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Formula SAE

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Formula SAE

Final Project Report

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Executive Summary

The Formula SAE senior design project was truly unique. This project had been a 5 year long process to design, build, and test a raceable car. The car was this team's prototype. While the original plan for the team was to develop an energy recovery system (ERS), this scope was altered because of the state of the car the team was left with. Upon examination, the car needed a lot of work before it was even going to start. Therefore, without a running car, there was no way of appropriately testing an ERS. Furthermore, had we developed a prototype for the ERS, there would have been no way to truly implement the design. It would only have stood as a proof of concept. Ultimately, the work required to start the car and develop and ERS would be a task that required two teams.

By making the change in scope, the team had been the closest to date to achieving a running car. Currently the car does not start. However, the team was able to get the engine to backfire in an attempt to get it to start. To get the full state, the issue has been identified as the engine control unit's (ECU) inability to get an accurate camshaft sensor reading. With a hardware adjustment, the team was recently able to deliver a reading to the ECU. It outputs a correct square wave, but its periodicity has yet to be tested. The team has left to test the new hardware with the engine. In order to get to the point where the car is in position to start, many major subsystems required re-working. These systems include the wiring of the car, the fuel injection system, and the engine control unit (ECU). First, upon receiving the car, its wiring was incomplete, and very unorganized. This was no easy feat to correct. Furthermore, wiring of the car was particularly challenging because the team had to develop its own wiring schematic that combined the wiring schematics of the 2007 Phazer snowmobile engine and the schematic of the MegaSquirt II ECU. Additionally, the team had to include adjustments to the schematic that included the primary master switch (Required by FSAE rule IC.9.3) and cockpit main switch (Required by FSAE rule IC.9.4). Next, the fuel injection system was not correct. The fuel system that the original snowmobile used was an in-tank fuel system. However, the car requires an in-line fuel system. The differentiation between these two fuel systems was critical because they each require different types of fuel pumps. The state of this subsystem when the team received the car was incorrect. While the set up was correct (an in-line fuel system), the pump used in the system was an in-tank pump. Additionally there was no fuel filter. The team was able to acquire the appropriate pump and a fuel filter for an in-line pump system and completely changed and corrected the fuel injection system. Lastly, the ECU was the most challenging of the subsystems to correct. The ECU acts as the brain of the car. It interprets the sensor readings all throughout the car and responds with signals so that the car can time itself

appropriately, start, and turn-off when it needs to. The first step towards completing the ECU was to install its two daughter boards. These were vital because they help to interpret the certain sensors that are specific to the Phazer engine (i.e. the VR sensor). Next, programming the ECU was critical. While there was a code provided specifically for the Phazer engine, it required tweaking. All of the program installation and critiquing was done through TunerStudio. This was the most challenging of the major subsystems because it was the topic that the team had no prior experience working with. However, the team did extensive amounts of research and had many conversations with experts to understand how to best program and implement the ECU.

It is important to note that this report is written as the car currently sits. That being said, it does not start. However, there is still time for the team to get the car running. The final step towards doing this is to make sure the hardware adjustment carries over appropriately to the final trial start of the car. Once it does this, the engine will have no issue injecting the fuel, and igniting its sparks (both of which have been tested and work). With the current status of the car understood, it is important to note that all design constraints, and applicability codes and standards were met. While the team's most pressing constraint was time and money, neither has put a hindrance on the team working on, and improving the condition of the car. The codes and standards that are most applicable to the team were those provided by the FSAE rule book. However, there were not many regulations that regard getting the car to start. As mentioned it was important to include the master switch and emergency shutoff switch in accordance with the code. However, not much else was required for the team to get the car to start. It will be important for future teams to dive deeper into these standards as they get closer to racing the car. Primarily for the safety of the driver, but also, by not following the rule book, the team will be disqualified. Additionally, it will be helpful for future teams to refer to the design manual produced by this year's team. It will encompass what has been completed by the team and what is left to do to get the car competition ready. Overall, the team progressed greatly with the car and has high hopes for the future of the FSAE senior design project.

1. Introduction

This year's Formula SAE Senior Design Team was originally tasked with developing an energy recovery system (ERS). However, the team had to reevaluate the scope of the project due to the incompletion of the car. This included incorrect wiring of the car, a poorly tuned and coded ECU, the need of a new fuel pump, and several other minor subsystems needing correction. Ultimately, with the car incapable of starting, an ERS system would not be able to be used or properly tested. Therefore, the scope was adjusted to solely get the car engine to start.

In order to get the engine to start, project objectives, design requirements, constraints, and codes/standards all had to be met. While this could seem like a rather basic task, there was a lot of work that needed to be completed to correct previous teams wrongs. Next, the project requirements are all primarily listed in the 2022 Formula SAE rules. In section V (Vehicle Requirements) of the rules, general specifications are listed. Additionally, functional and nonfunctional requirements needed to be clarified:

Functional Requirements:

- The race car shall be able to travel with a maximum piston test speed of 914.4 m/min on the racetrack made for the FSAE competition as stated in IN.10.4.1 of the FSAE rulebook. The subsystems of the car must give the user enough control to participate in the competition.
- The race car shall be built based on the requirements posted in the Vehicle requirements section V of 2021 Formula SAE rules.

Non-functional Requirements:

- The race car must stay intact during a race for the FSAE competition.
- The race car must have seat and lap belts for safety during travel. The seat must follow the standards presented in section T.1.5 “Driver’s Seat” of the *FSAE 2022 Rules.* Also, the lap belts must follow the standards presented in section T.2.3 “Harness Requirements” of the same rulebook.

Interface Requirements:

- The race car must include subsystems such as a steering wheel, accelerator and a speed indicator for user monitoring and control of the vehicle.

ERS Requirements:

- The energy recovery system must store energy mechanically.
- The system should not pose a safety hazard for the driver if the system were to fail.

In order to complete these tasks, and meet the project requirements, constraints needed to be understood and followed. These constraints were developed throughout meetings with the project sponsor and with consideration of the FSAE competition rules. The constraints are as follows:

- The car must be started with the remaining budget of $5155.11 plus the $1200 senior design budget. This budget may change if sponsors or donors invest money into the project.
- Effects of COVID-19 restrictions (waived mid March)
- 2022 Formula SAE Rules

Lastly, the codes and standards were mostly derived from the 2022 Formula SAE rules where there are General Regulations (GR) that include Good Engineering Practices and Rules of Conduct. These regulations are provided to give engineering teams an expectation and an efficient transition into the environment of the competition. Then depending on the subsystem of the design, there are a set of standards to follow to ensure the safety of the drivers and sustainability of the racetrack. This year's team is working on the completion of several systems for which sections D,V, F, T, VE, and IC may be applicable. Other than the competition rules, standards from ASME, ASTM and SAE will also be beneficial.

ASME:

-Inspection Planning Using Risk-based Methods

This standard is useful for analyzing the risk of pressure-dependent vessels. There are also guidelines for general risk management. With building the car, this standard can provide us with information on how to make rational decisions with regards to fragile components.

ASTM:

-Skid Resistance and Road-Surface Texture

This standard will help us identify the proper kinetic friction factor in our car’s wheels for making proper experimental efficiency tests.,

SAE:

-D.1.1 Dynamic Events and Maximum Scores

This standard is used to determine which event the car is applicable for and how many points they are worth.

-V.3.1 Suspension

This set of standards will be used during the application of bushings to the current suspension system.

-F.5.11 External Items

This standard applies to the types of ways parts can be added to the car's chassis. It also describes bracing requirements for all joints on the car.

-T.2.3 Harness Requirements

This standard describes the key features of the harness that must be installed.

-VE.1 Vehicle Identification

This standard describes the extra identification items required on the outside of the car after the new layer of paint has been applied.

-IC.1.1 Engine Limitations

This standard defines the constraints to the engine which we will use to generate our maximum energy output for the engineering analysis.

In order to comply with the design requirements, and the presented constraints, the team decided to focus on three main subsystems: wiring, the engine control unit, and the fuel system. These are fundamental components in making the car start; providing fuel, spark and control. It was assumed that these had significant issues which were preventing the engine from running.

2. Overview of the Final Design

The final prototype for the FSAE senior design project is the car. Furthermore, as mentioned above, this project has been the culmination of 5 years of work (one design team each year). This being said, the team felt as if they were working with a prototype that was incomplete. Due to its incompleteness, the team needed to focus on troubleshooting several aspects of the car, and fixing them along the way. Overall, the final design overview for our prototype is the combination of the several subsystems that were discussed in the previous sections. To reiterate, these major subsystems are the wiring, fuel injection system, and the ECU.

2.1 Wiring Subsystem

Many changes were made to the wire mesh delivered to the team at the beginning of the fall 2021 semester. These changes are summarized in Figure 1 and were made to complete functionality and increase understandability, and totalled to about 21 changes in the wiring, with more than 80 feet of wire removed from the mesh.

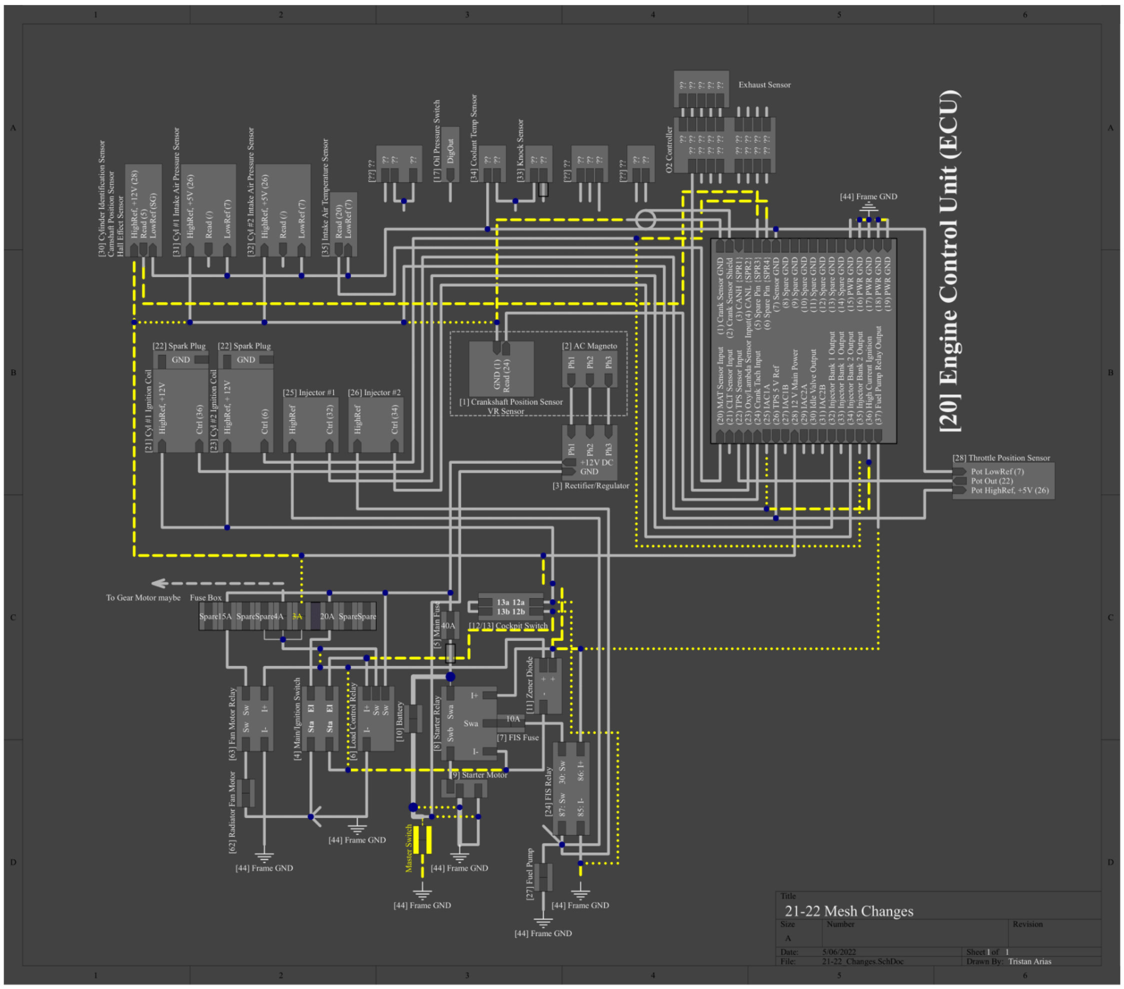

Figure 1. Wiring Changes between the Start and End of the 21-22 Project; New Wire Connections (dashed), Cut Connections (dotted)

Additionally, many diagrams were created to capture the state of the wiring at different chronological points in the project, propose rewirings, and legibly illustrate wiring specification. These included some made to capture the wiring specified by the Phazer engine manual and

illustrate the exact subtractions and changes made from the original snowmobile wiring to that currently in existence.

The creation of these circuit diagrams, in addition to that of a cleaner, updated circuit diagram of the wiring as specified by the Phazer engine manual, both in the style of the Phazer manual itself, and in the CircuitMaker style as seen in Figure 1, was accomplished in order to further increase legibility of the wire mesh, easing the on-boarding of new members to the team, and to aid in the future overhaul and reconstruction of the wire mesh necessary for FSAE competition. Different styles were pursued in order to increase options given to a future individual on approaches to organization and representation to aid in the understanding of the circuit.

Many of these diagrams were made in the CircuitMaker program, leveraging its graphical circuit design features. With those made in the style of the Phazer engine manual circuit diagrams done in Adobe Photoshop.

Functional changes to the mesh included the following:

- The removal of a fuse box bypass created by an improper wiring of the load control relay [6]
- The rewire of the non-functional engine stop switch [12] to function as a cockpit main switch as per FSAE 2022 rules section IC.9.4
- Electrical isolation of the rectifier/regulator [3] and battery [10] grounds from the starter motor [9] grounds in order to install a master switch which allowed the disabling of all power in the circuit as per FSAE 2022 rules section IC.9.3
- Pinout changes on several components including the crankshaft position sensor [1], camshaft position sensor [30], throttle position sensor [28], and cylinder ignition coils [21,23] to allow for proper control and voltage reference for these components.
- Rerouting of the ECU pin (28) +12V main power line to enable the ECU to receive power
- Rewire of main switch [4] and related wires to enable proper start mode functionality and disable fuse box main power bypass

The necessity of these changes to the mesh were identified largely by cross-reference with the circuit diagram specified in the Phazer Manual, a modified version of which can be seen in Figure 2.

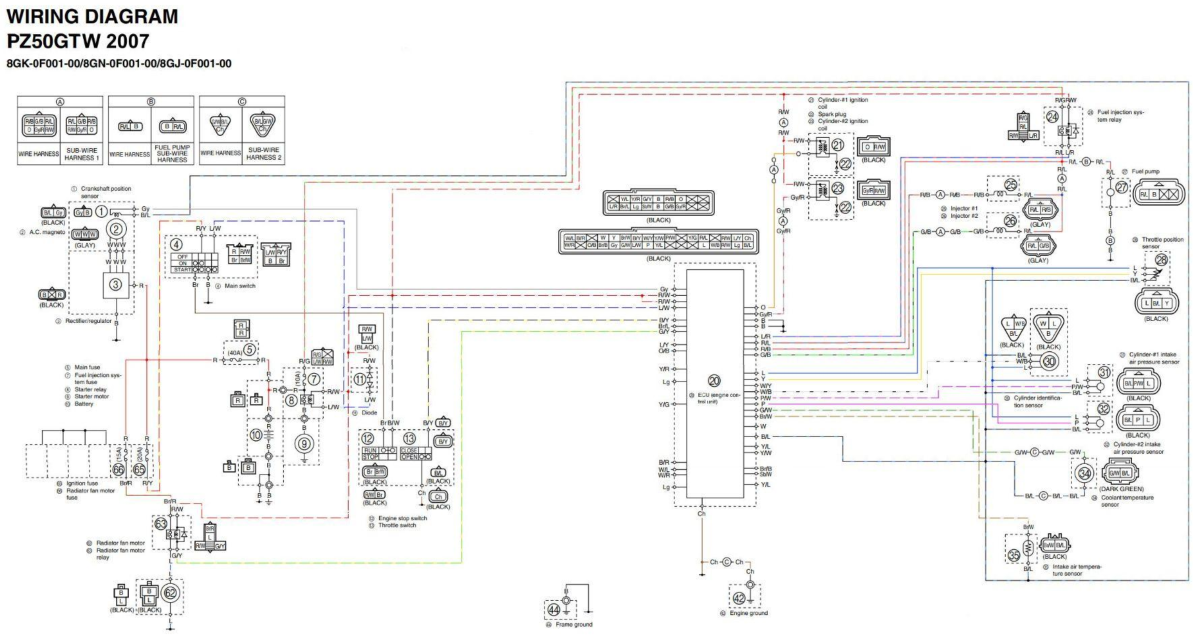

Figure 2. Simplified Phazer Engine Circuit Diagram

The final mesh was itself different from this specification, due to the second analysis tool used, functional analysis. A case of the second type of analysis is present in the shorting of the fan motor relay control terminal to ground. Since the team anticipated that the fan being on when the system was on would suffice, rather than implementing specific ECU control of the fan, a connection of the relay control pin to the ECU was unnecessary. In a more significant example, the load control relay was observed to have an initial configuration that simply served the purpose of bypassing the fuse box to directly feed main power to many relay control terminals. This both violated the wiring specification laid forth by the Phazer Manual and violated our electrical reasoning concerning the situation. Such a situation motivated a rewire of the load control relay and surrounding, related wires to repurpose the part towards its specified function of allowing power to flow to an otherwise disconnected fuse in the fuse box which allows the gear motor to actuate.

The exact implementation of each of these changes are listed below, sorted roughly by component:

- ~21 wiring changes
  - [1] Crankshaft position sensor
    - Moved ground pin to sensor ground ECU pin (7) from +5V ECU pin (26)
  - [3] Rectifier/regulator | [9] Starter motor | [10] Battery

        - Detached two starter motor [9] pins from battery [10] and rectifier/regulator [3] ground lines.
        - Attached ends of rectifier/regulator and battery ground lines to one pole of master switch, attaching the other end of the master switch to frame ground [44]
        - Attached both loose lines of the starter motor directly to frame ground
    - [4] Main/ignition switch
        - Moved main/ignition switch starter switch side A to common voltage with -inductor starter relay [8] node and -terminal of zener diode [11] from common voltage with +terminal of zener diode, etc etc.
    - [6] Load control relay
        - Bypassed switch side B directly to 4A fuse in fusebox without common voltage with +inductor pin of fan motor relay [63], +inductor pin of starter relay [8], and +terminal of zener diode [11]
        - Added common voltage with engine stop switch [12] switch side B to +inductor terminal of load control relay
    - [12] Engine stop switch
        - Removed connection between switch sides A and B
        - Moved switch side A to common voltage with +terminal of zener diode [11], +inductor terminal of starter relay [8], +inductor terminal of FIS relay [24], ECU pin (28), high reference terminals of [21,23], and high reference of camshaft sensor [30] from common voltage with FIS relay [24] -inductor terminal and high reference terminals of [21,23]
    - [20] ECU
        - Attached PWR grounds to frame ground [44]
        - Moved ECU pin (28) to common voltage with engine stop switch [12], +terminal zener diode [11] etc. from attachment to auxiliary DC jack fuse [69]
    - [21,23] Cylinder ignition coils
        - Moved cylinder-#1 ignition coil control pin to high current ignition ECU pin (36) from IAC1A ECU pin (25)
        - Moved cylinder-#2 ignition coil control pin to spare pin 4 ECU pin (6) from high current ignition ECU pin (36)
    - [24] Fuel injection system relay

        - Moved +inductor side relay control to a common voltage with the +zener diode, one side of the engine stop switch [12], and ECU pin (28) from fuel pump relay output ECU pin (37)
        - Moved -inductor side relay control to frame ground [44] from common voltage with both sides of the engine stop switch and both cylinder ignition coil [21,23] high voltage reference pins.
    - [28] Throttle position sensor: switched + and - reference terminals
    - [30] Camshaft position sensor
        - Moved high reference to +12V ECU pin (28) from +5V ECU pin (26) for more reading stability
        - Attached read pin to ECU pin (5)
    - [69] Auxiliary DC jack fuse: removed fuse from fuse box

In addition to these functional changes, many hours were spent on the following tasks to increase the legibility of the wire mesh:

- Reducing the number of wire color-changes between a given source and destination
- Reorganizing to more clearly distinguish connected networks of wires
- Pathing wires more directly from their source to destination, trimming excess length to reduce clutter
- Removing vestigial wires
- Trimming and bundling spare ECU pin wires
- Removing and reconnecting poor joints
- Removing excessive joint wrapping with a reasonable amount of electrical tape (i.e. replacing a 10 layer, 4 piece, 3 inch-long electrical-duct tape wrap on a 1/4 inch solder joint with a 3 layer, 1/2 inch yellow electrical tape wrap)
- Introducing additional wire and node labels with less residue-prone tape in clearly visible, distinguishable locations
- Replacing gooey, dirty, faded, worn labels and wire grouping bits with cleaner, smaller, less residue-prone labels and grouping bits (i.e replacing large pieces of duct tape with small pieces of electrical tape and racing tape)
- Improving color-association, with yellow electrical tape reserved for marking wire joints, and small black strips of racing tape used to bundle small groups of wires
- Bundling spare sensor wires and connecting them to the chassis, away from the engine

In total, these efforts resulted in a removal of over 80 feet of wire from the mesh, reducing complexity and increasing manageability. We expect additionally that other organization efforts will increase legibility for future teams.

2.2 Fuel Injection Subsystem

The fuel injection system was one that the team was unaware needed correction upon receiving the car. It was noticed as an issue when the team realized that there was no power connection for the existing fuel pump in the car. This pump was the Kemso 13826. Aside from not having a power connection, the issue with this pump was that it was designed for the Yamaha snowmobile and operates as an in-tank fuel pump. The FSAE car requires an in-line fuel pump system. To meet the specification for the engine, the in-line pump needed to meet engine requirements, including: pump flow rate above 130 L/hr, 40-70 psi pressure rating, and it needed to have the appropriate fitting to adapt to a rubber fuel tubing. To find the best option, the team consulted a parts specialist at O’Reilly Auto Parts. He helped the team to match the Kemso and Phazer specifications to the Precision 35 GPH Fuel Pump. It is important to note that the pump requires 12V to operate to its optimum potential.

The next component that was required for the fuel pump was a fuel filter. It was recommended that for fuel systems configuration a fuel filter was utilized. Specifically, it was recommended to be from 60-100 microns. This way particulate impurities in the fuel are removed. This component is helpful to keep the pump clean and healthy. The first fuel filter identified was a 70 micron filter. While this was an appropriate micron rating, it was not ideal because the fitting for the filter was for a solid fuel line. However, for the car's in-line fuel system configuration, the car utilizes a 5/16 inner diameter rubber fuel line. Therefore, the second fuel filter we identified had 40 microns. While this was slightly lower than the suggested micron filter size, it had the appropriate fittings to adapt to the tubing system. It is not a major concern that the 40 micron filter is lower than the recommended range because it does not hinder the pump from producing its optimal flow rate.

The final aspect that was important to include in this system was the return fuel line. This was a necessary inclusion because it allows for unused fuel to cycle back into the system and be used. However, this was not a system that needed to be constructed because a previous team had already set it up.

There were no serious constraints that needed to be followed here except the monetary constraint. It is important to note that this system has the potential to be very expensive,

particularly if it is designed for its peak performance (nearing $500). However, our configuration works very well and was $140.

For the physical construction of this subsystem, the maker space was not utilized heavily, however several of its tools were used. These tools were primarily used to tighten clamps around fittings in the fuel system. This was completed using screwdrivers and pliers (dependent upon the location and clamp style).

2.3 ECU Subsystem

The ECU is the car's engine control unit, which manages all requirements for the engine, prioritizes and then implements them. This is essential for the engine to start, as well as improve its performance for competition.

At the beginning of the project, it was thought the ECU was ready and would not pose a major problem for the team. Nonetheless, this proved to be wrong since the engine did not start, pointing to a defect within this system. The team did not know anything about engine control units and therefore began by analyzing its options. We could have either worked with the current ECU, or bought a new one. After performing a benefit-cost analysis it was decided that we would attempt to fix the current ECU.

The team started by learning the basics about engine control units and learned that the ECU can be tested before vehicle installation with the use of a JimStim 1.5V MegaSquirt Stimulator and EFI Analytics TunerStudio software. In addition to tuning, the JimStim can be used to determine if there are any short circuits in the circuitry. Along with many other engine components, the ECU gets information from the manifold air temperature sensor, oxygen/lambda sensor, coolant temperature sensor, throttle position sensor, and controls the fuel injection system, spark relay, fuel pump, and tachometer. The FSAE car currently utilizes the MegaSquirt II V3.0 and is wired with a modified version of that seen in Figure 3.

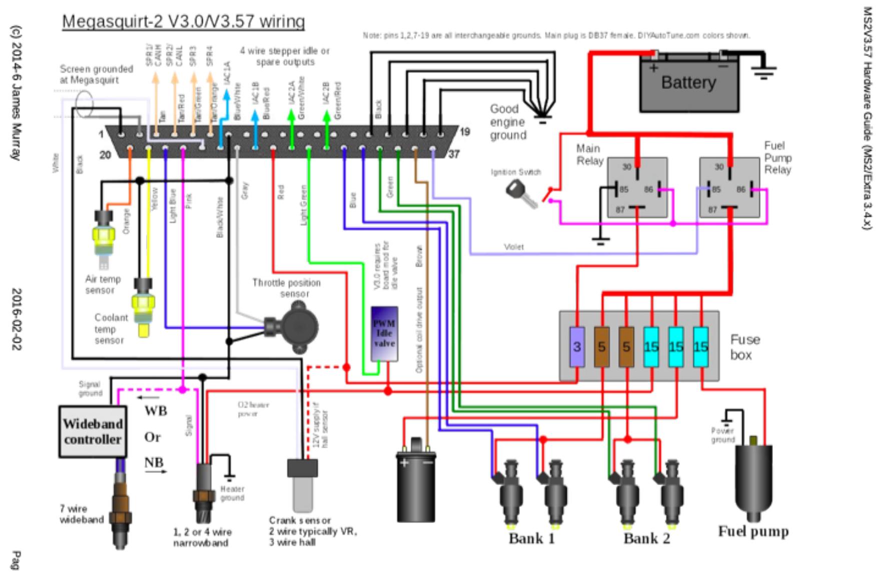

Figure 3. Megasquirt II wiring configuration

The engine control unit was inherited, already pre-built, by previous years' teams, but needed some additional modifications to accurately function with the engine. For example, the Megasquirt can only handle one tachometer input, but the Yamaha Phazer engine has both a Crankshaft and a Camshaft sensor; therefore, an installment was made to fit this specification and can be seen in Figure 4.

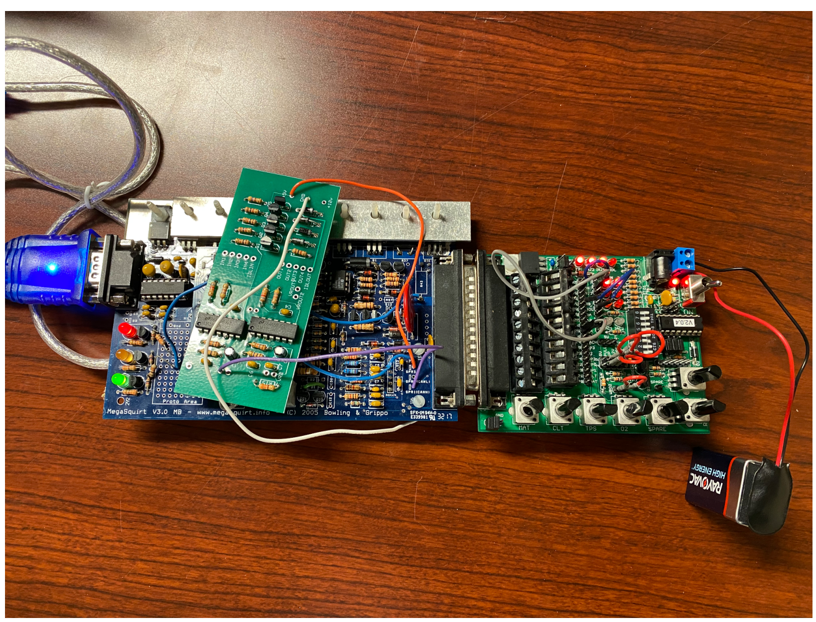

Figure 4. MSII ECU with External Daughterboard and JimStim

At the beginning of the project, the team was told by previous design groups that in order to connect an additional CAM input, the ECU needed a Dual VR conditioner daughterboard with an LM1815 chip (the green daughterboard seen in Fig. 4). The team worked under this advice for the majority of the year, but just recently discovered, via testing, that this is not the case. The tachometer inputs were being wrongly wired and the daughterboard did not match the needs of the car or the ECU. Throughout most of the year the team encountered setbacks like this one, caused by false information due to lacking documentation by previous years' senior design projects. To further support this claim, the team was told that the Phazer Engine had a missing tooth wheel for both the crankshaft and camshaft wheels, and after dismantling the engine, it was found that this was not the case either. The crankshaft has a 12 tooth wheel with no missing teeth, and the cam has a wheel with a single reversed tooth. These settings are critical for having a running engine, and have now been inputted correctly into the ECU program.

As seen, a major factor affecting the performance of the engine is the tuning of its control unit. While we have made progress towards a basic functional tuning of the ECU, optimal tuning will require extensive study and testing, and many fine adjustments in programming resulting from that process; in consequence, the team decided to program the basic settings that would allow the engine to start and leave the fine tuning for future teams.

In terms of construction techniques and tools, the team used the soldering station in the Electronics Shop of CSI; but, since most of the control unit was already built, it did not require major manufacturing or installments.

3. Design Evaluation

The main design requirement that the team attempted to fulfill was making the engine start. It is important to recognize that this encompasses several subsystems, which need to be working perfectly for an engine to idle. The subsections described below will go into detail on how the team carried out different tests, an evaluation of each, as well as a conclusion on factors still being considered.

3.1 ECU Core Functionality

3.1.1. Test Overview

The ability of the ECU to power on when supplied the proper voltage was tested first, as the foundation to the rest of the functionality of the car.

3.1.2. Test Objectives

The test evaluated if the ECU was able to utilize the +12 V supplied by the battery.

3.1.3. Features evaluated

This test assessed the engine control unit design feature, which collects all electrical input signals traveling from various sensors, handles the computation and analysis of these inputs, and sends electrical output to systems such as the fuel injectors and spark plugs.

3.1.4. Test Scope

The test had a limited scope, with a specific topology and components involved in its performance. The conclusions were limited to the ability of the ECU to utilize the +12 V supplied by the battery, and did not extend to the ability of the ECU to function within the existing car circuit.

3.1.5. Test Plan

The test required: the ECU, one 1 Amp fuse, the fully-charged car battery, the ECU wire bus, a computer running TunerStudio, the ECU-to-computer connector, and wires to connect all components. Limited skills were required to perform this test. These components were assembled as in Figure 5, with the wire bus connected to the ECU, and ECU to the computer.

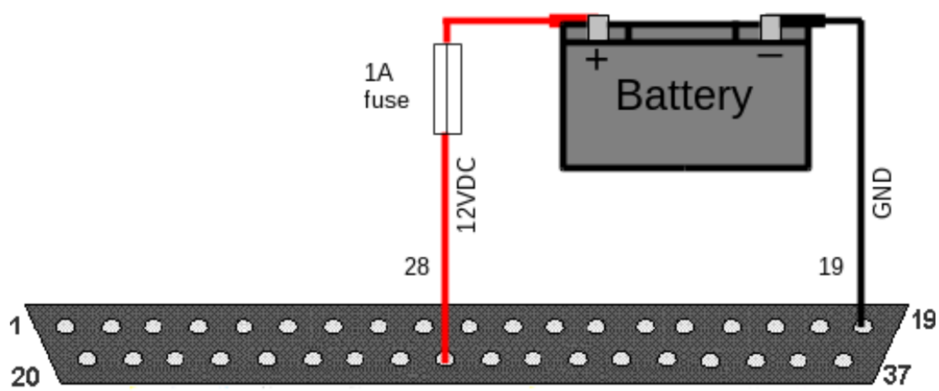

Figure 5. Minimum Bench Test Wiring Topology

It was assumed that if the ECU functioned properly during this test, it would work to the same level of performance if supplied equivalently within the larger car wire harness.

3.1.6. Acceptance Criteria

The criteria for success in this test was in the assessed function of the ECU. If TunerStudio recognized the ECU as being functional, this would constitute a success.

3.1.7. Test Results and Evaluation

Result: **Success**

When connected directly to the battery through a 1 Amp fuse, ECU's lights turned on and it was recognized by TunerStudio as being functional. This can be seen in Figure 6, a screenshot of TunerStudio where the gauges indicate readings coming from the control unit.

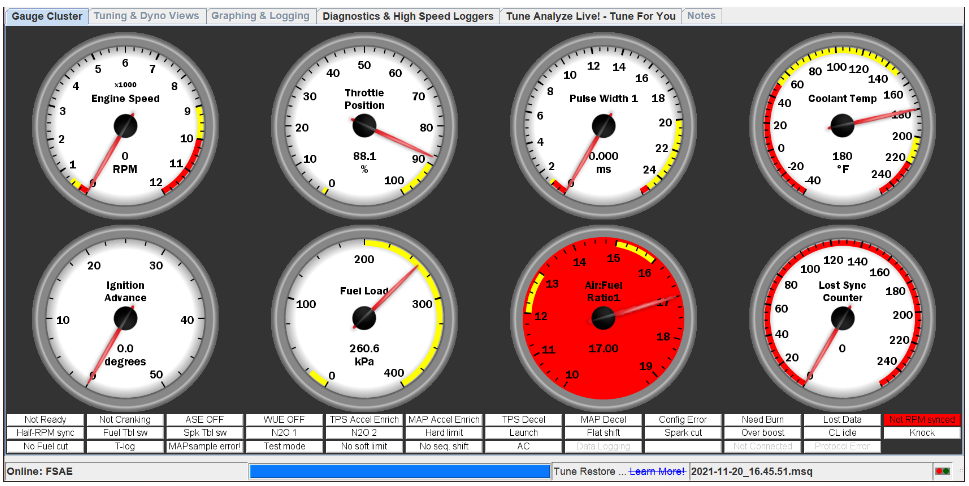

Figure 6. TunerStudio Snapshot

This indicates that the ECU is capable of accepting and utilizing a +12V input in complete isolation.

3.2 Sensor Functionality

3.2.1. Test Overview

The ECU was connected to both the car and TunerStudio in order to determine if it was able to read the engine sensor signals appropriately.

3.2.2. Test Objectives

The goal of this test was to determine which sensors were being read by the ECU, and which ones were not. This ultimately enabled the team to fix any remaining wiring issues or broken connections.

3.2.3.Features evaluated

The main features being evaluated were the engine control unit and the existing wire harness connecting sensors to the ECU.

3.2.4. Test Scope

This test was very specific and the team tested the ability of the engine control unit to recognize that the inputs are there, as well as if they were being processed correctly or not. Additionally, it was assumed that the ability of the ECU to recognize inputs would not be affected by the car attempting to start or any future changes on the control unit's code.

3.2.5. Test Plan

The ECU was directly connected to the car through the existing D port, and then to TunerStudio using an external serial cable. The only instrument required during this process was the team's computer which contained the necessary software, and the ECU code.

The team followed the MegaSquirt Setting Up manual which listed a procedure to test if each sensor was being read appropriately.

3.2.6. Acceptance Criteria

The team developed a spreadsheet that listed the ECU pins expected to have a sensor reading, and compared it with the test results. If there was no reading where there is supposed to be one, the team targeted that specific portion of the wiring and fixed it immediately. All sensors provided information to the engine control unit.

3.2.7. Test Results and Evaluation

Result: Success

This test was successful, since it allowed the team to determine which sensors were sending the appropriate signals as well as if the ECU was able to read them, process them, and send the appropriate response back.

The first steps consisted in reading and calibrating the throttle position sensor, and the manifold air pressure sensor. Then, appropriate readings were obtained from the coolant temperature sensor, manifold air temperature sensor, oxygen sensor, and the battery voltage check. The team then tested the control unit's ability to engage the fuel injectors, and this was done by sending a 10ms interval output signal with a pulse width of 4ms to each of the injectors. The ignition coils were then separately tested by sending a 50ms interval output signal with a 2ms dwell time to each coil. This proved to be successful. The next step was to test the fuel system, which was easily done under the ECU's test functionality.

The team then encountered some difficulties when it came to reading the crankshaft and camshaft signals. According to the manual, the high speed data log viewer should record signals as seen in Figure 7, but the team was getting the readings seen in Figure 8.

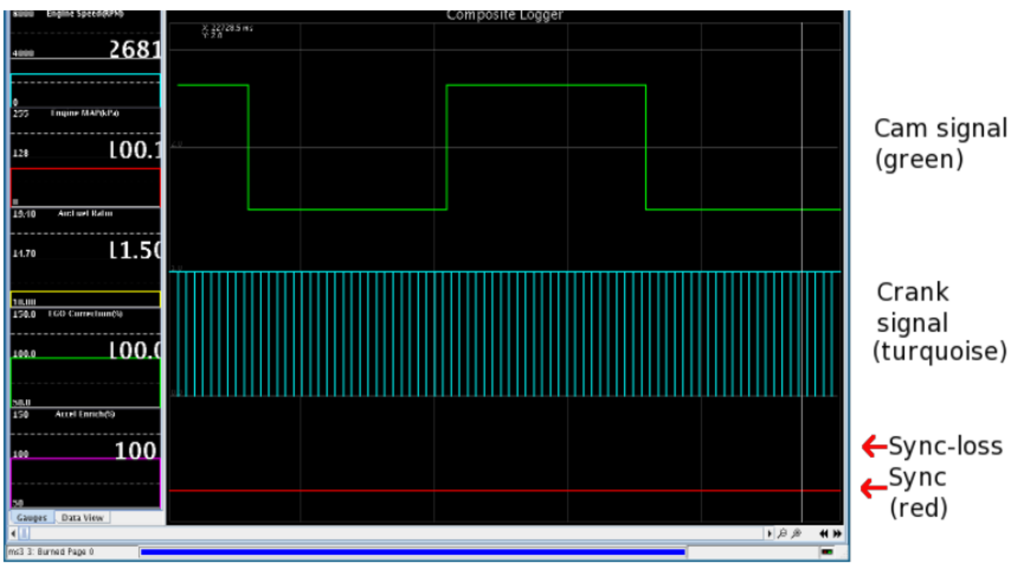

Figure 7. Expected Crank/Cam Input Signals

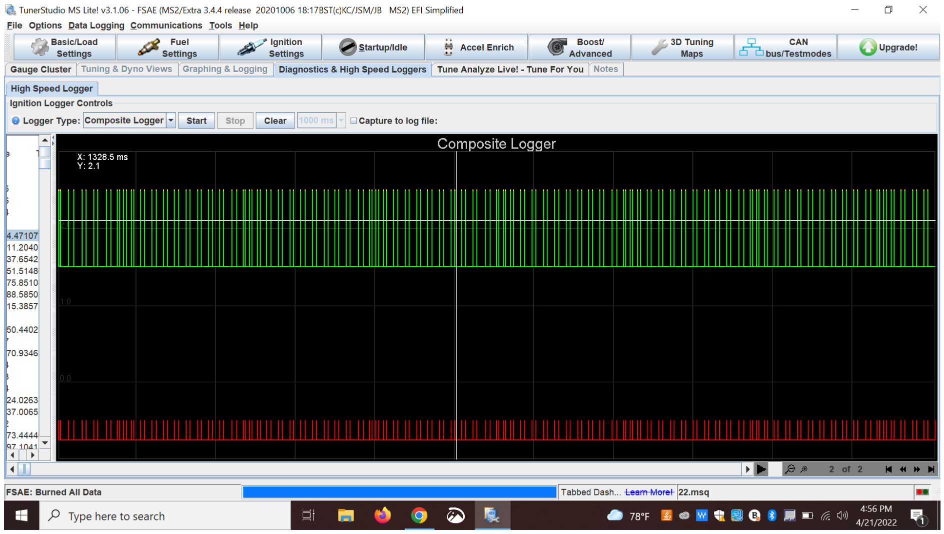

Figure 8. Initial Crank/Cam TunerStudio Readings

In order to tackle this issue, the team used an oscilloscope to measure the crank/cam signals from the source to verify good sensor output, and traced them towards the ECU to verify good transfer to the ECU pins. It was discovered that the ECU daughterboard was not necessary and the crank needed to be directly connected to the tachometer input ECU pin 24, with the cam sensor output routed to ECU contact JS10 through ECU pin 5 while connected to a 470 kΩ pullup resistor to the ECU board +5V.

After fixing this wiring error, a measured signal resulted which can be seen in Figure 9.

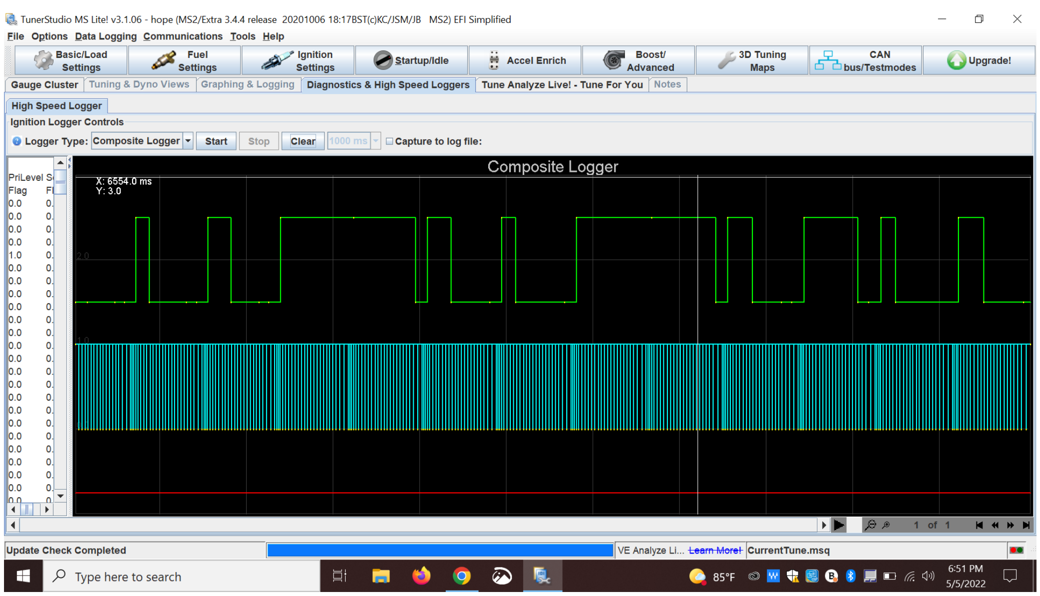

Figure 9. Good Crank/Cam TunerStudio Readings

As seen, the test resulted in a success, since it allowed the team to identify which signals were being read properly; but, also aided in fixing wiring errors. With regular signals of proper amplitude and roughly proper period, chances of the engine starting during the next test are good, with a great deal of next steps dealing with proper setting of the ECU configuration and alignment of crank and camshafts with engine cylinder top dead center (TDC).

3.3 Emergency Shutoff Functionality

3.3.1. Test Overview

A critical FSAE element, the emergency shutoff (consisting of the master switch and the emergency shutoff button) needed to work correctly before the circuit was deemed correct.

3.3.2. Test Objectives

The goal of this test was to verify that the emergency electrical shutoff properly controlled the current in the engine and sensors.

3.3.3.Features evaluated

The features evaluated were a master switch, that acts like an open or closed circuit for all electrical elements, and an emergency shutoff button, that cuts the power in the car no matter the state of the master switch (on or off).

3.3.4. Test Scope

This test had a limited scope since there were only two subsystems being tested with the emergency shutoff: the engine and the ECU sensors. The functionality of the parts was not taken into account since this test only accounted for whether the engine and ECU would shut off when the switch was opened, or that the subsystems were receiving current when the switch was closed

3.3.5. Test Plan

For this test, the emergency shutoff was wired to the correct circuit location. This meant that the master switch had to be wired into a location where it could disconnect power to all electrical circuits, including the battery, alternator, fuel pump, ignition, and electrical controls. Additionally, all battery power needed to flow through this switch and not rely on relay circuitry

(IC.9.3, 2022). Additionally, at any time, if the emergency shutoff button was pushed, no power should flow through the car.

3.3.6. Acceptance Criteria

The team developed a spreadsheet including information on which systems should be turned off by the emergency shutoff switch. The test would be deemed successful if the switch disconnected power to the engine block and the ECU sensors.

3.3.7. Test Results and Evaluation

Result: **Success**

The master electrical switch succeeded in cutting off power distribution from the battery. When the master switch was disengaged, power was not delivered to any of the car components (ECU, pump, starter, etc.). This correctly reflects the state of the master switch when it is turned off. Upon turning the master switch on, all electrical components in the car received power. Therefore, the master electrical switch was a complete success.

The emergency shutoff button was also a success. This switch proved to be successful in two forms. First, when this switch was engaged, and the master switch was turned on, no power was received by any of the car's electrical components. Second, when the master switch was turned on and the car was receiving power, the emergency button was pushed, and all power in the car shut off (the pump, ECU, sensors, etc.).

Since both the master switch and the emergency shutoff switch worked correctly, this entire test was successful.

3.4 Engine Starting - Idle

3.4.1. Test Overview

The test plan culminated in this test, which assessed the ability of the ECU to control the engine as a whole.

3.4.2. Test Objectives

The test aimed to assess whether or not the ECU could make the engine start when it was otherwise error free with respect to connected sensors.

3.4.3.Features evaluated

The ECU and wiring were assessed in this test.

3.4.4. Test Scope

This test assessed whether or not the ECU, wiring, and attached sensors functioned in their current topology to start the engine. This ultimately determined if the ECU or engine were faulty.

3.4.5. Test Plan

The test plan was very simple for this test. An attempt was made to start the engine using the attached starter key. We attempted to do so three times, holding the key in the start configuration for 10 seconds each time.

3.4.6. Acceptance Criteria

If the car started during any of the three attempts and ran for at least 10 seconds, the test was declared a success.

3.4.7. Test Results and Evaluation

Result: **Mixed Success**

While this test was rather basic, achieving a safe idle where the cylinders are not misfiring is pertinent to making the car run safely. When testing the car for idle we found that because the engine did not start, a successful idle was not achieved. Nonetheless, there was promising progress towards achieving a 15s+ idle. First, the team was able to successfully, through some troubleshooting and trial and error, get the engine to backfire and ignite some fuel in the engine. We could tell this was happening because a flame was produced and seen at the car's exhaust. The team could also hear the engine barely missing its ignition. Second, all of the components that the engine needs to start: starter, fuel injectors, sparks, fuel pump, etc. (and just recently a corrected cam signal) all functioned according to the engine specifications. To reiterate, at the time of the most recent tests, the team has obtained successful cam reading but has yet to attach the ECU to the car and try the whole system together. Once the engine reads all of the appropriate signals at one time and receives power from all the necessary subsystems, the car will achieve its idle.

Overall, while the team has not yet fulfilled the design specification to make the engine start, a significant amount of progress has been made and the root of the problem is pinpointed. All the engine wiring has been traced, labeled and tested, as well as the ECU inputs and outputs. It all boils down to a software setting in TunerStudio that needs to be set to read according to the newly achieved CAM signals and putting it all together in one final engine-start test.

4. Conclusions

As of this moment, the car does not start. However, the team is very close. Of the four tests that were conducted, three were successful: we unlocked the core capabilities of the ECU when power was connected to its D-sub port, completed a sensor functionality test, and constructed a functioning emergency shutoff system. The shutoff had to be corrected between the period of the test report and the final report. Starting the engine presented a multifaceted problem, since it involved a function of many variables that are not limited to the fuel rate, injection timing, and even syncing the crank and cam tooth positions. Such an expansive project should not be limited to the discrete outputs but acknowledge the challenges encountered throughout the duration of the project. The team consulted with three experts during the semester: Stefan Schluter, a car mechanic; Dr. Kevin Nickels, mechatronics professor; and Dr. Peter Kelly-Zion, heat transfer and fluid mechanics professor, to try and diagnose the best steps forward with the project. The team also extensively consulted the internet for potential sources of information on working with our ECU. This research was critical since we identified a guide to starting our engine (the megasquirt start-up guide) as well as identified which switches were needed for the minimal emergency shut-off system. Every time the team learned something new about the car, it took a step in the right direction. Currently, the team is the closest iteration to achieving a working motor car in the history of the program; however, the motor has yet to start.

The problems associated with the car are prevalent throughout the actual components and with the ECU configuration. The key sensors (as specified in the megasquirt start-up guide) passed their functionality tests via the ECU testing mode; however, undocumented faults in the starter relay and the unnecessary daughter board configuration, delayed the results of these tests. The car is contaminated with undocumented issues that hindered the speed at which we worked. It is paramount that all future teams uphold diligent documentation so they do not have to succumb to the hurdles that we have had to work through to catch up to speed. We

have already started the process of creating a more efficient and comprehensive documentation system - design manual given to future teams.

The future of the car depends on the documentation established by the prior teams. We recognize that the car is extremely close to starting, perhaps even the next day. We have discovered that the addition of the daughter board has lost us a month of development as the megasquirt already has an analog to digital converter built into it. The crank and cam sensors can now be plugged into the board with minimal modifications required and likely provide a working configuration. However, all of this progress goes to waste if the next team is not properly taught how to use this information, so future teams should be given time to discuss the current state of the project with the current team members.

Appendices

Due to the nature of this project, the team recommends a separate design manual containing all of the team's progress, reasoning and task checklist. This manual will be delivered alongside the Final Project Report.