouting the lines in order to prevent future leaks.

2.5 Wheels

A new set of wheels with a larger 14-inch inner diameter set. These were purchased and installed on the car because the front brake calipers were consistently rubbing and getting caught on the rims. The rear calipers are smaller and did not contact the inside of the rear rims. A new set of tires were purchased and installed as well. The reason that all the wheels were replaced was because the wheels were all drastically bent, meaning that vibrations would have made the car undrivable in the best-case scenario. The vibrations could also cause the car to fall apart, thus it was necessary to replace the wheels.

Previous years teams also decided to buy drag racing tires, because they were cheaper. However, drag racing tires are designed to go straight. While they are great in straight lines, their strategically soft walls make them perform very poorly in cornering. Thus, the team also decided to invest in track compound tiers. Pictures of the new tires can be found in Appendix 5.6.

2.6 Alignment

When the team received the car, the rear wheels had no method of restraining the rear toe angle. The concept of toe angle is highlighted in Figure 18. The team used the tie rods from the snowmobile to develop a system that allowed us to not only constrain the rear toe angle, but also to tune it for each track that the team encountered. The main challenge was that in order for the angle to remain constant with suspension travel, the mount for the tie rods needed to be exactly half way between the top suspension mounting point and the bottom suspension mounting point. The mount shown in Figure 19 is used to securely attach the tie rod, yet still allow it to be moved if the team decides it is not perfect. It was placed at the halfway point and tightened, but it is not to be welded in place until the car has been driven and both the driver and the telemetry confirm that there is no variation in the rear toe angle.

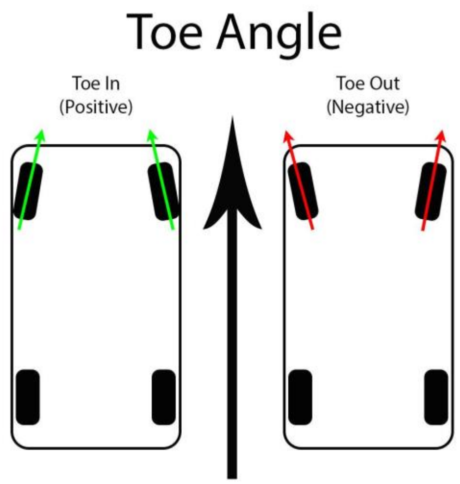


Figure 18. Toe Angle diagram

https://help.summitracing.com/app/answers/detail/a_id/5257/~/what-is-toe%3F

Figure 19. Alignment mounting point

2.7 Bearings

When the team received the car, the wheel hub bearings on the car were not secure. The result of this was that the tires would be wobbly at best and would likely result in the tires falling off of the vehicle at any attempt of moving it. The mounts for the bearings were designed by the 2017 team, and the design included a snap ring design to hold the bearings. Due to time constraints as well as a lack of the necessary tools, the team was not able to fabricate the slits necessary to install the snap rings. Subsequent teams neglected the problem and left the car as it was before, despite it being an immediate and an important safety concern. Had the car been driven in such a state it would have likely resulted in substantial damage to the car and injury to the driver and bystanders.

The design cutting slits into the mount to place thick snap rings that are intended to keep the bearings from sliding out of the mount. However, even with the snap rings, the wheels still had wobble, not enough for the tires to fall off, but enough to be a safety concern. This led us to design carbon reinforced nylon spacers with 0.1 mm thickness to insert between the snap rings and the bearings. 2 to 3 spacers were installed on every bearing based on the wobble needed to be eliminated.

3. Design Evaluation

Design requirements and constraints

3.1 Body panels

The functional requirements the team established for constructing the car body include that it needs to be lightweight, aerodynamic, vibration resistant, and safe.

Evaluation:

When evaluating the body panels in general compared to the car, the team had to take into consideration the effects and changes made to the vehicle by adding the body panels to the chassis of the vehicle, in terms of weight distribution and aerodynamics. Each of the body panels weigh roughly around 2 to 5 pounds, which is considered to be lightweight when compared to the overall weight of the vehicle at over 800 pounds. The weight of each body panel is considered to be negligible, which will not alter the weight distribution of the car parts by a noticeable amount. When testing out the aerodynamics of the body panels, the team used the Fusion360 application and ran an aerodynamics simulation illustrated in Figures 20-21, to test the overall forces that will be acting on the body panels and how it may affect the speed of the car. The team could not physically test the aerodynamics of the vehicle because the team did not have a wind tunnel available.

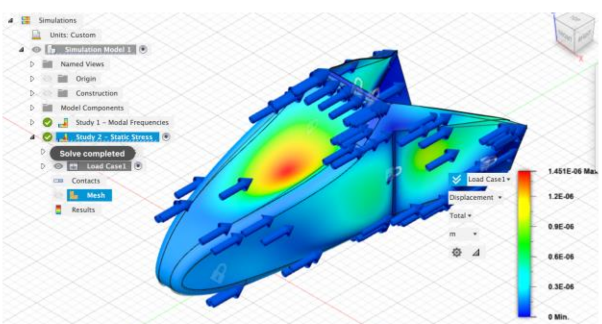


Figure 20. Static Stress test on Displacement

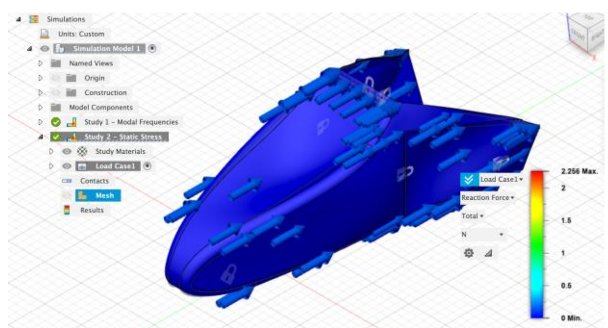


Figure 21. Static Stress test on Reaction Force

For the vibration resistance part of the body panels, the team ran a simulation of the Fusion360 application to find out the points that would need more stability at different frequencies. From the simulated results depicted in Figure 22-24, the team were more concerned about the lower frequencies and how the body panels would be affected at different low frequencies. A mount was designed to stabilize the body panels by attaching them to the chassis of the vehicle at the pin points that showed deformation in the simulation. By doing so, the mounts would prevent the body panels from deforming at certain frequencies, ensuring the safety of the overall car.

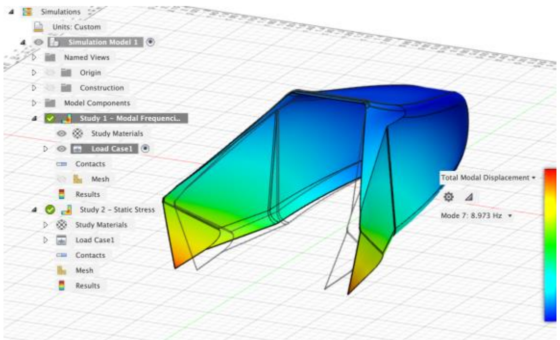


Figure 22. Modal Frequency test at 8.973 Hz

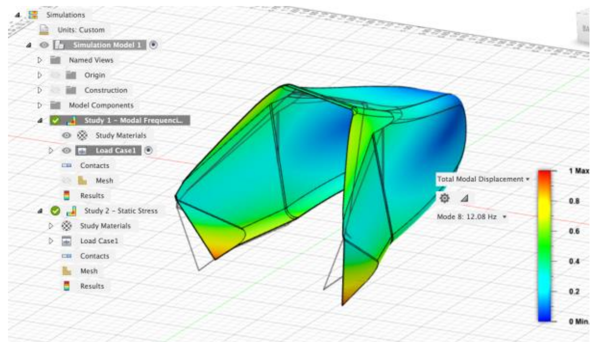


Figure 23. Modal Frequency test at 12.08Hz

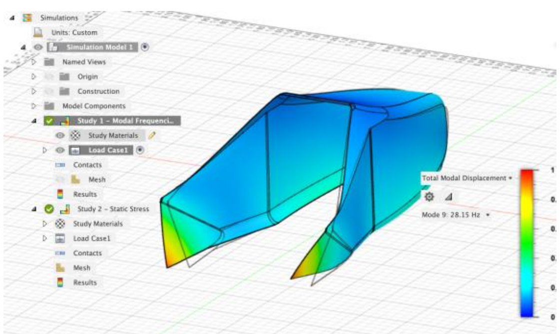


Figure 24. Modal Frequency test at 28.15 Hz

3.2 ECU

Associated test #1: ECU code download

Objectives:

The ECU must have the SQL code downloaded onto it and tuned such that it can optimally direct the car's internal cooperation including (but not limited to) fuel flow rate, position measurement, oxygen level management, etc.

Features Evaluated:

The ECU was judged on its ability to run the code on TunerStudio and display reasonable base values on the simulation. In addition, its ability to be modified and tuned using the JimStim was also evaluated.

Test scope:

The ECU must display zero tire rotation and medium oxygen readings when the engine is on and idle. In addition, the ECU must display all green on the gauges for fuel line pressure and air intake pressure.

Test plan:

The plan for testing the ECU is simply to observe its behavior when connected to the JimStim after downloading the SQL base file and viewing the base readings.

Acceptance criteria:

If the readings are zero for speed and within the green ranges for the pressure gauges, then the test is deemed as passed. Any sort of major fluctuation or within red range for the pressures will result in failure.

Test results:

Our team required two tries for the ECU, the first being a failure and the second being a success. The first time, the ECU was improperly identified due to improper ordering form specifications. Once our team deduced the correct model and version of the ECU motherboard chip, the code was refreshed and updated.

Evaluation:

The ECU is officially confirmed and documented to be operational.

Associated Test #2: *ECU/Powertrain Test*

Test Overview:

This test will provide an overview evaluation of the performance of the EFI system and the powertrain integration as a whole.

Objectives:

The objectives of this test plan are to show the satisfactory performance of the EFI system through the healthy idle and running conditions of the engine.

Features Evaluated:

Evaluated features include all the dependent ECU/Powertrain subsystems tests, such as accurate as well as precise sensor and actuator response. Additional features to be considered

Test scope:

The engine will be run at various conditions, such as idle, half throttle, and full throttle, in order to determine the overall functionality and performance of the integration of the dependent subsystems.

Test plan:

This test requires that the ECU/Powertrain subsystem test be completed and verified. Once the components are determined to have successfully passed their individual evaluations, the overall test can be completed.

This test is more so a qualitative one, as the team does not have access to a dynamometer. The engine will be run at various throttle positions listed here: closed (idle), half open, and fully open. The test will be three times at each throttle position, and the average of each of the runs will be taken to represent that data at that point. In each of these positions, the team will be looking at the engine performance using TunerStudio, as well as listening for any misfires and engine skipping. Using TunerStudio, the team will observe whether or not the spark and fuel outputs are timed correctly. The spark must fire before the engine reaches TDC, as determined by the crankshaft position sensor. Additionally, the fuel must be injected after the engine passes TDC and before the engine reaches BDC. The test will be performed three times at each throttle position to confirm repeatability. Using the information given by the MS2 on the Megasquirt website for the RPM measurement, the team is assuming an accuracy within 1% for the measurements recorded in TunerStudio.

If the team is not ready to perform the test plan for the ECU, the team will then allocate all our resources to getting the car ready for testing as soon as possible.

Acceptance criteria:

In order to pass this test, this system must show that it is operating according to the programming of the ECU within the TunerStudio observation software. Additionally, it must not have audible misfires or skips while the engine is running under any of the loading conditions. Under the relevant ignition stroke pertaining to a four-cycle engine, the spark must be shown to occur just before the crankshaft position sensor measures TDC. Additionally, during the intake stroke, the fuel must be shown to be injected between the regions of TDC and BDC, as shown by the crankshaft position sensor.

Test results:

The team reached a solid and consistent level of communication between the ECU and the TunerStudio software on the laptop. This was determined to be successful when the JimStim output the correct fuel injector pulse and the ECU connected to the correct TunerStudio COM port on the laptop. After this successful connection, the ECU was tuned with the help of an online source from the University of Maine. More information on this in section *5.2 EFI TunerStudio Specifications* in Appendix. After moving the car from the garage, filling it with gas and oil, connecting the battery, and putting water in the radiator, the team could not get the TunerStudio software to connect with the ECU. After cancelling the test, the team began to brainstorm possible errors. Throughout the following week, the team made several adjustments to the ECU to try and solve the issue. The team checked for short circuits, tested and replaced a fried zener diode, resoldered on the pressure sensor, retested COM ports on the laptop and regained communication with the ECU, and re-uploaded the code and began the tuning process again. Similarly, it was determined that the additional transistor used for the spark configuration was not a BIP 373 transistor and that the uploaded code was for a MicroSquirt, not a MegaSquirt II. Therefore, the old transistor was replaced and the correct code was uploaded.

Evaluation:

Although the test was not performed on March 22nd, the team was able to produce a functional ECU. The test plan was not a daily event, but took place over a series of weeks. There were setbacks along the way. With the ECU thought to be up and running, the team proposed a weekend car test on April 18th. The new code allows the MegaSquirt II to account for the dual spark configuration modification and essentially changes the MegaSquirt II into a MegaSquirt II extra. After all of these adjustments, the ECU responded correctly to the JimStim, connected to the laptop, and was re-tuned for proper engine performance.

3.3 Cockpit

Associated Test #3: *Headrest Test*

Objectives:

The objective of this test is to ensure that the built headrest is able to withstand a frontal force of 900 N and a lateral force of 300 N on both sides to comply with FSAE rule T.2.8.4, located in the Appendix section 5.12 of this report.

Features Evaluated:

The features evaluated would be the structural integrity of the headrest due to the frontal and lateral forces. In addition, any damage to the headrest from any external forces will be noted.

Test scope:

In the test, the headrest will resist force from a hydraulic press, up to 900 N from the front and up to 300 N from the sides. The test will stop once the headrest starts to show any forms of major deformation, breaks, or if the hydraulic press manages to unleash the full criteria force.

Test plan:

The headrest is designed to be able to withstand a certain amount of force from each angle. To test this, the team will be testing on Instron. The team will be using a hydraulic press to pressure up to 900 N and 300 N to the front and sides of the headrest. In order to evaluate the performance of the headrest, the team will be examining the headrest position and functionality as the team increases the forces from any direction. If at any point throughout the test that the headrest breaks or majorly deforms, the test will stop and result in a failure.

Acceptance criteria:

The acceptance criteria require that the headrest be completely stable and not break into multiple parts after being pressured up to 900 N frontally and 300 N laterally.

Test results:

Using the hydraulic press, the headrest soundly handled a weight of 900N frontally and 300N laterally.

Evaluation:

Since the headrest passed the acceptance criteria in the test, the next steps of fabrication were taken. This included adding the headrest pad and securing the headrest to the chassis.

3.4 Brakes

Associated Test #1: Stop the car with brake application only

The team tested whether or not the braking system was able to fully stop the car when pressure was applied to the brake pedal by the driver, and without the brake lines leaking any fluid.

Objectives:

The goal of this test was to ensure the driver had control in stopping the car, and maintain that control over many applications of the brakes. A leak would reduce the pressure in the brake lines and reduce the stopping power of the system.

Features Evaluated:

This test examined the functionality and reliability of the brake lines.

Test scope:

Ideally, the test would be performed with the engine running and car up to normal race speeds. In addition, the weight of the car with body panels must be considered. However, since the team were unable to start the engine in time to run these tests,

Test plan:

Since the team did not yet have the engine running, the test would be performed by pushing the car to a low speed, releasing it, and the driver applies the brakes shortly after. If the test is able to be performed with the engine running, start the car into motion at a specific speed and measure how long it takes for the car to come to a complete halt using the brake system. **Accepted criteria:**

Without the engine running, if the car comes to a full stop, then the test is considered to be successful. If the test is performed with the engine running, the test is deemed a success if the car comes to a complete stop in an acceptable amount of time given the starting speed.

Test results:

Three trials of this test were conducted, and the driver was able to rapidly bring the car to a complete stop every time. Although the car was moving no more than a few miles per hour during each trial, the car came to a full stop nonetheless. After each trial, there were no leaks from the brake lines in the car or on the ground.

Evaluation:

The car being brought to a full stop confirms the functionality of the brakes for giving the driver control over the deceleration of the car. By successfully stopping the car without any leaks in brake fluid, the reliability of the braking system was confirmed since it can continue satisfying its purpose after many uses.

3.5 Wheels

3.5 Associated Test #2: *Skidpad test - tests the car as a whole*

This test will measure the vehicle cornering ability on a flat surface while in constant radius turn.

Objectives:

The objective of the test is to evaluate the reliability of the steering system. It tests whether the car can remain on a path while making a tight turn. With a running car, it will also test the driver's capability in driving in a steady path.

Features Evaluated:

The steering system will be evaluated, specifically its performance with the new steering mount. Then based on the results of the test, the assessment of the driver will be important for the final evaluation.

Test scope:

In the test the driver will first take two full laps of the right circle and the immediately after will take two more laps on the left circle as shown in Figure 1. In the 2nd and 4th laps, they will be timed.

Test plan:

A car's cornering ability will be tested using the course for the skidpad event at the California SAE competition. The course will be designed as a track in the shape of two concentric circles overlapped into a figure pattern. The pattern will be traced with cones and chalk. The chalk and cones will be used to help determine if the car was able to remain on the path. Then during two of the laps, the driver will be timed using a stopwatch.

To evaluate the performance, the scoring system from Formula SAE will be adopted. In the test the driver is allowed 4 runs or attempts. For any test run, a penalty of 0.125 seconds per hit cone will be applied to the final time.

- Corrected Time = (right lap time + left lap time)/2 + (cone * 0.125)
- Best - best corrected time
- Tmin - lowest corrected time

- Tmax - 125% of Tmin

When the Best < Tmax, the score is determined as:

Skidpad score = $$71.5 \times \frac{(Tmax/Best)^2 - 1}{(Tmax/Tmin)^2 - 1} + 3.5$$

When Best > Tmax, Skidpad score = 3.5

If for some reason the team is not ready to perform the test plan for the skidpad, the team will then allocate all our resources to getting the car ready for testing as soon as possible.

Acceptance criteria:

It was observed that the average score for most teams is 45 points, yet the placement in the overall competition is determined by cumulative points. Therefore, a higher score than 45 will be our goal.

Test results:

Since the power supplied by the engine is needed in order for results to be accurate representations of the car's ability to corner, this test has yet to be conducted. Until the engine can be started, and once the ECU is tuned, there is no value in performing this test.

Evaluation:

This test was unable to be performed as the tuning of the ECU and the engine were not ready. Since this test was not pivotal in our promised final deliverable, our team decided to omit this test.

3.6 Alignment

Maintaining proper alignment of the wheels is essential for maintaining control and stability in the tires. Tie rods from the snowmobile were used as an adjustable system to secure the rear toe angle of the wheels to improve the handling of the car.

Evaluation:

After rolling the car in and out of the CSI building multiple times, the front and rear toe angles were still constrained in their parallel positions, providing the driver with control of the car. Additionally, the adjustability of the tie rods before welding them into their permanent positions allows for future teams to optimize the toe angle and maximize control.

3.7 Bearings

The wheel hub bearings are crucial for maintaining the safety of the driver and control of the car. They need to be secure in order to prevent the wheels from falling off and risking serious injury to the driver and damage to the car, as well as prevent wobbly rotation of the wheels that will decrease handling ability. The snap rings and spacers were inserted into slits cut into the mounts for the purpose of securing the bearings.

Evaluation:

The team has been able to roll the car in and out of the CSI building multiple times without the wheels falling off and with minimal wobble in their rotation. While there is room for improvement by finding a way to eliminate the need for the spacers, this design successfully provides safety and control of the car to the driver.

4. Conclusions

Our FSAE team is pleased to report that the team has successfully performed the brake test, headrest test, and ECU/powertrain test. Our team has accomplished the design and fabrication of the body panels, realignment of the wheels, correcting the previous team's work on the brake lines and the ECU's connections. In addition, our team located the relay system and assembled the car's internal wiring successfully. Aside from the vinyl wrap which has been postponed until the car is fully functional, the construction of the car has been successfully completed. The team is now troubleshooting and tuning the completed car by upgrading the ECU motherboard. Even though the team has not been able to start the 2007 Phazer engine, there were significant advancements made. The team started off the 2020 fall semester with the goal of fabricating body panels. This goal was a yearlong accomplishment that took the coordination of all team members, professional advice from university faculty, and help from several outside parties. Along the way, the team learned more about the functionality of the vehicle systems, uncovered new arising problems that had to be researched and reconstructed, and worked together to create a functional formula style race car. The car is able to roll, steer, brake, and is even able to start.

There were several tests detailed in the full prototype test plan memorandum. The preliminary designs serve as a proof of concept for the final subsystem prototypes and system integration. Upon the completion of the final prototype with all of the various subsystems fully integrated, more rigorous testing involving the complete integration of all of the subsystems can be performed in order to fully evaluate the performance of the car and its compliance with FSAE standards. Due to COVID-19 restrictions and unfortunate ordering delays, tests such as the skidpad test have not been performed.

Overall, the 2020 - 2021 FSAE team constructed the most advanced design of the formula race car to date at Trinity University, that complied with the relevant FSAE rules [2] found in section 5.12 of the Appendix of this report. Future teams will need to move away from broad overview car analysis and transfer to manipulating the finer details of the car. The majority of this includes the electronic subsystems and the electronic control unit. The team believes that this is where the main difficulty lies in starting and driving the car. So far, our final product does not fully deliver the promised results, but given this year's difficulties and setbacks, our team is pleased to deliver a car that is ready to start and has never been closer to running on its own.

The entire team would like to thank our senior advisor Dr. Enright for his continual support and guidance, our CSI Makerspace shop technician Ryan Hodge for all of the knowledgeable advice, Ronnie Hodge owner of Mammoth Architectural for the use of his fiberglass shop, Dr. Leifer for his commitment to the success of the FSAE team over the years, Dr.'s Peter Kelly-Zion, Kevin Nickels and Daniel LaCroix for their timely input, Clayton Mabry for ordering all of our many car parts, and the Trinity University Motorsports team for their time and hard work along the way and for trusting us to work on their car.

5. Appendix

5.1 Electronic Control Unit specifications

5.1.1. BIP 373 Transistor

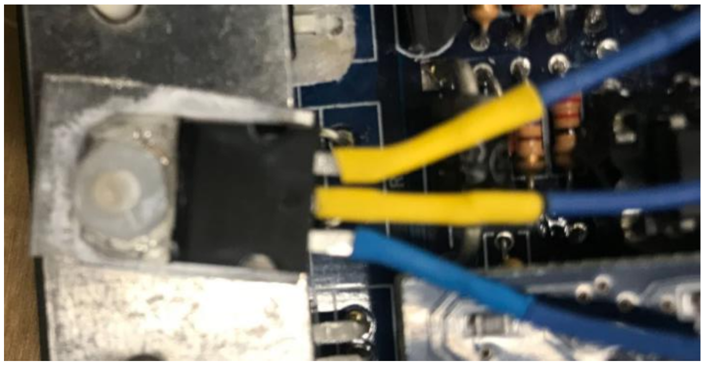


Figure 25. BIP373 Transistor modification for dual spark configuration

1. **Purpose**

   The purpose of this section is to provide detail on modifications made to the ECU in order to connect with the Phazer engine.

2. **Scope**

   This section will detail the installation of the BIP373 Transistor that is needed to use the high output coil driver ignition system with the MegaSquirt protoboard. Instructions on the procedure needed to install the BIP373 Transistor are covered in the *Specific Procedure* section.

Definitions

Acronym	**Expanded Term**
ECU	Electronic Control Unit
MAP	Manifold Absolute Pressure
CKP	Crankshaft Position Sensor

IAT	Intake Air Temperature Sensor
IGBT	Insulated Gate Bipolar Transistor
All remaining acronyms found at the following link	http://www.msextra.com/doc/ms1extra/glossary.html

3. **References**

Bosch Microelectronics BIP 373 Data Sheet http://www.megamanual.com/Tutorial.htm
https://secu-3.org/wordpress/wp-content/uploads/pdf/bip373_datasheet.pdf

Bosch BIP373 Ignition Module
https://www.diyautotune.com/support/tech/other/bosch-bip373-ignition/?gclid=Cj0KCQjw-LOEBhDCARIsABrC0Tmc1QgsTJKdjf9TXbq5e776vPbCKKhOHjVuJuU34PcbIegr1bKTq3MaArF8EALw_wcB

4. **Responsibilities**

This modification was already installed on the ECU when the 2020 - 2021 team began work on the car in the fall. However, it took much research and reaching out to former members to figure out what the modification actually did. The resources given above are very helpful if any troubleshooting is needed in the future. The team also has extra BIP373 kits if a replacement is needed.

5. **Specific Procedure**

Hardware mods required:

Jumper IGBTOUT to IGN to send to IGBT ignition coil driver signal out of pin 36 on the DB37. (not needed on a V3.57)

Cut out R57 if fitted on a V3.0

Our assembled V3.57 boards, if not fitted for direct coil control, will have a jumper from JS10 to the center hole of Q16. Remove the jumper.

Now for constructing the outputs…

Get a 330 ohm 1/4w resistor and cut the leads down to about 1/2″ at each end. Maybe a bit less.

Tin each end of the resistor with a bit of solder.

Cut a 5″ piece of hookup wire (22ga is fine) and strip just a 1/8″ or so. Tin the stripped wire with solder.

Melt the tinned wire tip to one end of the tinned 330-ohm resistor tip and let it cool.

Heat shrink wrap this wire/resistor assembly.

Use this wire/resistor combo to jumper the ‘top’ (top as in when you facing the silkscreen side of the PCB, with the text so that you can read it normally) lead of R26 to IGBTIN on the opposite side of the PCB. (On a V3.57, this is kind of tricky. It’s easier to use pin 7 on the U1 socket instead, on the underside of the board.)

Now, you will be constructing duplicates of this BIP373 circuit for each coil output you need. For a 1 cylinder, you’ll use 1 output; for more cylinders, you will use 1 output for every 2 cylinders (for our purposes, the team will use two outputs, with coil 1 on our engine connected to spark output 1, and coil two on our engine connected to spark output three). You can mount the additional BIP373s on a second heat sink stacked on top of the first, attached on top with long screws. Or you can mount the BIP373s to the case.

Each BIP373 will need a resistor-on-a-wire assembly, running to its left leg. You will get the BIP373 input signal from the following locations:

Output Input Location (V3.0) Input Location (V3.57)

Spark A Top of R26 U1 pin 7

Spark B	Top of R29	U1 pin 8
Spark C	Top of R27	U1 pin 9
Spark D	JS11	JS11
Spark E	JS5	JS5
Spark F	JS4	JS4

The center leg of the BIP373 is the spark output. The team has found that the IAC traces can carry enough current for normal use, so you can use one IAC trace for each spark output. You may need to add an extra connector with the V3.0 on 12-cylinder applications, or if you are running a stepper IAC. You can use this pinout if you are not running a stepper IAC, for up to 8 cylinders. Note that if you have anything else connected to the IAC pins, you must remove these wires before connecting the BIP373 outputs.

Output Board connection DB37 pin

Spark A	IGN 36
Spark B	IAC23B1
Spark C	IAC2A29
Spark D	IAC1B27

Connect the right leg of each BIP373 to a ground, preferably the DB37 ground pins, the right leg of R37 or R38, or the bottom hole of R43. The proto grounds can be used but this creates more noise on the signal ground plane.

5.1.2. MegaSquirt II

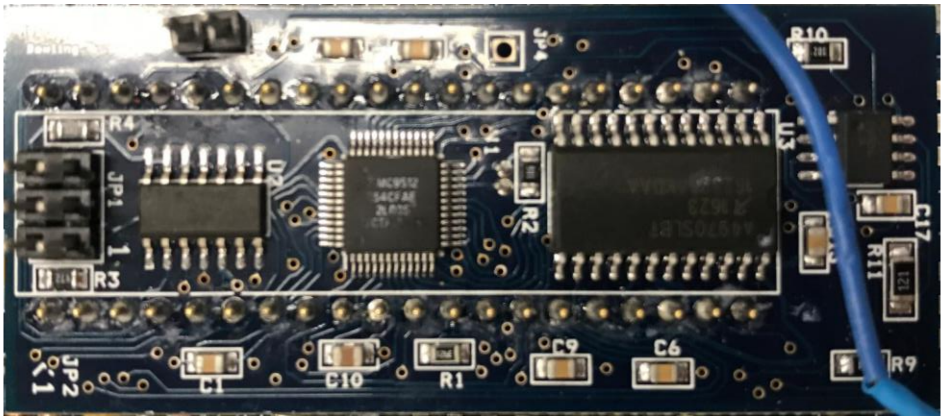


Figure 26. MegaSquirt II modification

1. **Purpose**

   Detail the specific electronic components, overall purpose of the MegaSquirt II (MS2), and installation processes.

2. **Scope**

   The MS2 is a plug-in processor card that uses a MC9S12 processor and includes supporting hardware with a stepper motor chip and an ignition module chip. It increases CPU core storage, process speed, and flash and RAM storage.

3. **References**

   MegaSquirt II Overview

   - http://www.megamanual.com/ms2/indexright.htm

   MegaSquirt II Installation

   - http://www.megamanual.com/ms2/install.htm

4. **Responsibilities**

   The installation of the MS2 was the responsibility of the ECU team, Stan Shao and Benjamin Witt. Their responsibilities were proper installation and understanding of significance of the processor card.

5. **Forms/Templates to Be**

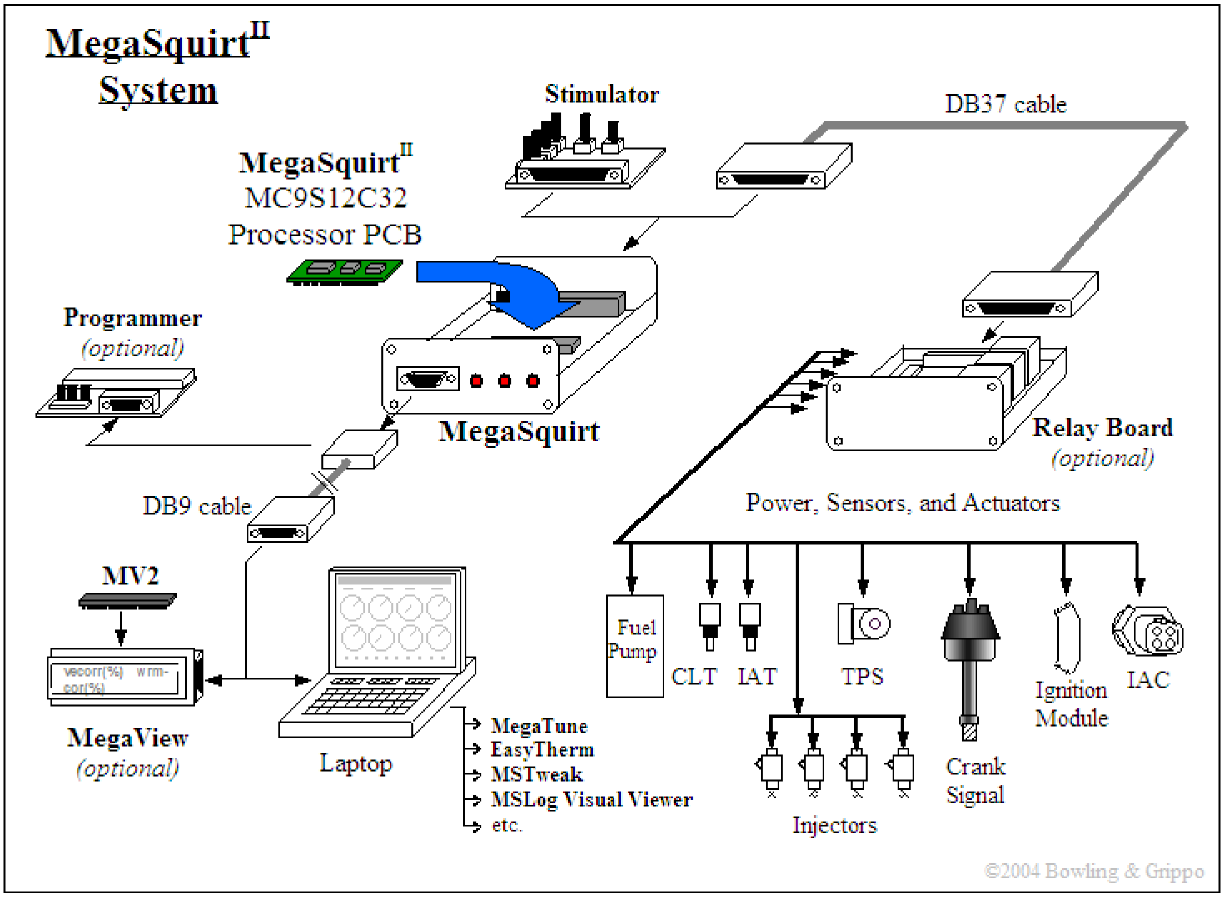


Figure 27. MegaSquirt System Overview with MS2 processor [1]

[1] http://www.megamanual.com/ms2/indexright.htm

6. Specific Procedure

a. Physically install the MegaSquirt II into the 40-pin socket

b. If the jumper is only on 1 header pin, then you also have the operating program loaded, and if you plug in to a main board with a stimulator you should see the injector lights flashing, meaning the program is running. In most cases the jumper will be over both pins. This means only the bootloader program is loaded and you must load the operating program using Eric Fahlgren's downloader program [1].

5.1.3. JimStim Stimulator

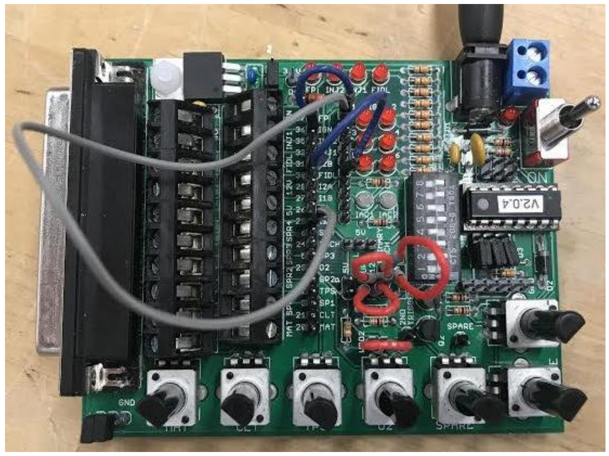


Figure 28. JimStim 1.5v MegaSquirt Stimulator

1. **Purpose**

   The purpose of the JimStim is to test and tune the ECU before its installation into the car. It acts as an engine simulator, a microcontroller which generates up to 30 different toothed wheel signals, and includes the standard distributor signal. By tuning before installation, the team can safely set up the engine parameters in the ECU to match that of the actual engine.

2. **Scope**

   This section will cover the many different sources of information that the team gathered to understand how to set up and operate the JimStim effectively.

3. **References**

   The link below provides a reference to DIYAutoTune, which is where the JimStim was purchased.

   - https://www.diyautotune.com/product/jimstim-1-5-megasquirt-stimulator-w-wheel-simulator-assembled/

   The link below was a very helpful video that detailed how to set up the JimStim to correctly output the desired ECU data. This included explaining which voltage and component pins to jumper (using jumper wires made in the CSI machine shop) in order to record the desired outputs.

- https://www.youtube.com/watch?v=zxKSVzzmN70&t=178s

Choosing the wheel mode is another important JimStim component. There are many different types of wheel modes that were detailed in the link below. The team used the 2007 Phazer engine manual to determine the correct wheel mode and then used the link below to implement it on the JimStim device. The wheel mode used for our car was a dual trigger wheel arrangement.

- http://jbperf.com/JimStim/JimStim_v2_0_Wheel_Simulator_Setup.html

4. Responsibilities

The ultimate responsibility of the ECU is to start and correct the engine. This includes, but is not limited to the starter relay, dual spark ignition system, and coordinating the timing of the fuel injector system. The JimStim is able to visually verify that ECU has the correct parameters uploaded.

5. Forms/Templates to Be Used

The JimStim was purchased pre-built. However, the following link references a builder's manual that details all of the parts used in case of any future adjustments or replacements.

- http://jbperf.com/JimStim/JimStim_v1_5_assembly.html

6. Specific Procedure

a. Set the Trigger Setup
b. Jumper the VR sensor (the team have a VR sensor, not a Hall sensor)
c. Jumper the 12V source pins (this will correctly read the TAC signal)
d. Jumper the wideband O2 sensor
e. Use jumpers to connect any other pins you want to see the output for on the JimStim or TunerStudio software

5.1.4. Wiring

The internal component wiring was conducted using the 2007 Yamaha Phazer Snowmobile wiring diagram as illustrated by Figure 24. This diagram goes into much greater detail involving the relay systems. All electrical, relay, and fuse systems were troubleshooted using this diagram.

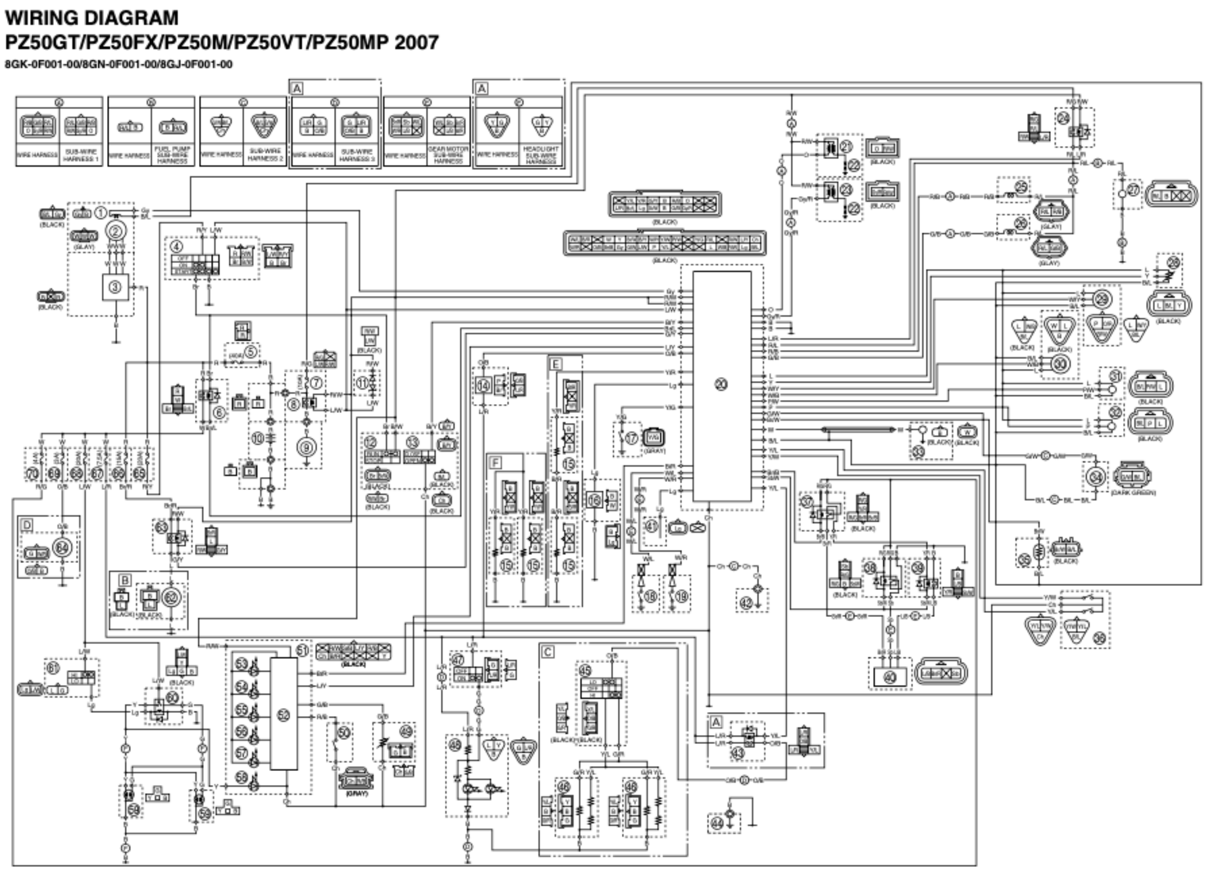


Figure 29. 2007 Phazer Wiring diagram with all relay and fuse systems

5.1.5 ECU Code

Firmware Installation

- This link runs the ECU as a MegaSquirt II extra, which is required for the Phazer engines dual spark system
- http://www.msextra.com/doc/pdf/html/Megasquirt2_Setting_Up-3.4.pdf/Megasquirt2_Setting_Up-3.4-17.html

The following link should be referenced when uploading the firmware and INI files. However, instead of using the *v3.83. s19* file for the firmware, use the firmware provided at msextra.com. The *v3.83. s19* file will incorrectly run the MegaSquirt II as a MicroSquirt. Pay careful attention to the placement of the bootloader when uploading the code to the ECU.

- http://www.megamanual.com/ms2/code.htm#downloader

The programmer language is called *Assembly Language Programming*. This specific language is used to shorten the overall code length and help with the processing speed. It is also the only programming scheme that has a one-to-one correspondence with the machine language operational codes that the Mega Squirts processor recognizes. The link below offers an introduction for this general understanding of the programming language.

- http://www.megamanual.com/Tutorial.htm

5.2 EFI TunerStudio Specifications

In order to run the TunerStudio software, it must be purchased from EFI Analytics. The team’s registration information is included so that future team members can still access the tuning from the 2020-2021 FSAE team. The team did long hours or research to gain an understanding of the tuning process and sort through the large amount of information. Initially, the team was using the version 3.8 code and referenced the MegaManual website [1]. This website has a large amount of information regarding the ECU, the ECU code, and the tuning setup. Even though the team did not use this specific code or tuning page, it is a credible and reliable resource that should be used. Once the team discovered the MegaSquirt II extra code, it was decided to discard the version 3.8 code. The link for this code can be found in section *5.1.5 ECU Code* and the tuning information was taken from a very detailed report done by the Mechanical Engineering Department at the University of Maine [2]. This report details the entire process that the University of Maine engineering team went through in converting their own rebuild of a 2007 Yamaha Phazer. The tuning setup used here is the one current being run on the Trinity University race car rebuild.

FSAE 2021 Registration:

[Registration]

First Name: **Benjamin**

Last Name: **Witt**

Registered email: **bwitt@trinity.edu**

Registration Key: **W4K5UP5UCW7DPBTVGVDJ**

[End Registration]

[1] http://www.megamanual.com/mt38.htm#s

[2] https://studylib.net/doc/8062235/2012-clean-snowmobile

5.3 Fiberglassing Materials

- 20 by 1 yard of matted glass fiber cloth
- 2 pints of PVA mold release agent
- 4 gallons of polyester hardening resin
- 2 gallons of polyester based ‘sandy’ primer

5.4 Seat Harness

Below is the Sabelt Enduro Silver Series 6-Point Harness that was installed in the cockpit of the race care. The team picked the harness up from Winding Road Racing in Austin, Texas. The 6-point harness was specifically chosen to meet the FSAE requirements mentioned in section *5.10 Relevant Sections of 2021 FSAE Rulebook.*

Figure 30. Sabelt Enduro Silver Series 6-Point Harness

5.5 Creofoam Bead Seat

The creofoam bead seat was ordered from Pegasus Auto Racing Supplies. The seat was formed using a vacuum, seat pan, and driver to mold the seat. The seat is still in the process of being completed, however Figure 31 shows how the seat will look when completed with the racing tape.

Figure 31. Creafoam Bead Seat

5.6 Wheels & Tires

Figure 32. New track tires and wheels ordered from Summit Racing

5.7 Aim Solo 2

The Aim Solo 2 was purchased from Winding Road Racing. The detailed unit specifications are included below. Notice that it operates on 12V of external power, which is perfect for the 12V small motor battery the team has installed on our car.

Technical Specifications	
Display	Graphical
Resolution	128x64 pixels
Display Pages	Up to 8 freely configurable
Backlight	7 configurable RGB colors
Shift lights/alarm LEDs	10 configurable RGB LEDs
Integrated track database	Yes
Internal platform	Internal 3 axis +5G/-5G accelerometer, 3 axis gyro, and 3 axis magnetometer
WiFi connection	Yes
GPS	10 Hz
External power	12 V
Memory	4 GB
Battery type	Rechargeable Lithium
Pushbuttons	Metallic
Dimensions	98.0x73.7x30.2 mm
Weight	240 g, battery included
Waterproof	IP65
Solo 2 DL (only)	
ECU connection	CAN,RS232 or K-Line to 1,000 + leading ECUs

Figure 33. AiM Sports Solo 2 GPS Lap Timer [1]

[1] https://store.windingroad.com/AiM-Sports-Solo-2-DL-GPS-Data-Logging-Lap-Timer

5.8 Welding

The primary form of welding used on this vehicle was MIG welding as it is an easier method to weld irregular shapes while adding extra material to the base. When welding non-polyester clothing must be worn, ideally long sleeves and pants to protect the skin. The university provides an online training course to provide the general welding information required to start the process. A short lesson with a shop technician is also required before one can start welding on campus. Welding was used to attach the seat pan and mounts for the oil can to the chassis of the vehicle and to extend an axle purchased by a previous group that was slightly too short.

5.9 Fuel, Oil, & Power source

Fuel: Premium Gasoline

- Premium gasoline has an octane level of 91 or greater that aids in engine lifespan and decreased plaque buildup [1].

Oil: Mobil 1 Advanced Fuel Economy 0W-30

- This specific oil is a low viscosity oil that is used to increase engine efficiency and improve fuel economy versus higher viscosity oils [2].

Power source: EverStart Lead Acid 12 V/230 CCA battery

- This is a small engine battery

[1]https://www.geico.com/living/driving/auto/auto-care/premium-vs-regular-gas-whats-the-difference/#:~:text=Premium%20gasoline%20is%20generally%20considered,premium%E2%80%9D%20in%20some%20cases).

[2]https://www.mobil.com/en/lubricants/for-personal-vehicles/our-products/motor-oils/mobil-0w-30-low-viscosity-oils

5.10 Trinity University Motorsports (TUMS)

The car the senior FSAE design team worked on all year belongs to the TUMS team at Trinity University. Throughout the course of the project, the senior design team utilized the TUMS members to aid in wiring, initial papier mâché body mold blueprints, body panel sanding, fiberglassing, and several other pertinent tasks. All work done by TUMS members was done in accompaniment with a senior design member. Seeing as significant progress was made on the car this year, it is the hope of the entire Senior FSAE design team that the TUMS organization will become more prevalent on the Trinity University campus and continue work on the car or other motorsport projects.

5.11 Budget and Purchase Order Forms

Below is the budget for the 2020-2021 Senior FSAE team. The team started the year out with a budget of $10,840.95 and currently have $5,620.56 left to spend. This means that the team spent around $5,200 on the car in the 2020-2021 school year. The team has a proposed plastic wrap decal for the body panels of the race car. This aesthetic addition to the car is now in the hands of the TUMS team and will be given to the team as a donation. It will not affect the budget.

Formula SAE Team						
Project Sponsor: Dr. Jack Leifer						
Budget	$10,841	Engineering Designated Account				
					FSAE Designated Funds	
Date	**Pmt Method**	**Description**	**Vendor**	**Purchaser**	**Amount**	**Balance**
8/21/2019		Opening Balance				10,840.95
9/29/2020	P-card	Wheel Hub Housing Nut - Rear	RCV Performance	Jack Harvell-DeGolier	90.00	10,750.95
10/5/2020	P-card	Digital Tach /Hour Meter	Amazon	Antonio Domit	19.99	10,730.96
10/5/2020	P-card	GPS Lap Timer	Winding Road Racing	Antonio Domit	399.00	10,331.96
10/5/2020	P-card	Fan Mounting Kit	Mishimoto	Antonio Domit	19.31	10,312.65
10/21/2020	P-card	Creafoam Bead Seat Kit	Pegasus	Jack Harvell-DeGolier	294.99	10,017.66
10/20/2020	P-card	Asst Bolts and Nuts	FastServ Supply	Antonio Domit	56.13	9,961.53
10/20/2020	P-card	Tuner Studio MS License	EFI Analytics	Benjamin Witt	59.95	9,901.58
11/10/2020	P-card	Lanyards black 50 ea	Amazon	Antonio Domit	14.56	9,887.02
11/10/2020	P-card	Q-Glase Brushed Aluminum	Gravotech	Antonio Domit	41.67	9,845.35
11/13/2020	P-card - PR	Fuel Hose	Autozone	Antonio Domit	18.32	9,827.03
11/13/2020	P-card - GC	DIY Autotune	Stimulator, Pwr Supply	Benjamin Witt	162.13	9,664.90
11/16/2020	P-card	Nuts, bolts, washers	Fastenal	Jack Harvell-DeGolier	62.30	9,602.60
11/18/2020	P-card	Custom Axle	RCV Performance	Jack Harvell-DeGolier	395.00	9,207.60
1/15/2021	P-card	Foamular six 4x8 sheets	The Home Depot	Antonio Domit	305.98	8,901.62
1/15/2021	P-card	Internal Retaining Ring 6 ea	McMaster-Carr	Antonio Domit	43.08	8,858.54
1/21/2021	P-card	Internal Retaining Ring 6 ea	McMaster-Carr	Antonio Domit	107.96	8,750.58
1/27/2021	P-card	U-bolts 2 ea	Fastenal	Jack Harvell-DeGolier	20.72	8,729.86
1/27/2021	P-card	Lug Nuts 16 ea	Dennis Kirk	Antonio Domit	27.75	8,702.11
2/2/2021	P-card	Bondo Putty	Amazon	Antonio Domit	13.28	8,688.83
2/2/2021	P-card	Loctite, Carpet Tape - 2 ea	Amazon	Antonio Domit	56.32	8,632.51
2/3/2021	P-card	Coolant Overflow Tank	ECS Tuning	Standley Shao	47.02	8,585.49
2/4/2021	P-card	Fuel Pump 2 diff	Partzilla	Benjamin Witt	118.81	8,466.68
2/4/2021	P-card	Fuel Pump	Ebay	Benjamin Witt	29.98	8,436.70
2/23/2021	P-card	hose, clamps, screws, nuts	McMaster-Carr	Domit, DeGolier	49.98	8,386.72
2/24/2021	P-card	hose, clamps	McMaster-Carr	Antonio Domit	32.93	8,353.79
2/22/2021	P-card	Brake Line 2 ea	Summit Racing	Antonio Domit	55.43	8,298.36
2/23/2021	P-card	Tee Brass Fittings 3 ea	Amazon	Antonio Domit	6.28	8,292.08
3/2/2021	P-card	Spackling Paste 3 qt	Amazon	Brandon Fischer	37.47	8,254.61
3/8/2021	P-card	Brake Rotor Snap Ring 5 ea	RCV Performance	Antonio Domit	20.07	8,234.54
3/4/2021	P-card	PLA Red 2 spools	ImageNet Consulting	Antonio Domit	89.91	8,144.63
3/9/2021	P-card	Wheel 1 ea	Summit Racing	Antonio Domit	115.98	8,028.65
3/10/2021	P-card	Wheel 3ea, Tire 4ea	Summit Racing	Antonio Domit	1,213.97	6,814.68
3/16/2021	P-card	Hot Rolled Steel 16 Ga 1x2ft	Metals Depot	Antonio Domit	28.47	6,786.21
3/16/21	P-card	fiberglass, resin, MEKP	Plastic Supply of SA	Brandon Fischer	141.1	6,645.11
3/18/21	P-card	Fiberglass supplies & tools	Fiberglass Supply	Brandon Fischer	178.62	6,466.49
3/19/21	P-card	Fiberglass supplies & tools	Fiberglass Supply	Brandon Fischer	193.31	6,273.18
3/17/21	P-card	Half Face Mask Respirator 2ea La	Amazon	Domit, DeGolier	62.40	6,210.78
3/17/21	P-card	Ultimaker Red PLA	MatterHackers	Antonio Domit	99.90	6,110.88
3/17/21	P-card	Half Face Mask Respirator 1ea M	Amazon	Antonio Domit	29.90	6,080.98
3/19/21	P-card	Surface Agent	Fiberglass Supply	Antonio Domit	85.98	5,995.00
3/19/21	P-card	Harness	Winding Road Racing	Antonio Domit		5,995.00
4/1/21	P-card	Fiberglass Tools	Fiberglass Supply	Brandon Fischer		5,995.00
4/1/21	P-card	Resin 2 gal Activator 2 btl	Plastic Supply of SA	Brandon Fischer		5,995.00
3/16/21	P-card	Fiberglass Tools	Fiberglass Supply	Brandon Fischer	374.44	5,620.56
3/23/21	P-card	Respirator Cartridge Filters 6pk	Amazon	Antonio Domit	125.94	5,494.62
3/25/21	P-card - RS	Mount 4 tires, stems, balance	Pep Boys	Antonio Domit	63.96	5,430.66
4/1/21	P-card	Sandy Sprasyable 1 gal	Colortone Paint	Antonio Domit	119.24	5,311.42
4/1/21	P-card	SFI 45.2 Foam Sheet	BSCI	Antonio Domit	156.31	5,155.11
4/8/21	P-card	Screws, nuts, washers	McMaster-Carr	Brandon Fischer		5,155.11
4/9/21	P-card	Fiberglass Tools	Fiberglass Supply	Antonio Domit	0.00	5,155.11
4/1/21	P-card	Fiberglass Tools	Fiberglass Supply	Antonio Domit	0.00	5,155.11
4/9/21	P-card	Hex screws 1/4-20	McMaster-Carr	Brandon Fischer		5,155.11
4/14/21	P-card	Starter Relay	Babbits / Yamaha	Benjamin Witt		5,155.11
4/15/21	P-card	Fiberglass Matte 300ft	Plastic Supply of SA	Antonio Domit		5,155.11

5.12 Relevant Sections of 2021 FSAE Rulebook

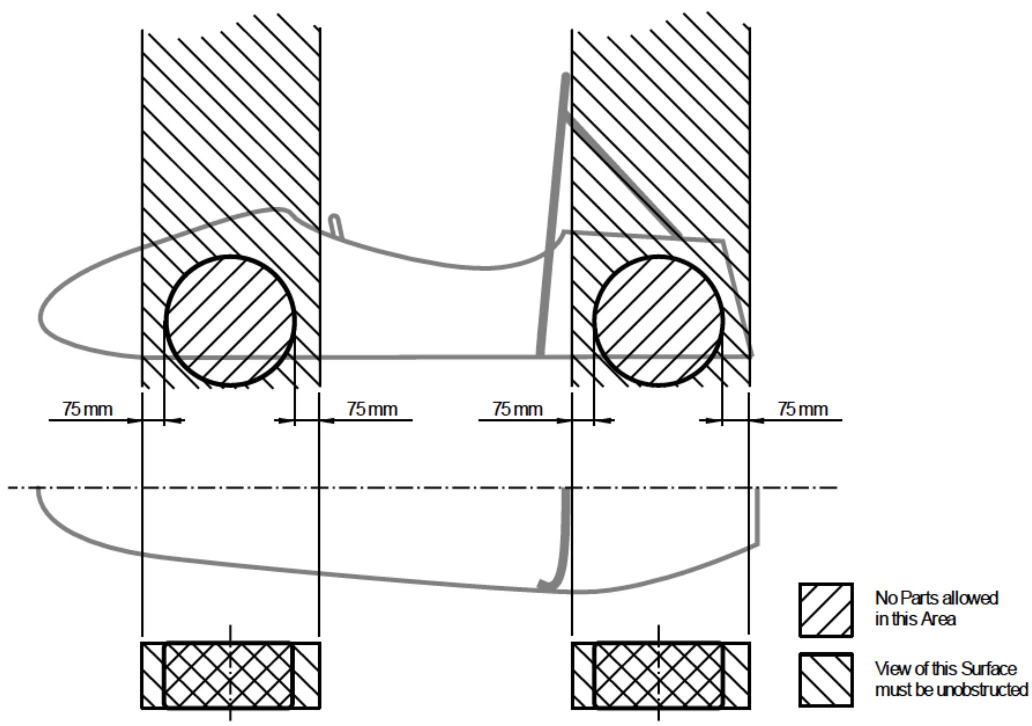
V - VEHICLE REQUIREMENTS

V.1 CONFIGURATION

V.1.1 Open Wheel

Open Wheel vehicles must satisfy all of the following criteria:

a. The top 180° of the wheels/tires must be unobstructed when viewed from vertically above the wheel.
b. The wheels/tires must be unobstructed when viewed from the side.
c. No part of the vehicle may enter a keep out zone defined by two lines extending vertically from positions 75 mm in front of and 75 mm behind, the outer diameter of the front and rear tires in the side view elevation of the vehicle, with tires steered straight ahead. This keep out zone will extend laterally from the outside plane of the wheel/tire to the inboard plane of the wheel/tire.



V.2.2 Visibility

a. The driver must have sufficient visibility to the front and sides of the vehicle

b. When seated in a normal driving position, the driver must have a minimum field of vision of 100° to both sides

V.3 SUSPENSION AND STEERING

V.3.1 Suspension

V.3.1.3 All suspension mounting points must be visible at Technical Inspection by direct view or by removing any covers.

V.4 WHEELS AND TIRES

V.4.1 Wheel Size

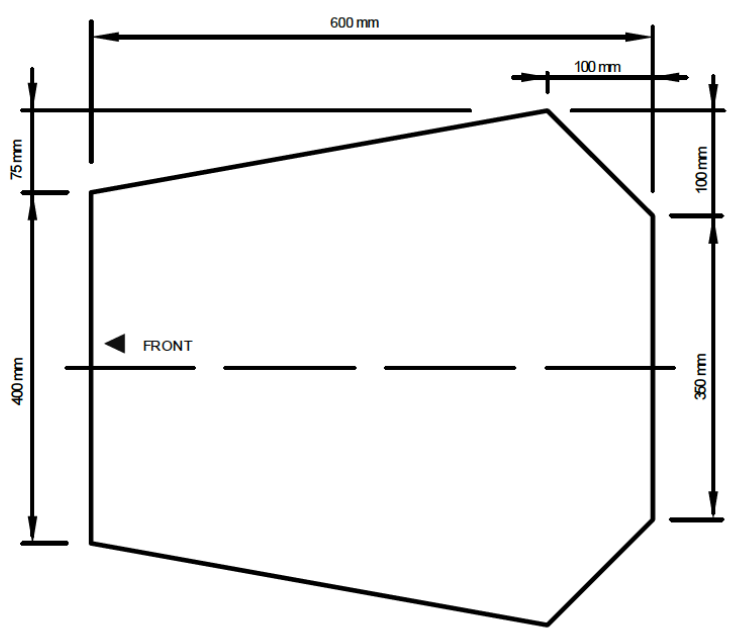
Wheels must be 203.2 mm (8.0 inches) or more in diameter.

T - TECHNICAL ASPECTS

T.1 COCKPIT

T.1.1 Cockpit Opening

T.1.1.1 The template shown below must fit into the cockpit opening



T.1.5 Driver's Seat
T.1.5.1 The Driver's Seat must be protected by one of the following:

a. In side view, the lowest point of any Driver's Seat must be no lower than the upper surface of the lower frame rails

T.2 Driver Accommodation

T.2.1 Harness Definitions

a. 5 Point Harness – consists of two Lap Belts, two Shoulder Belts and one Anti-SubmarineBelt.

b. 6 Point Harness – consists of two Lap Belts, two Shoulder Belts and two leg or Anti-Submarine Belts.

c. 7 Point Harness – consists of two Lap Belts, two Shoulder Belts, two leg or Anti-Submarine Belts and a negative g or Z Belt.

d. Upright Driving Position - with a seat back angled at 30° or less from the vertical as measured along the line joining the two 200 mm circles of the template of the 95thpercentile male as defined in F.5.5.4 and positioned per F.5.5.5

e. Reclined Driving Position - with a seat back angled at more than 30° from the vertical as measured along the line joining the two 200 mm circles of the template of the 95th percentile male as defined in F.5.5.4 and positioned per F.5.5.5

f. Chest to Groin Line - the straight line that in side view follows the line of the Shoulder Belts from the chest to the release buckle.

T.2.2 Harness Specification

T.2.2.1 The vehicle must use a 5, 6- or 7-Point Harness meeting one or more of the following:

a. SFI Specification 16.1

b. SFI Specification 16.5

c. FIA specification 8853/98

d. FIA specification 8853/2016

T.2.2.2 The belts must have the original manufacturers labels showing the specification and expiration date.

T.2.2.3 The Harness must be in or before the year of expiration shown on the labels. Harnesses expiring on or before Dec 31 of the competition year are permitted.

T.2.2.4 The Harness must be in new or like new condition, with no signs of wear, cuts, chafing or other issues.

T.2.2.5 All Harness hardware must be threaded in accordance with manufacturer’s instructions.

T.2.2.6 All Harness hardware must be used as received from the manufacturer. No modification (including drilling, cutting, grinding, etc.) is permitted.

T.2.3 Harness Requirements

T.2.3.1 Vehicles with a Reclined Driving Position must have:

a. A 6 Point Harness or a 7 Point Harness

b. Anti-Submarine Belts with tilt lock adjusters (“quick adjusters”) OR two sets of Anti-Submarine Belts installed.

T.2.3.2 All Lap Belts must incorporate a tilt lock adjuster (“quick adjuster”). Lap Belts with “pull-up” adjusters are recommended over “pull-down” adjusters.

T.2.3.3 The Shoulder Belts must be over the shoulder type. Only separate shoulder straps are permitted. “Y” type shoulder straps are not allowed. The “H” type configuration is allowed.

T.2.4 Belt, Strap and Harness Installation - General

T.2.4.1 The Lap Belt, Shoulder Belts and Anti-Submarine Belt(s) must be securely mounted to the Primary Structure.

T.2.4.2 Any guide or support for the belts must be material meeting F.3.2.1.j

T.2.4.3 Each tab or bracket to which any part of the Harness is attached must:

a. Have a minimum cross-sectional area of 60 mm2 of steel to be sheared or failed in

tension at any point of the tab

b. Be 1.6 mm minimum thickness

c. Be aligned such that it is not put in bending when the attached part of the Harness is put under load.

d. Where Lap Belts and Anti-Submarine Belts use the same attachment point, there must be a minimum cross-sectional area of 90 mm2 of steel to be sheared or failed in tension at any point of the tab.

e. Not cause abrasion to the belt webbing

T.2.4.4 Attachment of tabs or brackets must meet the following:

a. Where brackets are fastened to the chassis, no less than two 6 mm or 1/4” minimum diameter Critical Fasteners, see T.8.2 or stronger must be used to attach the bracket to the chassis.

b. Where a single shear tab is welded to the chassis, the tab to tube welding must be on both sides of the base of the tab. Double shear attachments are preferred. Tabs and brackets for double shear mounts should be welded on both sides.

T.2.4.5 Harness installation must meet T.1.8.1

T.2.5 Lap Belt Mounting

T.2.5.1 The Lap Belts must pass around the pelvic area below the Anterior Superior Iliac Spines (the hip bones).

T.2.5.2 The Lap Belts must not be routed over the sides of the seat. The Belts must come through the seat at the bottom of the sides of the seat and continue in a straight line to the anchorage point.

T.2.5.3 The seat must be rolled or grommeted where the Belts or Harness pass through a hole in the seat

T.2.5.4 In side view, the Lap Belt must be capable of pivoting freely by using a shouldered bolt or an eye bolt attachment.

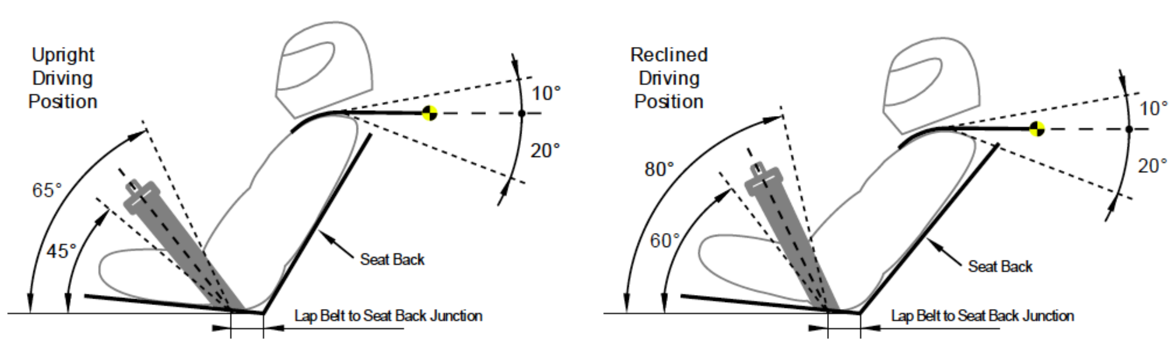
T.2.5.5 Lap Belts must not be mounted by wrapping them around frame tubes.

T.2.5.6 With an Upright Driving Position: (see figure below)

a. The Lap Belt Side View Angle must be between 45° and 65° to the horizontal.

b. The centerline of the Lap Belt at the seat bottom should be between 0 – 75 mm forward of the seat back to seat bottom junction.

T.2.5.7 With a Reclined Driving Position, the Lap Belt Side View Angle must be between 60° and 80° to the horizontal. (see figure below)



Any bolt used to attach a Lap Belt, directly to the chassis or to an intermediate bracket, is a Critical Fasteners, see T.8.2, with a minimum diameter that is the smaller of:

• The bolt diameter specified by the manufacturer

• 10 mm or 3/8”

T.2.6 Shoulder Harness

T.2.6.1 From the driver’s shoulders rearwards to the mounting point or structural guide, the Shoulder Belt Side View Angle must be between 10° above the horizontal and 20° below the horizontal. Refer to figure following T.2.5.7 above

T.2.6.2 The Shoulder Belt Mount Spacing must be between 178 mm and 229 mm. Refer to figures in T.2.7 below

T.2.6.3 Any bolt used to attach a Shoulder Belt, directly to the chassis or to an intermediate bracket, is a Critical Fasteners, see T.8.2, with a minimum diameter that is the smaller of:

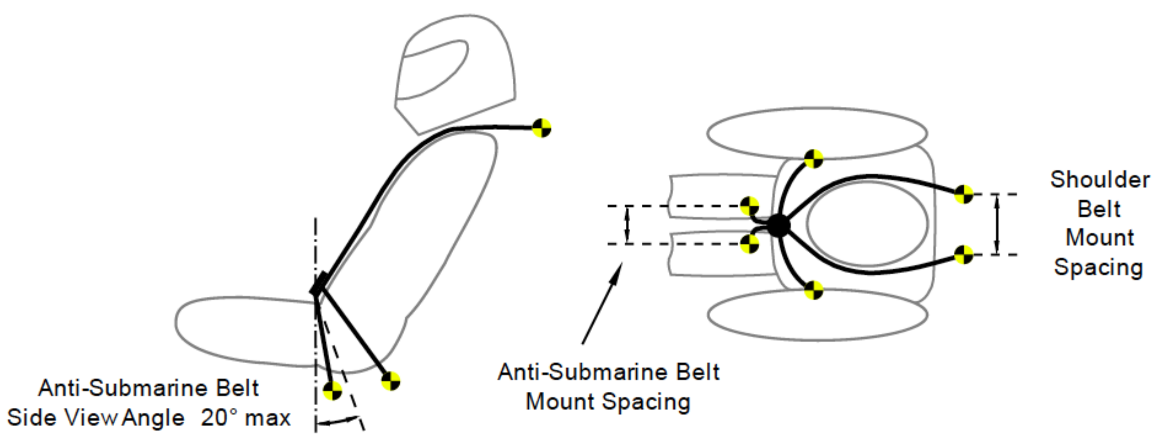
• The bolt diameter specified by the manufacturer

• 10 mm or 3/8”

T.2.7 Anti-Submarine Belt Mounting

T.2.7.2 The Anti-Submarine Belts of a 6-point harness must be mounted in one of the following ways:

a. With the belts going vertically down from the groin, or with an Anti-Submarine Belt Side View Angle up to 20° rearwards. The Anti-Submarine Belt Mount Spacing should be approximately 100 mm apart.



T.2.7.3 All Anti-Submarine Belts must be installed so that they go in a straight line from the Anti-Submarine Belt Mounting Point(s) without touching any hole in the seat or any other intermediate structure until they reach:

a. The release buckle for the 5 Point Harness mounting per T.2.7.1

b. The first point where the belt touches the driver's body for the 6 Point Harness mounting per T.2.7.2 without touching any hole in the seat or any other intermediate structure

T.2.7.4 Any bolt used to attach an Anti-Submarine Belt, directly to the chassis or to an intermediate bracket, is a Critical Fasteners, see T.8.2, with a minimum diameter that is the smaller of:

• The bolt diameter specified by the manufacturer

• 8 mm or 5/16"

T.2.8 Head Restraint

T.2.8.1 A Head Restraint must be provided to limit the rearward motion of the driver's head.

T.2.8.2 The Head Restraint must be vertical or near vertical in side view.

T.2.8.3 All material and structure of the Head Restraint must be inside the Rollover Protection Envelope F.1.12

T.2.8.4 The Head Restraint, attachment and mounting must be strong enough to withstand a force of:

a. 900 N applied in a rearward direction

b. 300 N applied in a lateral or vertical direction

T.2.8.5 For all drivers, the Head Restraint must be located and adjusted so that:

a. The Head Restraint is no more than 25 mm away from the back of the driver's helmet, with the driver in their normal driving position.

b. The contact point of the back of the driver's helmet on the Head Restraint is no less than 50 mm from any edge of the Head Restraint. Approximately 100 mm of longitudinal adjustment should accommodate a range of specified drivers. Several Head Restraints with different thicknesses may be used.

T.3 BRAKE SYSTEM

T.3.1 Mechanical

T.3.1.1 The vehicle must be equipped with a braking system that must:

a. Act on all four wheels

b. Be operated by a single control

c. Be capable of locking all four wheels

T.3.1.2 The braking system must have two independent hydraulic circuits such that in the case of a leak or failure at any point in the system, effective braking power is maintained on minimum two wheels.

T.3.1.3 Each hydraulic circuit must have its own fluid reserve using separate reservoirs or an OEM style reservoir.

T.5.4 Coolant Fluid

T.5.4.1 Water cooled engines must use only plain water with no additives of any kind.

T.5.5 System Sealing

T.5.5.1 Any cooling or lubrication system must be sealed to prevent leakage.

T.5.5.2 The vehicle must be capable of being tilted to a 45° angle without leaking fluid of any type.

T.5.5.3 Flammable liquid leaks must not be allowed to accumulate.

T.5.5.4 Two or more holes of minimum diameter 25 mm each must be provided in the lowest part of the structure or belly pan in such a way as to prevent accumulation of liquids and/or vapors.

T.5.5.5 Absorbent material and open collection devices (regardless of material) are prohibited in compartments containing engine, drivetrain, exhaust and fuel systems below the highest point on the exhaust system.

T.5.6 Catch Cans

T.5.6.1 Separate catch cans must be employed to retain fluids from any vents for the engine coolant system and engine lubrication system. Each catch can must have a minimum capacity of 10% of the fluid being contained or 0.9 liter, whichever is greater.

T.5.6.2 Any vent on other systems containing liquid lubricant or coolant, including a differential, gearbox, or electric motor, must have a catch can with a minimum capacity of 10% of the fluid being contained or 0.5 liter, whichever is greater.

T.5.6.3 Catch cans must be:

a. Capable of containing boiling water without deformation

b. Located rearwards of the Firewall below the driver’s shoulder level

c. Positively retained, using no tie wraps or tape

T.5.6.4 Any catch can on the cooling system must vent through a hose with a minimum internal diameter of 3 mm down to the bottom levels of the Chassis.

T.7 BODYWORK AND AERODYNAMIC DEVICES

T.7.2 Bodywork

T.7.2.3 Bodywork must not contain openings into the Cockpit from the front of the vehicle back to the Main Hoop or Firewall. The cockpit opening and minimal openings around the front suspension components are allowed.

T.7.2.4 All forward facing edges on the Bodywork that could contact people, including the nose, must have forward facing radii minimum 38 mm. This minimum radius must extend 45° or more relative to the forward direction, along the top, sides and bottom of all affected edges.

T.7.4 Length

In plain view, any part of any Aerodynamic Device must be:

a. No more than 700 mm forward of the fronts of the front tires

b. No more than 250 mm rearward of the rear of the rear tires

T.8 FASTENERS

T.8.1 Critical Fasteners

A fastener (bolt, screw, pin, etc.) used in a location designated as such in the applicable rule

T.8.2 Critical Fastener Requirements

T.8.2.1 Any Critical Fastener must meet, at minimum, one of the following:

a. SAE Grade 5

b. Metric Grade 8.8

c. AN/MS Specifications

d. Equivalent to or better than above, as approved by a Rules Question or at Technical Inspection T.8.2.2 All threaded Critical Fasteners must be one of the following:

- Hex head
- Hexagonal recessed drive (Socket Head Cap Screws or Allen screws/bolts)

T.9 ELECTRICAL EQUIPMENT

T.9.1 Low Voltage Batteries

T.9.1.1 All batteries and onboard power supplies must be attached securely to the Chassis.

T.9.1.2 All Low Voltage batteries must have Overcurrent Protection that trips at or below the maximum specified discharge current of the cells.

5. 13 Bibliography

[1] CycleHippie. *Yamaha Service Manual*. 2007. https://snowparts.ru/manuals/Phazer%2007-08.pdf

[2] 2021 Formula SAE Rules. Downloaded from https://www.fsaeonline.com/cdsweb/gen/DocumentResources.aspx

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