Michigan Technological University
SAE Supermileage® Competition
Design Report

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I hereby confirm that this vehicle has undergone design changes significant enough to allow vehicle re-entry

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Supermileage Systems Enterprise

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SAE Design Report Contents

1.0 Preface

Supermileage Systems Enterprise (SSE) is a student run organization representing Michigan Technological University in the 2011 SAE Supermileage® Competition. SSE exists solely to provide a structure and funding for the development of a Supermileage vehicle. The following document outlines the design and development of this year's vehicle. It includes designs, manufacturing, cost analysis, and other fundamental parts of the project.

2.0 Basic Vehicle Configuration

This year's entry includes many improvements over last year's design. While the same carbon fiber body and chassis will be used, it has been modified to allow for a new single side drive power train as opposed to last year's jack shaft system. Figure 1 shows the basic body and chassis layout that will be used. The basic vehicle dimensions are as follows: 118 inches long, 19.6 inches wide and 26 inches tall with a wheel base of 72 inches and a track width of 31 inches. See Appendix A-1 to A-3 for engineering drawing.

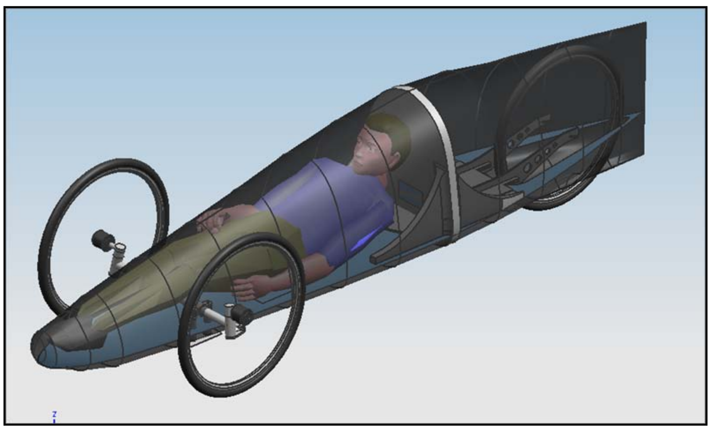


Figure 1: Chassis Layout

In order to allow for a new one side drive a new wheel hub was manufactured. A normal bike hub cannot be setup with left side drive and right side brake. The rear uprights were also shortened to increase the rigidity of the rear tire. A new engine plate was also made with slotted engine mounts to allow for adjustable chain tension.

A new steering system was implemented in this year's vehicle using the same rack and pinion as in the previous design. The steering utilizes a gear box that gives the driver a three to one ratio to reduce the amount of movement required to steer the vehicle. The new steering wheel includes an LCD display, which will display general vehicle running statistics such as vehicle speed, engine speed, throttle position and others. Also included on the steering wheel is a twist throttle, brake lever, and run, start and kill switches. The steering wheel is attached to a vertical shaft from the gear box positioned between the driver's legs.

3.0 Body/Chassis Design

3.1 General Overview

Changes made to this year's vehicle reflect the need for a more efficient and reliable overall design. Projects completed include the redesign of the rear uprights to add stiffness to the rear end, a custom rear hub that allows same side drive and a custom through axle, a new steering design that fits better in the cabin space and incorporates all of the driver controls into one area, and new mirrors to comply with **Rule B9.3**. The design process for each of these is described in the following sections.

3.2 Rear End

The rear uprights of the vehicle attach the rear wheel to the chassis. Any twisting or pulling loads on the uprights causes flexing that has negatively impacted the function of the vehicle. Flex in the mounts caused the rear tire to make contact with the body during cornering, resulting in multiple tire blowouts. This flexing also caused the chain to go out of alignment with the chain tensioner, resulting in downshifting on the cassette or the chain coming off.

Several designs were considered, including two completely new upright designs that would have involved removing the old structure. A better concept was developed that modified the existing structure. One issue negatively affecting the stiffness of the old design is that the clamping force which constrains the two uprights together at their ends comes only from the hub skewer clamp, which is not rigid enough to prevent the hub from shifting position within the slots in the uprights. The new design addressed this issue by adding bolt-down clamps to the existing structure at the end of the uprights. The hub axle will be held rigidly in place by the new pieces. This design change is being made along with a redesign of the rear wheel hub, which is described further in section 3.3. The new hub has a larger diameter through axle, which allows for greater clamping surface area. The final design concept is shown in Figure 2.

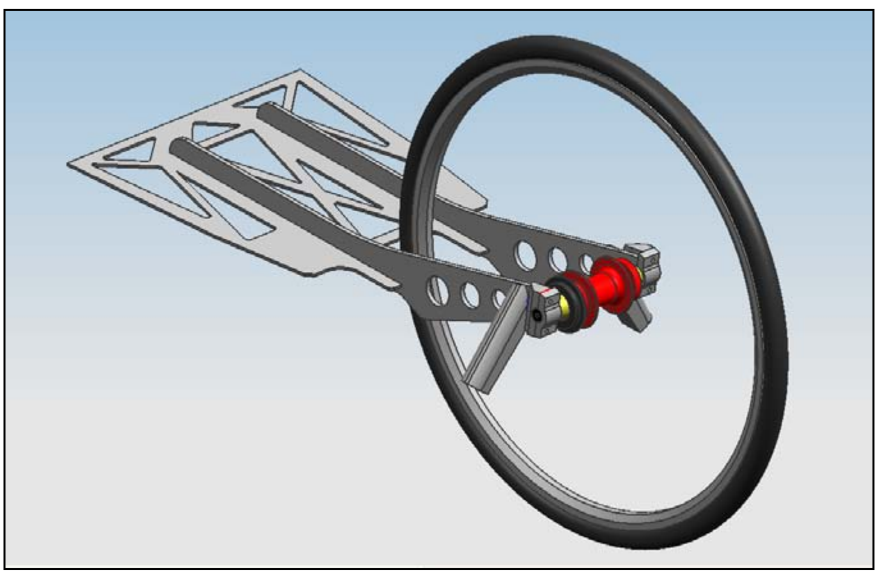


Figure 2: Rear Upright Design

The existing uprights were shortened, moving the wheel forward. This, along with the custom hub, helps with the desired same side drive and removal of the jackshaft between the engine and wheel sprocket. The through axle clamps were machined out of aluminum and welded to the uprights.

Stiffness testing was conducted on the old uprights and wheel. The results of this are shown in Figure 3. The slope of 1.178 kg/mm is the stiffness of the old design. The slope of 1.807 kg/mm is the stiffness of the old design when in the wheel is in contact with the body, which is an increase of 53% in stiffness. Carbon fiber tubes will be added, attaching the end of the rear uprights to the chassis to mimic this result. Further increases in stiffness will come from shortening the uprights and using a larger through axle. At the time of the publication of this report, the rear uprights have not been completed to begin testing to determine the increase in stiffness seen from the upgrades. Additional information on the rear end redesign can be found in Appendices A-4 and A-5.

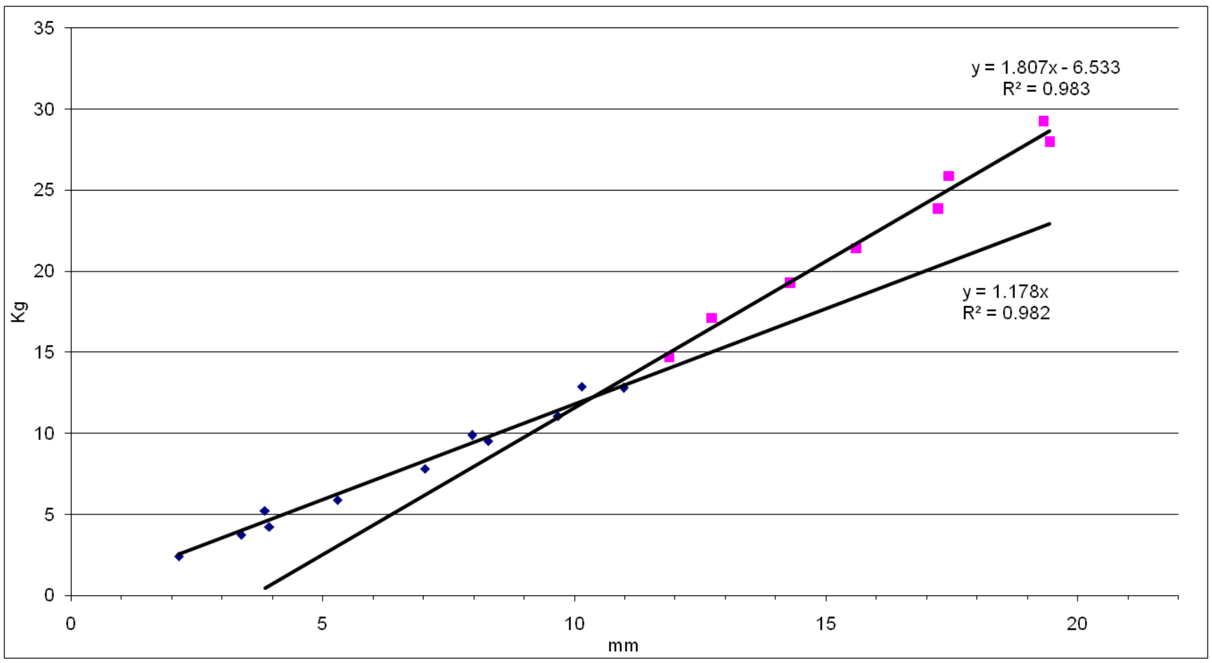


Figure 3: Rear Upright Stiffness Testing

3.3 Rear Hub

In an effort to increase driveline efficiency and reliability the decision was made to remove the jackshaft. However, the engine is designed for left hand drive and the old hub was designed for right hand drive. To solve this, a new hub was designed and manufactured. A custom hub allows for left hand drive as well as mounting of a right side braking system. It also allows for custom dimensions of the through axle.

The hub design was based on pre-existing designs. A view of the hub is shown in Figure 4. Since most bike hubs are designed to take loads far outside of the range expected on the vehicle, it is expected that the custom hub will be able to handle any loads experienced during testing or competition. The difference between the new hub and hubs currently manufactured is the drive side, and the ability to mount a disc brake. The custom hub also mounts to a non-standard sized through axle to increase stiffness of the rear uprights. A standard J-bent spoke/hub flange design was chosen over a more reliable but costly straight pull spoke design seen on high end bikes. This decision was made based on the cost, better availability of j-bent spokes, and the relative ease of machining a hub with spoke flanges that accept j-bent spokes.

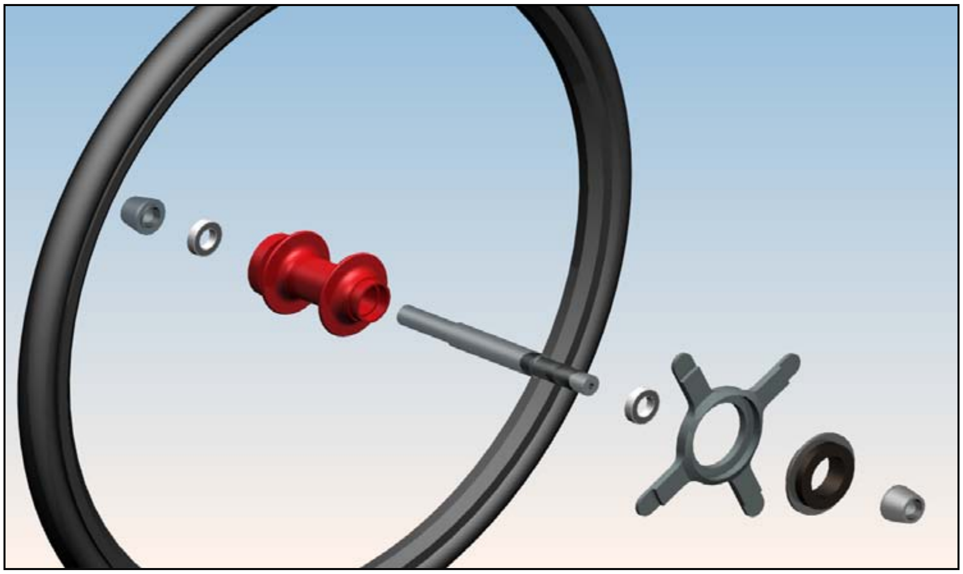


Figure 4: Rear Hub Assembly Exploded View

The hub is machined out of 6061 Aluminum, which is an industry standard for bike hub material. See Appendix A-6 through A-8 for further drawings and manufacturing process details.

3.4 Steering Design

Steering and driver control interface are critical to efficiently, comfortably, and safely driving the vehicle. The previous steering system had a slow response and had no integration of control features. The steering, throttle, brake, and kill switches were all separate components, making the handling of the vehicle difficult. A new steering system was designed to fix theses issues. The new design was built while trying to keep any play in the system to a minimum.

The new design was modeled after that of a motorcycle or scooter with all of the controls mounted on handle bars instead of a wheel. On the right side of the handle bars is a twist throttle and brake lever. The kill switches and starter are located on the left side of the handle bars. In the middle is a platform to mount the LCD that gives the driver information about the vehicle. A model of the new steering design on the left and the old design shown on the right is shown in Figure 5.

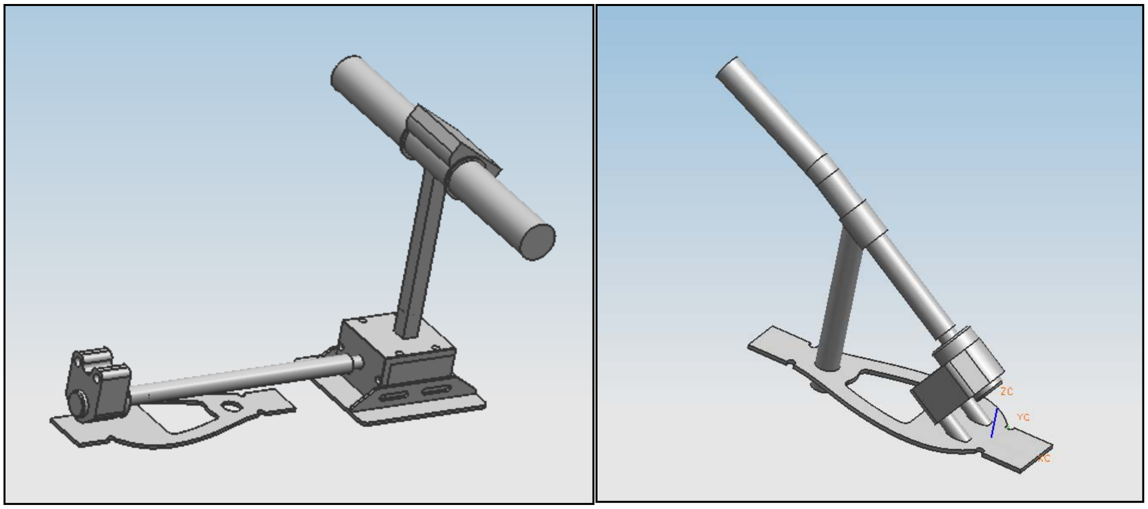


Figure 5: Steering Design Assembly New vs. Old

A gearbox was added that allows for a vertical steering column with a 90° turn to the rack and pinion. The gearbox inverts the steering direction, so the rack and pinion was also inverted to keep the turning intuitive (**Rule B1.5.2**). An exploded view of the gearbox is shown in Figure 6. The gears are straight tooth precision bevel gears with a 3:1 ratio. There is limited room for movement in the vehicle cabin, and the ratio will allow for a large response only a small turn to the steering is applied. The original design required a full 360 degrees to turn between the two ends of the rack and pinion. The redesign reduces this to 120 degrees. The gearbox is mounted to a plate that is bolted to the chassis. The mounts have room to allow the gearbox to move forward to accommodate different drivers. The box mount is being mounted directly to the chassis also adds stability to the system.

The gearbox handlebars, rack mount, and box mount are machined out of aluminum. The shafts inside of the box are machined from steel with the drive shafts made out of carbon fiber. Making them out of carbon fiber allows them to be permanently attached to the output shaft without welding. They are also very light and strong.

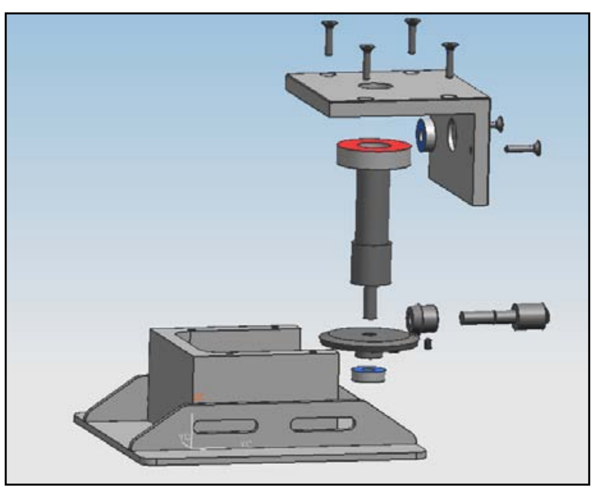


Figure 6: Steering Gear Box Assembly Exploded View

3.5 Mirrors

The mirrors on the vehicle have been redesigned due to a change in rules. The new rules, **B9.5.3**, **B9.5.4**, and **B9.5.5**, state that the mirrors must be adjustable by the driver in the normal driving position, while still adhering to the rule from the previous completion.

The new design is shown in Figure 7. This design uses ball joints to allow the driver to rotate the shafts that the mirror is mounted to. Using the ball joint gives full rotation parallel to the shafts, while giving some rotation perpendicular. In the joint is a set screw that can be adjusted by the driver, making the mirror setup ridged when driving the car, but can be easily adjusted if the mirror was to be dislodged from its correct position.

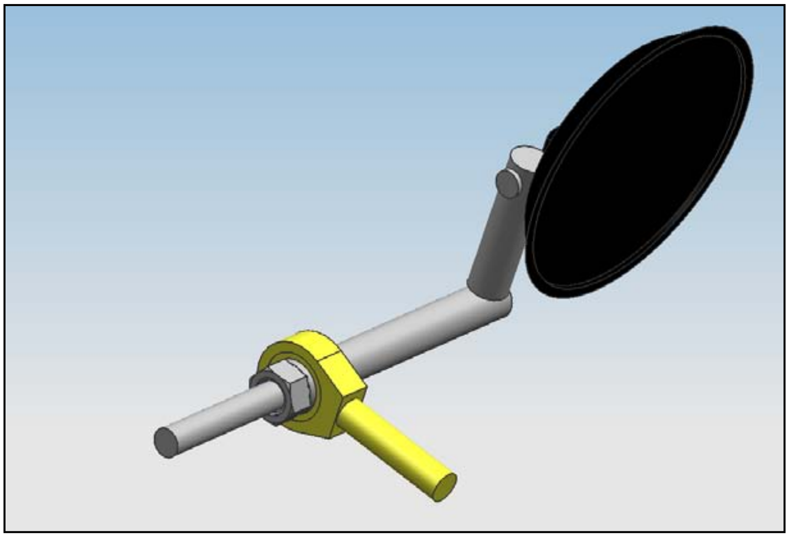


Figure 7: Mirror Design Assembly

3.6 Braking

The same basic braking system as last year is being used on the vehicle. This is a mountain bike disk brake that is connected to a brake lever in the cab of the car. Calculations were made to determine the coefficient of friction needed to stop the car using only a rear brake. The necessary coefficient of friction was found to be 0.825 which is less that the assumed coefficient of static friction (1.09). Calculations made can be seen in Appendix A-9 through A-14.

This year's vehicle still only has a rear disk brake with a large rotor to get the maximum braking force. In order to have same side drive from the engine, the brake was moved to the other side of the car on the custom rear hub. The brake calipers were placed upside down under the wheel mounts to make the best use of space.

3.7 Shell and Aerodynamics

The overall body of the car was completed before the competition 2010. It was redesigned from the car used in the previous two competitions. A computational fluid dynamics (CFD) analysis of the air flow around the vehicle was completed in Fluent®. Drag on the vehicle is caused by air pushing and flowing over it. The air was modeled in Unigraphics®, and meshing and analysis performed on half of the model due to symmetry in geometry and boundary conditions. The air was modeled as a rectangle with dimensions ten times that of the cord length of the vehicle, in every direction. The bottom face of the air rectangle was dimensioned six inches from the bottom surface of the car, to account for ground effects caused by the road. These dimensions insured that the boundaries of the modeled air did not inhibit the pattern of air flowing over the vehicle. Once the rectangular air volume was modeled, the geometry of the vehicle was removed, and this subtraction created a void in the air that served as the shell of the vehicle, over which the air must flow. Gambit® was used to created a volume mesh in the air and create the boundary conditions of the analysis. The boundary conditions that were applied to the model were wall, symmetry, velocity-inlet and pressure-outlet.

The CFD analysis (Found in Appendix A-15 through A-20) found that a force of 1.39 N will be applied to the vehicle at 15 miles per hour, using this drag force the drag coefficient was found using Equation 1. The vehicle has a frontal surface area of 0.2373 m^2 and a drag coefficient of 0.22. The modeled flow of air over the vehicle is shown in Figure 8.

Equation 1

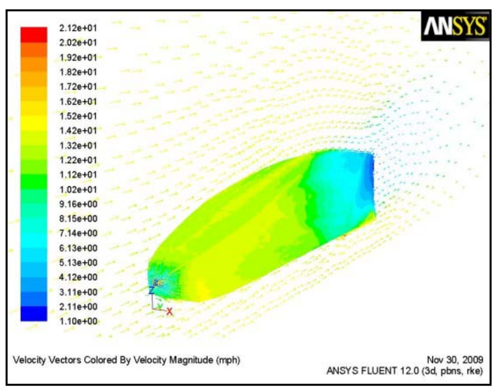


Figure 8: CFD analysis on vehicle

The model used is nearly an ideal model. The vehicle has several features that will increase the drag force acting on it. The body surface is not completely smooth, and the front wheels are exposed on both sides of the vehicle. The new mirrors will also increase drag. They are mounted about halfway back and halfway up the vehicle near where the driver sites and will be sticking out on both sides.

4.0 Engine

4.1 General Overview

This year, the primary goal of the Power Train Team was to produce a more reliable and more functional engine than last year's vehicle while maintaining a similar overall set up. It was decided that the continuation of the overhead valve-train Honda project that was started last year would be delayed due to time constraints that would not allow the project to continue at this time. Several system level engine components were changed this year, all of which were found to be problem areas in the past.

The ignition module mount was redesigned to increase rigidity over previous designs for more reliable ignition timing. The throttle body was redesigned to eliminate air leaks and improve reliability. A new exhaust was researched and designed because it was seen as an area for possible improvement over the existing bent straight pipe design. The fuel system was redesigned with new components due to a leaky system that was used previously. All engine modifications were made this year with careful consideration to produce measureable improvements in engine performance and reliability which can be verified either with dynamometer testing or though on track vehicle testing.

4.2 Ignition Module Mount

This year's vehicle features a new ignition module mount that shows an improvement in estimated rigidity over last year's design of over 620%. This improvement was deemed as a necessary upgrade as the previous design experienced significant issues with flexing and vibration while the engine was running. Several design concepts (found in Appendices B-1 and B-2) were analyzed through both finite element analysis, as seen in figure 9 to determine deflection under loading and thermal analysis to determine the effects of thermal expansion that a steel part mounted to an aluminum part would experience. The frequency response of the part was also taken into consideration to determine the effects of the engine's vibrations on the bracket (see Appendix B-6)

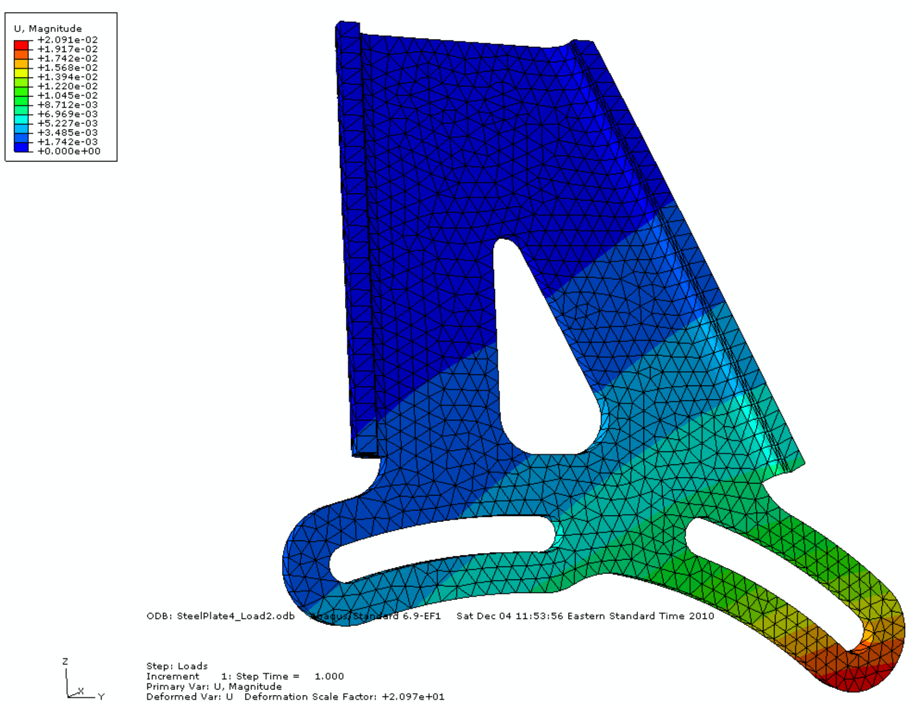


Figure 9: FEA Analysis on Ignition Mount. Refer to Appendix B-3 through B-5 for more details on FEA of this part

The final design of the mount was to meet all of the desired objectives of increased rigidity, minimal increase in weight, maintained adjustability, minimal size increase and high machineability. All objectives were fulfilled with exception to the weight objective. The objective was to increase the weight of the part by 2 oz. or less. The final part resulted in a 4.9 oz. increase in weight over last year's design. This extra weight was found acceptable as no other designs were found to provide equivalent rigidity with less weight increase.

The mount was designed using Unigraphics® NX 5.0 and manufactured by cutting the part out of 1/8 inch steel plate using a plasma cutting table. The design features slotted mounts which allow for 20 degrees of adjustment to ignition timing. In order to improve rigidity, two tabs were added to the design which were bent at a 90 degree angle using a brake. In order to avoid failure due to thermal expansion from mounting a steel part directly to the aluminum cylinder head using the head bolts, the steel part was mounted to an already existing aluminum block from the previous design which is mounted by the head bolts to the cylinder head. In this manner, the stress due to thermal expansion is concentrated in the steel mount and the aluminum block rather than being transmitted to the head.

4.3 Throttle Body

A new throttle body was designed to replace the previously used ball valve design which leaked at low throttle positions. A new throttle body was cast of 300 series aluminum using a 3D printed mold that was created using ZCast® 501 Direct Metal Casting System. The new design utilizes a butterfly valve from a stock Briggs and Stratton carburetor. The design also provides a mounting surface for the existing stepper motor used for electronic throttle control. Appendix B-7 through B-9 show detailed models of different aspects of the throttle body design.

4.4 Exhaust

This year a new exhaust system has been designed for the engine. The exhaust has been developed using two methods of reducing reversion of exhaust gasses during the overlap of the exhaust and intake strokes of the engine cycle. The exhaust has a tuned length of approximately 21 inches, determined from hand calculations which can be found in Appendices B-10 and B-11. This length is tuned to cause the pressure at the exhaust port to be the lowest at the time of the valve closing. The other new feature to the exhaust is the incorporation of an anti-reversion chamber. This new chamber features a small expansion of the primary exhaust pipe approximately 7 inches from the exhaust port. Figure 10 illustrates the design of such a chamber. This design has been used recently in many performance exhaust headers to prevent reversion of exhaust gasses. This chamber creates a pocket in the exhaust which is to prevent returning pressure waves from returning to the cylinder. While this design has been proven to improve performance on many naturally aspirated racing applications and is in use in header design by a select few companies such as HY-TECH Performance, it is not certain if it will have an impact on as small an engine as the one in use. At the time of publication of this report, testing has not yet been performed using the new exhaust design. The results of testing will determine whether the exhaust will be used on the competition vehicle.

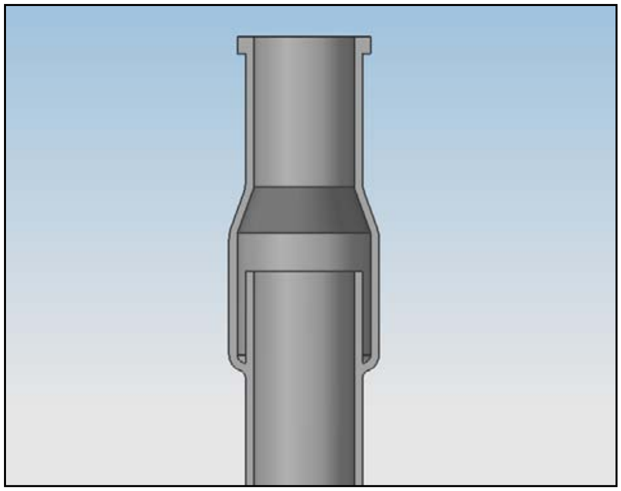


Figure 10: Exhaust Anti Reversion Chamber Design

4.5 Electronic Fuel Injection System (EFI)

Electronic Fuel Injection (EFI) allows for precise control in adjusting engine performance parameters such as power density, fuel efficiency, and emissions. Through proper set up and testing, EFI offers numerous improvements over a carbureted engine. While EFI relies on many of the same inputs as carburetion, the EFI's control system is able to respond in a more dynamic manner as opposed to the linear relations between inputs and outputs used by carburetion. EFI allows tuning for best performance at several operating points. Air flow into the engine is measured by a Manifold Absolute Pressure sensor (MAP) and a Throttle Position Sensor (TPS). From this information, the correct amount of fuel is determined and injected into the intake. This system eliminates the restrictive Venturi found in carburetors. This year the EFI system has been modified in several ways to make the engine more efficient and reliable. These changes include the selection of a proper fuel injector, the manufacturing of an improved fuel injector port with optimized spray angle, and modifications to the fuel delivery system.

4.5.1 Fuel Injector Selection

To improve efficiency of the EFI system, a proper fuel injector was needed that met certain specifications. One of the specifications it had to meet was the flow rate. Each fuel injector considered for use in the vehicle was sent out to RC Engineering to determine its flow rate in cc/min. So far two fuel injectors have been tested, the Bosch injector and the Honda injector. Their flow rates are 105 cc/min and 125 cc/min, respectively, at a pressure of 43.5 psi. The calculated fuel flow rates are 21 cc/min, so both of these injectors satisfy our requirements (see Appendix B-12). We plan to test each injector on our engine to see which one gives us better efficiency.

4.5.2 Fuel Injector Mount

A new port was then made to hold the fuel injector in the correct position. The new fuel injector port refocuses where the injector spray on the valves, allowing for increased efficiency. The previous design held the injector at an angle that sprayed fuel away from the intake valve. This was corrected with the new port, which sprays fuel directly onto the valve head. This allows the intake system to atomize the fuel more efficiently without wasting a significant amount of energy. The port design also took into account the flow rate of the injector. Since a final fuel injector has not yet been chosen, the port was designed to hold both the Bosch and Honda fuel injectors. Research on injector placement can be seen in Appendix B-13 through B-22.

The new injector port was then coded and machined on the HAAS, a CNC machining center. This allowed us to keep the machining time down while producing a highly precise part. The port was machined out of 6061 aluminum due to its availability, lightweight, and satisfactory strength properties for our application.

It was essential that the fuel injector mounted to the port securely while still being easy to remove and install. This was accomplished by mounting the fuel injector with a cap held in place with three screws. This allows for proper force to be put on the fuel injector to keep it sealed and in place resulting in no fuel leaks. The risk of fuel leaks at the injector were further minimized by tolerancing the injector port per the o-ring tolerancing guide (see Appendix B-23 through B-27) The port is then attached with two TORX head bolts, making it easy to remove and install on the engine. For a full assembly view see Appendices B-28 and B-29.

4.5.3 Other Fuel System Components

Fuel delivery was improved from previous years, with more focus on creating a reliable, leak free system. The major design changes include a change in fuel line hose and use of brass barbed fittings with hose clamps, while minimizing the amount of fuel line used. This will result in a compact, reliable system. The tubing used will be suitable for our fuel pressure to comply with **Rule B4.3**. A pressure gauge is also incorporated into the system in compliance with **Rule B4.5**. A fuel filter is also incorporated in the system. A schematic of the fuel system can be seen in Appendix B-30.

4.6 Engine Machining and Preparation

Over the past three years, the same engine has been used by Michigan Tech's Supermileage team. In addition to the number of hours accumulated on the engine, several changes and modifications have been made, many with limited or no documentation. As a result, this year the Power Train Team decided to start with the brand new engine supplied by SAE, establish a performance baseline on the dynamometer, and then replicate and document all critical engine modifications that had been incorporated in previous years. A reverse engineering approach was used for this; with many new team members on the Power Train Team, it served as a valuable learning experience to understand first-hand what modifications were made, and why.

This method of checking for changes ended up working exactly to plan and the team was able to find numerous changes to the engine. All of the modifications to the stock engine, besides removing hardware, were machining operations to the existing crankcase.

The first operation was to machine off the bosses from the cylinder wall that hold the stock Briggs ignition module in place. After that operation a second milling operation was completed that removed two extending bosses from underneath the stock flywheel and existing grooves that ran underneath the flywheel from each boss in a semicircular pattern.

Once the engine was assembled the flywheel was mounted onto the crankshaft and it was discovered that a machining operation was done to the crankshaft bearing housing to allow clearance for the custom flywheel. Without machining down the bearing housing, when tightened onto the crankshaft, the housing would interfere with the flywheel and prevent the engine from operating Since the housing was being machined the inner pocket needed to be bored out as well so that the bearing could seat properly.

Photographic documentation of the engine machining operations can be found in Appendix B-31 through B-33.

Once the flywheel fit on the crank properly, the cooling fins on the flywheel side of the engine were removed so that the ignition module bracket could be mounted properly.

The next operation was to remove a protruding boss off the cylinder head by first cutting it on the band saw and then finishing with a grinding operation.

To properly mount the starter two holes were drilled into the crankcase and bolts were threaded through. This allowed the starter to be mated with the crankcase without the need of a cantilevered mounting system used on previous versions of the competition engine. This new mount plate provides a more rigid surface for the starter, which is important due to the high torques created by the starter when cranking the engine on startup.

5.0 Drive Train Configuration

5.1 General Overview

In the previous design, the transmission was designed to accommodate shifting through the use of a bicycle derailleur and rear cassette. This required a jack shaft to reduce the gear ratio and transfer the chain drive from the right side of the engine to the left side of the rear wheel. This year's drive train eliminates the need for a jack shaft and chain tensioner through the introduction of a single side drive configuration. The decision to convert the vehicle to a single side drive line was made to increase reliability and durability of the vehicle's drive train. With the elimination of the jack shaft and chain tensioner, the majority of the play in the system from the previous design will be eliminated, resulting in a more reliable overall system. This also resulted in a weight loss of nearly three pounds from the overall vehicle weight. To achieve a single side drive, the rear end (section 3.2) and rear hub (section 3.3) were redesigned. A new single gear ratio will be calculated which will eliminate the need of the intermediate jack shaft for gear reduction. This new gear will be used in place of the cassette and will not require the use of a chain tensioner, as chain tension will be adjusted with a slotted engine plate.

5.2 Transmission and Gearing

A simple model was developed using the MATLAB® programming language to simulate the operation of various transmission designs. The model incorporates an estimated engine performance table including power, BSFC, and engine speed drawn from an engine simulation in GT Power. The model neglects aerodynamic drag and rolling resistance, focusing on the energy required to accelerate the mass of the vehicle from a given minimum to a given maximum speed. Various versions of the model simulate idealized 1, 2, and 3 speed transmissions as well as an ideal CVT. For each, the simulation indicates the optimal gear ratio(s) for a given vehicle mass and engine parameters.

For this year's competition, the team decided to return to a single-ratio drive system until problems with last year's multi-ratio system, such as unintended shifting and creep in the jack shaft mount, can be worked out. The team plans to use fuel consumption and power data obtained from its engine dynamometer, which is not yet available at the time of the publication of this report, to improve the model and select a gear ratio for use at competition. An example output of the model accelerating from zero to fifteen miles per hour using GT-Power engine data is shown in figure 11.

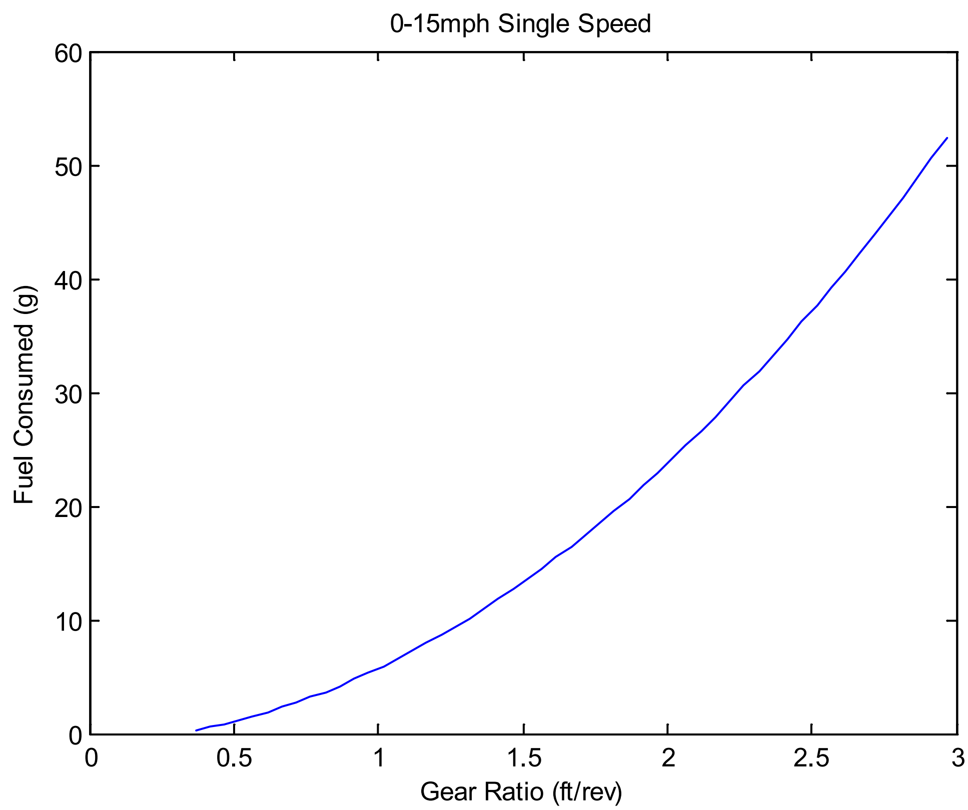


Figure 11: Transmission Model 0-15 mph Acceleration. Gear Ratio vs. Fuel Consumption

6.0 Electrical Systems

6.1 General Overview

The goal of the Electrical team for this year was to provide a stable, fully functioning electrical system for the vehicle. In order to achieve this goal, the team created a new circuit board to simplify the electrical box. Furthermore the team has added a new LCD along with a twist throttle to allow the driver to have more control over the vehicle. To aid in updating the wiring of the vehicle, the previous year's wiring diagram (see Appendix C-1) has been updated to include the various additional features of this year's vehicle.

6.2 Driver Controls

This year's vehicle includes two new driver controls: a new LCD and a new throttle. Along with the two main additions, kill switches and the starter button were mounted closer to the driver for ease of access.

6.2.1 LCD Display

A new LCD (see Appendix C-5) was purchased for use on the vehicle this year. The LCD screen has a blue background with white letters for easy visibility in direct sunlight. The LCD screen will display valuable information for the driver such as vehicle speed and recommendations of when to turn the engine on and off (this recommendation is computed through speed and position on the track). It is mounted on the steering column in plain view for the driver.

6.2.2 Throttle

Implementing a new driver throttle control was necessary to ensure safe driving. New to the vehicle is a scooter type twist throttle for throttle by wire. Previously the throttle was a very small joystick; when comparing the new twist throttle to the old joystick, the twist throttle out performs on many levels. It allows the driver to control the vehicle with minimum training. Furthermore with a larger range of motion the twist throttle makes it easier for the driver to maintain control of the vehicle. The throttle requires positive 5 volts and it is mounted on the right hand side of the new steering mechanism. The throttle is designed with the driver in mind, allowing ease of use and comfort.

6.2.3 Driver Interface Controls

Along with the LCD, kill switches and engine start have been mounted on the steering assembly. These kill switches include main kill and engine kill. The switches are single pole, double throw with coverings over them so as not to allow accidental flipping. When comparing to previous designs, the placement of the kill switches and starter switches are much easier for the driver to use. The driver doesn't need to take their hands off of the handlebars to kill/start or control the vehicle.

6.3 Electrical Box

Situated under the driver is the electrical box. The electrical box contains the 1.4 Ah battery, MegaSquirt® II EFI system, M100 Microcontroller and a printed circuit board (PCB). New to the vehicle this year is an updated version of the printed circuit board. Features of the PCB are the inclusion of an inversion chip for the starter; previous designs had the inversion chip as a separate board. The PCB is designed to take 12V and step down the voltage to 7 and 5 volts for use of equipment. This equipment includes stepper motor, starter, GPS, LCD etc. In accordance with **Rule B.5.4** two 5 amp fuses are implemented on the PCB. The main purpose of the step down board is to provide a source of power for the vehicle's components but it is also used for conversion of data via MOSFET for the M100 as described below.

6.4 GPS

A GPS receiver, the ETEK EB-85A (see Appendix C-11), will be incorporated into the electrical systems. The primary intent of this receiver will be to provide the driver with information about the velocity of the vehicle and allow the driver to make an informed decision on when to start/stop the engine. The information from the GPS will be filtered through the M100 (described below) and displayed on the LCD display.

6.5 M100

The Pi Shurlok™ M100 (see Appendix C-13) microcontroller has provided the team with a reliable and customizable way of managing control and auxiliary functions of the vehicle. As in previous years, the microcontroller is responsible for interacting with various components: Input from driver throttle, GPS, and a number of switches and buttons, as well as output to an LCD monitor, the engine ignition, stepper motor for engine throttling, and status lights. The primary functionality goals have not changed from previous years; however, the design and implementation has undergone a significant rework. As new functionality was needed in previous years, it was haphazardly injected anywhere the coder felt would work. This caused overly-dependent parts that were not easy to troubleshoot or modify. This year, a major focus has been placed on producing readable, well-documented, and modifiable code.

Due to a change in the rules (**Rule B5.6.8**) automatic control of the engine has been removed. The primary logic for this feature has been kept intact, but instead of starting and stopping the engine, the driver is notified of a recommendation to turn the engine on or off, either via an LED which turns on and off or via the LCD screen. In this way, the previous work is not lost, and the driver maintains full control of the vehicle.

6.6 Arduino Uno

As a backup solution to the M100 microcontroller, the electrical team has researched various backup controllers. An Arduino Uno (see Appendix C-19) was purchased for development as a backup solution to the M100, as it has been determined to meet our needs. The microcontroller core on the Uno is an ATmega328. This controller operates at a frequency of 16 MHz, which is slower than the M100 which operates at 24 MHZ but still sufficient to suit our needs. There are 14 digital I/O pins and 6 analog pins as well as a pair of pins which may be used for TTL serial communication. Due to the fact that the Arduino Uno is a hobbyist’s board, it provides some very intuitive libraries, allowing rapid development of many of the essential vehicle functions. One major pitfall is that the Uno is not capable of communicating via the Common Automotive Network (CAN). CAN communication would allow for communication with the MegaSquirt® controller that controls the engine. To solve this issue of the Uno not being able to communicate via CAN, a possible future project of a CAN-Bus shield can be developed to allow for communication with the MegaSquirt® II controller. Doing this will allow for the team to acquire real-time engine information.

6.7 Megasquirt II (MSII) Fuel Injection System

This year the team continues to use the MSII ECU, by Bowling and Grippo, to control fuel injection. It has proved to be a reliable controller over the years and the team has not found a controller that can offer the features, flexibility, and support of the MSII for the price. The MSII controller uses a variety of sensors to determine the proper amount of fuel needed based on the mass of air entering the engine cylinder during each cycle (see Table 1).

Table 1: MSII Sensors

Sensor Type	Details
Intake Air Temperature (IAT)	Standard automotive style. Placed before throttle body for less restriction on air flow.
Manifold Absolute Pressure (MAP)	Plumed to intake manifold on the MSII ECU.
Throttle Position Sensor (TPS)	Monitors throttle blade angle. 10K Ohm single turn potentiometer, coupled to throttle shaft. Rapid change in angular displacement will lengthen injector pulse. Functions as an accelerator pump on a carburetor. Also used in Dyno testing.
Coolant Temperature	Detects temperature of engine oil. Starting and warm-up fuel enrichment are altered accordingly. Mounted within one oil cap.
Speed Encoder	Allows MSII to time injections based on crankshaft angular position. 24 tooth encoder wheel mounted on flywheel.
Wide-Band Oxygen (O_2) Sensor	Determines the exhaust gas composition and indicates how much the fuel-air charge was rich or lean. Used to tune the fuel map across the engine operating range.

7.0 Performance

7.1 Vehicle Testing

Vehicle testing was used to acquire fuel efficiency data of the complete vehicle. Vehicle testing was conducted with a carbureted engine. As of the publication of this report, EFI testing has not been completed. The data found during carbureted testing will be used as baseline data which will provide a standard to measure future modifications added to the vehicle. Testing also provided valuable driver training and highlight any reliability issues with the vehicle.

7.1.1 Carburetor Testing

Testing was conducted on Michigan Technological University's ¼ mile running track that surrounds the football field. Each test run utilized the 'burn and coast' method to simulate the driving style used during competition. Since this track is significantly smaller than the track driven at competition it was not possible to safely attain the same speeds we usually see at competition. Practice laps were taken to let the driver get a feel for the highest speed they were comfortable driving on the track. Speed was measured using a bike speedometer calibrated to the vehicle, and the fuel usage was measured by replacing the fuel bottle with a buret.

Before each test run a visual inspection of all drive train, steering, braking and electrical components was conducted, as well as a test of all kill switches to ensure the safety of the driver and a successful test run. Originally one fuel consumption run was defined as twelve (12) full laps (3 miles) around the track, whereby the driver would accelerate to the safest obtainable speed, kill the engine and coast down to 7mph for each 'burn and coast'. This plan was modified slightly due to limitations of the vehicle and driver, such as not being able to kill the engine during cornering since killing the engine required the driver to take their hands off the steering wheel. There were also several failures including the tire rubbing and blowing out. The fuel mileage results as well as the reliability and failures experienced during testing contributed significantly to the design changes made to the vehicle.

The fuel mileage results are shown in Table 2. Using the carburetor the average mileage was 395 mpg. There is a significant difference between several of the test runs; this is likely due the different run lengths. The vehicle uses a large amount of fuel to begin moving and the efficiency increases as the length of the runs increased.

Table 2: Fuel Efficiency Testing, Carburetor Setup

Carb Testing				
Date	Laps	Miles	Fuel used (ml)	MPG
11/7/2010	3	0.75	8.58	332.2
	5.5	1.375	11.6	450.4
	3	0.75	7.22	394.7
11/12/2010	5	1.25	14.63	324.7
	6	1.5	13.7	416.1
	8	2	17.4	436.8
	8	2	18.57	409.3
Avarage	5.5	1.4	13.1	394.9

7.1.2 EFI Testing

As of the time of the publication of this report, the state of the vehicle as well as the weather has not allowed for vehicle testing using an EFI system. The team plans to conduct EFI vehicle testing with the same procedures used with carbureted vehicle testing to produce comparable results.

7.2 Dynamometer Testing

Dynamometer testing was completed on this year's competition engine to provide fuel consumption and horsepower data at various engine speeds, resistance loads, and throttle positions. Dynamometer testing provides a repeatable and quantitative means for evaluating engine changes and modifications.

Throttle position was controlled using a manual throttle cable with a notched control with 6 throttle positions varying from idle to wide open throttle. The load induced on the engine was controlled with an electrical load bank which varied from 0% to 100% load and could be controlled using a MATLAB® program on a computer. Power output of the engine is measured by the electrical resistance bank and recorded by the computer into a CSV file, which is later formatted into a table form. Engine speed is measured using an optical sensor on the engine that sends data to the MegaSquirt® unit. Engine speed can also be measured using the resistance bank when testing a carbureted set up. This outputs the engine speed in a CSV file similar to the power output data. Fuel consumption was measured using the same buret system that was used during vehicle testing and calculated as the amount consumed over a recorded time length.

7.2.1 Carburetor Testing

Dynamometer testing was conducted on a carbureted engine using the stock Briggs carburetor to provide a comparative base line for subsequent engine modifications. Through testing, the highest fuel efficiency of the carbureted engine was found to be at 60% load and wide open throttle. Test results were compiled into a three dimensional graph which represented fuel efficiency as a function of power output, throttle position, and engine load. This graph can be seen in figure 12.

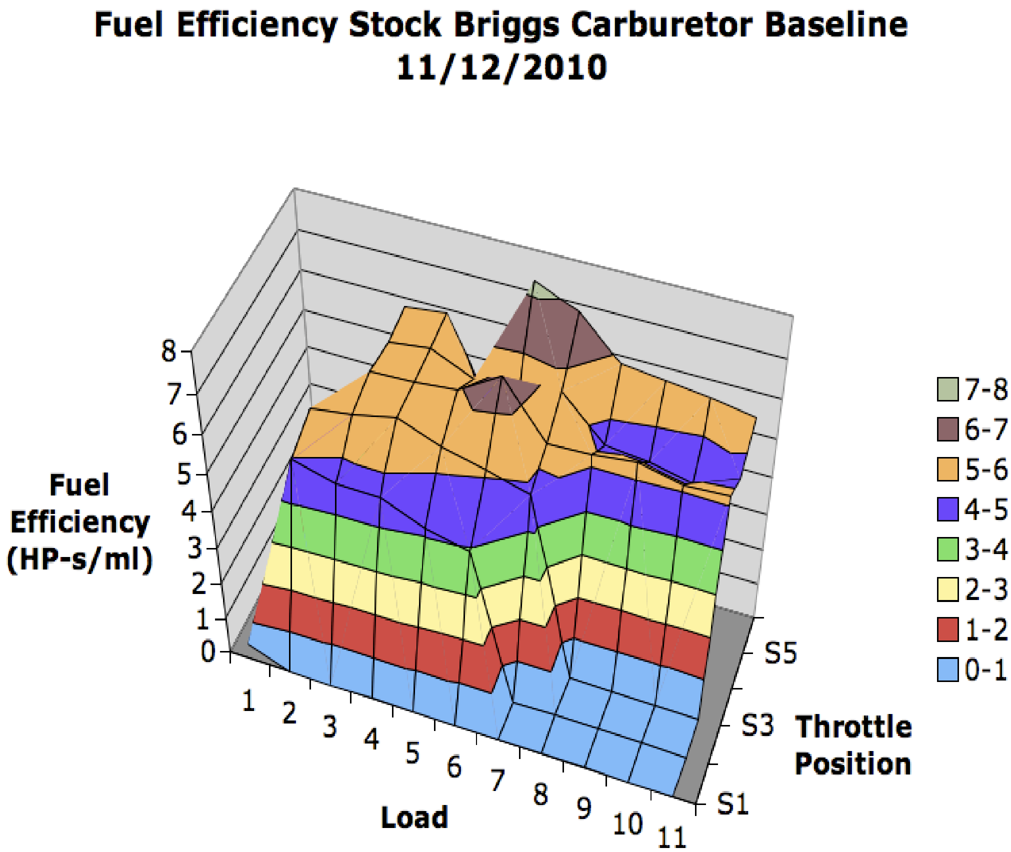


Figure 12: Fuel Efficiency Stock Briggs Carburetor Baseline

7.2.2 EFI Testing Plan

As of the time this report was written, the team has been unable to complete dynamometer testing on a working engine with an EFI system installed. Assuming ample time will be available once the engine is working, a testing plan has been devised to acquire measureable results showing improvement and allow for proper engine tuning.

The MegaSquirt® fuel map will be tuned using newly purchased TunerStudio software. TunerStudio has an auto-tune feature which will tune the fuel map while the engine is running to optimize fuel consumption throughout the entire range of engine speeds and intake manifold pressures that the engine is capable of running.

EFI Dynamometer Testing Plan:

- Baseline EFI System – A baseline will be collected using the same procedure as was used previously to obtain a baseline of carbureted engine data.
- Perform EFI Tuning – Using collected data; the system will be tuned to obtain the best efficiency by adjusting the system's air/fuel ratio, ignition timing, and fuel map.
- Ram Air Testing – Air will be forced into the intake at air speeds seen during competition to determine if ram air should be implemented for future designs.
- Removed Cooling Fin Testing – An engine will have the cooling fins found on a stock Briggs engine completely removed by machining. This will be tested to see if the change in thermal efficiency will positively or negatively affect overall engine performance.
- Spark Plug Testing – The team has ordered a new E3 Spark plug, which will be tested to determine if any efficiency gains are seen over tradition spark plugs.
- Exhaust Testing – The new exhaust will be tested in comparison to older exhaust designs to determine the effects on overall engine performance.

8.0 Cost Estimate and Manufacturing Methods

Supermileage Systems Enterprise (SSE) has access to a full machine shop, through Michigan Tech's Enterprise Program. The Enterprise shop includes a multitude of tools that students utilize, with proper supervision and training. These tools include three Bridgeport Manual Mills, a Haas CNC Mill, three Manual and one CNC Lathe, a plasma table, a Tube Bender, a Brake Press, and a welding area. The team has also utilized Michigan Technological University's foundry, separate from the Enterprise shop, to produce cast parts.

SSE receives generous in-kind and cash donations from various sponsors listed on the opening pages. Throughout the project, the team has kept records of the time and cost associated with completing the vehicle in a timely manner to meet individual team budget and timeline constraints.

The total budget spent preparing for this year's competition amounts to approximately $2823. This budget can be broken down into three basic sections; tools and equipment totaling $287.99, materials and parts (including estimated value of donated stock) totaling $1574.38 (This excludes the cost of carbon fiber resin and hardener that was purchased totaling $1634.92 but was not used), and organizational costs totaling $959.97. Breakdowns of team budgets can be seen in Appendix D-1 to D-7. The total time spent designing and building this year's vehicle (including professional labor) has been estimated to be around 2,400 hours. At a rate of $15/hour the cost of labor comes out to be around $36,000. This brings the total amount spent this year to $38823. Last year, approximately $4000 worth of materials was used in construction of the current body chassis and approximately 1400 hours of labor were put into parts that were reused on this year's vehicle. This adds $25000 to the total cost of the vehicle in parts that were reused. Including the cost of parts and labor that were reused from previous years, the total cost for the vehicle comes to $63823.

9.0 Driver Safety

Driver safety was a governing factor in the design of every part of the vehicle design. Our team was careful to consider all rules concerning driver's safety, as well as situations that were not covered (see

Table 3). Note that this is not an all inclusive list as additional features are outlined in other sections of the report.

Table 3: Vehicle Safety Features

Safety Item	Purpose	Rule Met		Safety Item	Purpose	Rule Met
Seat Belt	*3pt design to securely keep driver in car*	B8.1		*Roll Bar*	*To keep the ground 2" from driver head during rollover*	B6.1
Firewall	*Separates driver from possible fire in engine compartment*	B6.4		*Body mounting*	*Quick exit and access by/to driver in emergency*	B6.5
Fire Extinguisher	*Mounted to firewall. Sprays directly onto engine at drivers will*	B9.1		*Steering*	*Steering interface movement turns car in correct direction*	B1.5.2
Engine Guards	*Keeps limbs, fuel system from moving engine parts*	B2.6		*Stability*	lateral stability, slalom course maneuverability	B1.6
Helmet	Well-fitting helmet; Snell M2000, SA2000, or British Standards	B8.5.1		*Brake light*	*Separate from kill switches, bright enough to be seen in daylight.*	B7.4
Team Communication	*Driver can radio team in case of emergency*	B5.5		*Fuel System*	Fuel bottle mounted vertically to avoid fuel leakage	B3.2
Automatic Engine Starting Prohibited	*Electric start can only be initiated by the driver*	B5.6.8		*Mirrors*	Mirrors adjustable by driver while seated in vehicle	B9.3.5

10.0 Research and Future Designs

10.1 Body/Chassis Team

10.1.1 FEA on Composites

Research was conducted into the use of Altair® Hyperworks® for conducting finite element analysis (FEA) on composite structures. Hyperworks® is a complex tool capable of meshing, performing simulations using a number of available solvers, and other tasks (See figure 13). The focus of this year's research was becoming familiar with the meshing and loading simulation functions of the software. Two chassis team members received training during a workshop conducted by an Altair® representative.

In the future, the chassis team hopes to use Hyperworks® to optimize the structure of the chassis. Determining the areas of maximum stress concentration will allow the team to add structure where necessary. Reduction of carbon layers and foam thickness in other areas will allow our team to reduce vehicle weight.

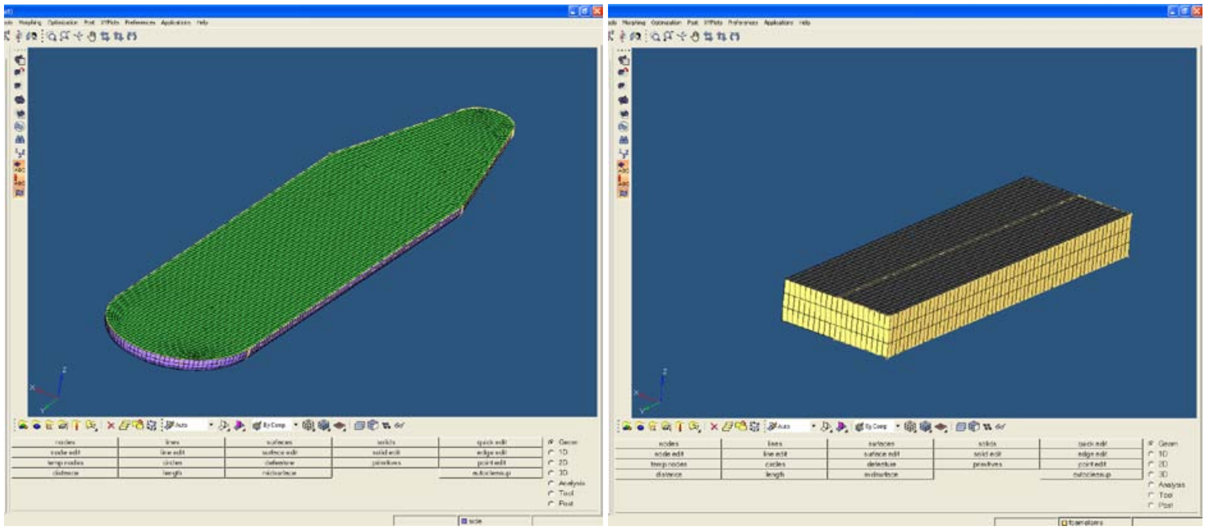


Figure 13: Meshed models of I-beam structure and rough chassis form

10.2 Power Train Team

Future plans of the Power Train team involve extensive research on several engine technologies to determine the merits relative to increased fuel efficiency. Such technologies include:

- Forced induction – Currently being implemented by Mahle North America for means of fuel economy. The team is highly interested in discovering the use of turbochargers and electric centrifugal compressors in a high fuel efficiency situation.
- High Compression – The team wants to research and find the optimum compression ratio needed to make to most efficient use of the higher octane fuel that is used in competition.
- Shaved cooling fins – Suggested by Mahle North America to improve the thermal efficiency of the engine. Testing will be conducted to prove the benefits of this before implementation.
- Direct Injection – This is where the fuel injector is placed such that it sprays directly into the combustion chamber as opposed to into the intake air stream or intake port. This should improve fuel efficiency and allow for a use of a much more lean fuel map.
- Overhead valve train – Last year's Honda overhead cam engine has currently been put on hold. The team plans to keep this option open in the future as it would provide much better engine tuning options.
- Variable Valve Timing/Lift – A working system would provide optimum fuel efficiency with different valve timing for both low and high rpm situations.

10.3 Electrical Team

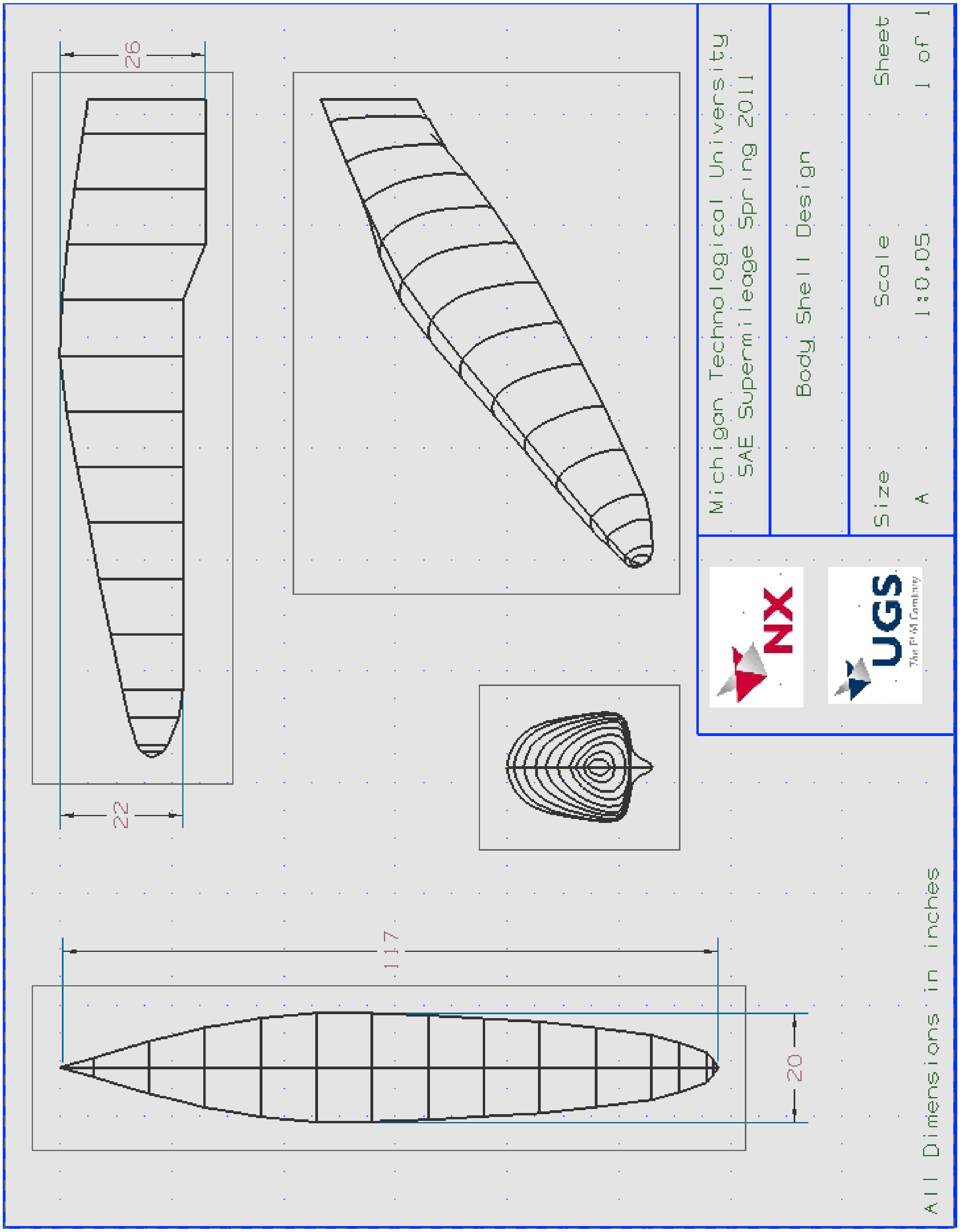
Future plans of the electrical team include extensive research into electrical components and the redesign of the dynamometer wiring.

- Arduino Uno - As a backup for the M100 the electrical team wants to improve on current functionality as well as implement pulse width modulation for the fuel pump.
- Step down board - The team wants to research more into solid state relays to replace mechanical relays. This should improve reliability of the vehicle's electronic system due to the removal of mechanical dependence.

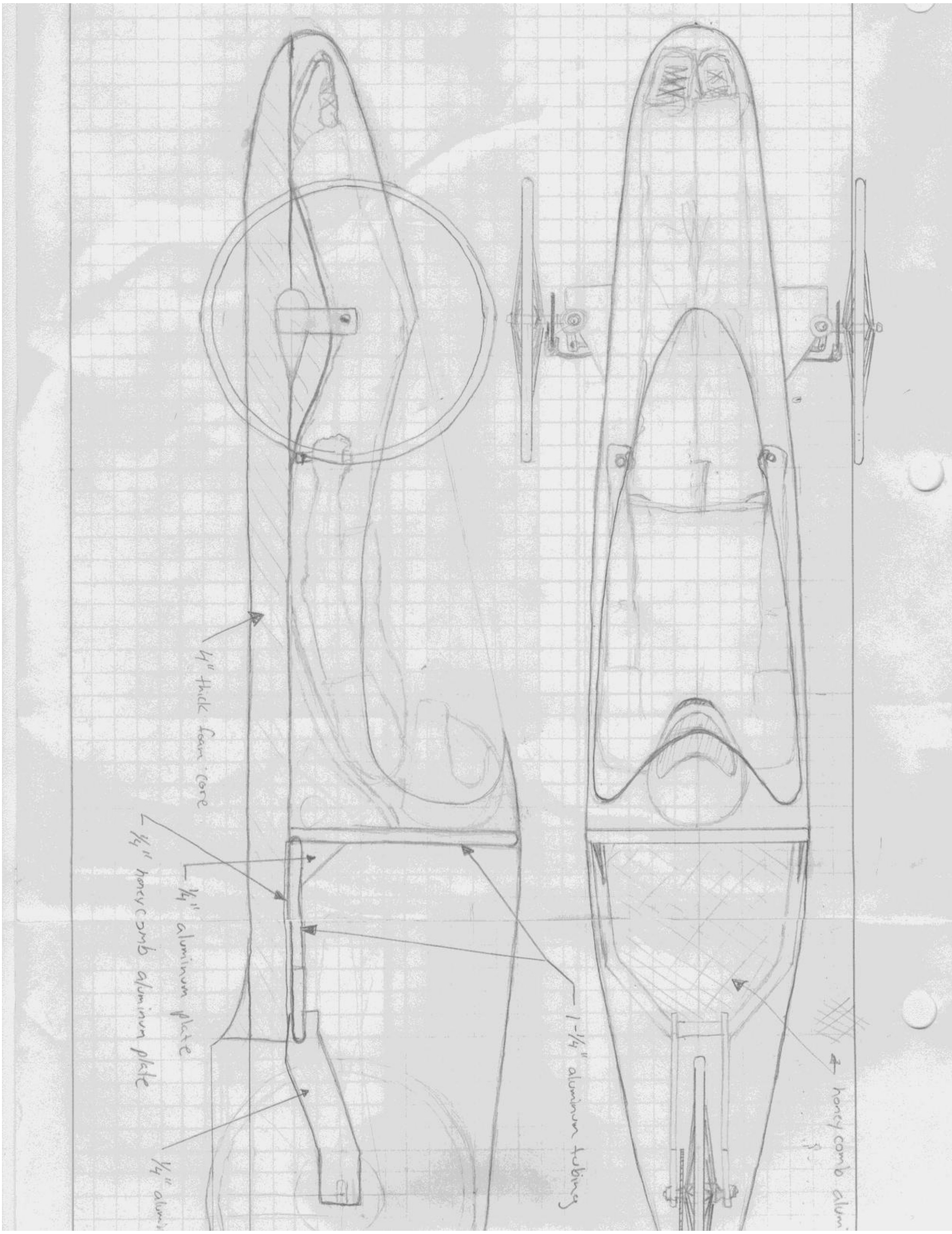
- Dynamometer- Current design of the dynamometer has little documentation of the electrical wiring. The electrical team would like to reverse engineer the dynamometer in order to clean up the wiring.
- Common Automotive Network (CAN) – Both the M100 and MegaSquirt® microcontrollers are capable of performing CAN communication. This channel may be used to collect information for future analysis and on-the-fly adjustment of engine performance.

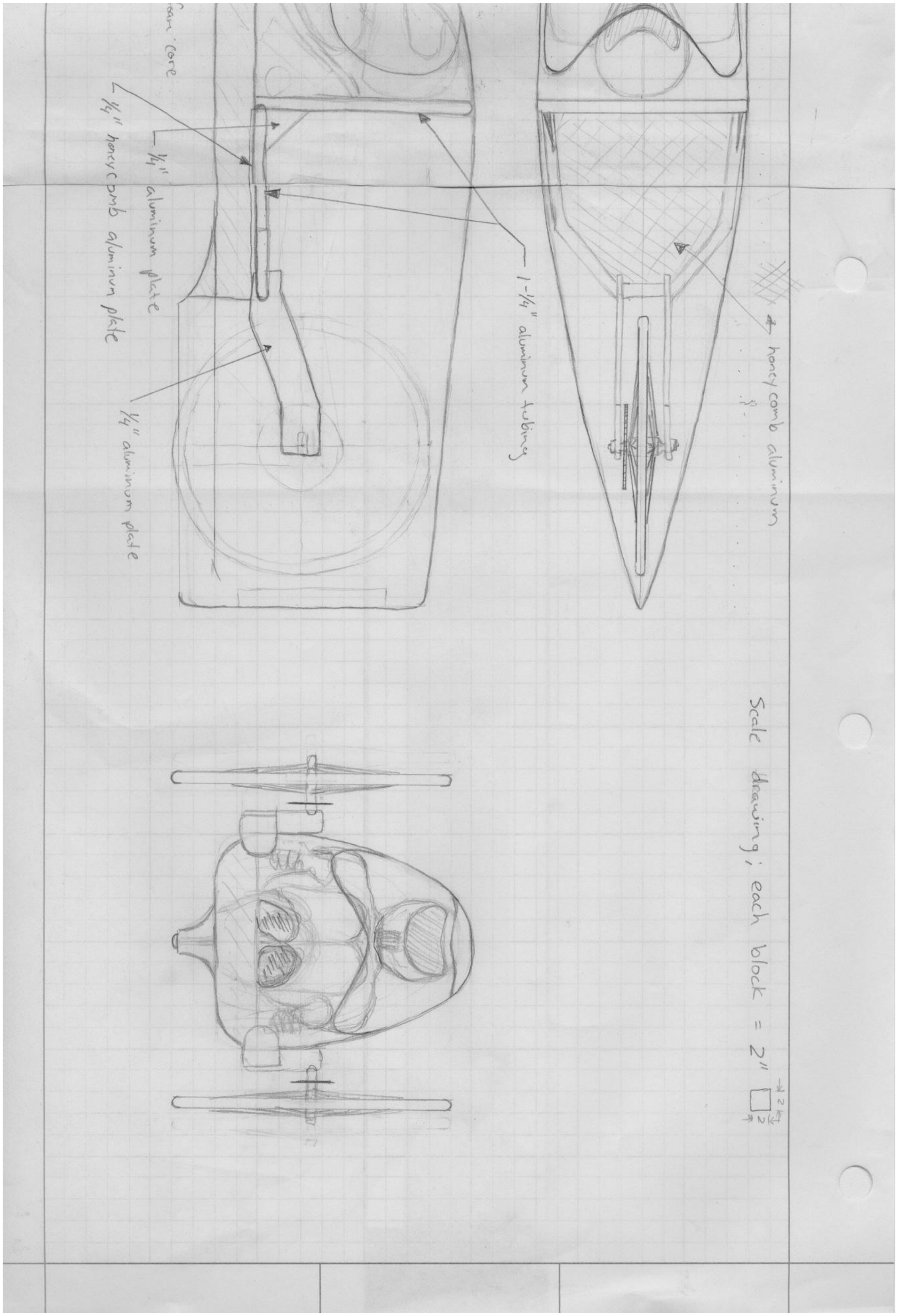
APPENDIX

Model of Shell Design

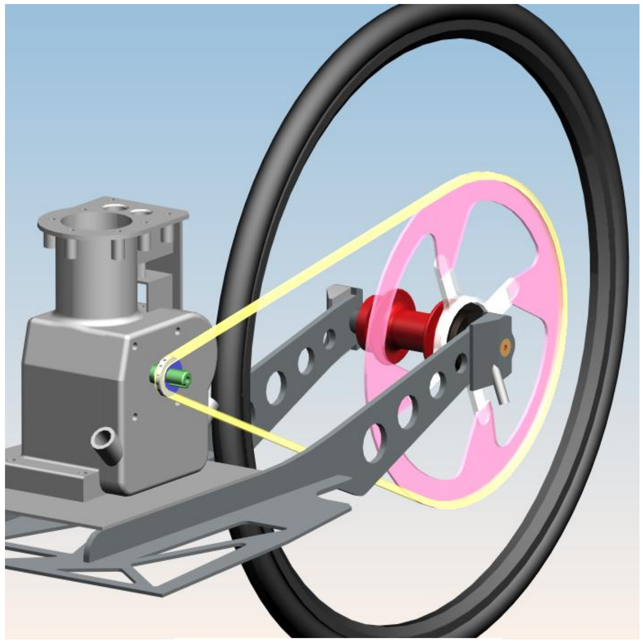


Sketch of Design

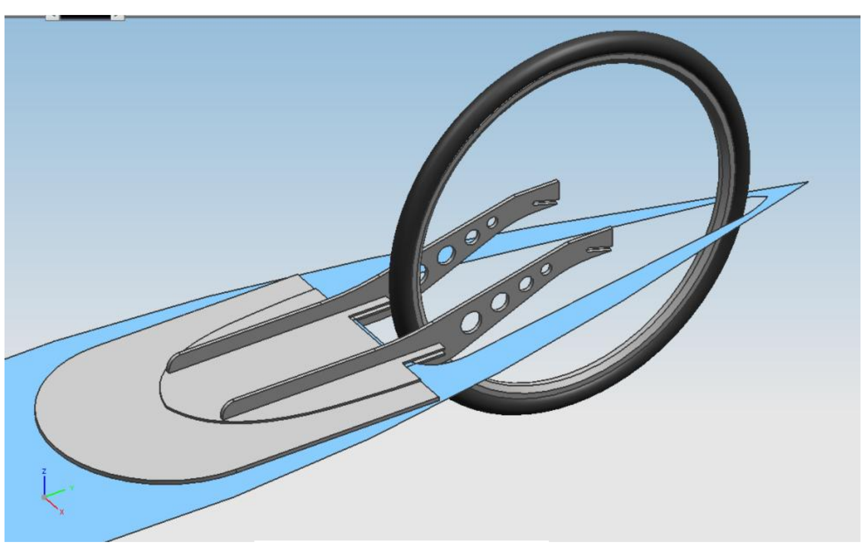



1/4" aluminum plate
1/4" honeycomb aluminum plate
1-1/4" aluminum tubing
1/4" aluminum plate
honeycomb aluminum
Scale drawing; each block = 2"

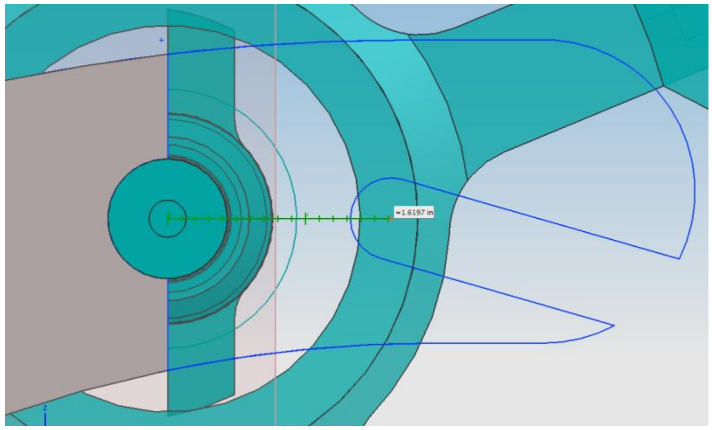
Comparison of Rear End Designs



New design

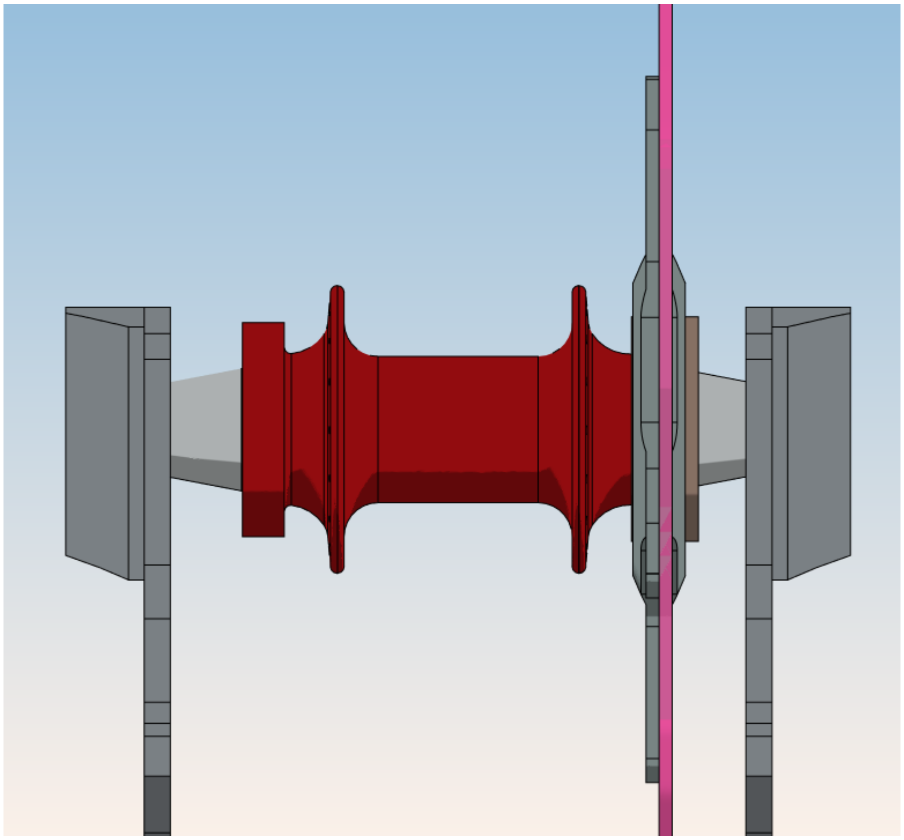


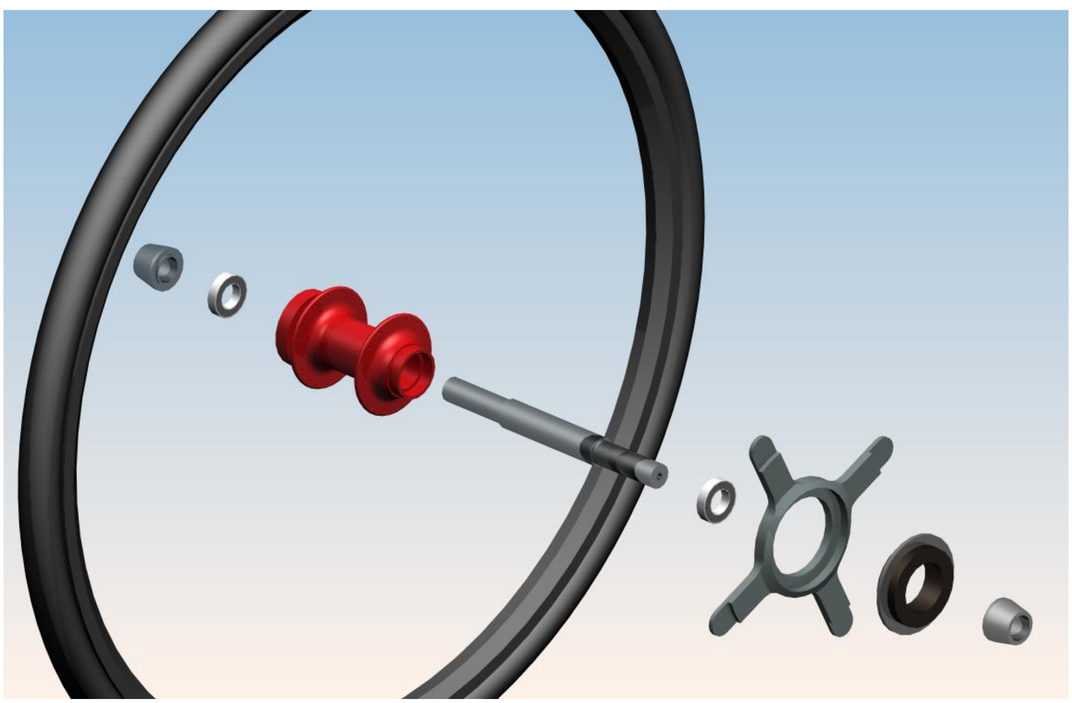
Old Design

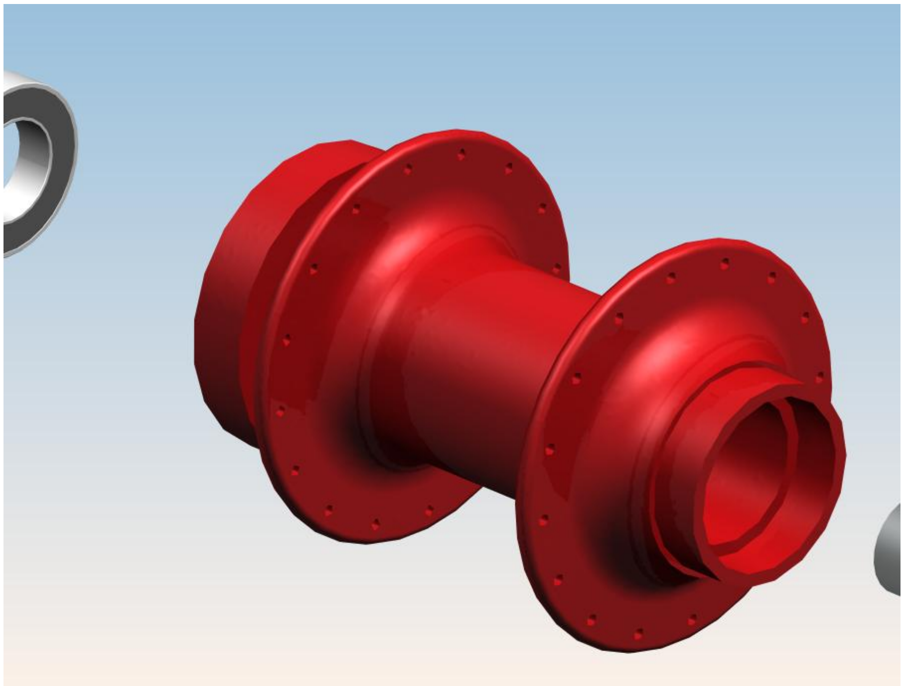


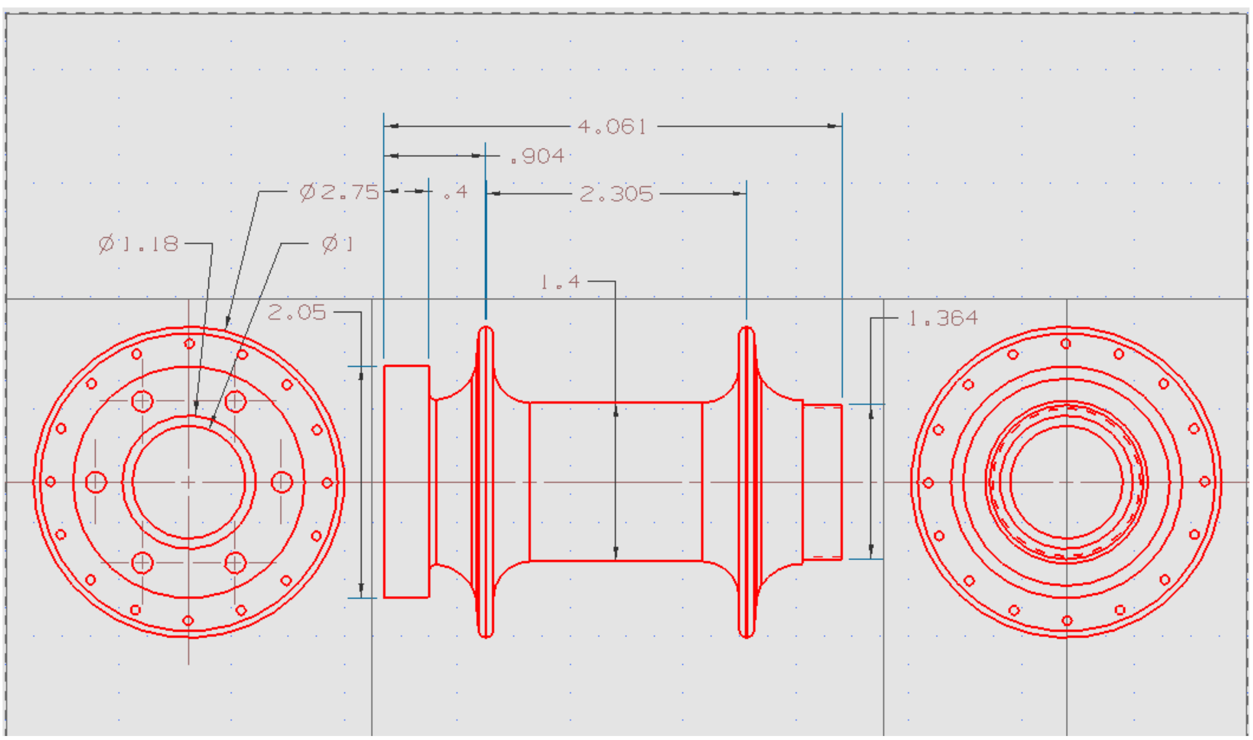
Material removed from old design to move new design forward on rear wheel mounts

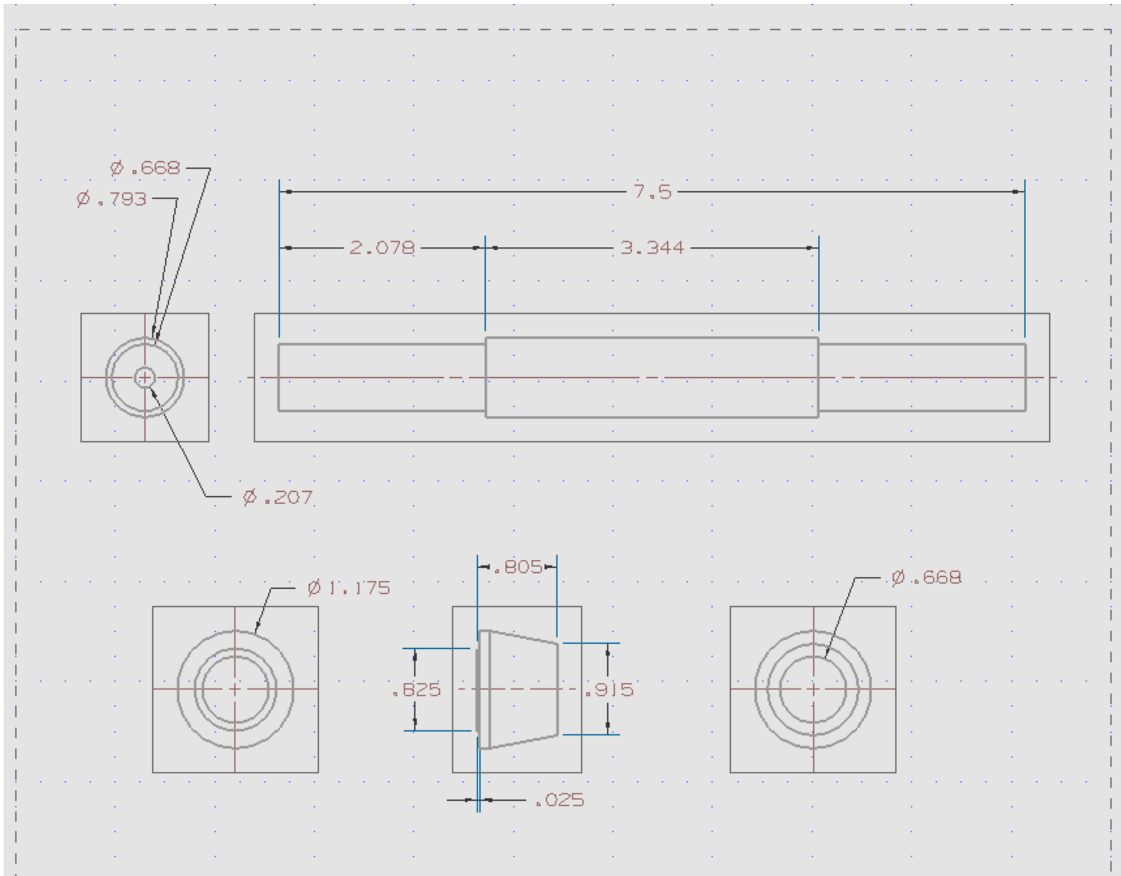
Hub views and Engineering Drawings







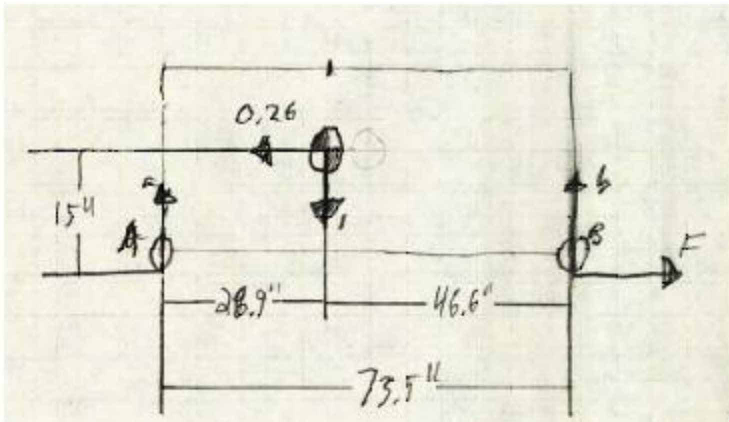

4.061
.904
Ø2.75
.4
2.305
Ø1.18
Ø1
1.4
2.05
1.364



Ø .668
Ø .793
7.5
2.078
3.344
Ø .207
.805
Ø 1.175
Ø .668
.625
.915
.025

Braking calculations

Required coefficient of friction (μ):



$\text{moment}_a := 0$

$\text{moment}_a = 1 \cdot 26.9 - 0.26 \cdot 15 - 73.5 \cdot b \text{ solve}, b \rightarrow 0.31292517006802721088$

$b := 0.3129$

under braking: rear weight distribution = 31.3%

required μ:

$N := b$

$F := 0.26$

$F = \mu_{required} \cdot N \text{ solve}, \mu_{required} \rightarrow 0.83093640140620006392$

$\mu_{required} := 0.8309$

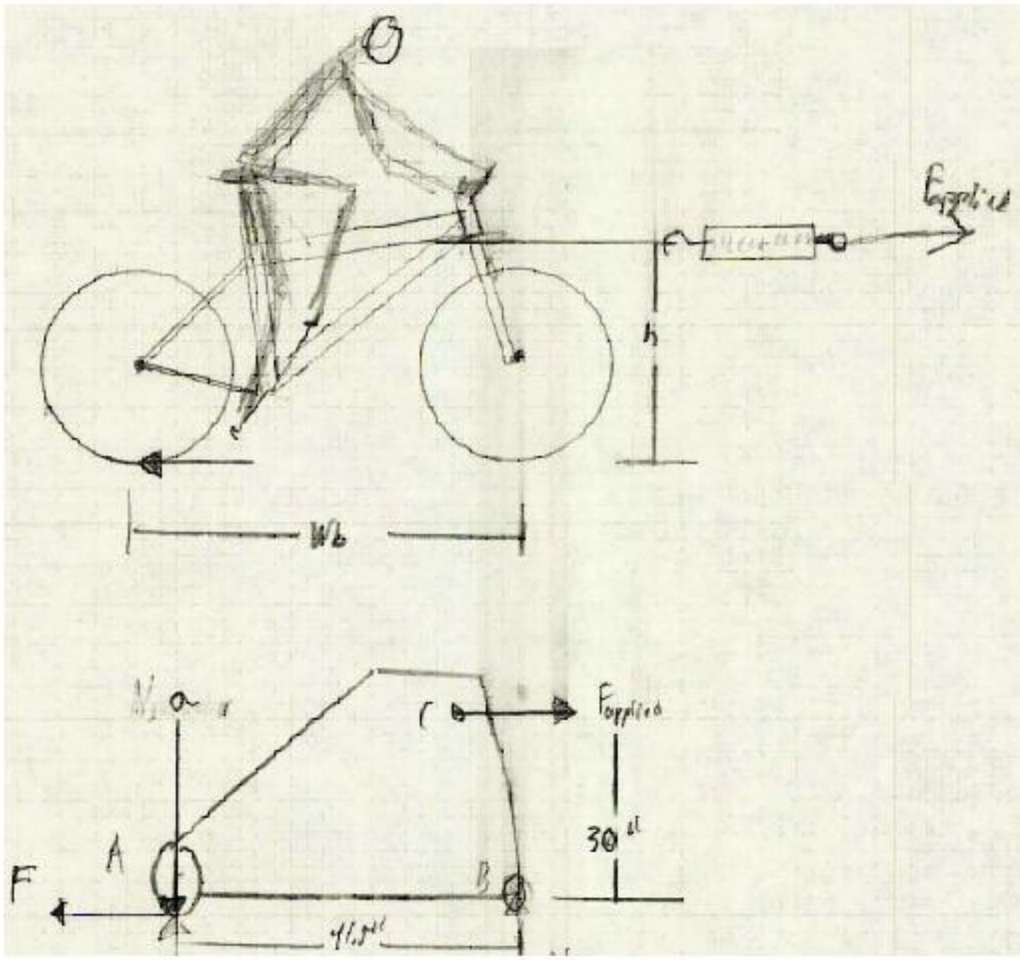
$\mu_{tire} := 1.09$

$\mu_{required} < \mu_{tire}$

$$\frac{\mu_{required}}{\mu_{tire}} \cdot 100 = 76.229$$

With the current weight distribution and μ the car can pass the brake test by stopping with 76% of its calculated μ value. This alows a safe margin to account for varying track surfaces and driver error.

Coefficient of friction (μ):



Frictional force (F) was measured with a spring scale. The test was run on a variety of paved surfaces and the lowest measured force was recored.

wheel base:

$wb := 41.5$ inches

$h := 30$ inches

$F := 70$ lbs

$F_{applied} := F$

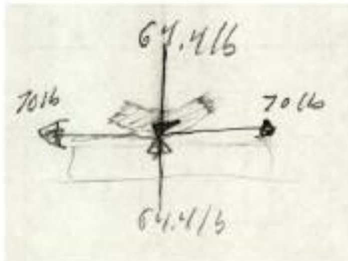
$moment_B := 0$

$moment_B := F \cdot 30 - a \cdot 41.5 \text{ solve}, a \rightarrow 50.602409638554216867$

$a := 50.602$ lbs

Static weight distribution as measured at tires

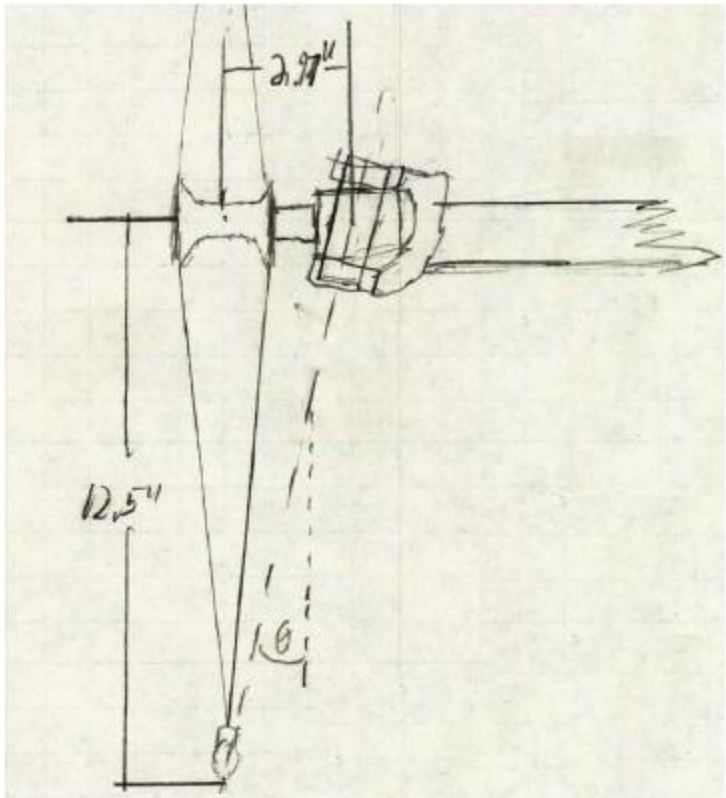
$sw := 115 \quad lbs$



$N := sw - a = 64.398 \quad lbs$

$$\boxed{\mu := \frac{F}{N} = 1.087}$$

KPI Calculations



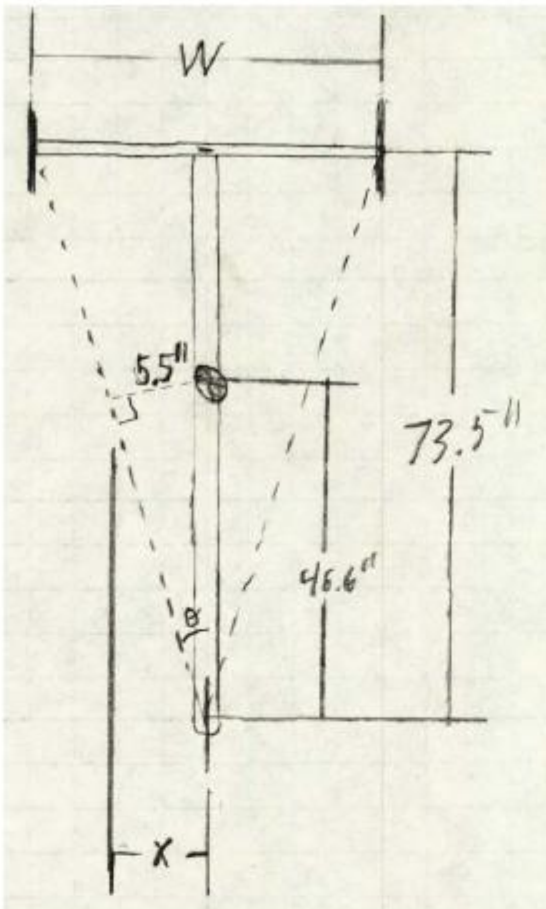
$a := 2.97$

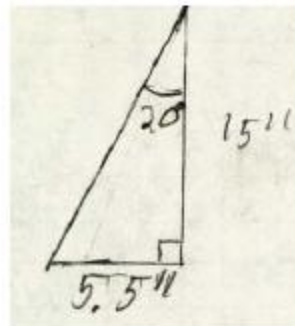
$b := 12.5$

$\theta := \operatorname{atan}\left(\frac{a}{b}\right)\cdot\frac{180}{\pi} = 13.366$

$KPI := \theta = 13.366$ degrees

Tilt Test Calculations





$$\theta_1 := \frac{20}{180}\cdot\pi \quad \text{rad}$$

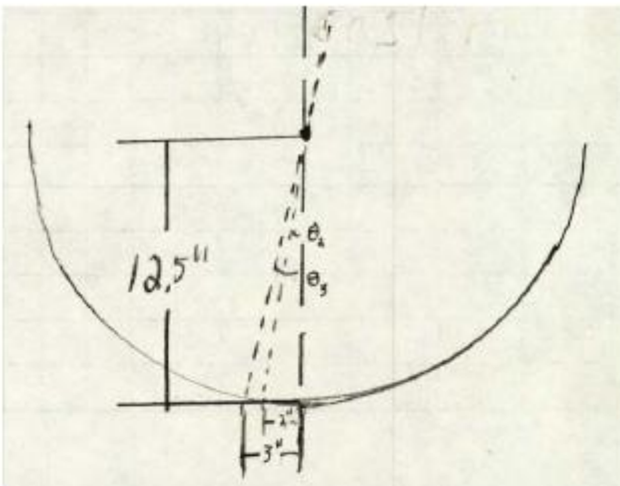
$$15\cdot\tan(\theta_1) = 5.46 \quad \text{inchs}$$

$$\theta := \operatorname{asin}\left(\frac{5.46}{46.6}\right)\cdot\frac{180}{\pi} = 6.729 \quad \text{deg}$$

$$wb := 2\cdot 73.5\cdot\tan\left(\frac{\theta}{180}\cdot\pi\right) = 17.343 \quad \text{in}$$

In order to pass the tilt test the front wheels must be at least 17.5 inches apart

Caster Calculations



$$\theta_2 := \operatorname{atan}\left(\frac{2}{12.5}\right)\cdot\frac{180}{\pi} = 9.09 \quad \text{deg}$$

$$\theta_3 := \operatorname{atan}\left(\frac{3}{12.5}\right)\cdot\frac{180}{\pi} = 13.496 \quad \text{deg}$$

Aerodynamics

Coefficient of Drag Calculations and Gambit Meshes

$$F_D = \frac{\rho * V_F^2 * A_F * C_D}{2}$$

Average temperature of Marshall, MI on June 10th= 81°F or 27C

Density of Air at 30C=1.164 and at 25C=1.184

$$\frac{30-25}{1.164-1.184} = \frac{30-27}{1.164-\rho} \rightarrow \rho = 1.176\,\frac{kg}{m^2}$$

$$V_f = 15\frac{mi}{hr} * 1609.344\frac{m}{mi} * \frac{1\,hr}{3600\,sec} = 6.7056\,\frac{m}{sec}$$

$$A_{F,new} = 367.7541\,in^2 * .00064516\frac{m^2}{in^2} = .23726\,m^2$$

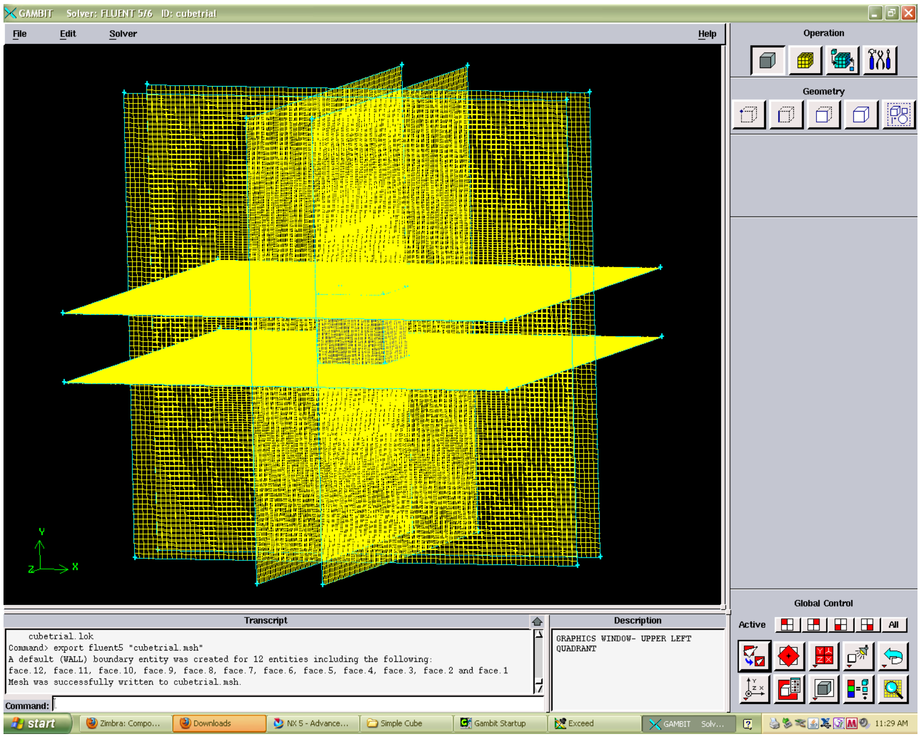
$$F_{D,new} = 1.388722$$

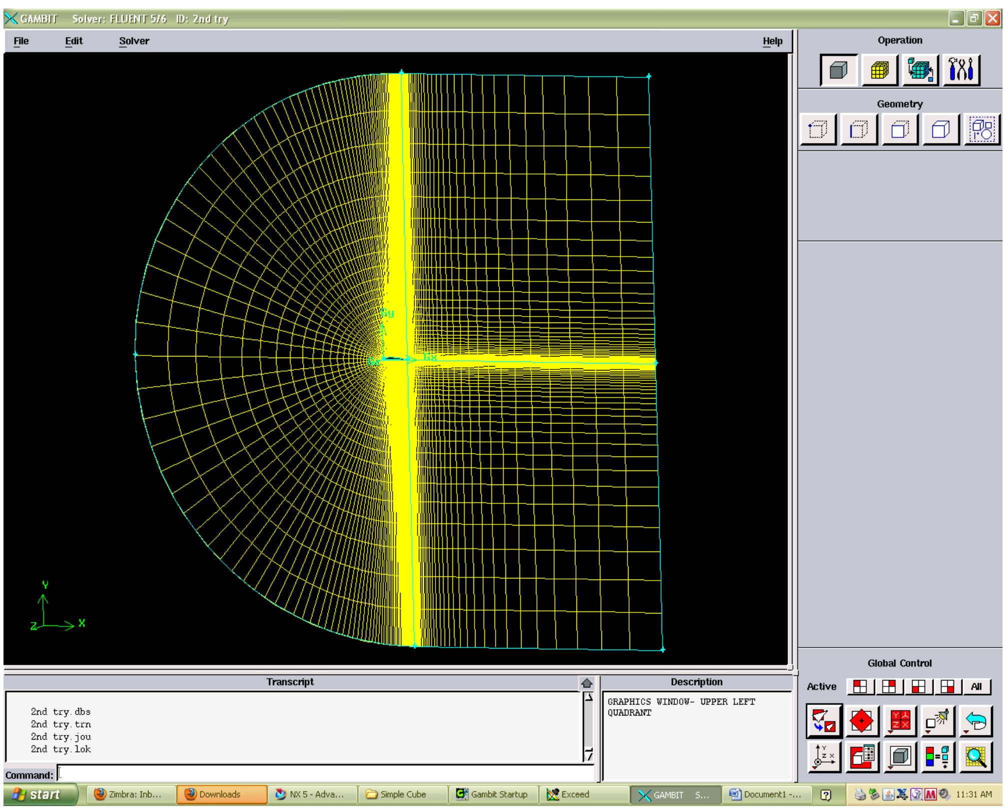
$$C_{D,old} = \frac{1.38872 * 2}{1.176 * (6.7056)^2 * .23726} = .221$$

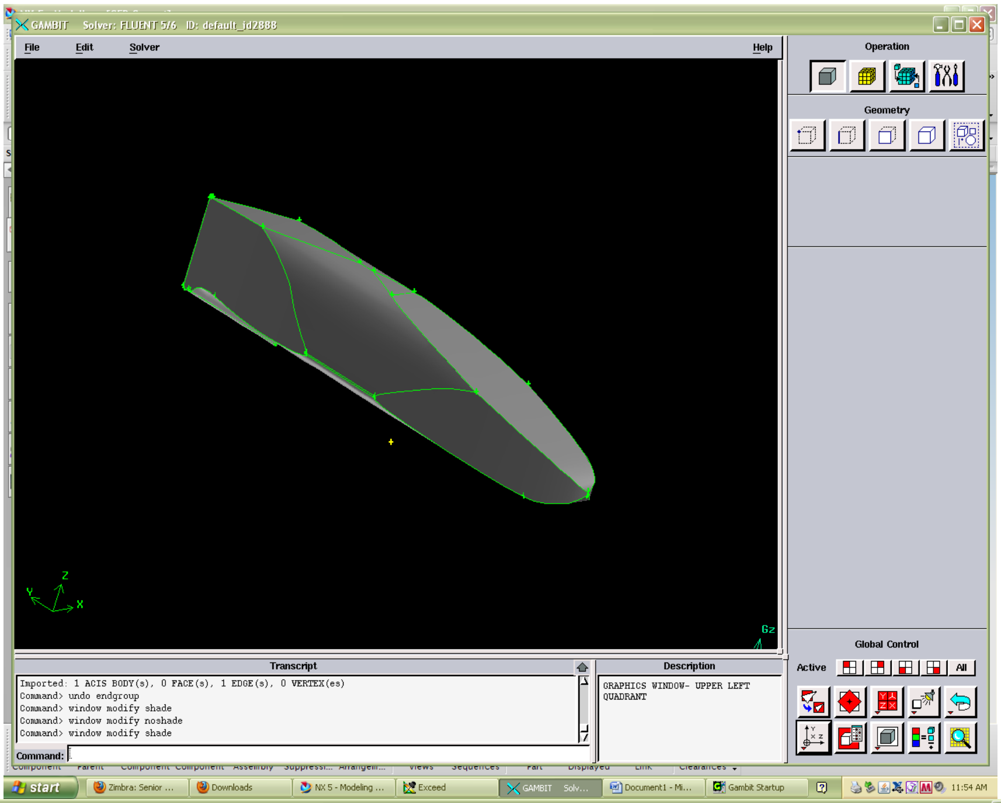
New Car Drag Force		
Refinement	Result	Total (N)
0	0.738018	1.476037
1	0.884736	1.769472
2	0.694361	1.388722

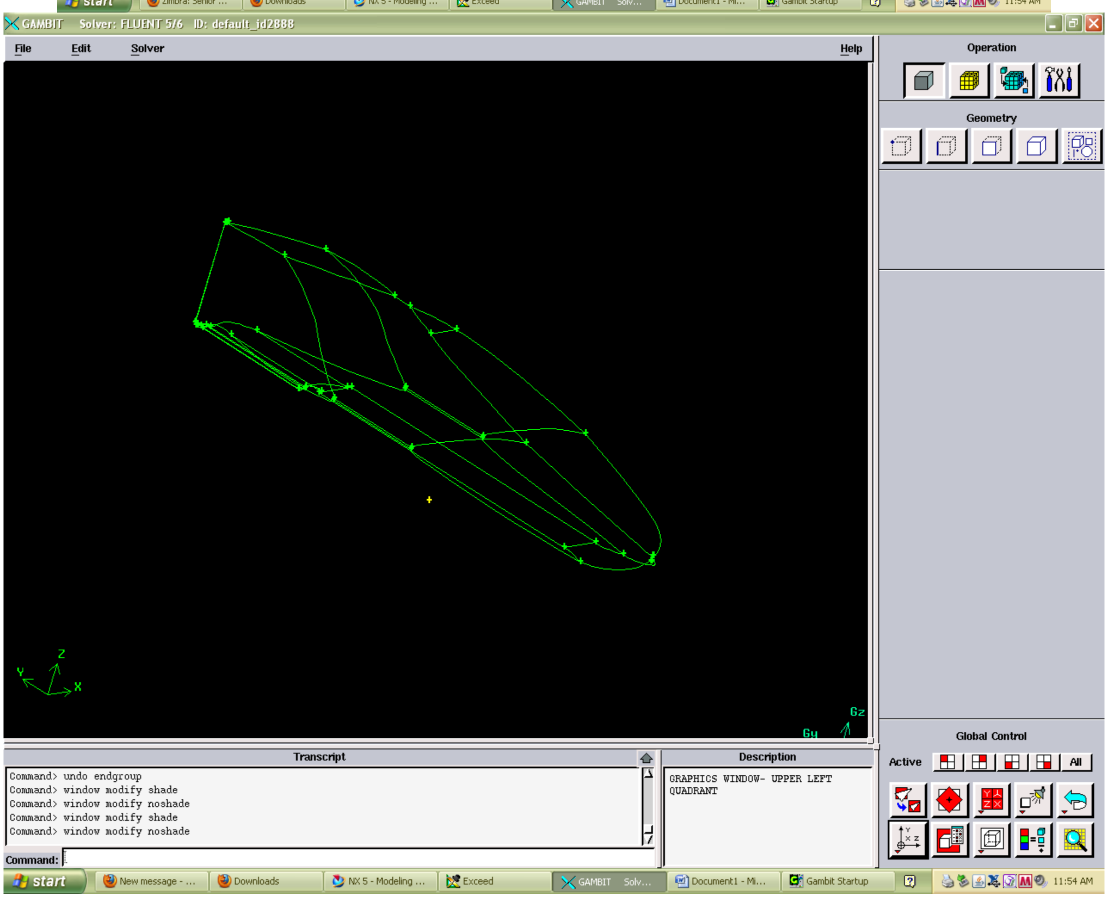
C_{drag}=0.2213

Screen shots of CFD analysis

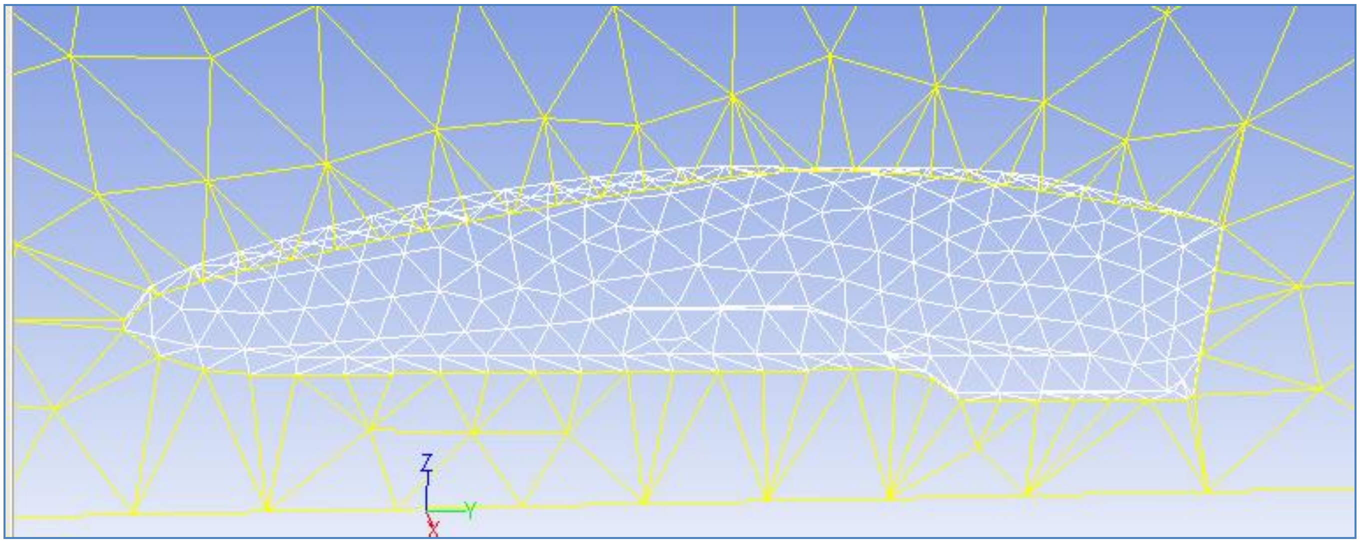


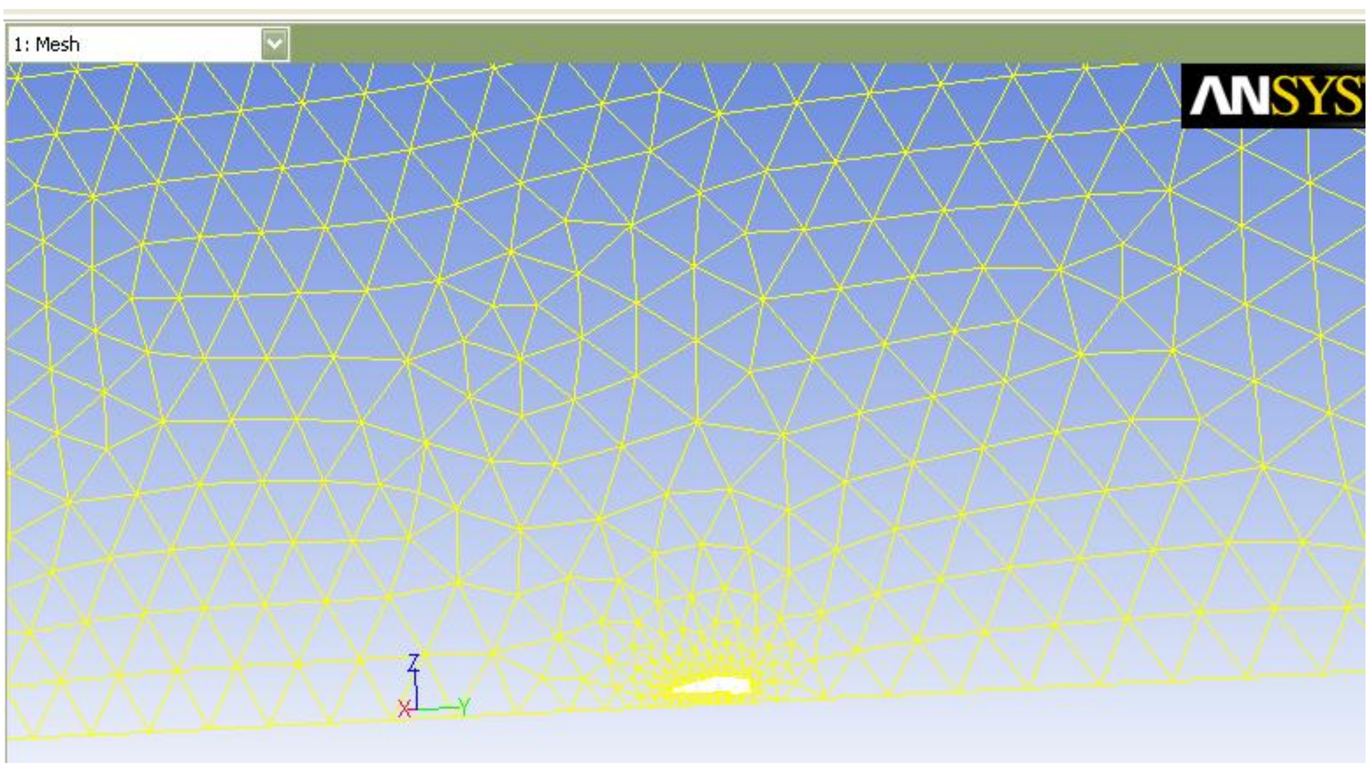




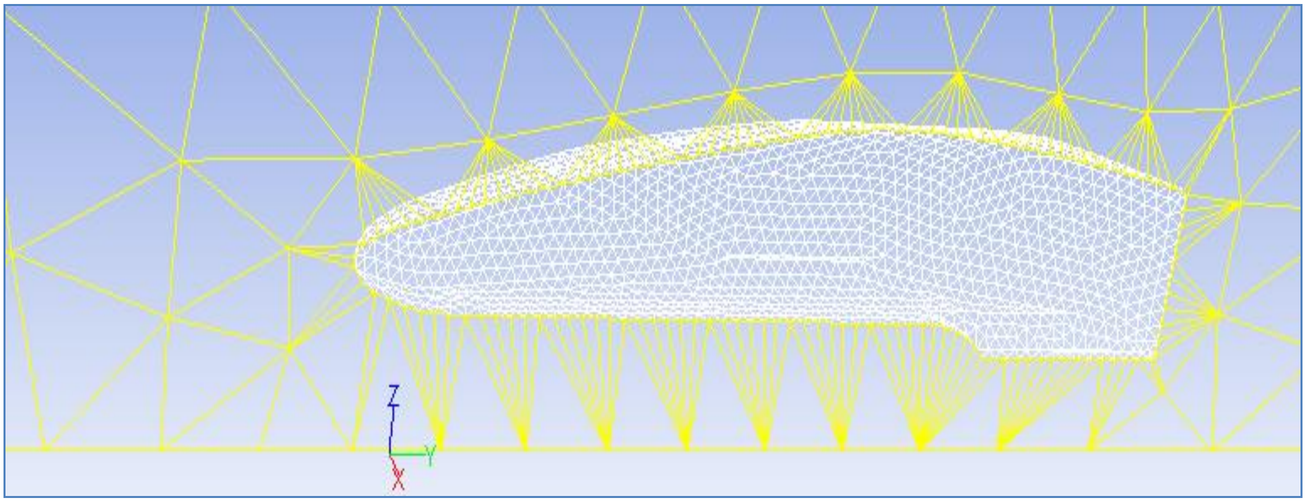


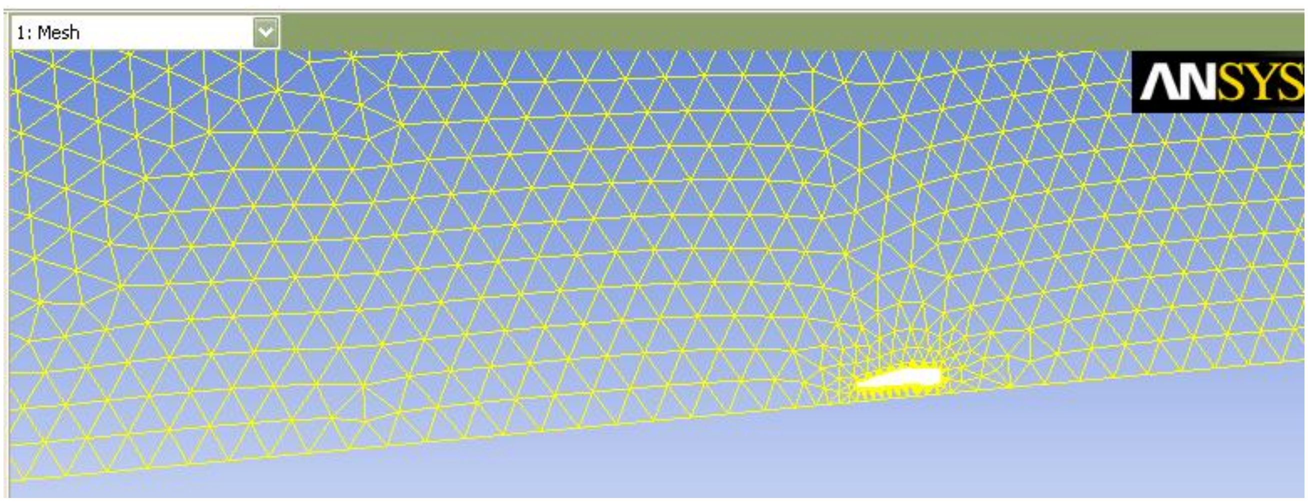
Crude Mesh



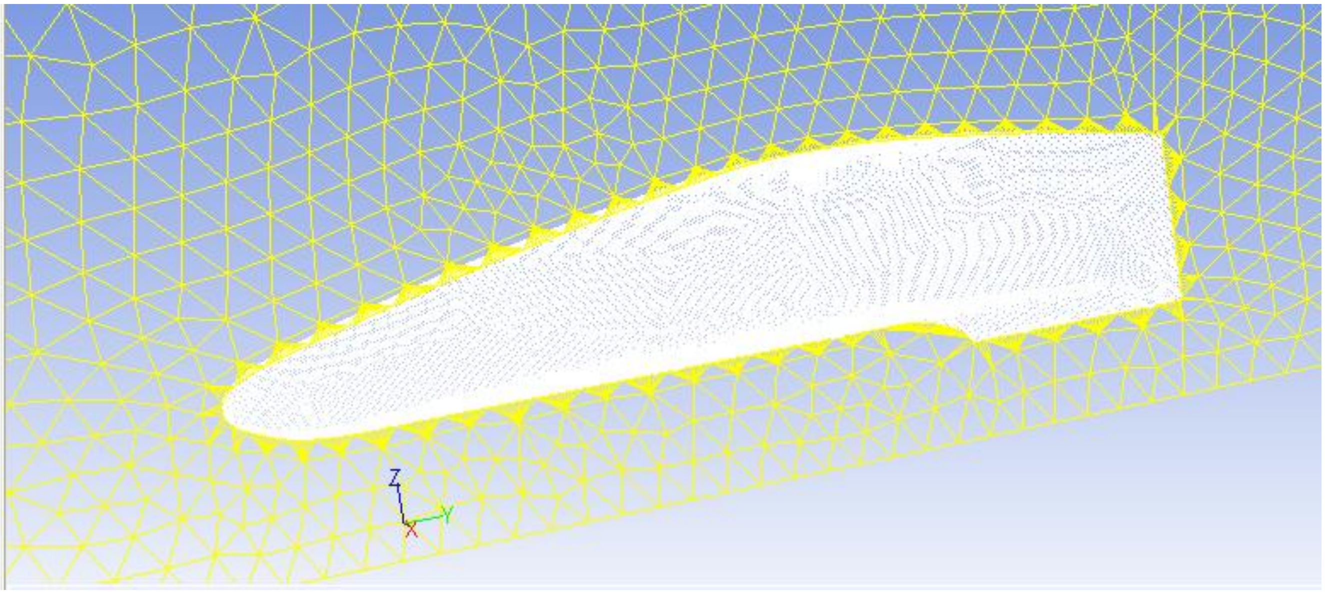


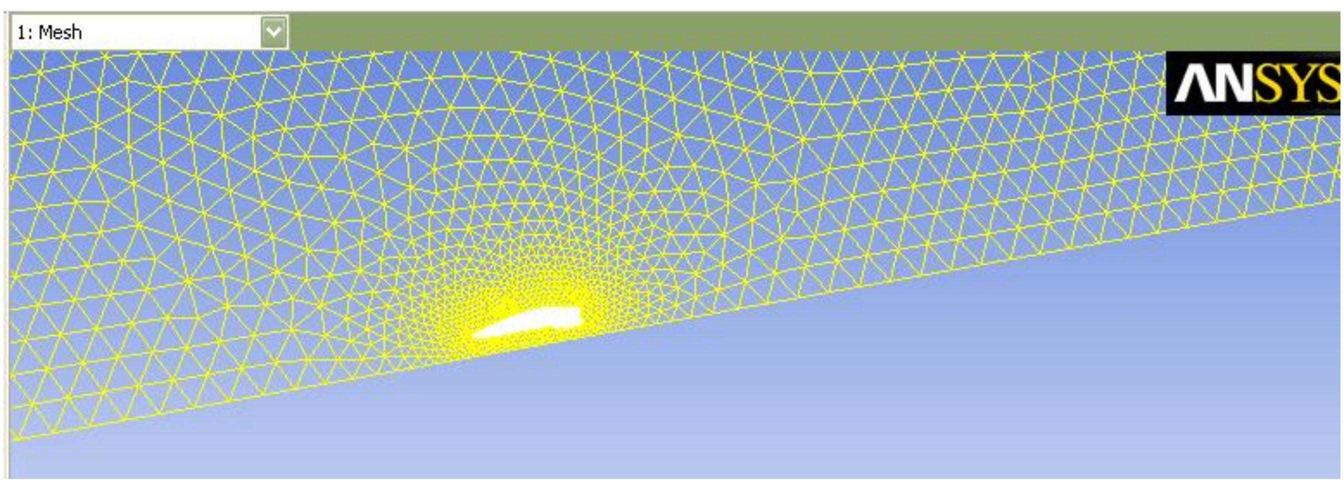
Refined 1

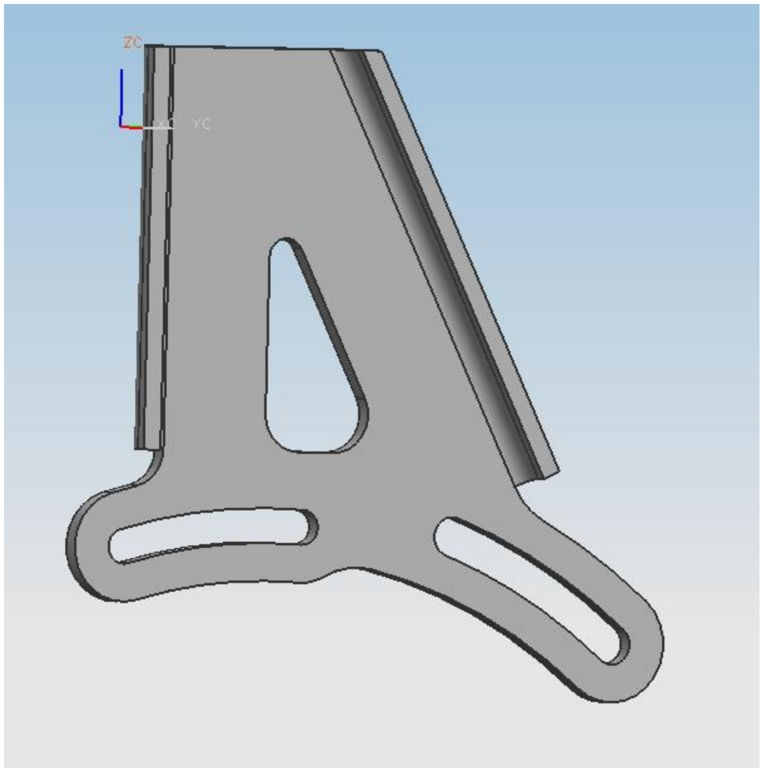




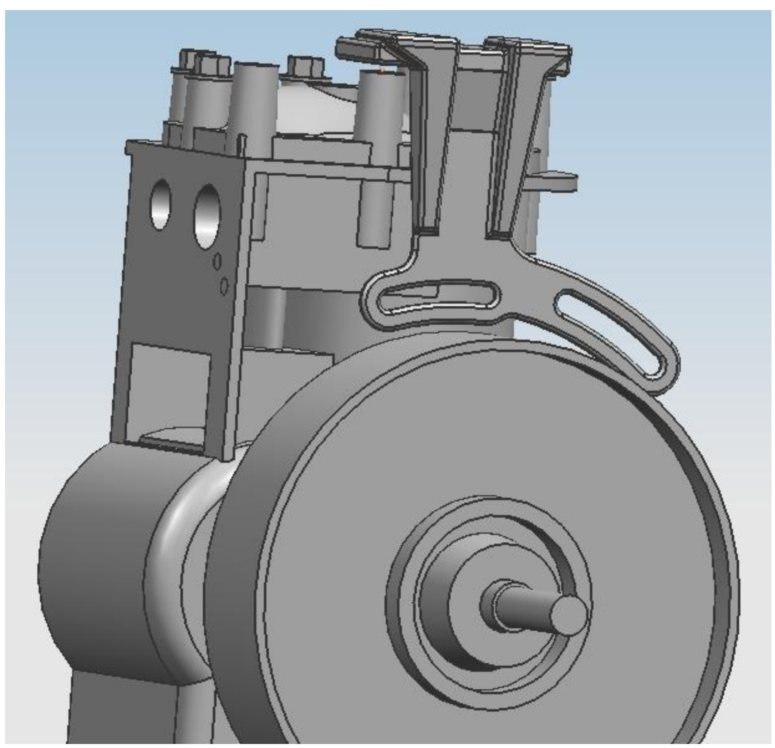
Most refined



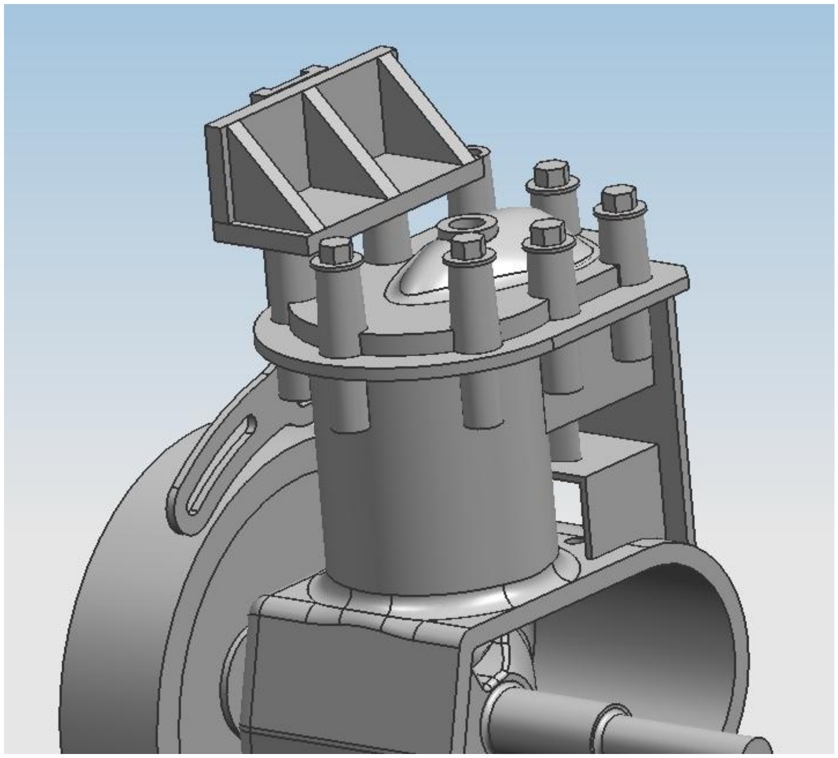




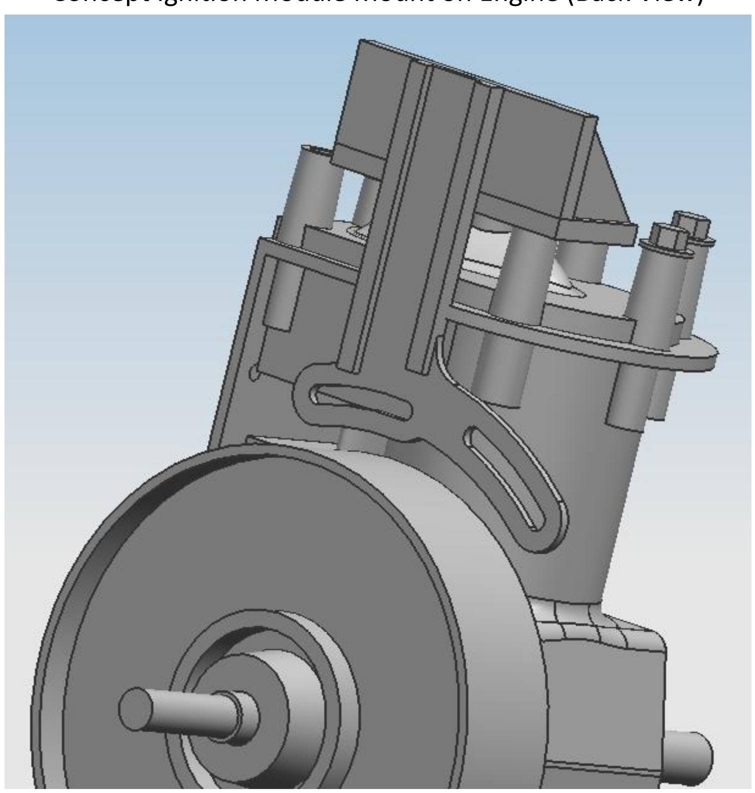
Final Design: Ignition Module Mount 3d Model



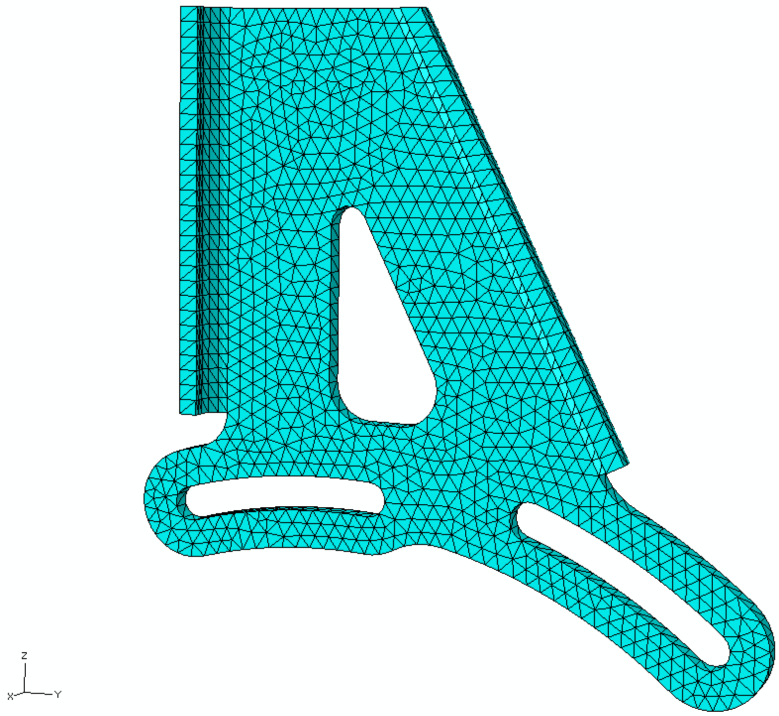
Concept Ignition Module Mount on Engine



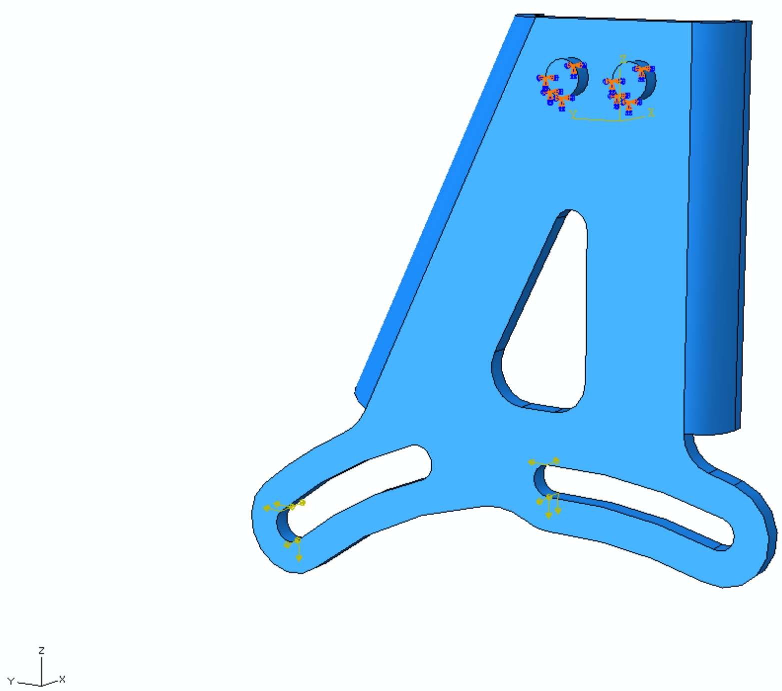
Concept Ignition Module Mount on Engine (Back View)



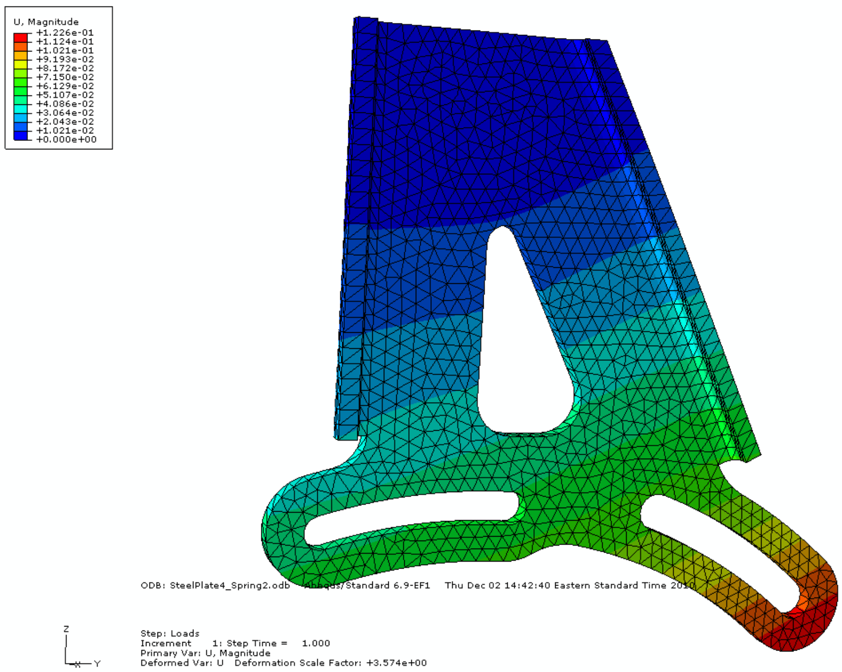
Concept Ignition Module Mount on Engine (Front View)



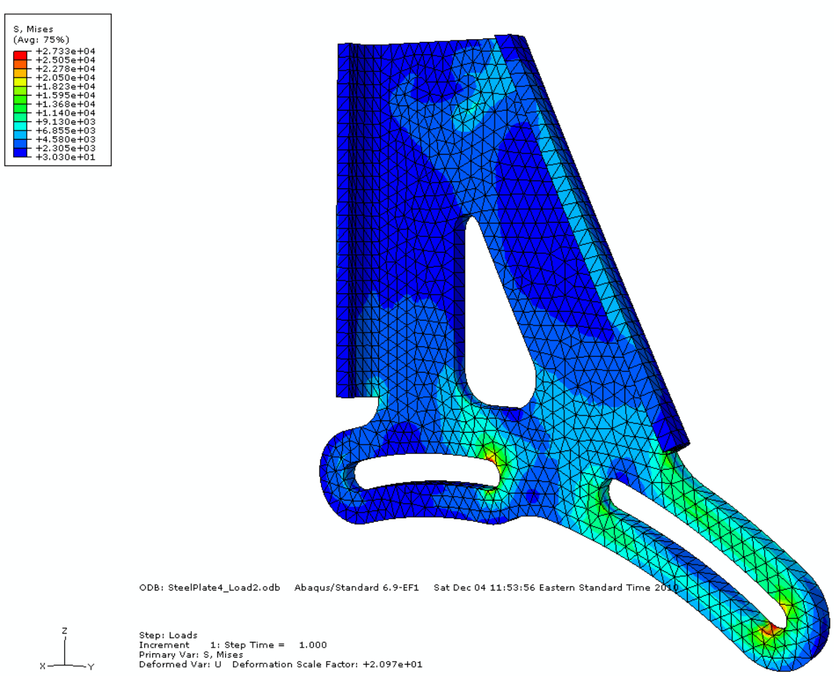
Ignition Module Mount, Mesh, Front



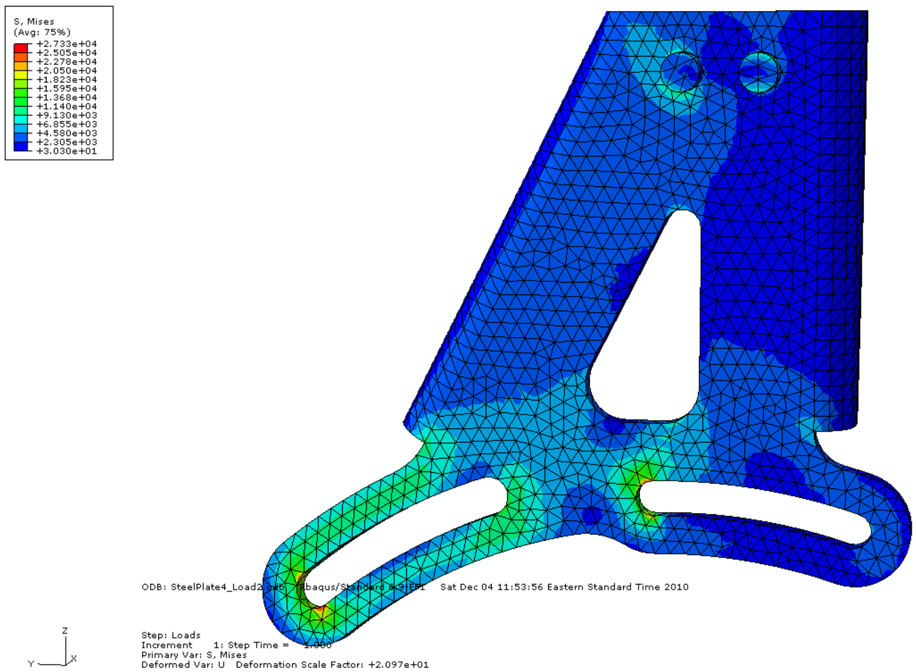
Ignition Module Mount: Loads and Boundary Conditions



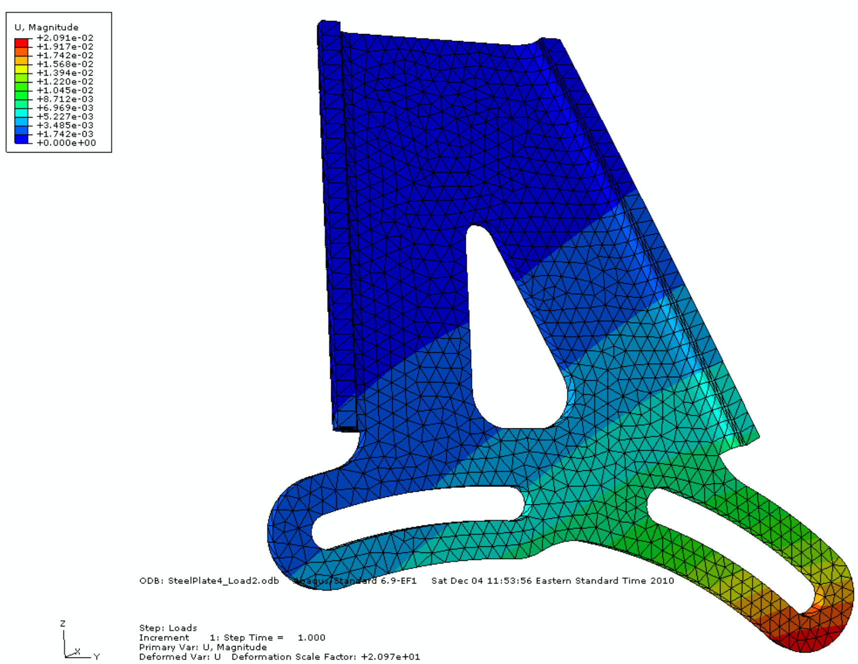
Ignition Module Mount: Spring Constant Deformation



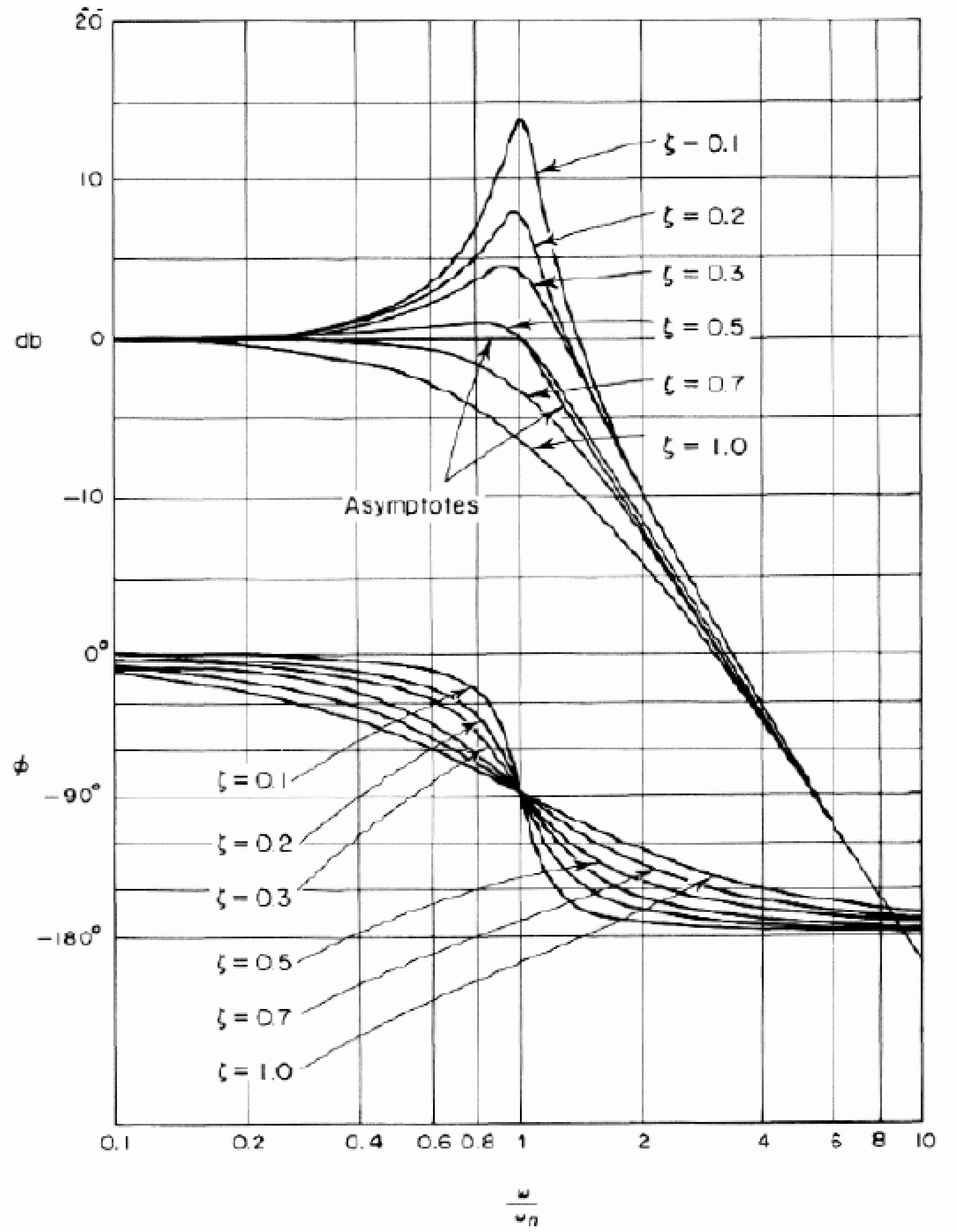
Ignition Module Mount: Stress Contour, Front



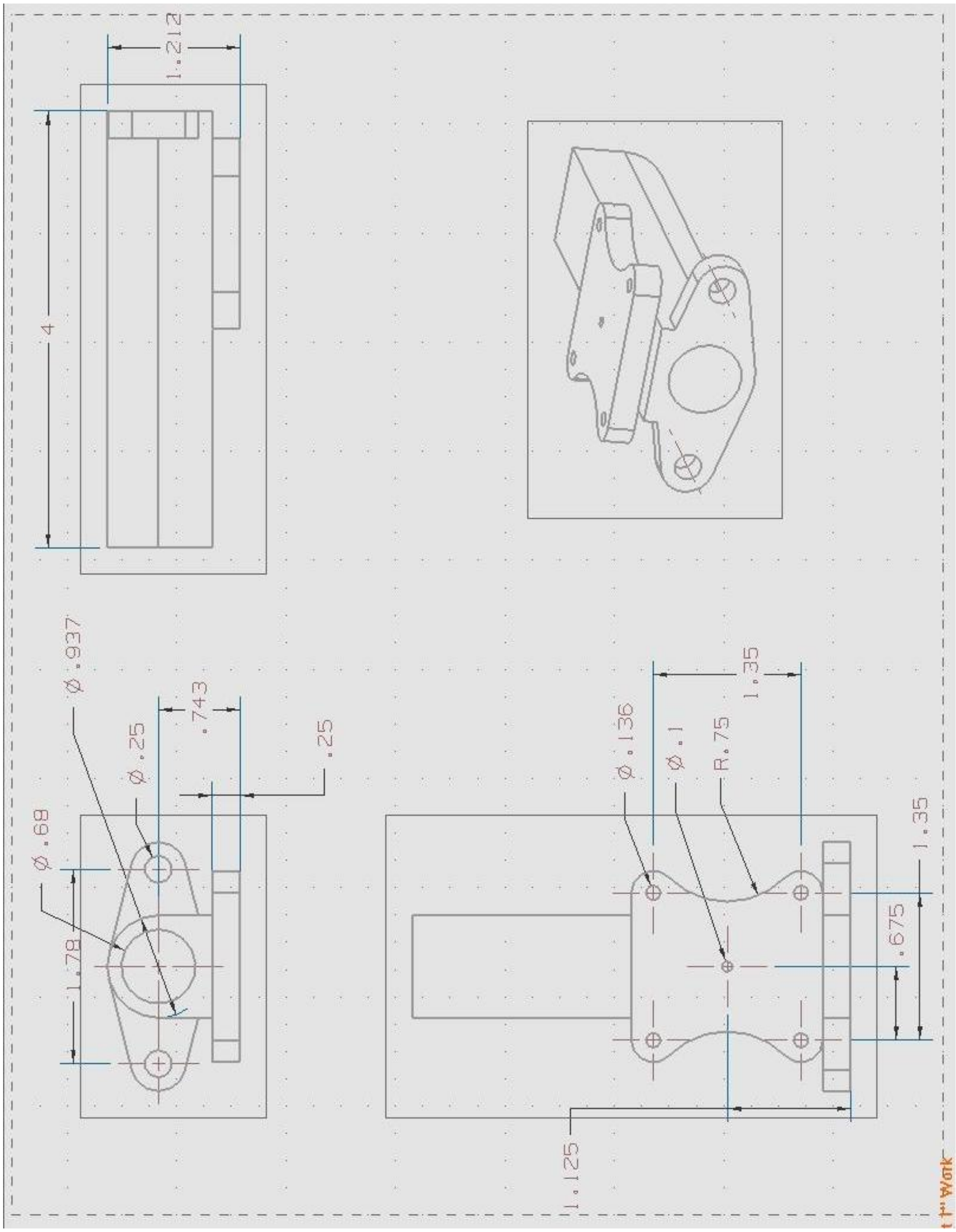
Ignition Module Mount: Stress Contour, Back



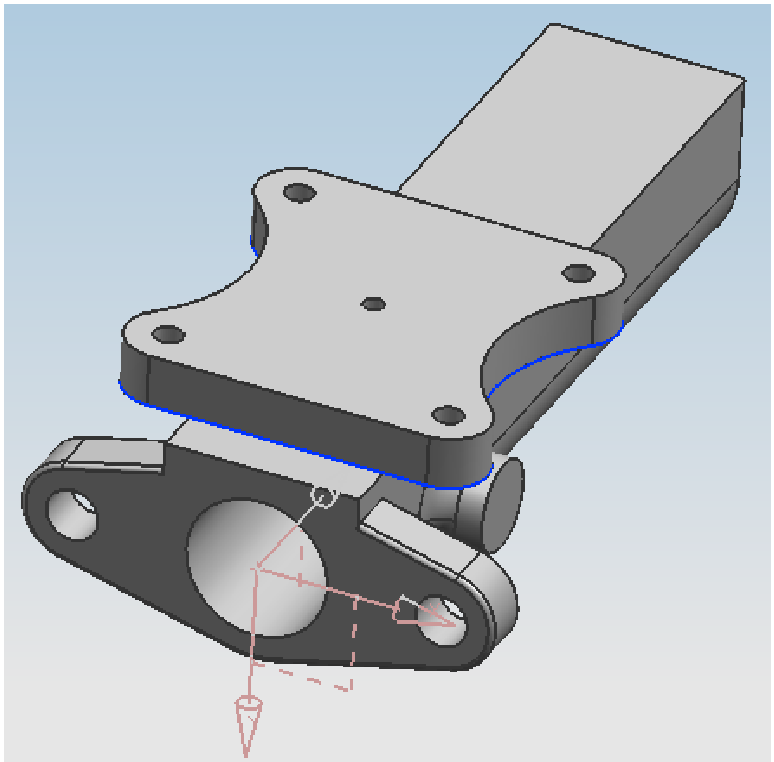
Ignition Module Mount: Static Deformation



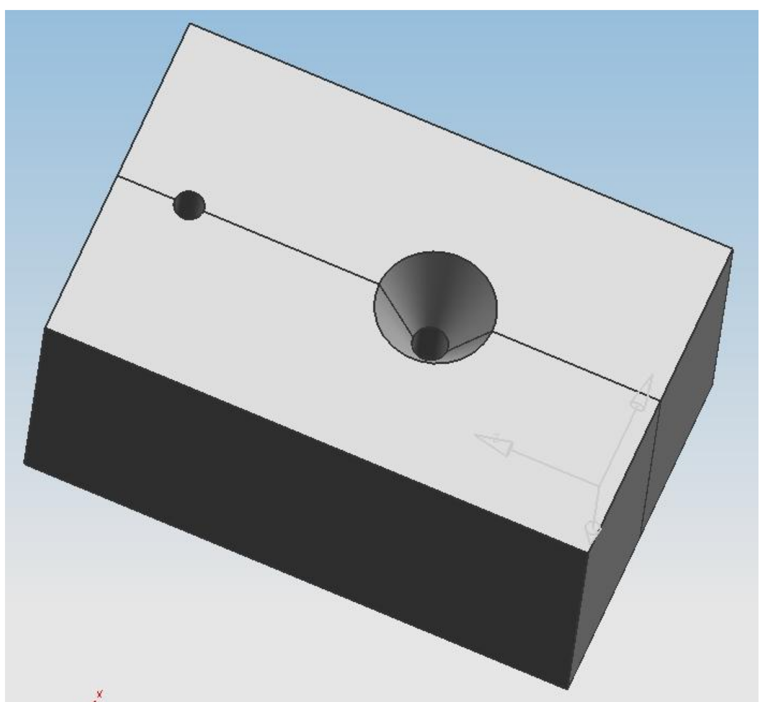
Ignition Module Mount: Frequency Response Plot



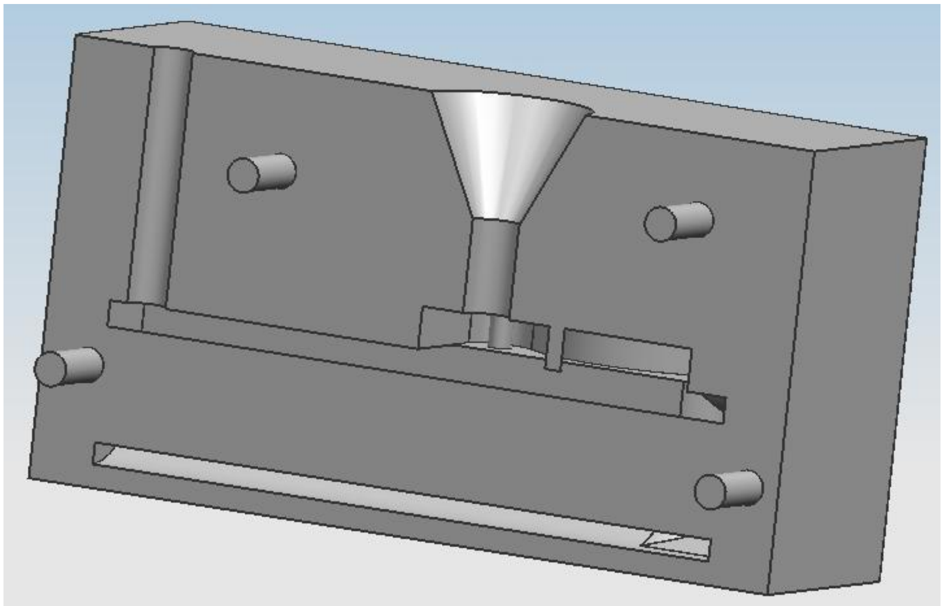
Throttle Body Drawing



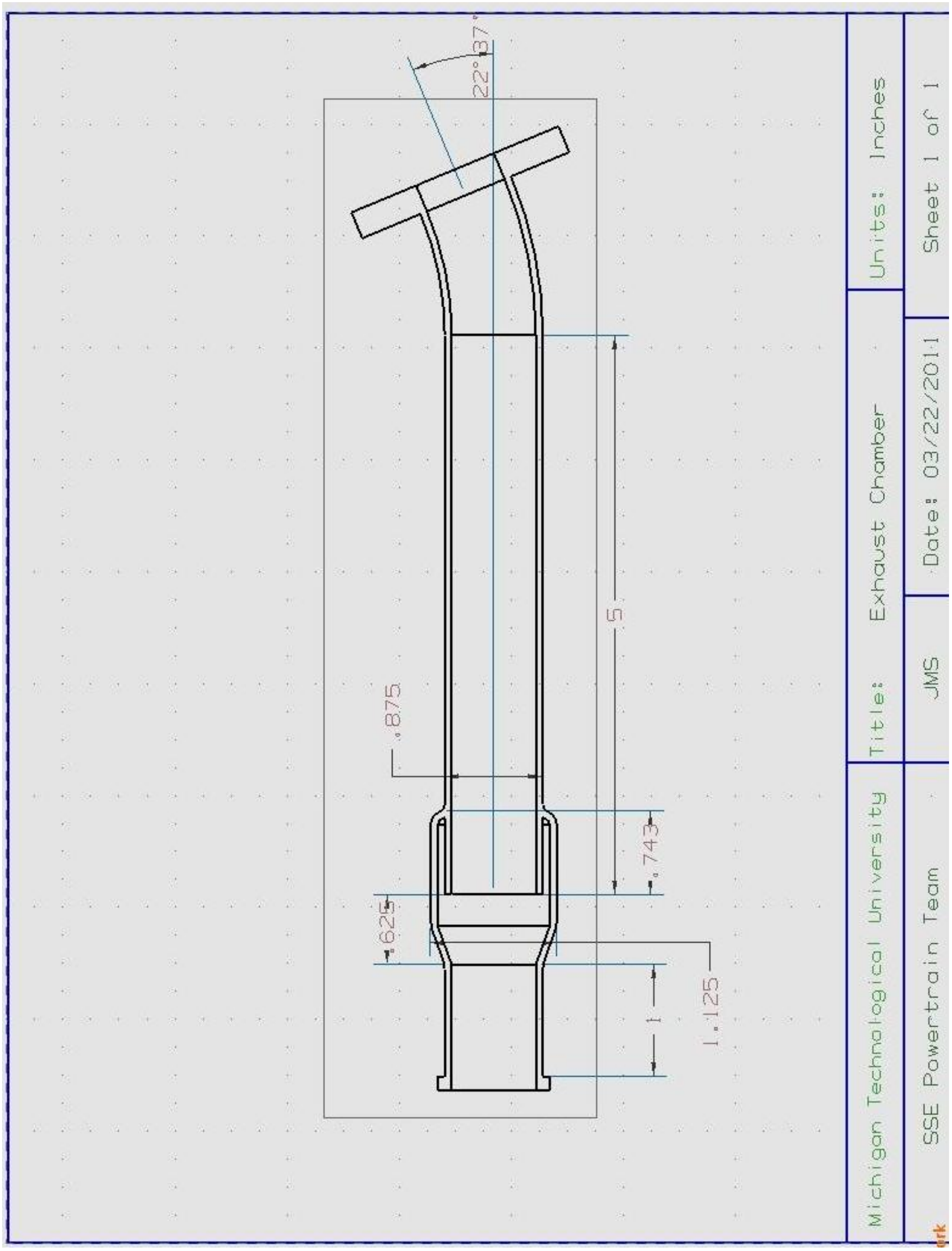
Throttle Body 3d Model



Throttle Body Mold (Outside View)



Throttle Body Mold (Inside View)



Section View of new Exhaust

Here is the equation for the length.
Length = (CID * 1900)/(rpm_max * tube_od^2)

CID= in^3 disp. I used 23.25 in^3
tube_od= outside diameter of exhaust. I used 0.75in.
I used 3600rpm for rpm max.

	A	B	C	D	E	F	G	H	I
1	Fuel Pressure	42	psi						
2	Mass Flow Rate	2.4	Lb/hr						
3	Density of gasoline	737	kg/m^3						
4	Volumetric Flow Rate	24.62	ml/min			Vol. Flow Rate=(Mass Flow Rate/(60 min/hr))*(0.4535924 kg/lbm)*(1000000 mL/m^3)			
5									
6	Required Injector Flow Rate								
7	Engine Power	3.5	HP						
8	Assumed BSFC	0.5	lb/hp*hr						
9	Manufacturer Flow Rate	1.75	lb/hr						
10	Assumed Duty Cycle	85%							
11	System Flow Rate	2.06	lb/hr						
12		21.12	ml/min						

Injector Flow Rate Calculation

EFI Nozzle Location

Stressing the importance of fuel injector location on an EFI intake manifold

From the February, 2009 issue of Hot Rod

EFI Nozzle Location
-April 2007-

Duttweiler's 294ci twin-turbo...

read full caption

Question: I'm going to be putting electronic fuel injection onto a Buick 455 street engine. There are few choices of intake manifolds for this engine, so a custom one with EFI bungs will be necessary. I see that most aftermarket companies that make intakes with bungs design them so the injectors sit vertically, placing them perpendicular to the airflow path. If you look at most factory EFI setups, the injector sprays toward the valve, or parallel to the airflow stream. Would it be worth my while to attempt to spray the injector toward the valve, or should I keep it perpendicular to the airflow? Are there any gains to be had in angling the injector?
Nate Hankins
Milwaukee, WI

Answer: High-end experts like turbocharging guru Ken Duttweiler and EFI University's Ben Strader have spent countless hours on the dyno and in the lab playing with fuel-injector location and angle. There are several observable trends from this research, but in the end, any individual engine may deviate from theory or previously observed trends, so the following should be taken as only a baseline recommendation, as your outcome may vary.

Basically, there are three factors that have to be juggled: idle quality (which would also include emissions in an OEM smog-legal application), proper fuel/air atomization, and the physical constraints of the engine and intake-manifold configuration. These factors combine to determine injector location and angle within the intake manifold's inlet runner.

In a perfect world, nozzle location should be as parallel to the airflow stream as possible. The nozzle angle in relation to the airflow stream is termed the "intercept angle." According to Strader, the intercept angle should "not be more than 45 degrees, although it can be less." Maintaining the proper intercept angle generally helps low-speed driveability and may also improve performance throughout the engine's operating band. The lower the inlet airspeed at idle, the more critical it is to maintain the ideal intercept angle. Idle vacuum correlates well with inlet airspeed-if you have 14-18 inches Hg of vacuum at idle as read on a vacuum gauge, maintaining the proper intercept angle is not as much of an issue in terms of driveability, although there still could be some emissions ramifications.

Two Duttweiler sheetmetal...

read full caption

So much for injector angle-what about injector placement? Should it be closer to the valve (downstream, near the cylinder head) or closer to the air meter (upstream, toward the top of the inlet runner)? It depends on the engine and application. A stocker is primarily concerned with idle quality, low emissions, fuel mileage, and engine-compartment packaging constraints. On a stocker, fuel-injector capacity (rated in lb/hr) is low (compared with a race engine), while inlet-runner velocity and low-speed vacuum are high. The small-capacity nozzle develops a good spray pattern that disperses uniformly within the incoming air stream. With good atomization, the nozzle can be located downstream, close to the valve. Small injectors don't have a lot of fuel to waste, so targeting the spray toward the back side of the valve ensures that the available fuel is used most efficiently. On the other hand, in theory, high-idle vacuum generated by mild stock engines permits placing the injector farther upstream without significant low-speed driveability degradation. In the end, OEM-style downstream injector placement simplifies system packaging and makes it easier to mount the fuel rails.

Everything changes with really large injectors (over 96 lb/hr). High-capacity injectors generate a relatively poor spray pattern with a large fuel-droplet size. As Duttweiler puts it: "You're practically just spraying raw liquid. If you put a big injector too close to the valve, there's not enough time for the fuel to mix with the air." Large injectors would most likely be used in large-displacement or high-rpm engines with lumpy cams. High rpm translates into less time between injector firing pulses, lumpy cams generate poor vacuum, and the typically large-volume inlet runners needed to feed all those cubes generally mean lower air velocity downstairs. Obviously, all this adversely affects proper fuel atomization. Moving the injector farther away from the valve allows more time for the air/fuel to atomize properly and remain in suspension when air velocity comes up at high rpm. This should improve peak power but-because of poor low-rpm velocity-at the expense of idle quality (there's no free lunch).

Looking at some real-world examples, Strader reports that on a 1,000hp engine, the injectors were originally located 7 inches back from the valves. Doubling this distance to 14 inches was worth 50 hp on top, a 5 percent gain-but "it wouldn't idle below 1,600 rpm." For an even more extreme example, consider the injector placement on today's 15,000-rpm Formula I engines. The injectors, wiring harness, and fuel-distribution rails are located topside, even inside the manifold plenum area, so they can maintain the proper intercept angle.

In the real world, mass-produced aftermarket cast-aluminum manifolds have the bosses added as an afterthought to a preexisting design. The placement is more for convenience than for best engineering practice-the available packaging architecture (including fuel-rail mounting and clearance) to a large extent dictates the nozzle location. A decent compromise for a hot-rod engine is to locate the nozzle about 1-2 inches upstream from the manifold flange to give atomization a chance, positioning the fuel rail at the best angle you can get away with and still package the harness and fuel rails. As Duttweiler puts it: "If you aim the injector more toward the valve, the fuel rail usually hits the plenum" on a converted classic V-8 carburetor-style intake. Note that at the OEM level, the trend on today's new-tech V-8 engine designs is to make them wider than a similar-displacement, old-school, classic engine. The included valve angle in some of the new late-models is nearly straight up and down in relation to the bore. That means the runners are also near vertical, which in turn allows mounting the injectors more vertically to provide room for the fuel rails and wiring harness while still maintaining a good intercept angle to the runner.

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Saticoy, CA
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866/316-7744 or 909/972-6865
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Russ Collins - RC Engineering Said:

ATOMIZATION
High atomizing injectors are usually used in Throttle Body applications only, and have a rather wide spray pattern. A wide, finely atomized pattern is wonderful for emissions and economy but can cause problems in higher performance engines. At low RPMs, with a low air flow rate, the slow moving finely atomized fuel has enough time to get past the valve and create a close to stoichiometric mixture. (Air/Fuel mixture of 14.70 - Chemically ideal) As RPMs increase this mass can't keep up, with valve open time, and many of the fuel droplets impinge the port wall and condense. Atomized fuel can only travel at "port air speed" and *in large quantities it can actually displace air in the port*. With a highly atomized mix in the port, *at intake valve opening, the lighter droplets of fuel will be partly blown back up the port* [intake port reversion]. This is caused by the residual exhaust pressure [overlap period] still residing in the combustion chamber. Some of this reverted mixture will adhere to port walls and condense. This puddling fuel may find its way home, on the next intake cycle, but it will cause cycle-to-cycle air/fuel ratio variances. *The higher inertia of the more condensed fuel will carry it to its target*. "The liquid film that wets the walls represents a capacitance that greatly reduces the transient response of the engine." (SAE 950506) This problem is compounded in Gang fire and Semi-gang fire systems, but is not as troublesome in sequential fire systems. Gang fire systems fire all injectors, every rotation, at the same time, discharging half of the required fuel at each event. Semi-gang fire systems fire groups of injectors in the same fashion, half-and-half, each rotation. Sequential systems fire each injector at a pre-determined time and discharge all required fuel in one event, **prior to intake valve opening**. In either of the Gang fire systems there is no timing-of-event technology in operation, and as you can see it's a rather simple system.

At 8000 RPM the intake valve is opening and closing at 66 times a sec. and is only open for an average of 9 Mil/Sec. At this cyclic rate the transient time to complete the delivery of fuel from injector to valve, is critical. This is why Indy car injectors are very precisely targeted and *timed to provide a solid stream of fuel with non-existent atomization*, LBDS - Laser Beam Delivery System. In these engines the injectors can discharge fuel, at a "**just prior to valve open position**" and get it all down the hole. *As the fuel impinges the hot intake valve it virtually vaporizes and mixes quite well with the incoming air forming a very homogeneous charge*. This is one of the most extreme situations but it's a real interesting one. As an added benefit, the latent heat of fuel vaporized in the chamber also provides charge cooling that makes the mixture denser. *A denser, heavier mixture (cold and thick) will produce more power then a thin (hot and light) charge*. This is why Turbo intercoolers are so effective. Injector timing, phase angle, is altered by the ECU according to RPM in these systems and can control the delivery impact time precisely. In a Steady State Pressure Fuel System, the injector pulse is always moving at the same speed, regardless of engine speed changes. The velocity of discharged fuel is relevant to the area of the discharge port and the net operating pressure. Pressure changes activated by boost, at a 1:1 ratio, only compensate for port pressure and don't change the static pressure, flow rate or velocity. RPM adjusted fuel timing is utilized for this reason, it advances the injector timing based on engine speed, and maintains perfect impingement timing at all speeds.

It's a known fact that you can't burn fuel until it's atomized. It's also known that you can't burn fuel without air. The most important, of all known facts is that you can't burn anything, if it's not in the combustion chamber. The secret is to provide 'adequately atomized' fuel with as much air as possible. 'Adequately atomized' is the secret phrase of the day. *Fuel does not have to be completely atomized at the injector tip* (SMD of 10um - 20um) but it does have to get past the valve to do us any good. The more condensed the fuel delivery is the faster it will travel, (regulated by discharge area and pressure) and the more accurately it can be targeted. Recent (S.A.E.) "Injector Atomizing and Targeting" studies have provided us with one of the most prominent advances in High Performance Engine Management. These test programs have concluded that "accurate impingement onto the center of the valve head is vital for good vaporization" and "the targeting orientation of the injected fuel spray is a critical parameter in fuel evaporation" also that "fuel injected directly onto the intake valve yields a significantly better engine response" (SAE950506) What all this means is, different engine designs require a different type of injector to operate efficiently and that *100% atomization is not always required or desired*. In racing situations we usually have to do the best we can with what we have or what's available. The goal, of course, is to do the best in all cases and in all situations. The best injector for your engine is the one that will yield an optimal fuel-air mixture and provide the required power output consistent with smooth and reliable operation. This is our goal, and all things considered, we feel that we provide an excellent service in this very specialized field.

The Art of Fuel Injection

Written by Don Guhl

http://www.600scene.com/index.php/articles/tech-talk-mainmenu-59/71-the-art-of-fuel-injection

Fuel injection offers a powerful, low maintenance alternative for 600cc micro sprint racing. It is important to choose the fuel injection system that is appropriate for your needs. After carefully choosing your fuel injection system, proper tuning is imperative. Maintaining the optimized performance that you attained from dyno tuning requires a basic maintenance program. With a few simple weekly steps, you can keep your system in top notch condition.

Fuel Injection vs. Carburetors

In the past, carburetors ruled the track, but made tuning difficult with often substandard results. Fuel injection is the perfect solution to the "carburetor headache" that we've become so accustomed to. With the appropriate knowledge and a good technical support team, even the novice racer can find great success with fuel injection.

There are several fundamental differences between carburetors and fuel injection. Though both may be capable of similar peak horsepower numbers, actual "on-track" performance characteristics vary greatly. On track performance begins with a strong tuning program. When tuning carburetors, there are very limited tuning opportunities for wide-open-throttle adjustments, mostly limited to main jet changes. Conversely, fuel injection allows a tuner to make adjustments at every 250 RPM's in addition to 10 throttle positions. Successful fuel injection tuning requires little or no compromise. Carburetors force you to compromise between reach and lean areas in the fuel curve to find that "happy medium". In order to make some areas run at optimum performance, it causes the tuner to compromise the fuel curve with other areas being too rich and/or too lean. A fuel injection system allows the tuner to make far fewer compromises due to the highly increased adjustment capabilities.

Fuel Injection vs. Carburetors on the Dyno

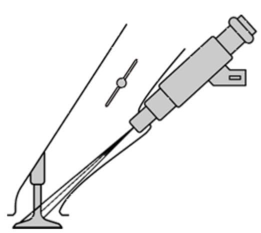
Note that the dotted green line (fuel injected air/fuel curve) remains virtually constant from the beginning of the pull to the end. The solid green line (the carbureted air/fuel curve) starts out overly rich, quickly falls to the lean side, and then ends the pull balanced.

Now compare the dotted blue line (fuel injected torque) with the solid blue line (carbureted torque). The torque curve on the injected engine is much broader which leads to superior performance on the track.

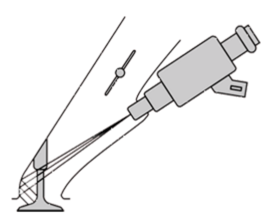
Carburetors must be re-jetted for altitude and atmospheric changes. This includes adjusting air/fuel for simple changes in the weather. Properly tuned fuel injection systems have sensors that direct the computer to automatically adjust for these changes with no need to retune at all. Fuel injection systems have the ability to “self-preserve”, meaning that if something happens to cause the engine to overheat, the system will detect this condition, it will automatically make changes, like add additional fuel and retard the timing to preserve the engine for as long as possible. Carbureted systems have no ability to “self-preserve”.

Fuel Injection System Selection

Making the most out of a fuel injection system begins with the system selection. Not all fuel injection systems are the same and there are many things to take into consideration before making a purchase. The most important part of any fuel injection system is the actual injector and its placement. It’s extremely important that the injector’s placement allows it to aim fuel directly at the intake valve. The fuel vaporizes when it makes contact with the hot valve, delivering the entire, finely atomized, fuel load into the cylinder. If the injector is not aligned properly or has an incorrect spray pattern, it will deliver fuel directly against the intake wall causing a poorly atomized fuel mixture, as well as inconsistent and poor combustion.



Correct Injector Angle



Incorrect Injector Angle

Contrary to popular belief, an injector's spray pattern and its actual atomization are two seperate entities. A wide spray pattern does not automatically lead to efficient atomization, nor does a narrow spray pattern. More importantly, injector design and fuel pressure determine the level of atomization in a fuel injection system. In very high RPM engines a narrow spray pattern provides better performance in the useable racing RPM range (8,000 to 15,000+RPM). Wide spray patterns provide better performance below 6,000RPM, well below the useable racing RPM range. Even on a track that uses the broadest RPM range, injectors with a narrow spray pattern will still be a better choice.

Another important aspect of the injector is its response time, or the time it takes to open once energized. At 15,000 RPM, the injector has only 4 milliseconds to deliver its entire fuel load while the intake valve is open. The stock fuel injector only takes 1 millisecond to open, while some of the older, larger design injectors with their heavy internal parts take up to 1.8 milliseconds to open. That takes up nearly half the time available to deliver the fuel load and much too long for optimum high RPM performance. Due to cost and availability, these larger, old-style injectors are widely used in *most* fuel injection conversion systems. It's also important that the fuel flow rates are closely matched across all injectors in the system. This maintains even fueling across each cylinder allowing air/fuel ratios to remain constant while maximizing efficiency. It is also extremely important that the injector selected is appropriate for your fuel requirement. For example, if you use alcohol to fuel your racecar it is important that the fuel injectors selected are appropriate for use with alcohol. Finally, electrical compatibility is a must in order for your system to function properly. The stock fuel injection controllers are designed for "saturated" injectors. These injectors have a high coil resistance (12 to 18 ohms) and only draw about 1 amp. The other type injector is a peak/hold injector. These injectors have a low coil resistance (1 to 5 ohms) and require a special injector driver circuit for proper control. If a peak/hold injector is used in a system designed for a saturated injector, the injector driver circuit can be permanently damaged.

In conjunction with the proper injector selection is fuel rail selection. Each fuel rail must be custom designed to handle the increased fuel requirements and hold the injector in place securely. A large plenum fuel rail is also important for even fuel flow to each injector. The stock fuel rail will not be able to supply the additional fuel required in an alcohol system. The fuel rail must allow for proper injector alignment and hold the injector securely.

Single vs. Dual Fuel Injection

Depending upon your particular set of rules, you may be able to choose between single or dual fuel injection systems. Single injection systems offer one injector near the intake valve. Most stock systems are single injection. Dual Injection offers one injector near the intake valve and one injector above the intake stack very far from the intake valve. Dual injection systems may be offered as an upgrade to older model engines or they may come stock on the newer generation of engines.

In a dual injection system, when the injector above intake stack is activated, the fuel travels much further and has more time to vaporize and take more heat out of the air. This generates increased mid-range performance. The lower injector is used for low rpm cruise and supplies additional fuel during quick throttle movements for best throttle response.

Adding dual injection to a single injection system always increases power in the mid-range. This increase in mid-range power can be valuable in two ways. First, the system can be left as-is to allow maximum benefit exiting the turn. Secondly, the engine can also be mechanically tuned for more top-end performance which would normally decrease the mid-range power, but since the dual injection adds mid-range power, there is no loss in mid-range power.

Fuel Injection System Optimization

After a fuel injection system has been selected, there are still several steps to optimization. Though system selection is very important, dyno tuning and proper maintenance is the key for success. A good system can run poorly when it has been set up improperly or if maintenance is neglected. Dyno tuning is the most efficient method for optimizing power. Since there is no such thing as a "generic" fuel curve or fuel map, dyno tuning each system individually is very important. You will want to be sure that the tuner you select is knowledgeable in your specific application and understands the importance of broad power curves and the theory behind internal combustion engines. Though it is easy to tune a system for high peak numbers, it is much less simple to tune for drivability and overall performance. You will also want to be sure that the dynamometer is best suited for your application. Choosing the right dyno will eliminate inconsistencies of the testing/tuning process. Be sure that you are tuning for all variables in the entire system so that maximum power can be achieved; these include fuel curve, intake stack length, exhaust system, ignition/cam timing, and air box. When you leave the dyno, you will not only have optimized your fuel curve for peak performance and maximum drivability, but you will also know prior to race day that your system is operating correctly.

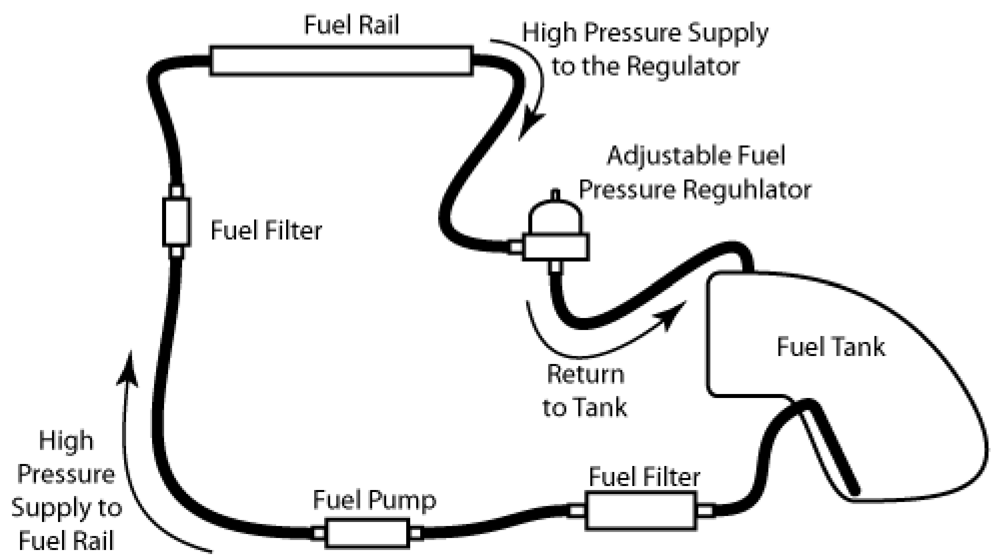
During the tuning process, your tuner should be asking questions about the type of track you race on and the driver's experience. These are all factors that contribute to optimal tuning. Generally tuning for the "big" peak-power numbers does not make the best race engine. Big peak-power numbers are usually attained by sacrificing mid-range power which hurts the all-important corner exit performance. Different tracks and driving styles require different power curves. A track with long straights and tight turns requires very wide power curves that drive the car out of the turn and continue to pull to the end of the straight. Small tracks with sweeping turns and short straights might require a more narrow power curve for best performance.

Fuel Injection System Maintenance

In order to keep your system in top condition, proper maintenance is required. Luckily, maintenance on a fuel injection system is considerably easier than what is required for a carbureted system. Most importantly, don't change anything. Your fuel map was optimized for your particular combination and changing any part of that could significantly decrease performance. In particular, your system was tuned in accordance with your exhaust, injection setup, airbox, fuel pressure, cam timing, and compression. Any of these, if altered, would likely harm performance. Weekly maintenance is also very important. You should flush your system with straight gasoline (absolutely no 2-stroke oil should be used) directly after each weekend of racing. This entails five simple steps:

- Disconnect the return line and put it in an empty jug.
- Disconnect the feed line from the tank and connect to a gas can
- Run the pump until gas exits the return
- Start/run the engine for about 5 seconds
- Disconnect gas can and cap the lines

Inspecting the system weekly (as well as careful initial installation) is also important for maintaining reliability. Be sure that all electrical components are mounted with the plug facing down to prevent water from gathering in the connector. Inspect all wiring weekly for loose, bad, or corroded connections. Pay special attention to the switches. You will also want to clean and inspect the primary fuel filter weekly.



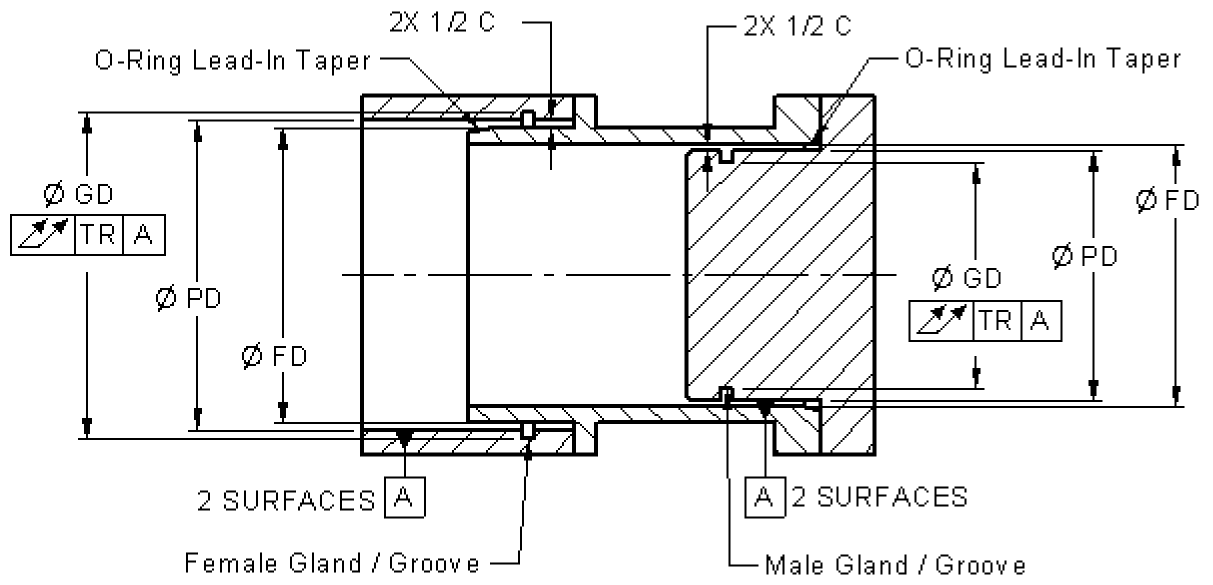
Overall, fuel injection can be a much less complicated solution than carburetors. It increases tuning opportunities while decreasing maintenance. When an injection system is properly tuned, there is no need to make changes for altitude or atmospheric conditions. For additional information on fuel injection, please feel free to contact Guhl Motors at 717-625-1411 or visit us online at www.guhlmotors.com. In addition to our winning line of fuel injection systems, we also offer "best-in-the-business" dyno tuning services, wire harness conversions, vehicle wiring systems, and full service fuel injection repair, as well as a variety of quality accessories.

O-ring Sizing:

The following chart gives typical gland dimensions for common o-ring sizes. Please consult with your o-ring manufacturer for custom or application specific requirements.

To use this document, first identify if you have a female or male o-ring gland requirement. From the chart below, identify your nominal or-ring desired size, then your o-ring gland depth and runnout requirements. After you have verified your nominal o-ring size functionality within your assembly, specify / design your o-ring groove/gland.

Male and Female O-Ring Gland / Groove Installation



Female O-Ring Gland

GD max = FD min + 2L max
or
2L max = GD min - PD min

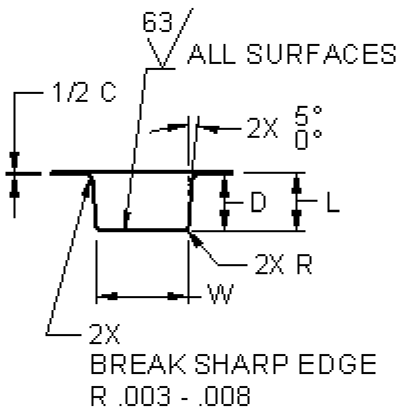
Male O-Ring Gland

GD min = FD max - 2L max
or
2L = PD max - GD min

Where:

GD = Gland Diameter
PD = Pipe Diameter (adjacent to gland)
FD = Fit Diameter (cylinder which o-ring mates against)
C = Clearance
C = PD - FD for Female Gland Cylinders
C = FD - PD For Male Gland Cylinders

O-Ring Gland / Groove Detail



Where:

W = Width at bottom surface intersection of groove
L = Gland Depth, distance from mating surface.
D = Actual depth of groove in part containing gland / groove
C = Radial clearance between mating parts.
R = Radius

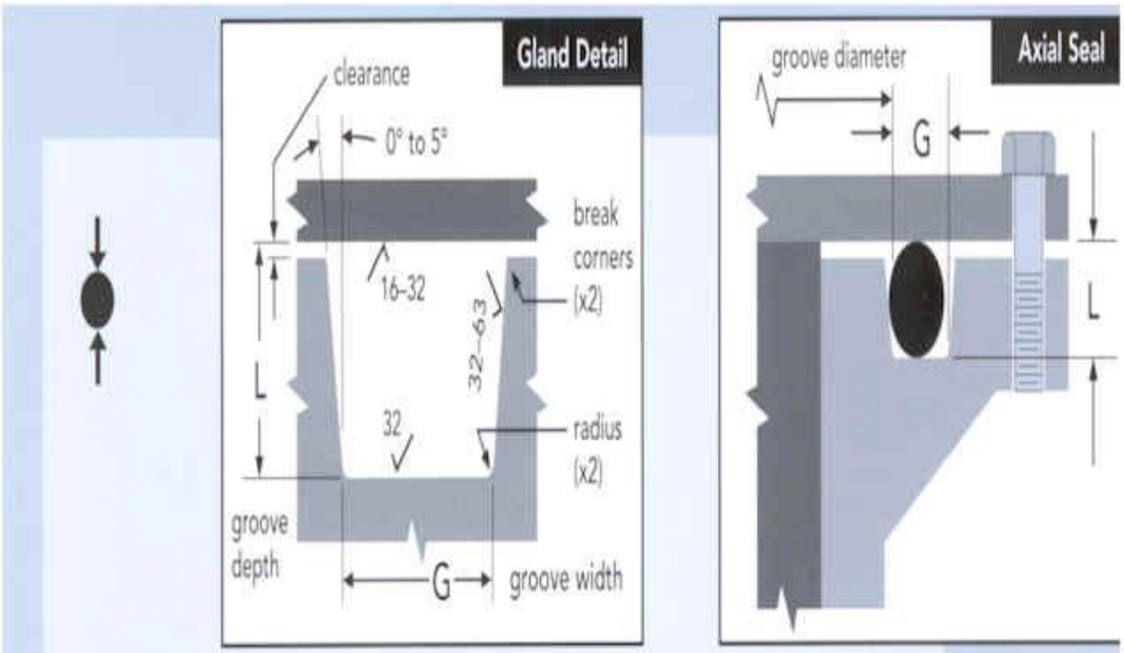
Typical O-Ring Static Seal Glands / Grooves
See "Gland / Groove Detail" above

O-Ring Nominal Diameter	Actual Diameter	Gland Depth (L)	Compression Actual	Compression %	Diametric Clearance (C)	Gland / Groove Width (W)	Groove Radius (R)	Total Runout Maximum (TR) (1)	Total Runout Maximum GD relative to FD (2)
1/16	**.070 ± .003**	**.050 to .052**	.015 to .023	22 to 32	.002 to .005	.093 to .098	.005 to .015	.0010	.002
3/32	.103± .003	.081 to .083	.017 to .025	17 to 24	.002 to .005	.140 to .145	.005 to .015	.0010	.002
1/8	.138± .004	.111 to .113	.022 to .032	16 to 23	.003 to .006	.187 to .192	.010 to .025	.0015	.003

3/16	.210± .005	.170 to .173	.032 to .045	15 to 21	.003 to .006	.281 to .286	.020 to .035	.0020	.004
1/4	.275± .006	.226 to .229	.040 to .055	15 to 20	.004 to .007	.375 to .380	.020 to .035	.0025	.005

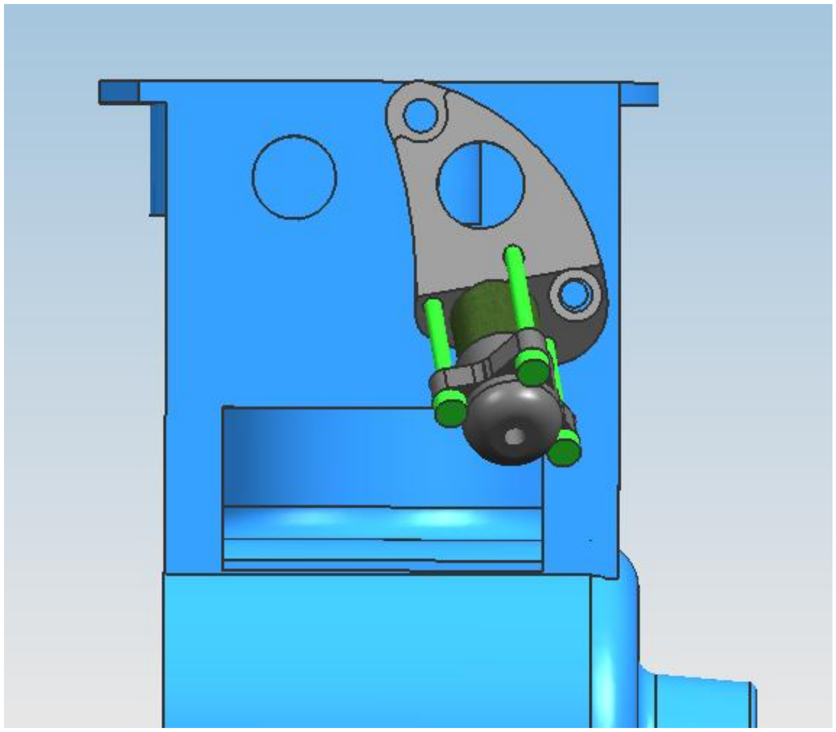
(1) This is the total runout (TR) between the o-ring gland / groove and the associated cylindrical feature.
(2) This is the total runnout between contacting cylindrical surface FD and the o-ring gland diametral contacting surface.

Static Glands - Axial (Face)

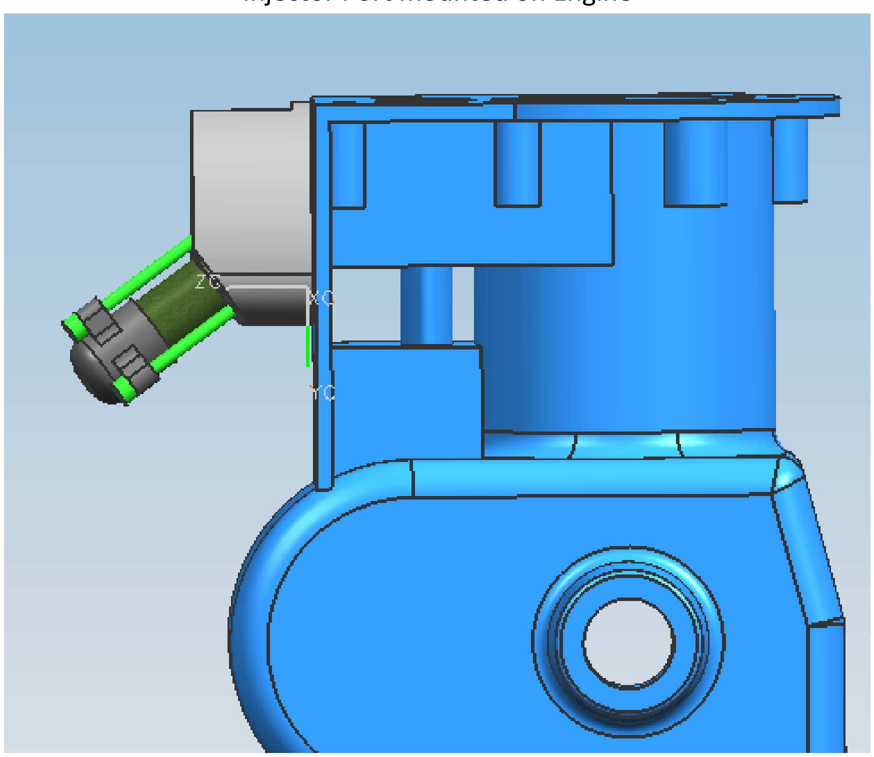


O-ring Gland Design Table for Industrial Static Axial (Face) Seals

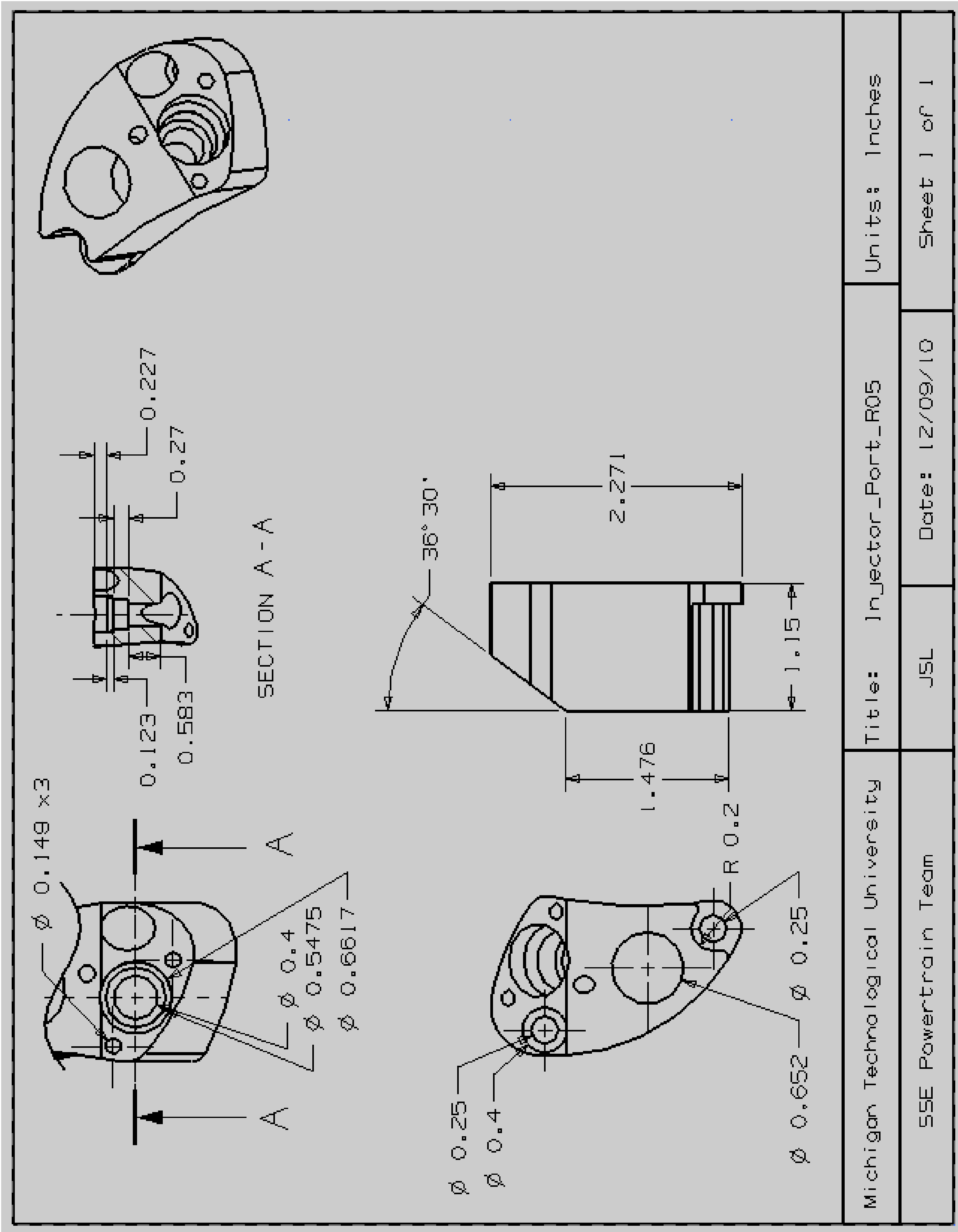
		GLAND DIMENSIONS									
AS 568 SIZE	CSD (inches)	L-Depth (inches)	+/- (inches)	G-Width (inches)	+/- (inches)	L-Depth (mm)	+/- (mm)	G-Width (mm)	+/- (mm)	CSD (mm)	AS 568 SIZE
-000	0.070	0.052	0.002	0.088	0.002	1.32	0.05	2.24	0.05	1.78	-000
-100	0.103	0.081	0.002	0.122	0.003	2.06	0.05	3.10	0.08	2.60	-100
-200	0.139	0.112	0.003	0.162	0.004	2.84	0.08	4.11	0.10	3.53	-200
-300	0.210	0.172	0.004	0.244	0.006	4.37	0.10	6.20	0.15	5.30	-300
-400	0.275	0.233	0.006	0.312	0.008	5.92	0.15	7.92	0.20	7.00	-400



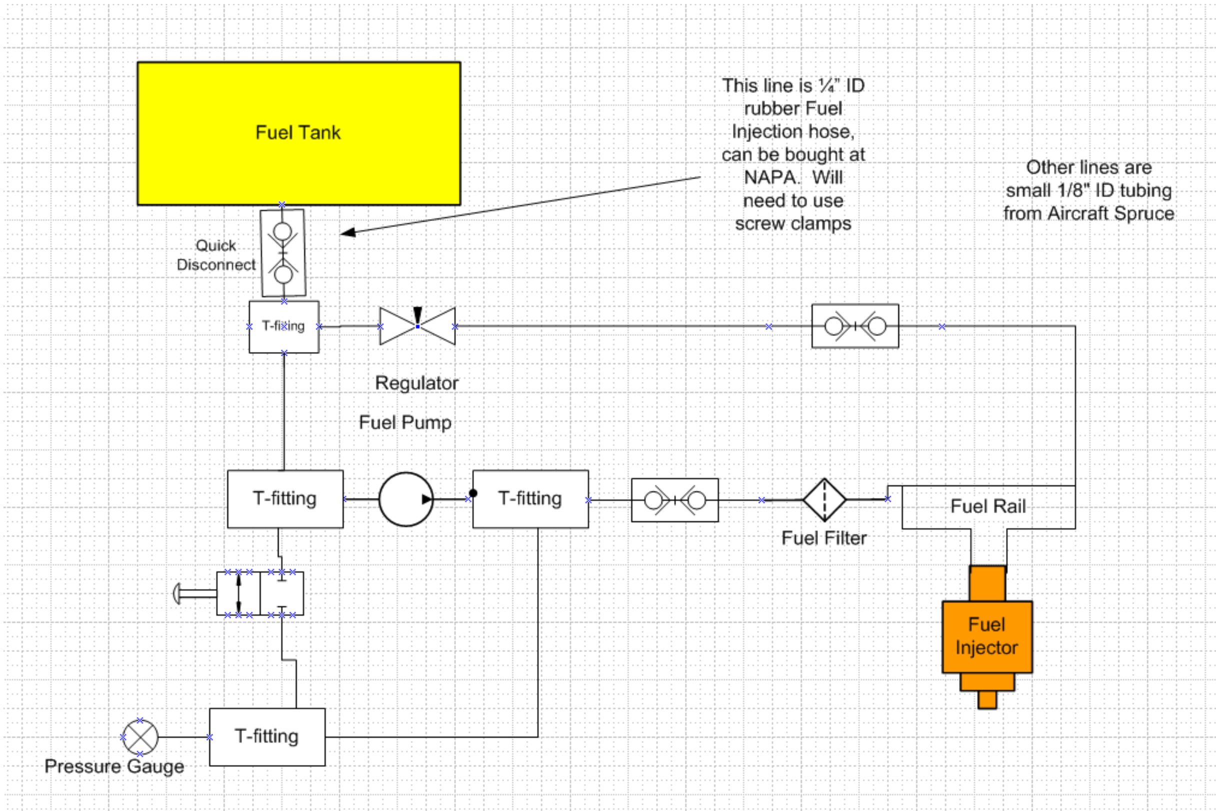
Injector Port mounted on Engine



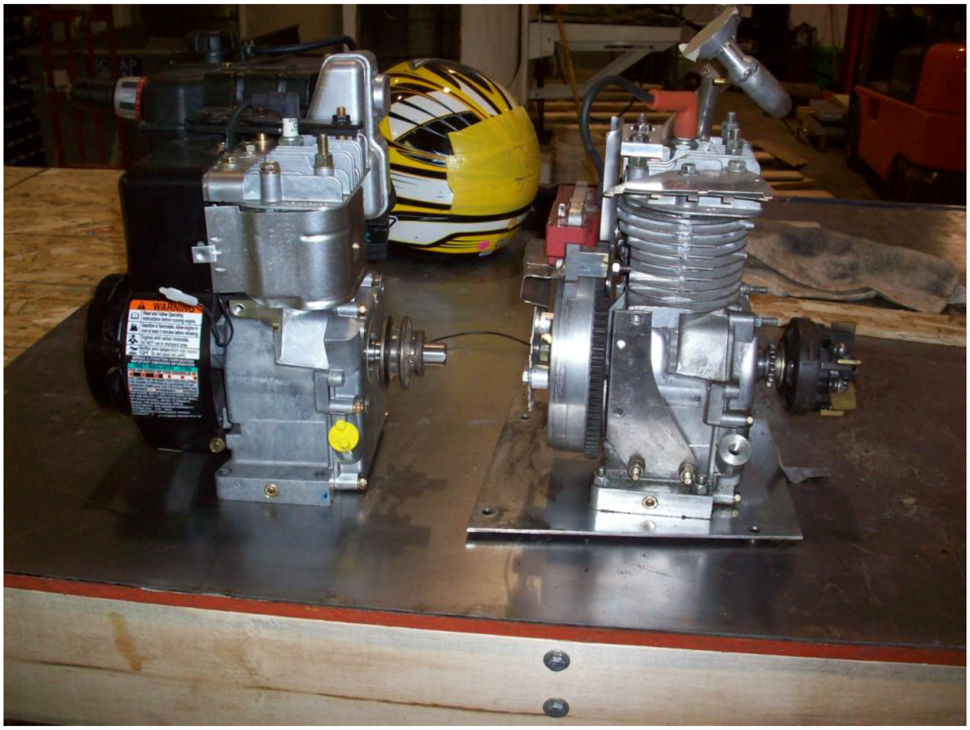
Injector Port mounted on Engine (Side View)



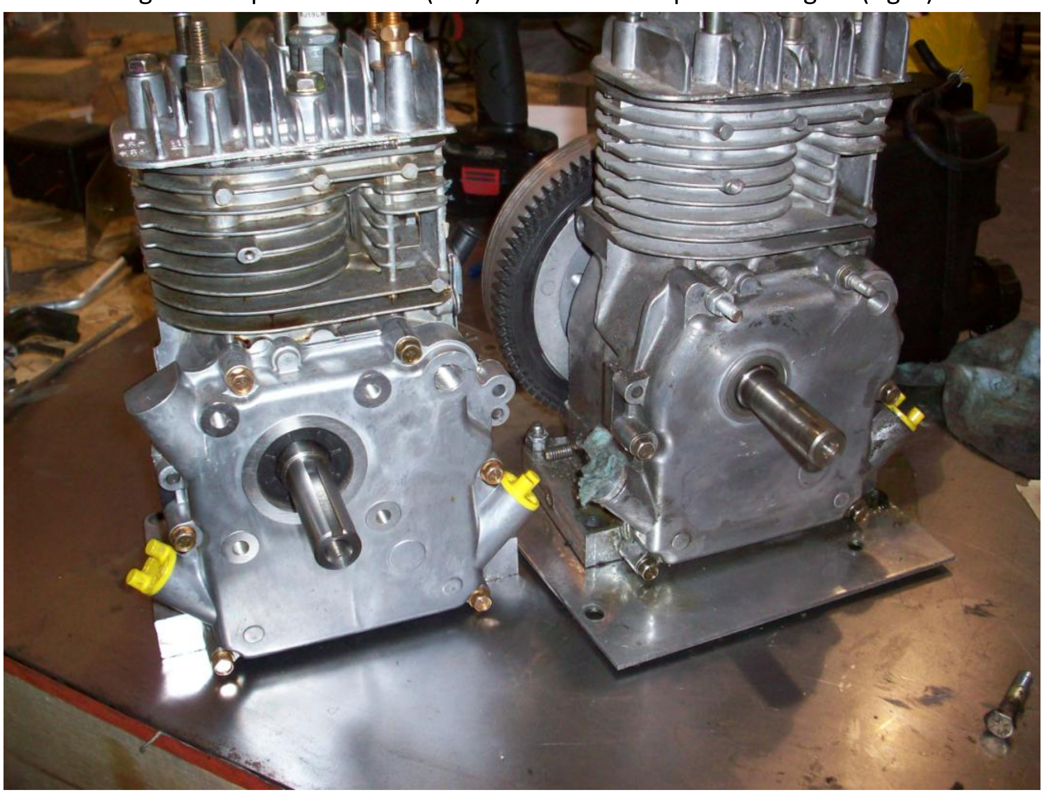
Injector Port Drawing



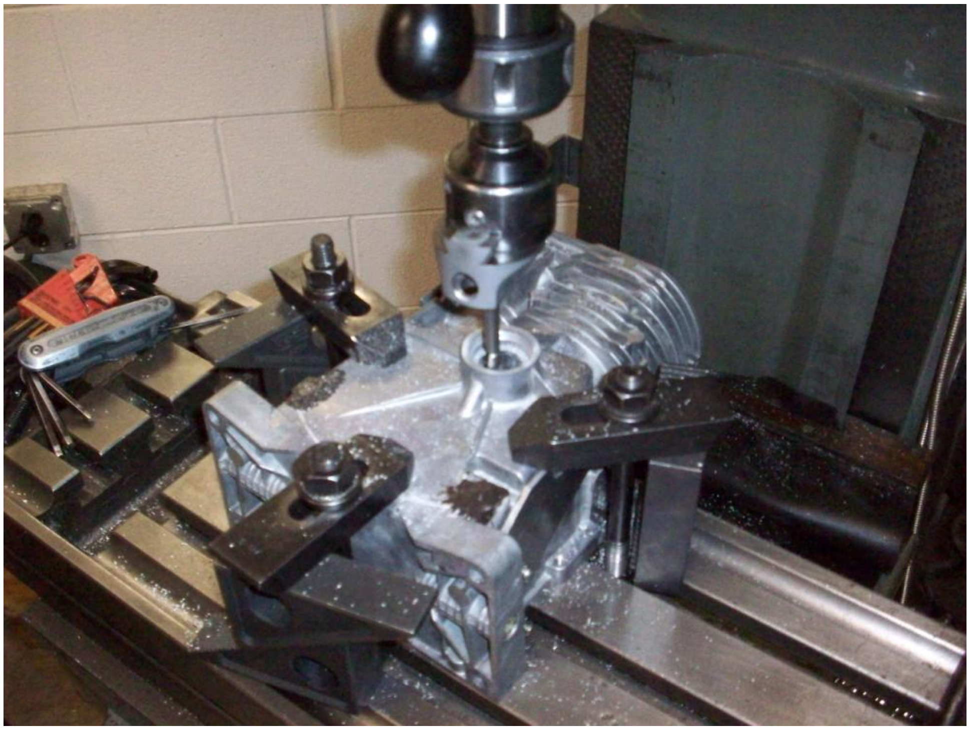
Schematic of Fuel System



Engine Comparison: Stock (left) vs Current Competition Engine (right)

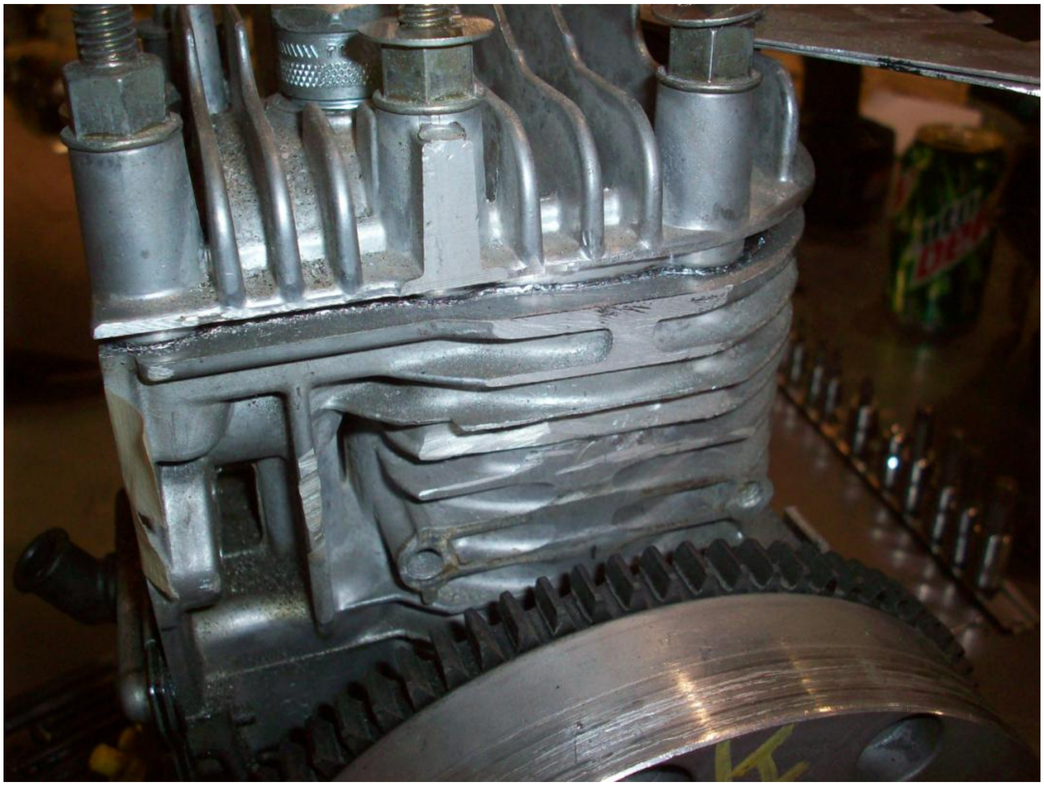


Engine Comparison: Stock (left) vs Current Competition Engine (right)



Machining new Competition Engine Seal Pocket

New Seal Pocket



Machined Competition Engine Fins to allow Ignition Mount fitment

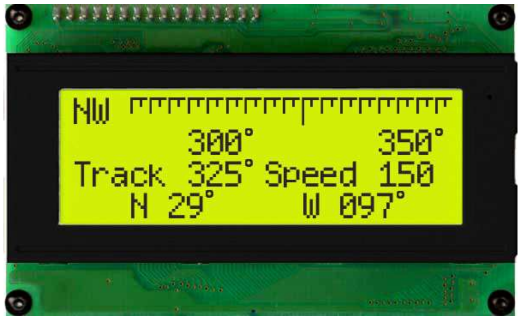
MATRIX ORBITAL

LK204-25
Technical Manual

Revision: 2.1

Contents

1 Getting Started



The LK204-25 is an intelligent LCD display designed to decrease development time by providing an instant solution to any project. With the ability to communicate via serial RS-232/TTL and I^2C protocols, the versatile LK204-25 can be used with virtually any controller. The ease of use is further enhanced by an intuitive command structure to allow display settings such as backlight brightness, contrast and baud rate to be software controlled. Additionally, up to thirty-two custom charaters such as character sets for bar graphs, medium and large numbers may be stored in the non-volitile memory to be easily recalled and displayed at any time.

1.1 Display Options Available

The LK204-25 comes in a wide variety of colors including the standard yellow/green or inverse yellow, the popular blue/white and the crisp white/grey as well as inverse red which is excellent for viewing at night. Extended voltage, and temperature options are also available, to allow you to select the display which will best fit your project needs.

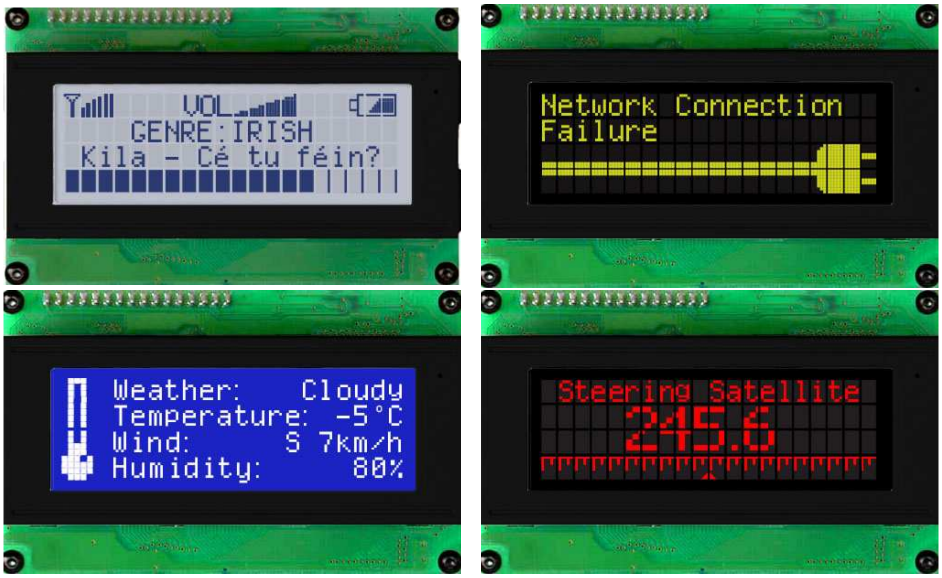


Figure 1: LK204-25 Options

1.2 Accessories

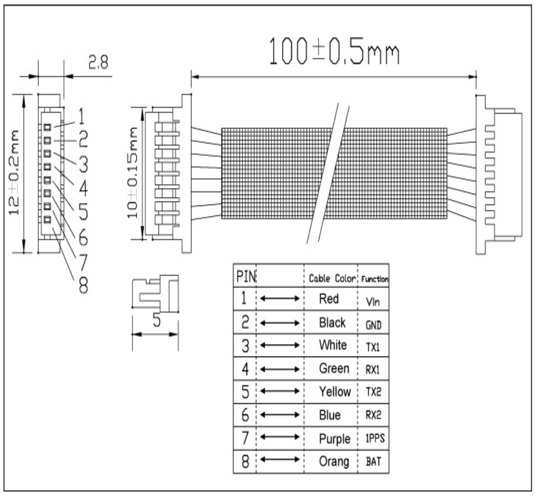
NOTE Matrix Orbital provides all the interface accessories needed to get your display up and running. You will find these accessories and others on our e-commerce website at http://www.matrixorbital.com. To contact a sales associate see Section 14.6 on page 58 for contact information.

Figure 2: 5V Power Cable Adapter

Figure 3: 12V Power Cable Adapter (V/VPT Models)

GPS Engine Board

Model: FV-M8



Specifications:

PHYSICAL CONSTRUCTION	
Dimension	L30mm*W30mm*H8.6mm
Weight	15 grams
Receiving frequency	1575.42MHZ; C/A code
Connector	8pin connector with 1.0mm pitch
Mounting	Soldering

PERFORMANCE		
Built-in Antenna	Highly-reliable ceramic patch	
Sensitivity	-158dbm	
SBAS	1 channel (Support WAAS, EGNOS, MSAS)	
DGPS	RTCM Protocol	
Receiver architecture	32 parallel channels	
Start-up time	Hot start	1 sec. typical
	Warm start	35 sec. typical
	Cold start	41sec. typical
Position accuracy	Without aid	3.3 m CEP
	DGPS (RTCM)	2.6 m

San Jose Technology, Inc. | 11F., No.2, Sec. 4, Jhongyang Rd., Tucheng City, Taipei County 236, Taiwan (R.O.C.) | Tel: 886-2-22694456 | Fax: 886-2-22694451 | sanav@sanav.com

SANAV

Construction	Full EMI Shielding	
ENVIRONMENTAL CONDITIONS		
Temperature	Operating: -30 ~ +80 ℃	
	Storage: -40 ~ +85 ℃	
COMMUNICATION		
Protocol	NMEA V3.01	
Signal level	UART @ 2.8V * 2	
INTERFACE CAPABILITY		
Standard Output Sentences	Default	RMC, GGA, GSV*5, VTG, GSA*5
	Optional	GLL, ZDA

Velocity accuracy	0.1 Knot RMS steady state	
Update Rate	1 ~ 5Hz	
Power Supply	3.3~5V +- 5%	
Current Consumption	Acquisition	63mA
	Tracking	59mA (first 5 minutes)
		42mA (after 5 minutes)
		33mA (after 20minutes)
Baud Rate	4800 bps (default) & 4800/9600/38400/57600/115200 bps are adjustable	

M100 User Guide (C API)

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Foreword

Before using OpenECU, it is very important to read and understand the warning and safety information given in Section 1.3, “Warning”.

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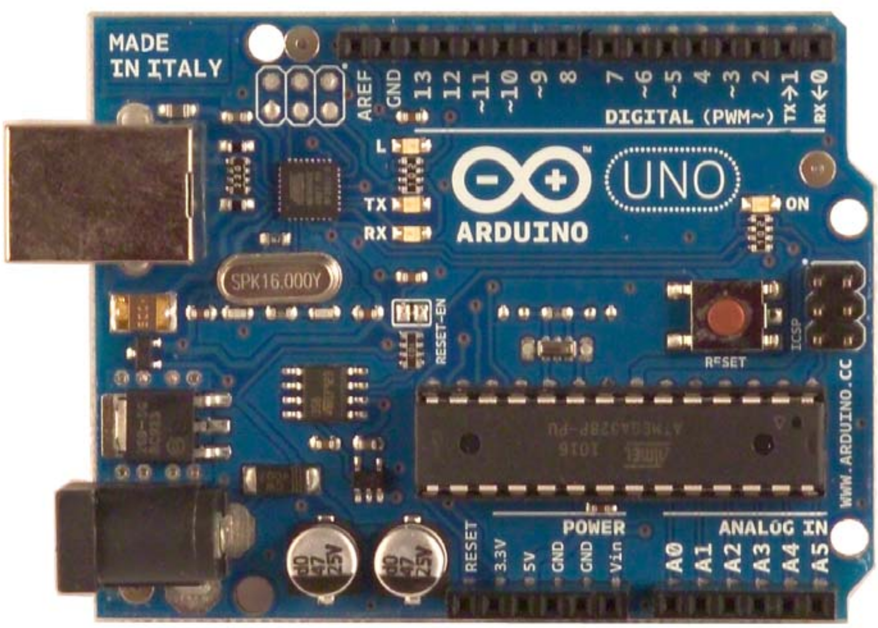
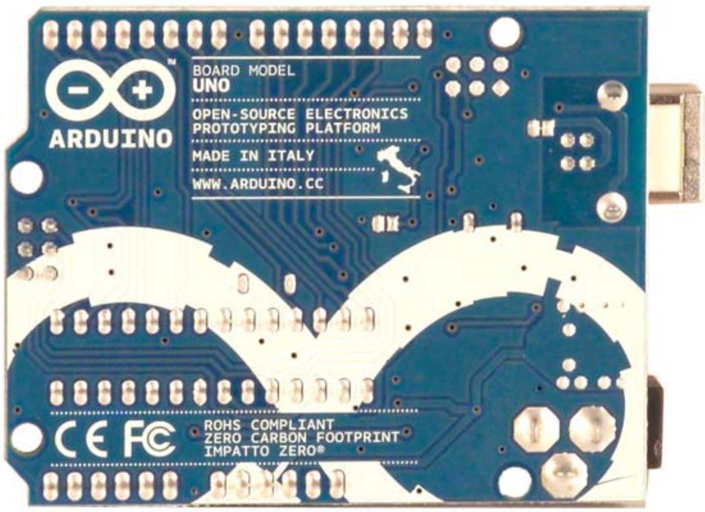
Arduino Uno





Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader

SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Schematic & Reference Design

EAGLE files: arduino-uno-reference-design.zip

Schematic: arduino-uno-schematic.pdf

Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The ATmega328 has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.

- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.

- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.

- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication using the SPI library.

- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **I^2C: A4 (SDA) and A5 (SCL).** Support I^2C (TWI) communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage (**0 to 5V only**) for the analog inputs. Used with analogReference().

- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and ATmega328 ports.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega8U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '8U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. For SPI communication, use the SPI library.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega8U2 firmware source code is available . The ATmega8U2 is loaded with a DFU bootloader, which can be activated by connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader). See this user-contributed tutorial for more information.

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Four screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

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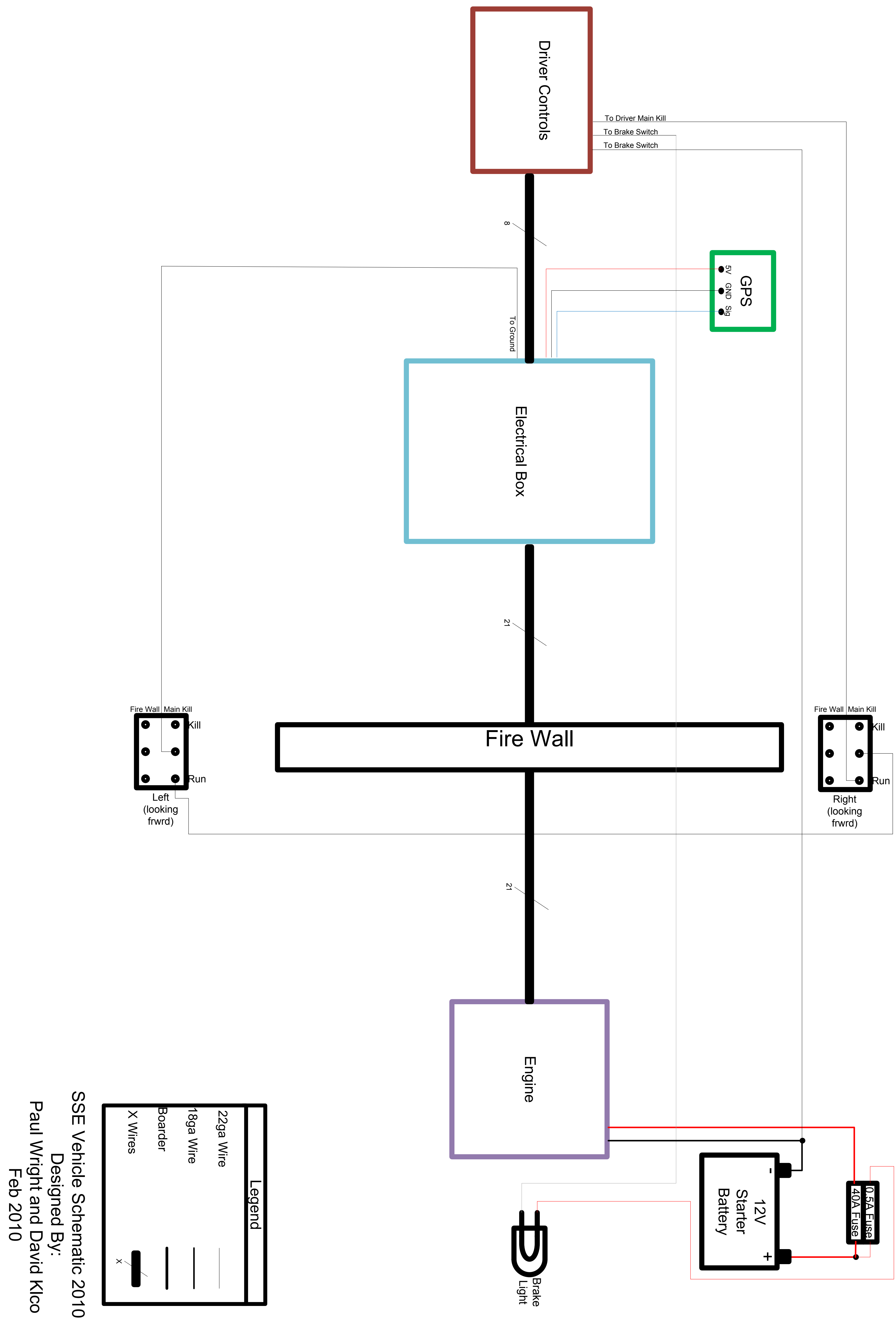
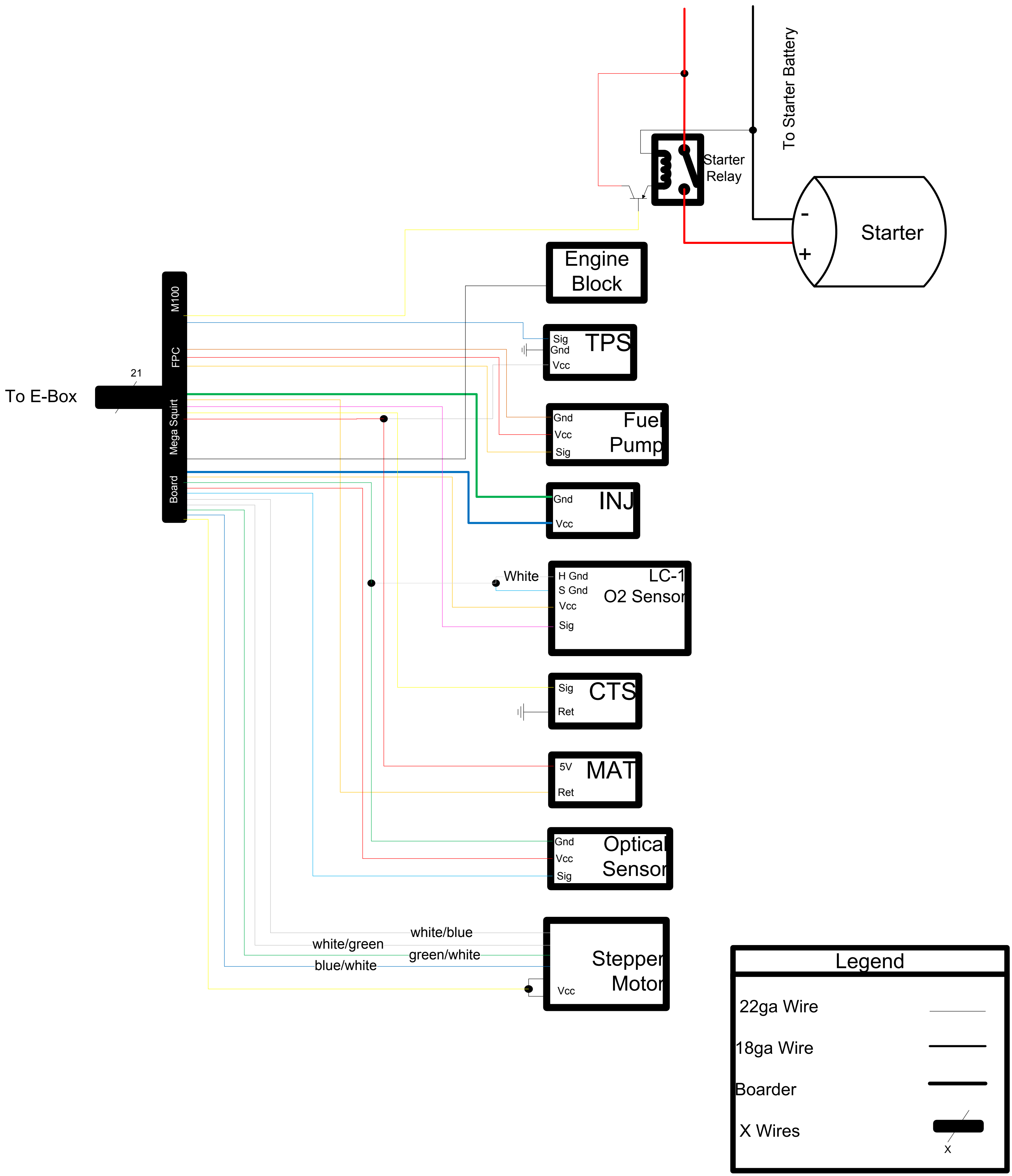

Driver Controls
To Driver Main Kill
To Brake Switch
To Brake Switch
8
GPS
5V
GND
Sig
To Ground
Electrical Box
21
Fire Wall Main Kill
Kill
Run
Left (looking frwrd)
Fire Wall
Fire Wall Main Kill
Kill
Run
Right (looking frwrd)
21
Engine
12V Starter Battery
-
+
0.5A Fuse
40A Fuse
Brake Light
Legend
22ga Wire
18ga Wire
Boarder
X Wires
x
SSE Vehicle Schematic 2010
Designed By:
Paul Wright and David Klco
Feb 2010


Starter Relay
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Engine Block
TPS
Sig
Gnd
Vcc
M100
FPC
Mega Squirt
Board
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To E-Box
Fuel Pump
Gnd
Vcc
Sig
INJ
Gnd
Vcc
White
LC-1 O2 Sensor
H Gnd
S Gnd
Vcc
Sig
CTS
Sig
Ret
MAT
5V
Ret
Optical Sensor
Gnd
Vcc
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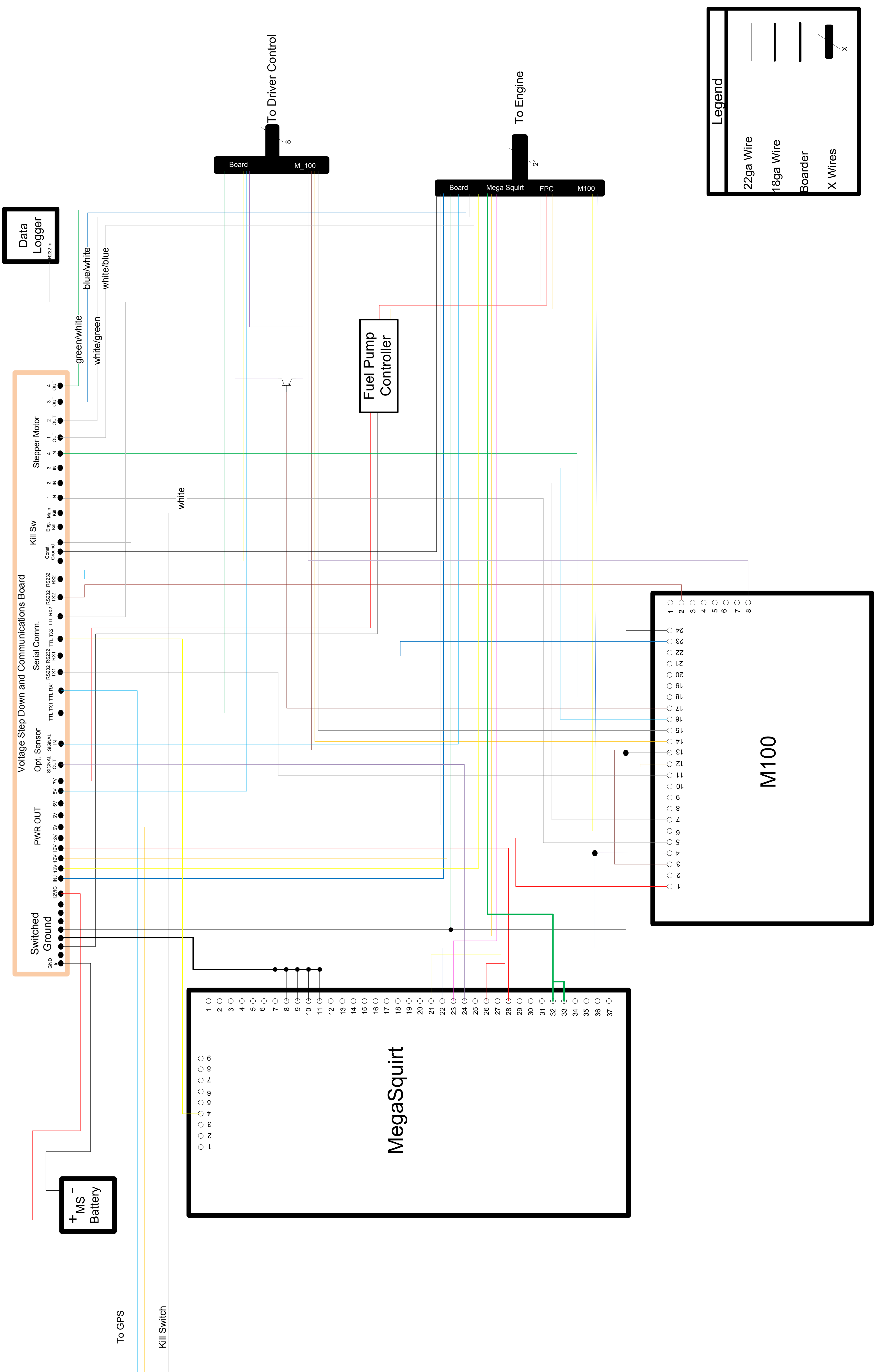
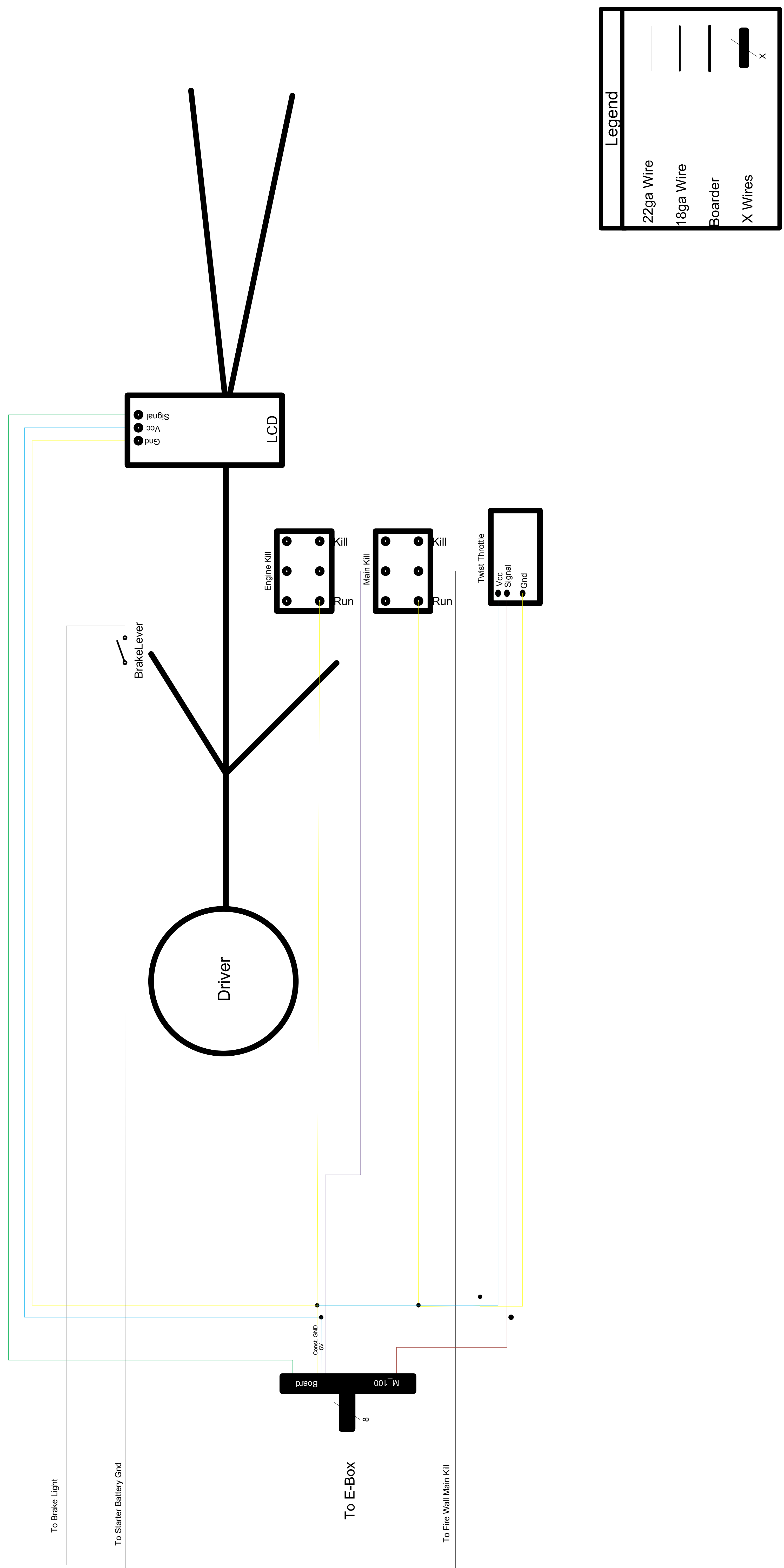
Stepper Motor
Vcc
Legend
22ga Wire
18ga Wire
Boarder
X Wires
X


Legend
22ga Wire
18ga Wire
Boarder
X Wires
x
To Driver Control
8
Board
M_100
To Engine
21
Board
Mega Squirt
FPC
M100
Data Logger
R232 In
blue/white
white/blue
green/white
white/green
white
Fuel Pump Controller
Voltage Step Down and Communications Board
Stepper Motor
Kill Sw
Serial Comm.
Opt. Sensor
PWR OUT
Switched Ground
M100
MegaSquirt
MS Battery
To GPS
Kill Switch


Legend
22ga Wire
18ga Wire
Boarder
X Wires
X
LCD
Signal
Vcc
Gnd
Engine Kill
Kill
Run
Main Kill
Kill
Run
Twist Throttle
Vcc
Signal
Gnd
BrakeLever
Driver
Const. GND
5V
Board
M_100
8
To Brake Light
To Starter Battery Gnd
To E-Box
To Fire Wall Main Kill

September 2010 Monthly Spending Report

Item	Cost	Vendor	CC or Reimbursement ?
General Operations:			
Notebooks	$1.86	Walmart	CC
Competetition Registration Fee	$600.00	SAE	CC
SAE Membership Renewals	$20.00	SAE	CC
Fuel	$10.50	Citgo	R
Powertrain Team:			
Fuel Injectors, 2	$226.35	BikeBandit.com	CC
Body/Chassis Team:			
Bike Parts	$93.94	Nashbar	CC
3 Hutchinson Top Slick 2 Road Tires, $59.97			
7 Speed Cassete, $11.99			
1" Headset, $11.99			
Resin and Hardener SAE Group Buy	$1,634.92	CASS Polymers	CC
Electrical Team:			
Electrical Switch for Testing (on-on switch)	$4.33	True Value	R

TOTALS	
General Operations	$632.36
Powertain Team	$226.35
Chassis/Body Team	$1,728.86
Electrical Team	$4.33
TOTAL SPENT (September)	$2,591.90

October 2010 Monthly Spending Report

Item	Cost	Vendor	CC or Reimbursement ?
General Operations:			
SAE Memberships	$100.00	SAE	CC
Lumber and Hardware for New Shop Table	$104.99	41 Lumber	CC
Notebooks for Design Journals (10)	$13.14	Walmart	CC
Powertrain Team:			
Fuel Injector Testing	$32.59	RC Engineering	CC
50% off discount for MTU Org			
Body/Chassis Team:			
Electrical Team:			
Driver Control Parts	$18.78	Digikey	CC
2 Slide Potentiometers, $5.90			
Thumb Joystick, $3.95			
Replacement LCD Screen	$81.27	Digikey	CC
Compact Slot PMS	$32.72	Sparkfun	CC

TOTALS	
General Operations	$218.13
Powertain Team	$32.59
Chassis/Body Team	$0.00
Electrical Team	$132.77
TOTAL SPENT (October)	$383.49

November 2010 Monthly Spending Report

Item	Cost	Vendor	CC or Reimbursement ?
General Operations:			
Powertrain Team:			
25 mL Buret for Fuel Consumption Testing	$36.31		MTU Purchasing Account
Body/Chassis Team:			
25 mL Buret for Fuel Consumption Testing	$36.31		MTU Purchasing Account
Electrical Team:			

TOTALS	
General Operations	$0.00
Powertain Team	$36.31
Chassis/Body Team	$36.31
Electrical Team	$0.00
TOTAL SPENT (November)	$72.62

December 2010 Monthly Spending Report

Item	Cost	Vendor	CC or Reimbursement ?
General Operations:			
Charcoal for recruit meeting	$9.48	Walmart	R
Powertrain Team:			
1/4 x 1/4 End Mill	$16.29	Fastenal	CC
Body/Chassis Team:			
Bearings for hub and steering	$90.90	VXB Bearings	CC
R4ZZ Bearing 1/4"x5/8"x0.196" Shielded x2, 1.99 each			
R10ZZ Bearing 5/8"x1 3/8"x11/32" Shielded, 5.99			
6903-2RS Bearing 17x30x7 Si3N4 Ceramic:Stainless:Sealed:ABEC-7 x2, 37.00 each			
Digital Calipers added to bearings for free			
Electrical Team:			

TOTALS	
General Operations	$9.48
Powertain Team	$16.29
Chassis/Body Team	$90.90
Electrical Team	$0.00
TOTAL SPENT (December)	$116.67

January 2011 Monthly Spending Report

Item	Cost	Vendor	CC or R
General Operations:			
Cables and Networking Equip for shop PCs	$43.24	monoprice.com	CC
Team Uniforms/Dickies Work Shirts x 9	$135.00	amazon.com	CC
Powertrain Team:			
2x38g/min Fuel Injector for Small Engine	$119.68	MBE Motorsports	CC
Oil, Extension Cords, Surge Protector	$20.84	Walmart	R
Body/Chassis Team:			
3:1 Bevel Gear Set	$73.25	Stock Drive Products	CC
Steel Square tube for Steering .5"x5", 12"	$10.51	mcmaster carr	CC
ACS SouthPaw 16t Left Hand 1/8"	$22.35	Niagra Cycle Works	CC
Electrical Team:			
Electric Twist Throttle	$29.94	scooterpartscatalog.com	CC
Electrical Components for New Board	$61.68	Newark	
Shipping not included in stated cost			

TOTALS	
General Operations	$178.24
Powertain Team	$140.52
Chassis/Body Team	$106.11
Electrical Team	$91.62
TOTAL SPENT (January)	$516.49

February 2011 Monthly Spending Report

Item	Cost	Vendor	CC or R
General Operations:			
SAE Memberships	$20.00	SAE	CC
SAE Memberships	$80.00	SAE	CC
Powertrain Team:			
Fuel System Brass Barbed Male Adapter x8	$25.43	plumbingsupply.com	CC
Body/Chassis Team:			
4043 Al Welding Rod	$14.94	weldingsupply.com	CC
Wheel parts+overnight shipping	$49.55	jensonusa.com	CC
258mm spokes x50: $22.10			
Spoke nipples x50: $7.50			
1 Tire, 7 Tubes	$55.92	nashbar.com	CC
Hutchinson Top Slick 2 Road Tire			
Nashbar 26x1.1-1.4 MTB Presta Tube			
Electrical Team:			
ARDUINO UNO Board	$30.25		
price does not include shipping			
Replacement Optical Sensor	$41.29	Omron Electronics	

TOTALS	
General Operations	$100.00
Powertain Team	$25.43
Chassis/Body Team	$120.41
Electrical Team	$71.54
TOTAL SPENT (February)	$317.38

March 2011 Monthly Spending Report

Item	Cost	Vendor	CC or R
General Operations:			
SAE Memberships (Logan W)	$20.00	SAE	CC
Racing Fuel for Engine Testing	$12.72	Krist Oil Company	
Powertrain Team:			
Tuner Studio Software License	$39.95	EFI Analytics	
Oxygen Sensor (Pt # 17014)	$76.34	NAPA Auto Parts	
Body/Chassis Team:			
Gorilla Glue Epoxy for gluing in steering x2	$10.54	Walmart	
Brake Cable and Housing	$12.00	Downwind Sports	
Electrical Team:			

TOTALS	
General Operations	$32.72
Powertain Team	$116.29
Chassis/Body Team	$22.54
Electrical Team	$0.00
TOTAL SPENT (March)	$171.55