Electronic Fuel Injection System for a 2-Stroke All-Terrain Vehicle

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by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Yamaha Banshee comes from Yamaha with a set of twin 26mm carburetors. These carburetors do not offer enough control of fuel flow that many owners want. The size of the carburetors is also restrictive for modified Yamaha Banshee. An Electronic Fuel Injection system would overcome both of these issues.

The majority of current Yamaha Banshee owners surveyed wanted a conversion kit that was cheap, easy to use and offered an increase in both power and fuel economy. Combining the survey results with engineering analysis lead to three different potentially EFI conversion kits. These three kits were analyzed utilizing engineering design tools. The single throttle body with port injection was selected as the most viable design concept for overall functionality and cost.

Size of throttle body, injections and fuel pump were calculated based of the following inputs: 100hp, a B.S.F.C of .55, and engine size of 369cc. The minimum sizes for the components were found and the next size offered was chosen. The manifold was design to match the diameters of the throttle body and reeds, the length was calculated using many different intake runner length equations. Some components were selected due to donations and sponsorships from companies. The others were selected from their functionality and cost.

The EFI conversion kit was a successful prototype that met most of the product objectives. It worked and it increased both power and fuel economy. To make this conversion kit a viable market ready product, more refines are needed to cut cost without cutting functionality.

INTRODUCTION

BACKGROUND

The Yamaha Banshee was produced for a longer period than all other all-terrain vehicles (ATV). The first Yamaha Banshee came off the production line in 1987 and last Banshee for the US market was produced in 2006. Yamaha continued to produce the Banshee for foreign markets until 2010. During this long run, few changes were made to the Yamaha Banshee and no changes were made to improve its performance. In 2006, the same year US sales of the Yamaha Banshee ceased, the Environmental Protection Agency (EPA) began to mandate the emissions standards for recreational vehicles including ATVs. The EPA claimed that ATVs were responsible for 130,000 tons of hydrocarbons, 550,000 tons of carbon monoxide, and 4,000 tons of oxides of nitrogen each year (1). In the same Announcement, the EPA pronounced that two-stroke engines and carburetors were the main violators and recommend switching to four-stroke engines and fuel-injection to help ATVs meet the mandated standards. In order to meet EPA standards, the Yamaha Banshee needed to be updated.

The Yamaha Banshee uses a twin carburetor fuel system to feed the engine. There are three main brands of carburetors used on a Banshee: Mikuni, Keihin and Lectron. The Mikuni and Keihin carburetors use jets, needles, and a slide to control the fuel flow. The Lectron carburetor uses a metering rod and a slide to control fuel flow. In all three, gas is stored in the carburetor's bowl. When moving air creates a vacuum, gas is pulled into the neck of the carburetor and mixed with the air then it flows to the engine. This configuration provides little precision in metering of the air to fuel ratio. Therefore, too much fuel is consumed, too many emissions are released, and optimal performance is not obtained.

An electronic fuel injection system (EFI) is a more complicated fuel system than a carbureted system. An EFI system relies on injector(s) and a fuel pump to control fuel flow and to feed the engine. The fuel pump pulls fuel from the gas tank, pressurizes it and forces it to the fuel injectors. The injector then squirts a specified amount of fuel into either a manifold or cylinder. Sensors, such as the mass air flow, the throttle position, the wideband O_2, and others, monitor air and fuel flow and help to make the EFI system efficient. The mass air flow sensor measures the amount of air entering the manifold. The throttle position sensor measures the position of the throttle plate/butterfly. The Wideband O2 sensor measures the amount of air and fuel in the exhaust gas. Air Intake temperature sensor measure the temperature of the air going into the manifold. An EFI system has an engine control unit (ECU) that is the brain of the system. The ECU takes in input data from the various sensors, interrupts the data, then send out a signal to the injector to release the correct amount of fuel. The more sensors that are used to monitor the engine functions and environmental factors, the more precise the EFI system will become.

Yamaha Banshee owners want to get the most power they can out of their engines. For Yamaha Banshee owner Mr. Green for Oregon, he wants an EFI kit for this turbocharged Yamaha Banshee. He wants to be able to not worry about temperature and elevation changes from different drag strip (2). Mr. Green always wants to gain as much power on top end without losing low end power for launching off the line (2). Another Yamaha Banshee owner

is Mr. Smith from Kentucky. Mr. Smith has a custom Yamaha Banshee with a nitrous system that he trails rides and always drag racing. Mr. Smith wants an EFI kit that he could program to automatically adjust fuel and timing when he using nitrous so he does not have to worry about blowing up his Yamaha Banshee (3). Both owners want the ability to infinity tune the fuel and timing and to not worry about losing any power.

The focus of this design project is to create a bolt-on EFI conversion kit for a Yamaha Banshee. This kit will include everything needed to convert a Yamaha Banshee from a carbureted fuel system to an EFI system. This kit will allow the Yamaha Banshee to perform more efficient, by increasing fuel economy and horsepower.

CURRENT CARBURETOR SYSTEMS

STOCK CARBURETOR

The Yamaha Banshee comes from the manufacturer with a set of twin 26mm Mikuni carburetors. See Figure 1 for picture of a set of stock Yamaha Banshee carburetors. These carburetors, designed specifically for the Yamaha Banshee, are a round slide twin carburetor system. These carburetors use a pilot jet, main jet, and needle, along with the round slide to control fuel flow into the engine. The stock carburetors use a single choke and are connected via a choke tube to help with starting and low end power. Yamaha uses a Throttle Override System (TORS) for safety. The TORS will cut ignition/spark when the slide is stuck open, the thumb throttle is closed. Many companies such as DynoJet sell complete jet kits for the Yamaha Banshee. These jet kits cost under $100 and can help power throughout the powerband (2). The stock twin carburetors work adequate with a stock engine and engines that have been slightly modified, but, the stock carburetors does not suffice for engines that have been more than slightly modified.

Figure 1 - Yamaha Banshee Stock Carburetors

AFTERMARKET CARBURETORS

Mikuni Carburetors

There are two main types of carburetors offered by Mikuni; the round slide and the flat slide. See Figure 2 for generic picture of VM round slide carburetors. The Mikuni carburetors use a pilot jet, main jet, and a needle to control the fuel flow. The VM carburetor is a round slide and is offered in sizes ranging from 18mm to 44mm. This large range of size selection provides many choices for owners to use on their modified Yamaha Banshee engines. Using a screw-on top makes it easy to take out the slide and adjust the needle. This screw-on top also allows for the carburetor to be removed from the quad without using any tools.

Figure 2 – Mikuni VM Round Slide Carburetors (3)

The TM series is the flat slide carburetor offered by Mikuni. The TM series includes the standard TM, the TMX, and the TMS carburetors. See Figure 3 for generic picture of a TM Series carburetor. These carburetors are offered in sizes ranging from 24mm to 38mm. The TM series carburetors are the most commonly used aftermarket Mikuni carburetors among Yamaha Banshee owners. The top of the carburetor is held on by two screws which allow for an air tight seal and better air/fuel control.

Figure 3 – Mikuni TM Series Carburetor (3)

Keihin Carburetors

The Keihin carburetors are separated into two main groups similar to the Mikuni carburetors; flat and round. Also, like the Mikuni, Keihin carburetors use a pilot jet, main jet, a needle and a slide to control fuel flow. The Keihin PJ carburetors are a flat slide. See Figure 4 for generic picture of a PJ carburetor. Instead of the completely rectangular TM series carburetors, the PJ slides are rounded on the edges. The PJ carburetors are only offered in 34mm, 36mm, and 38mm. This minimum selection of size difference is a reason why many Yamaha Banshee owners do not use the PJ carburetors. Wicked Performance sells a complete

intake system that includes a pair of 34mm PJ carburetors, pair of filter and intake manifold for $700. See Figure 5 for a picture of Wicked Motorsports intake system. Wicked says this system will show an increase of five horsepower over stock (4).

Figure 4 – Keihin PJ Carburetor (5)

Figure 5 – Wicked Motorsports 34mm PJ intake system (4)

The Keihin PWK carburetor is a round slide style carburetor. Where the Mikuni VM slide is a complete circle, the PWK slide is more shaped like a "D" with the front rounded and the back flat. See Figure 5 for generic picture of a PWK carburetor. The PWK carburetor is offered in sizes ranging from 28mm to 39mm. There are three sizes, 35mm, 36mm, and 38mm offered in a special quad vent Air Striker version. Quad vents help the carburetor's bowl from vapor locking where the fuel splashes. Vapor lock keeps the gas from being pulled into the carburetor's neck. Trinity Racing offers a constant velocity intake system for the Yamaha Banshee. See Figure 6 for picture of Trinity Racing's intake system. This system includes a 2-1 intake manifold and a single PWK carburetor and cost $500 (6). Trinity says this 2-1 intake system will show a 20% increase in bottom end power and a 15% intake in top end bottom over a stock carburetor system.

Figure 6 - Keihin PWK Carburetor (5)

Figure 7 – Trinity Racing Constant Velocity System (6)

Lectron Carburetors

Lectron carburetors are the third most commonly used brand of carburetors among Yamaha Banshee owners. See Figure 6 for picture of a generic Lectron carburetor. The Lectron carburetor works using the same basic fuel and air mix principle used by the Mikuni and Keihin carburetors. Where the Mikuni and Keihin carburetors use jets and needles to control fuel flow, the Lectron carburetor uses patented metering rods. The metering rod serves three important functions; fuel signal generating, fuel delivery metering, and air volume density sensing. This allows the Lectron carburetor to work in a greater range of environmental factors than other carburetors before a retuning is needed. The Lectron Carburetor is offered in sizes ranging from 25mm to 52mm giving it the biggest range of size among the three carburetors.

Figure 8 - Lectron Carburetor (7)

EFI CONVERSION FOR AUTOMOBILES

Carburetors to EFI conversion kits are popular among older muscle cars and street rods owners. Companies, including Edelbrock and Fuel Air Spark Technology (FAST) both sell EFI conversion kits for older V8 cars that were originally equipped with carbureted fuel systems. In an interview for Car Craft, Mark Hamel of ACCEL, said that EFI does everything right; it improves drivability, makes more torque, solves cold-start problems, lowers emissions, and improves gas mileage. He further stated all of these are reasons to run EFI on a vehicle where EFI was not factory equipped (8). Hamel is not the only one to say this, Stephen Kim stated in his article “How to buy EFI,” that EFI offers better drivability,

reliability, lower maintenance and consistent performance over carbureted fuel systems (9) . Both Kim and Hamel agree that EFI system is far better than a carburetored system and that these positive ascepts outweight the extra price tag.

The Edelbrock makes two EFI conversion kits, the Pro-Flo 2 and the Pro-Flo XT. Both kits are designed for older domestic V8 engines and the XT also works on the newer Chevrolet LS1 engine. See Figure 7 for a complete Chevrolet EFI kit from Edelbrock. Edelbrock claims increased horsepower, better fuel economy, better throttle response, and overall better performance compared to stock carburetor fuel systems on similar engines. A Pro-Flo kit includes everything needed to complete an EFI conversion: manifold, throttle body, injectors, fuel controller, wiring harness, and sensors. Figure 8 shows the torque and horsepower increase on a Chevrolet V8 engine using the Edelbrock Pro-Flo 2 EFI system compared to the stock carburetor system.

Figure 9 - Chevrolet 262-400 V8 EFI Kit (10)

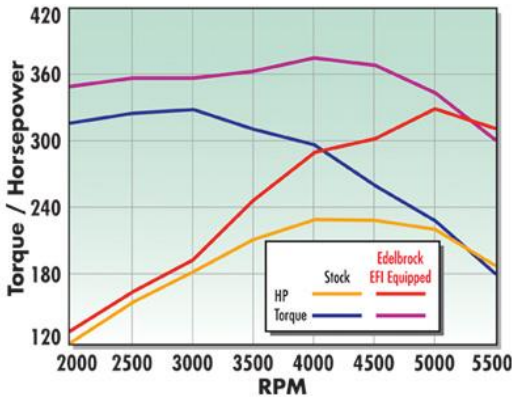

Figure 10 - Stock Carburetor vs. EFI system (10)

FAST is another popular company that produces EFI conversion kits. It sells kits for both Chevrolet and Ford V8 motors. FAST designs kits to work on engines producing up to 1000 horsepower. FAST does not make any comparison claims for EFI versus carburetor. FAST does however, claim that the conversion kits are the easiest to use; just install the kit

and the self-tuning software helps get the most out of the engine. The FAST EFI conversion kit cost under $2500 and it includes everything needed to do the swap from a carburetor (11).

Figure 11 - FAST EZ EFI Kit (11)

CUSTOMER FEEDBACK, FEATURES, AND OBJECTIVES

SURVEY ANALYSIS

Thirty Yamaha Banshee owners completed an online survey to rate the importance of EFI features. The thirty Banshee owners ranged from novice riders to skilled engine builders. A 1-5 scale with 5 being most important and 1 being least important was used and the results show that reliability and ease of programming to be the most important features and appearance was the least important feature. See Appendix B for full survey with results. Figure 10 shows each customer feature with the average importance results from the surveys and the relative weights in percent. The features are in order of greatest relative weight to least. The relative weights started with the results from the survey and were modified in the QFD. The full QFD can be seen in Appendix C.

Table 1 - Survey results with Relative Weight

Customer Importance		
Feature	**Ave Results**	**Relative Weight**
Reliability	4.7	10
Ease of Programming	4.5	10
Durability	4.4	9
Verifiable Results (HP)	4.5	9
Resistance to Environmental Factors	4.1	9
Ease of Adjustment	4.1	9
Ease of Maintenance	3.8	8
Precision	3.9	8
Ease of Operation	3.9	8
Ease of Installation	3.2	7
Verifiable Results (mpg)	3.3	7
Apperance	2.8	6

Also rating high in importance range are verifiable increase in power, resistance to environmental factors, and ease of adjustments. Taking these responses into account, future design concepts will address these desirable features for the customers.

PRODUCT FEATURES AND OBJECTIVES

The product features came from research of EFI conversion kits for older cars. Each feature was rated by future customers for importance. The features were cross-referenced with engineering characteristics and rated for a strong to weak correlation. The list of product features below is in order of relative importance starting with the most important feature. Below each feature is the list of objectives that will be used to design a working prototype. The product features and objectives are:

1) **Ease of Programming**: (10%)
    a. Programming will be completed on a laptop via a USB cord.
    b. Software for programming will be provided as a CD and filmware can be downloaded online.
    c. Basic knowledge of spreadsheet is required.
    d. Total time to adjust fuel and ignition charts from preset settings to desired settings will be less than two hours.

2) **Reliability**: (10%)
    a. All electrical connections will be soldered and then covered with heat wrap to ensure no loose connections or bare wires.
    b. Reliability of the kit measured by component life and proper design criteria specified in the following spec sheets:
        - Battery Spec Sheet
        - Injector Spec Sheet
        - Fuel pump Spec Sheet
        - All sensors spec sheets

3) **Ease of Adjustment**: (9%)
    a. Changing of throttle body will take less than 30 minutes.
    b. Changing of injectors will take less than 45 minutes.
    c. Changing of air filter will take less than 15 minutes.

4) **Durability**: (9%)
    a. Proper grade bolts will be used in the kit. Calculations will be done to select proper grade. Stainless steel bolts will be used because of looks.
    b. Mechanical assembly will follow allowable torques of mechanical fasteners.
    c. Loc-Tite will be used to keep all bolts from vibrating loose.

5) **Resistance to Environmental Factors**: (9%)
    a. All parts in the EFI kit will be effective in a temperature range of -30°F to 120°F.
    b. Heat from exhaust will not affect the EFI kit's ability to operate during a normal riding weekend of 8 hours a day for 3 days.
    c. Kit can be safely pressure washed.
    d. All visible metal parts will be powder coated or anodized to inhibit rust.
    e. Dialectical grease will be used in all electric plugs to mitigate water.

6) **Precision**: (8%)
   a. The kit will maintain the user selected air fuel ratio settings within 1% during a normal riding weekend of 8 hours a day for 3 days.

7) **Ease of Operation**: (8%)
   a. Thumb throttle will take less applied force to open the throttle body than the current carbureted system and will meet standards for human ergonomics.
   b. On/Off switch and key switch will take less force for setting selection than the standards for human ergonomics.
   c. Clutch lever will take less force to disengage than the standard for human ergonomics.

8) **Ease of Maintenance:** (8%)
   a. Fuel injector cleaner will be poured in gas tank to clean injectors.
   b. Throttle body cleaner will be used to clean throttle body.
   c. Replacement of individual worn out parts with new parts will take less than one hour.
   d. Outerwear on filter eliminates need to re-oil air filter. Simple clean and dry.

9) **Verifiable Results**:
   a. Horsepower (9%)
      i. EFI kit's power curve will be greater than the current carbureted system by 1%.
   b. Fuel Economy (7%)
      ii. EFI kit will increase fuel economy by 10% over carbureted system.

10) **Ease of Installation**: (7%)
   a. Any special tools will be included in the kit.
   b. Time to uninstall carbureted system and install EFI system will be less than 3 hours.
   c. Less than 20 steps will be needed to install EFI kit.
   d. No welding will be required by installer.
   e. Kit will include all new hardware.
   f. All electrical plug connections in the wiring harness will use a male/female plug connection.

11) Appearance: (6%)
   a. All visible bolts will be stainless steel Allen heads.
   b. No external sharp edges.
   c. All visible metal parts will be powder coated or anodized to user's desired color.
   d. No exposed wiring.

ANALYSIS FOR ENGINEERING CHARACTERISTICS

Ease of Programming

Programming of the EFI controller is important to potential customers. With a 10% relative weighting, it was tied for the first most important characteristics. Potential customers want the product to be simple to use. An engine control unit (ECU) that allows connection to a laptop will make reprogramming the fuel and timing curves simple. Large basic spreadsheet charts for fuel and timing will make programming easy for users.

Reliability

The reliability of a product means the product will perform correctly each time. Reliability was tied for first as the most important characteristic among future customers earning a 10% relative weighting. An ECU that uses quality parts, is waterproof and shockproof will ensure high reliability. The use of high quality sensors, injectors, fuel pump, and battery will help achieve a high reliability.

Ease of Adjustment

The ease of adjustment means a customer can change out parts such as injectors, throttle body, fuel pump, etc. without it taking a long time. Easy access to these parts will give customers the needed ease of adjustment. In the QFD, ease of adjustment received a 9% relative weight.

Durability

Durability is how well a product stays together. Keeping the kit lightweight and using the proper specification for material, the conversion kit will be very durable. Using the correct fastening technique and proper fasteners will keep the EFI kit from falling off the engine. Durability received a 9% relative weight from the QFD.

Resistance to Environmental Factors

Environmental factors include water, air, mud, heat, and cold. These factors can cause a product to malfunction or wear out prematurely. The electronic components need to be waterproof and need to be wrapped in a heat resistant material to keep them working in all conditions. All exposed metal will be covered in a protect layer to inhibit rusting. The QFD gave resistance to environmental factors a 9% relative weight.

Precision

Precision is the accuracy of the conversion kit. Customers want the kit to hold the air-fuel ratio and timing curve to the preset numbers in all environments and conditions. The use of quality sensors to measure specific environmental and engine inputs will increase the EFI kit precision. The ECU must interpret the input data received from the sensors and

determine the correct output changes for the injectors and ignition. Precision received a 9% relative weight in the QFD.

Ease of Operation

Ease of operation measures the ease of locating, using, and understanding the kit. Maintaining the original positions of the on-off switch and thumb throttle switch will increase the ease of operation. By decreasing the force needed to move the throttle thumb lever, less strain and stress will be put on the thumb. By decreasing the amount of kicks needed to kickstart the ATV; less physical exertion is required. Ease of operation received an 8% relative weight in the QFD.

Ease of Maintenance

Ease of maintenance the amount and difficulty of work a customer must do to maintain the conversion kit in top quality. The use of air and fuel filters will decrease the amount of maintenance work needed. Fuel filters will stop dirt and other foreign objects from entering the fuel system and damaging the fuel pump and injectors. An air filter with and outerwear will stop dirt and foreign objects from entering the air flow and damaging sensors and the motor. The use of high quality fluids for the coolant and premix oil will lessen the need to maintain sensors. Ease of maintenance received an 8% relative weight in the QFD.

Verifiable Results

Verifiable results were broken up into to two sections; horsepower and fuel economy. Potential customers want evidence that installing the conversion kit resulted in an increase of both horsepower and fuel economy. The use of a dynamometer will display the differences in the horsepower and torque throughout the power range. Fuel economy tests will be completed to show difference in fuel range and miles per gallon consumed. Horsepower received a 9% relative weight and fuel economy received a 7% relative weight in the QFD.

Ease of Installation

Ease of installation measures how easy it is to install a conversion kit on an ATV. By producing the conversion kit with a direct bolt-on, customers can complete the removal of the carburetor and installation of the conversion kit using basic tools. A step by step instruction manual will decrease the needed knowledge for installing the conversion kit and allow most customers the ability to install the kit themselves. Ease of installation received a 7% relative weight in the QFD.

Appearance

Appearance had the lowest importance to potential customers with only a 6% relative weight. Appearance measures how the kit will look. To increase marketability and aesthetics,

the color of all exposed metal in the kits can be selected by the customers. All wiring will be hidden to provide a clean finish.

SCHEDULE

A schedule was created to assist in the completion of the prototype conversion kit. See Appendix E for a week by week schedule of the prototype design. The schedule was behind on 3-D modeling, calculations, receiving parts and testing. Issues at the machine shop caused a delay in completion of manifold and flywheel which pushed back testing.

Table 2 - Schedule

SCHEDULE	Concept Sketches	3D Modeling	Design Freeze	Calculations	Order Parts	Machine Parts	Receive parts	Testing
Projected	24-Oct	24-Nov	15-Dec	5-Jan	5-Jan	2-Feb	23-Feb	23-Mar
Actual	24-Oct	8-Dec	15-Dec	12-Jan	5-Jan	2-Feb	29-Mar	30-Mar

BUDGET

A budget was created by determining the parts needed and their costs. A total budget of $3875 was recommended. The most expensive budgeted part was the ECU at $1200. The budget was divided into five assemblies; DC conversion, electronics, intake, fuel and tools. See Table 2 for breakdown of the cost of each assembly. Electronics assembly accounts for 56% of the total budget. See Appendix F for full breakdown of the budget. The final cost of the conversion kit was $1919 which is half of the budget. Full retail of the EFI kit is $2743. The difference in price comes from donated and discounted parts. GT Stators donated a custom stator for the conversion kit. RC engineering donated a set of injectors. A local machine shop donated material and labor for the manifold and modifying the flywheel. AEM Electronics sponsored the project with a 50% discount on all parts needed. These donations and sponsorships accounted for $824.

Table 3 – Budget Breakdown

Assembly	Projected Cost	Actual Cost
DC Conversion	325	75
Elecontrics	2180	1204
Intake	675	342
Fuel	295	198
Tools	400	100
Total	3875	1919

DESIGN

DESIGN CONCEPTS

Twin Throttle Bodies

The first concept shown in Figure 12 is called the Dual Throttle Bodies. This design utilizes two throttle bodies that are connected by a single rod. The throttle bodies will mount directly to the Yamaha Banshee motor using intake boots. The injectors will spray fuel into the air stream inside each throttle body. This design is known as throttle body injection (TBI). The TBI is an almost bolt-in replacement for carburetor so no drastic changes to an engine are needed (14). With this design, no manifold is needed to attach the throttle bodies to the engine. Since there is no manifold, there is no MAP sensor, instead, there needs to be a mass air flow (MAF) sensor to monitor the incoming air speed. To monitor incoming air conditions, a two into one air filter adapter is needed to house the MAF and AIT sensors. The twin throttle bodies concept is the most expensive and complicate of the three concepts.

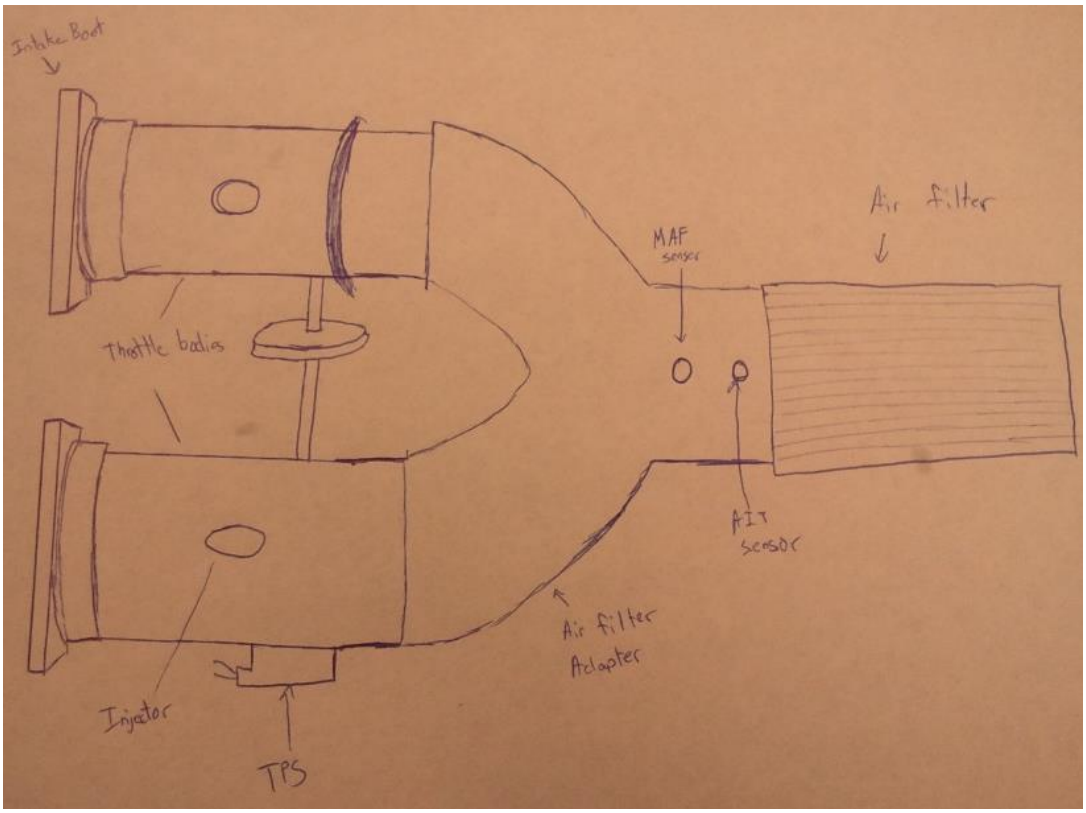

Figure 12 – Dual Throttle Bodies sketch

Single Throttle Body TBI

The second concept shown in Figure 13 is known as the Single Throttle Body with TBI. This design uses only a single throttle body to control air flow. A one-into-two manifold is needed to attach the throttle body to the engine and to direct air into each cylinder. This manifold will also be used to mount the sensors, MAP and AIT, which monitor the incoming

air conditions. Being a TBI design, only a single injector is used and is installed in the throttle body. By only needing a single throttle body and injector, the cost is kept low. The single injector used to supply fuel for both cylinders does not allow for precise controlling. The injector will be squirting fuel constantly allow for excess fuel to be used.

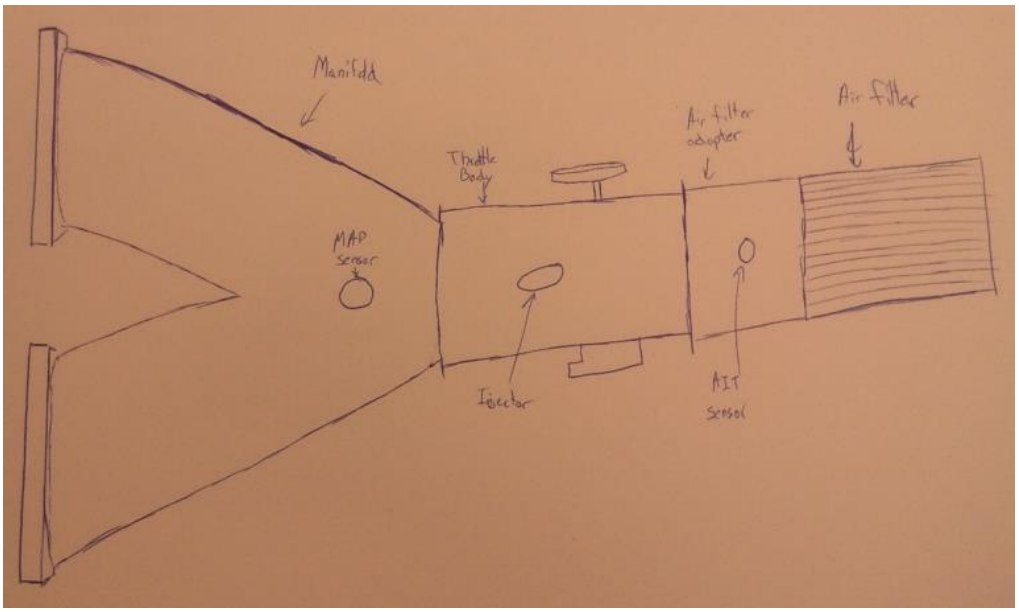

Figure 13 – Single Throttle Body TBI sketch

Single Throttle Body Port Injection

The final concept shown is Figure 14 is called Single Throttle Body Port Injection. This design is very similar to the Single Throttle Body TBI concept, but has two injectors. The two injectors are mounted in the manifold close to each intake port on the engine. By using an injector for each cylinder in the Yamaha Banshee motor, the ability to control the fuel to each cylinder is increased. This will help increase the efficiency of the engine. By having two injectors, the cost will be greater than the single throttle body TBI design.

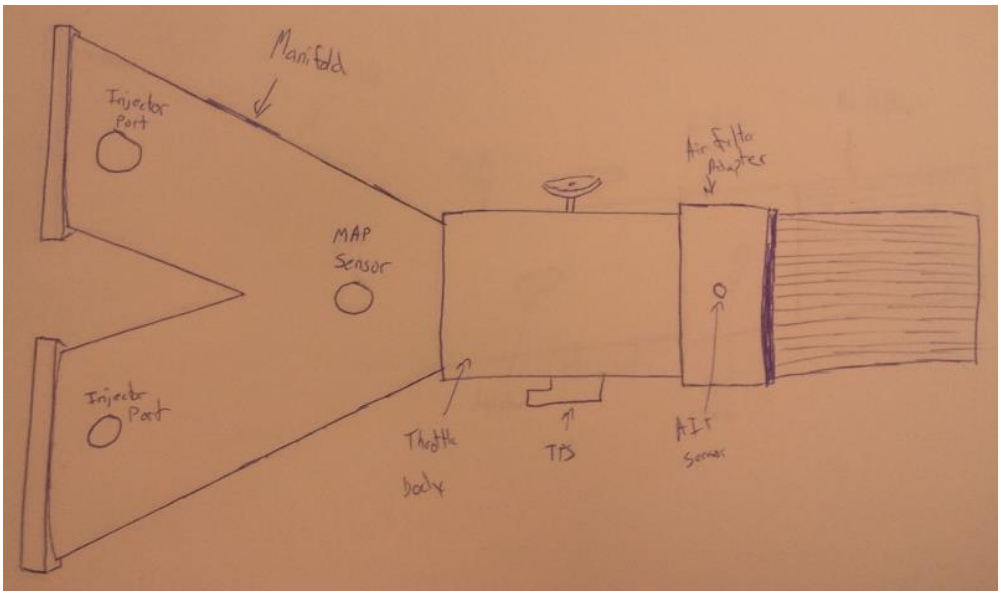

Figure 14 – Single Throttle Body Port Injection sketch

Design Selection

Each design has their pros and cons. The dual throttle bodies design offers the best efficiency of the three but also cost the most. The single throttle body TBI design is the cheapest but offers the least precision of fuel control. The single throttle body port injection is the middle choice. It offers good efficiency and fuel control but at a lower cost than the dual throttle bodies. For this project, the single throttle body port injection design has is the winner.

CALCULATIONS

Fuel Injector Size

Proper injector size is the key to an EFI kit. Too small injectors will not allow an engine run at peak horsepower, while too big injectors will cause too the engine to run rich and not efficient. See Equation 1 for injector size formula with sample calculations. B.S.F.C is brake specific fuel consumption. From pretesting, the carbureted Yamaha Banshee made 69hp at the wheels. With an estimated drivetrain loss of 20%, the Yamaha Banshee made 86hp at the crank. With hopes to gain more horsepower, an estimated 100hp will be used for this and all future calculations. The B.S.F.C is estimated to be .55, and number of injectors is 2. With these input conditions, 363cc/min injectors are needed to supply enough fuel for the EFI kit.

Equation 1 – Equation for Injector Size (15)

$$\frac{\text{Horsepower X B.S.F.C}}{\text{No. of RC Injectors X .80 (duty cycle)}} = \frac{200 \text{ X } .50}{3.2} = 31.25 \text{ lbs. / hr. (per injector)}$$

Convert to cc / min: 31.25 X 10.50 = 328 cc / min

Throttle Body Size

The throttle body size is another restriction on engine horsepower. Too small of a throttle body will restrict horsepower, but too large of a throttle will also not work. One drawback is great change in MAP pressure causing terrible drivability and the other is little acceleration enrichment when the engine needs it most (16). Using the estimator on MegaManual's website a single 45mm throttle body is estimated to make 116hp which is over the 100hp input used for the injector calculations. See Figure 15 for screen shot of estimator.

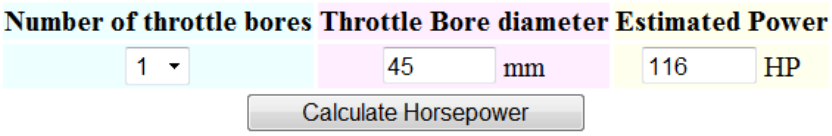

Figure 15 – Throttle Body Size estimation

Fuel Pump Size

The fuel pump supplies pressured fuel to the injectors. The correct size fuel pump is critical, too small and not enough fuel will be giving to the motor causing the motor to run at less than optimal power. See Equation 2 for fuel pump size formula. Using the equation and already estimated input variables, a 43.2 liter per hour fuel pump is needed for the Yamaha Banshee.

Equation 2 – Fuel Pump Size Equation (17)

$$\text{Horsepower} = \frac{1.2733 * \text{Rated Fuel Pump Flow}}{\text{B.S.F.C.}}$$

DESIGN DRAWINGS

'Y' Manifold

The manifold is the most important design part of the EFI kit. The manifold is where the air and fuel mix. The manifold houses both injectors, the MAP sensor, and connects the throttle body to the engine. See Figure 16 for 3-D drawing of the 2-1 'Y' manifold. To insure

that engine cylinder of the Yamaha Banshee engine get the same amount of incoming air, the 'Y' needs to split at the same degrees and the tubing needs to be the same size and length. To allow the most air to flow, the tube's inner diameter match the opening on the reed cages. Where the throttle body meets the manifold, the inner diameter of the tube needs to match the inner diameter of the throttle body so no turbulence is caused by any obstructions.

To find the length of the manifold, many different formulas were used. The needed data for these formulas were rpm for max torque, size of engine, speed of air, and degrees of opening and closing intake valve. These formulas gave an average total intake length of 11.45 inches. See Figure 17 for formulas and intake length. Actual manifold length is 7.6 inches. See Figure 18 shop drawing of manifold. The throttle body and air filter adapter make up the remaining 4 inches. The manifold flange is welded at a 65° angle, and combined with the engine flange angle of 30° means the manifold will have a 5° raise above horizontal clearing the frame rail.

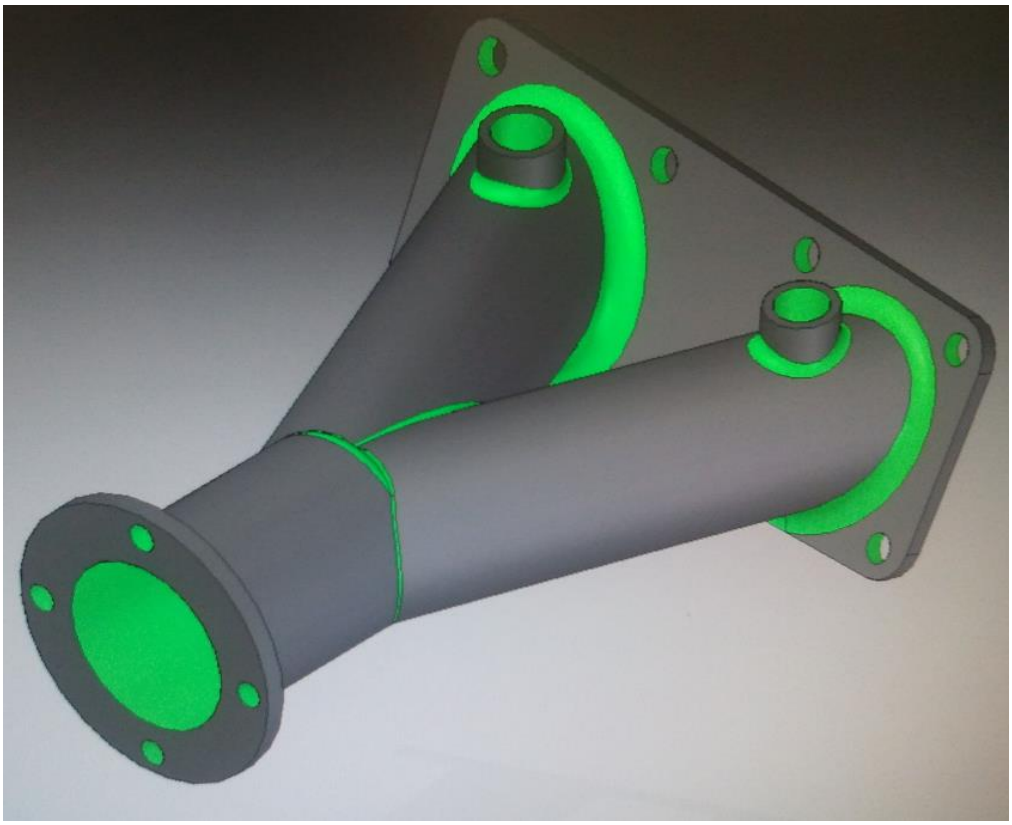

Figure 16 – 'Y' manifold 3-D model

Gordon Blair Formula - Intake Length is 11.73 inches
Simplified Chryser Formula - Intake Length is 11.20 inches
Simplified Chryser Formula (with bigger cam) - Intake Length is 10.71 inches
Simplified Formula - Intake Length is 10.56 inches
Simplified Formula 2 - Intake Length is 13.05 inches
Simplified Formula 3 - Intake Length is 11.29 inches

Intake Plenum Volume is 26 cc's

Figure 17 – Different manifold Formulas with Intake Lengths

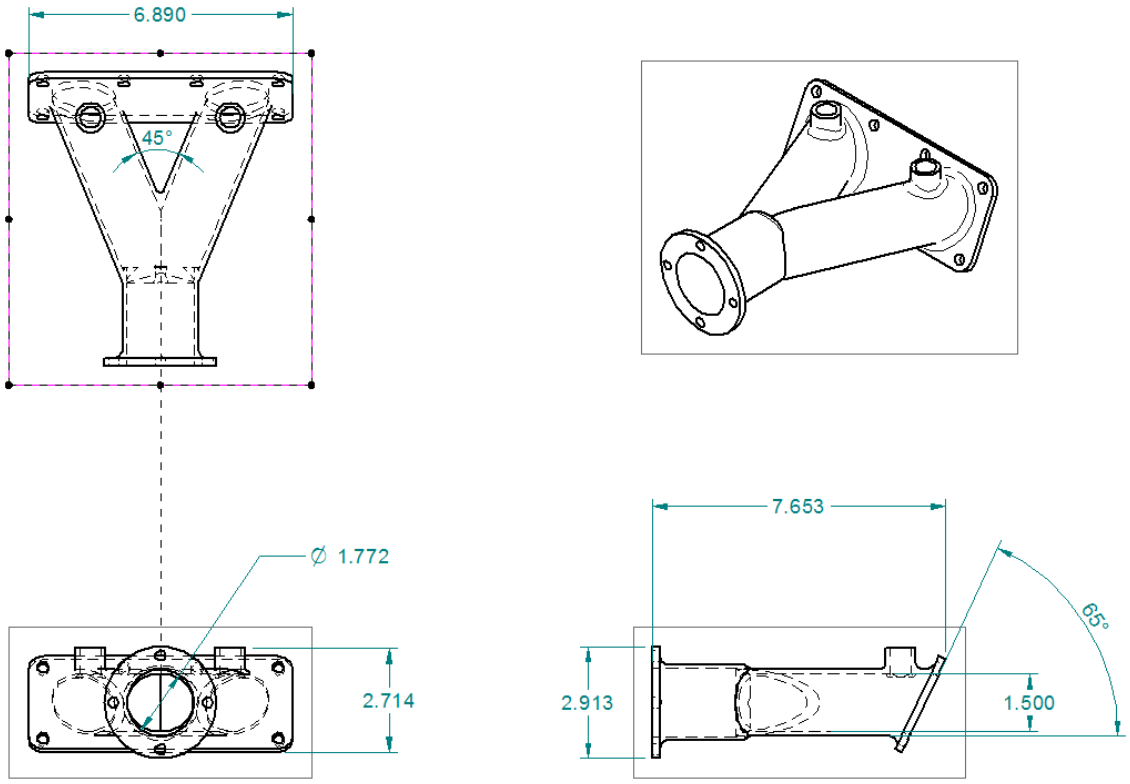

Figure 18 – Shop Drawing of Manifold

Coolant Temp Sensor Mount

To monitor the coolant temperature, a sensor needs to be contact with the coolant. To keep the customer from having to drill and weld while installing the EFI kit, a coolant temp sensor mount was designed. This mount is to be installed in the radiator hose and only requires the hose to be cut to the proper length for the mount. See Figure 19 for shop drawing of Coolant Temp Sensor mount. The outside diameter of clamping area needs to be the same as the inner diameter of the radiator hose. This will help give a good tight seal on the mount and not let any coolant leak. The wall thickness of the clamping area need to be thin to not impair coolant flow but thick enough to with stand the clamping force of the radiator hose.

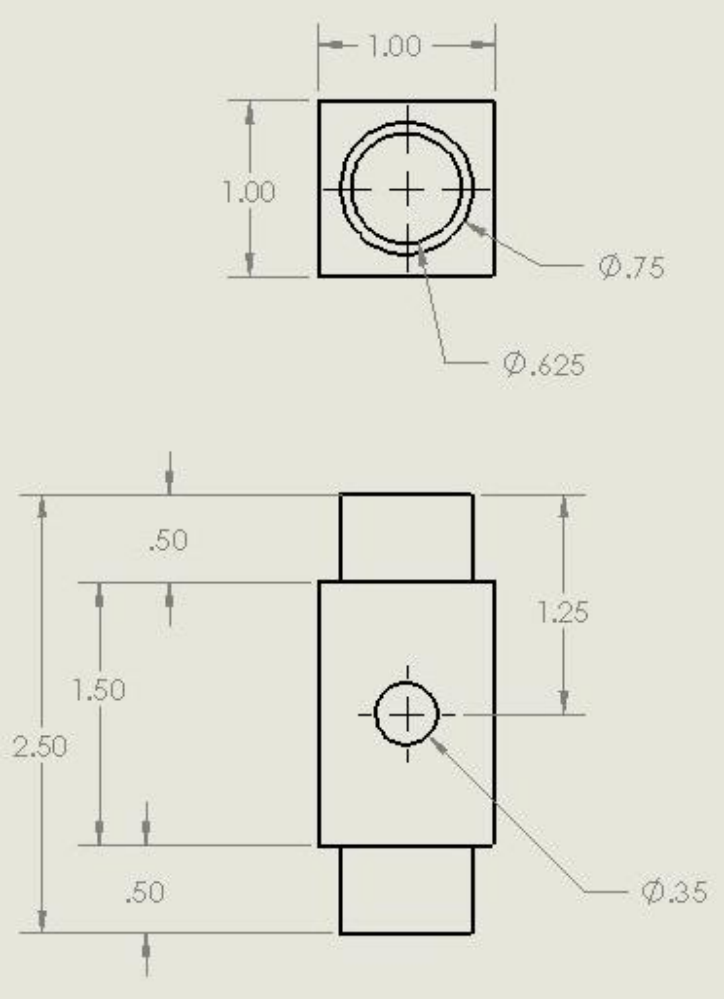

Figure 19 – Coolant Temp Sensor Mount shop drawing

Air Filter Adapter

The air filter is unable to clamp directly onto the throttle body. An adapter is needed. This adapter will mount directly to the throttle body and the filter will clamp to the open end. See Figure 20 for shop drawing of the air filter adapter. The inner diameter needs to be the same as the inner diameter of the inlet side of the throttle body. The outer diameter needs to match the inner diameter of an air filter so that a tight seal is created and has no air leaks. A threaded bung is welded to this adapter so the air intake temperature sensor can be mounted and monitor the incoming air. The adapter will be made from aluminum to keep weight down.

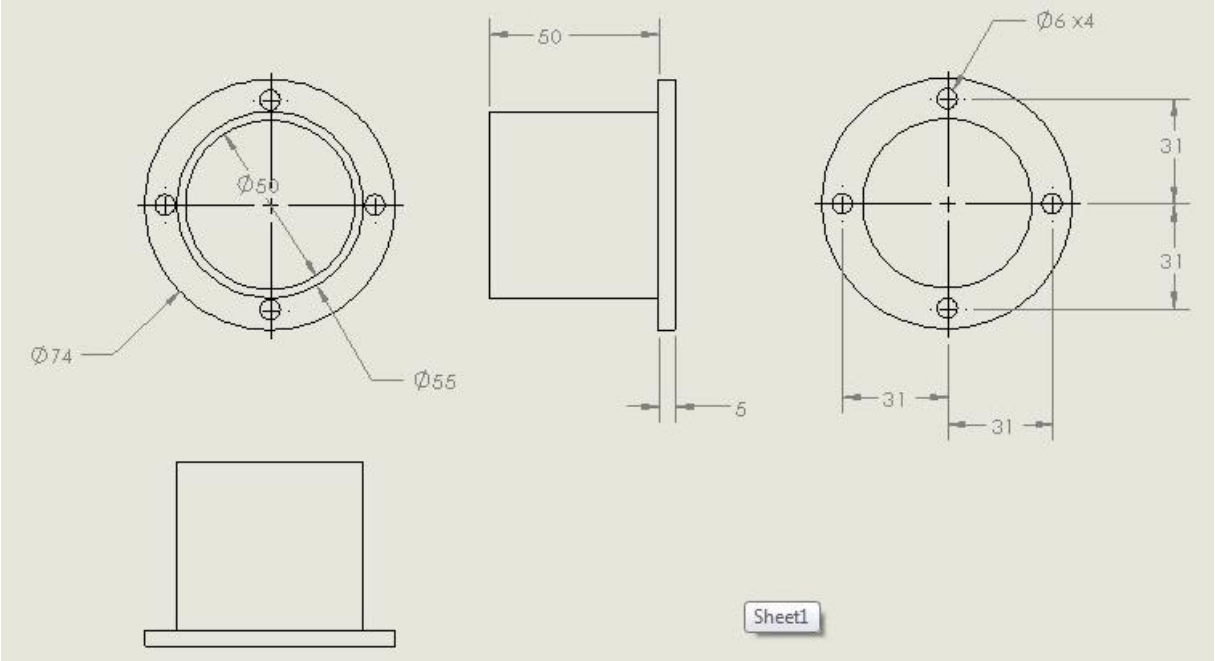

Figure 20 – Air Filter Adapter shop drawing

COMPONENT SELECTION

Throttle Body

The throttle body control air flow to the engine. The proper size throttle body is needed for the engine to run at optimal performance. A too small throttle body will not allow enough air to enter the engine and too big will not allow air to move fast enough into the engine. From previous calculations, a 45mm throttle body is able to flow enough air for 116hp. A throttle body from Extrudabody has been purchased. See Figure 21 for pictures of throttle body. It is a 45/50mm taper bore throttle body, meaning that the inlet side had a bore of 50mm and before the butterfly it has a bore of 45mm. The throttle body is made of all aluminum. Included with the throttle body is a TPS and cable holder.

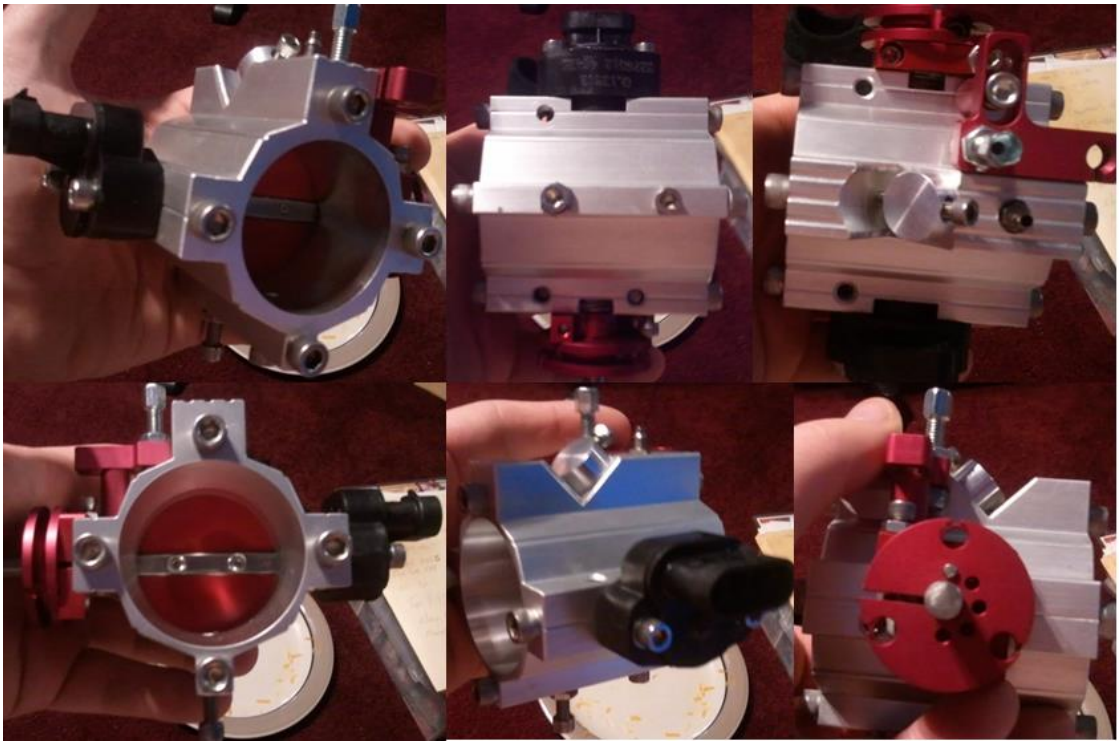

Figure 21 – Extrudabody 45/50mm Taper Bore throttle body

Injectors

Injectors come in many different shapes, sizes and designs. From the calculations above, a minimum size of 363cc/min is needed to fuel enough fuel for the engine. Wanting to keep the kit compact, a small injector was preferred. RC Engineering has donated two PL2-370 injectors for the EFI kit. See Figure 22 for picture of injectors. These injectors have a fuel flow rate of 370cc/min at 43.5 psi. They have O-rings on each end to make a tight seal and keep the pressurized fuel from coming out around the mounts.

Figure 22 – RCeng PL2-370 injectors

Engine Control Unit

The engine control unit is the brain of the EFI kit. The ECU reads all the input data from the sensors, calculated the data from the settings, and sends out the correct output signals to tell the injectors when to open and close and to tell the coils when to fire. The ECU needs to be able to control two injectors and two coils. The PE-ECU-3-SP from Performance Electronics is able to control two injectors and two coils. See Figure 23 for picture of ECU. The PE-ECUI-3-SP is a prototype unit that is a smaller version of the PE-ECU-3. It offers the same abilities but was designed for twin cylinder engines. See Appendix G for details on the PE-ECU-3. This ECU allows full adjustments for fuel and ignition. The small size of this ECU allows for it to be easy to mount and hide on the Yamaha Banshee.

Figure 23 – Performance Electronics PE-ECU-3-SP

Sensors

Many sensors are needed to make an EFI kit work efficiently. The sensors used in this kit are the Manifold Absolute Pressure sensor, Throttle Position Sensor, Air Intake Temperature sensor and Coolant Temperature Sensor. The TPS came with the throttle body from Extrudabody. The TPS has a range from 0-90 degrees or closed to fully open. The MAP, TPS and AIT sensors came from AEM Electronics. See Figure 22 for pictures of AEM Electronics sensors. AEM Electronics gave a discount of 50% on all parts needed for this project. The MAP brass sensor reads pressure from 0 to 1 BAR and can operate in temperatures ranging from -40F to 221F. The AIT sensor can read incoming air temperatures from -40F to 275F with an accuracy of less than 2.7F. The CTS can read coolant temperatures as low as -40F up to as high as 275F with less than 3.6F accuracy. These sensors allow the EFI kit to work in a temperature range of -40F to 221F which means the goals of -30F to 120F.

Figure 24 – AEM Electronics sensors (MAP, AIT, CTS)

TESTING

CARBURETOR TESTING

The Yamaha Banshee was initial tested using a single PWK 38mm A/S carburetor on a custom 2-1 manifold. Testing was done at Kennedy Powersports in Michigan. Peak horsepower and torque were found using a DynoJet dynamometer (dyno). The carburetor version made 69hp and 43ft-lbs. See Figure 25 for dyno graph. After tuning was completed, fuel economy test began. Testing for fuel economy included trail riding, steady throttle on dyno, and 300' drag racing at wide open throttle. Four runs of each test were performed and the total average of all was used to calculate the average MPG. See Table 4 for test runs. The average MPG for the carburetor was 8.2 mpg.

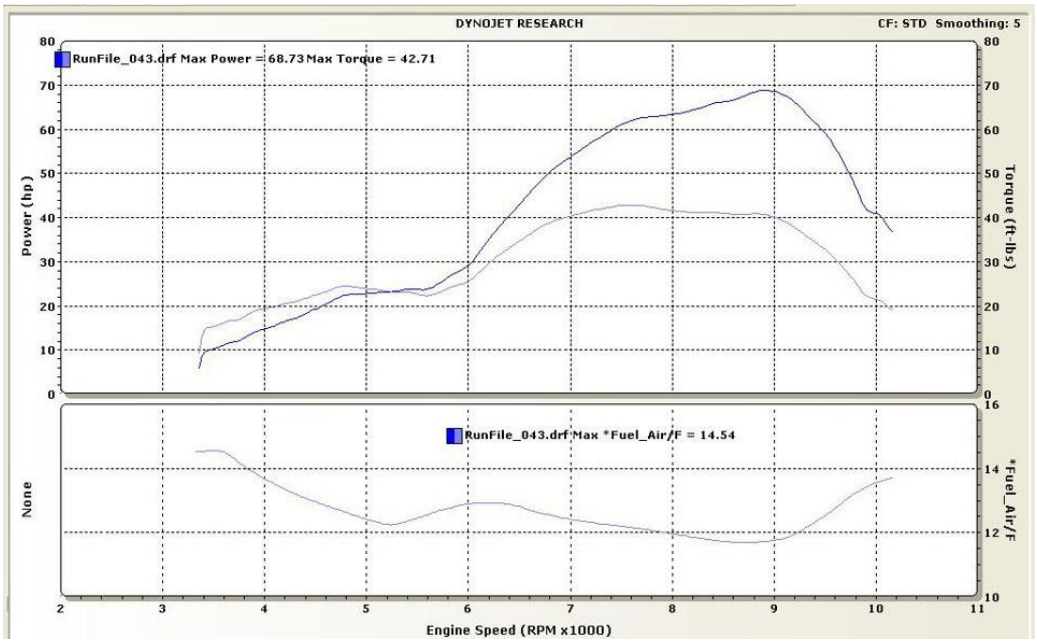

Figure 25 – Yamaha Banshee with single PWK 38mm A/S carb

Table 4 – MPG Testing for Carb version

MPG Testing	1	2	3	4	Average
WOT	3.8	4.1	4.2	3.8	3.975
Trail	12.1	11.5	11.2	10.9	11.425
Steady	9.5	10.2	8.2	8.9	9.2
Average	8.2				

EFI TESTING

After the EFI kit was installed and running, test began. Kennedy Powersports was used again for horsepower and torque measuring. The EFI version made 76hp and 41ft-lbs. See Figure 26 for dyno graph. A 10% increase of horsepower was the result of the EFI conversion. After power testing was completed and there were no issues with running, fuel economy testing started. The same tests as before were completed. See Table 5 for EFI fuel economy result. The EFI had an average fuel economy of 12.4 mpg. This is a 50% increase in fuel economy. Both goals for verifiable results meet. Reason for such a huge increase in fuel economy could be the results of using a large pilot jet in the carburetor. This large pilot jet was used due to the lack of air speed in the carburetor from using a big carburetor.

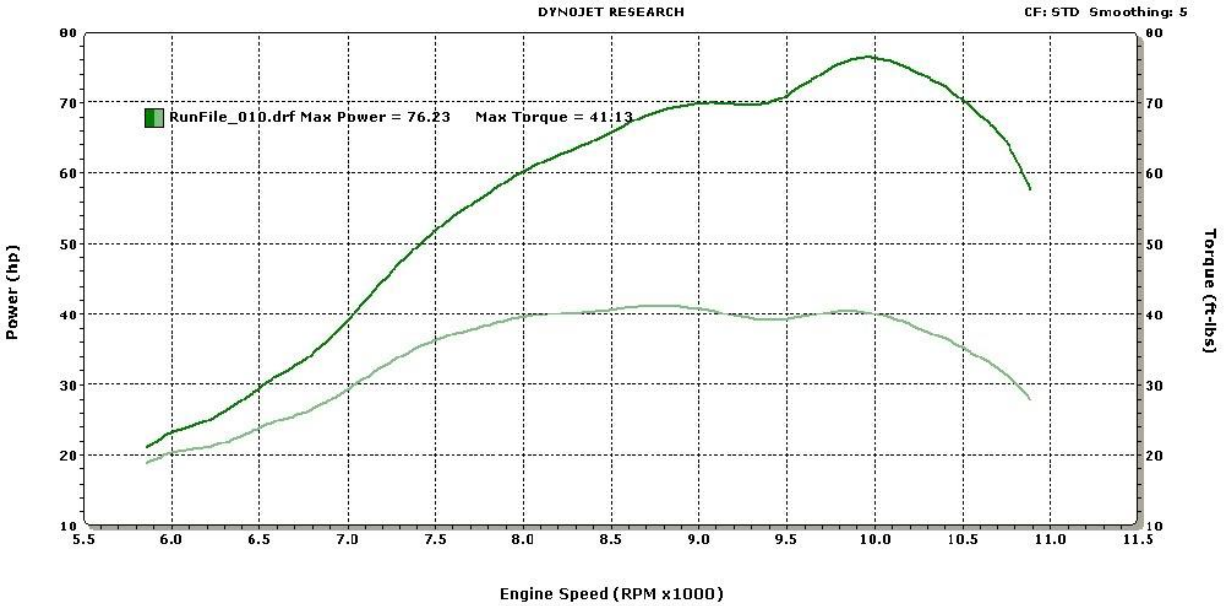

Figure 26 – EFI Yamaha Banshee Dyno Graph

Table 5 – MPG Testing for EFI version

MPG Testing	1	2	3	4	Average
WOT	4.9	5	4.7	5.1	4.9
Trail	15.5	14.6	16.4	15.7	15.6
Steady	12.2	16.2	20.1	18.2	16.7
Average	12.4				

RESULTS

The EFI conversion kit was an overall success. It was under budget and met most of the product objectives. Only issue with this kit was that welding was required by installer. The installer would have to weld the wideband bung to the exhaust and drill a hole in the exhaust. Some objectives were not able to be tested such as the range of temperature (-30F to 120F), if kit was pressure washer safe, and any long term testing. As all electronic components had a temperature range of -40F to 221F and were waterproof, there is no reason to believe that the EFI conversion kit shouldn't work in the objective temperature range and is safe to pressure wash.

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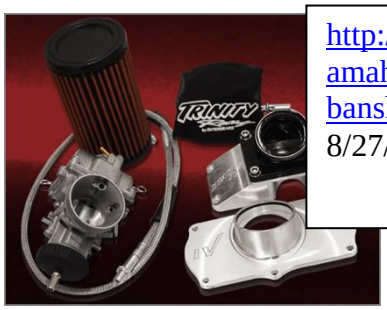
APPENDIX A – PRODUCT RESEARCH

Interview with current Yamaha Banshee Owner, August 20, 2012
N2otoofast4u, Yamaha banshee rider, Oregon,
Current has a turbo drag Yamaha banshee
Would like to be able to set up fuel and timing map in relation to turbo boost
Does not want to rejet for change in temperature or elevation
Want to gain as much overrev power as possible without losing off the line power

Interview with current Yamaha Banshee Owner, August 21, 2012
Sheerider1026, Yamaha banshee rider, Kentucky,
Current has a Yamaha banshee that he rides in the trails
Has single carbureted kit on banshee because it is easier to tune and rejet than dual carburetors
Has a nitrous kit for extra power but having issue
Would like EFI to automatically adjust timing and fuel when nitrous is used
Would like to have instant throttle response
Would like increase in fuel economy

Interview with Kevin Gigot, Owner of Gigot Performance August 31, 2012
Made an EFI kit for a Yamaha Banshee, was in Dirt Wheels
Kit was custom, used TBs off Snowmobile, very basic ECU.
Needed MS-DOS to program ECU
Quad only made 90hp with a 7mil Cub on E85
Parts cost him around $500, he charged $2500
"With EFI, able to see better throttle response, higher revving motor, and easier riding. Not messing when tuning, no gas on hands and no wasting gas. Hook laptop up and click a few buttons"

 http://www.trinityracing.com/yamaha-banshee2.html#performance 8/27/12 With the CV (Constant Velocity) system, your Banshee will see a drastic 20% improvement in bottom end power, all the while giving you a 15% increase on the top end. The CV manifold system comes complete with the CV manifold, 33mm or 35mm PWK carburetor, intake manifold, throttle cable, gaskets, o-rings, jets, and your choice of a K&N filter with Outerwear or the o-ringed, velocity air box adapter.	Direct Bolt on More power $500 Options (carb size) Compact Bad air flow Single Carb Easy of Jetting Complete intake
 http://www.wickedatv.com/DUportal30/home/detail.asp?iData=12373&iCat=288&iChannel=8&nChannel=Products 8/27/12 WICKED MOTORSPORTS YAMAHA BANSHEE CARBURETOR KIT AND RZ350. KIT COMES COMPLETE WITH KEIHEIN 34mm PJ's W/THROTTLE CABLE, WICKED MOTORSPORTS DUAL X-ROSS OVER INTAKE MANIFOLD AIR FILTERS AND OUTERWEARS PRE OILED WITH K&N OIL. THIS WORKS GREAT FOR THE RECREATIONAL RIDER/RACER FOR PORTED STOCK CYLINDERS TO 68mm BORE ATHENA CYLINDER KITS, SR-71 CYLINDER KITS,CHEETAH CUBS,WHOMPUSS,SERVAL AND OTHER POPULAR BANSHEE CYLINDER KITS FOR RECREATIONAL BANSHEE/RACER RIDERS! WE'VE DYNOED FROM STOCK 26mm CARBURETORS TO THESE 34mm CARBURETORS TO INCREASE A WHOPPING DIFFERENCE! OF 5-7 HP ON MOST APPLICATIONS. AS WELL BUILT A CLEANER THROTTLE RESPONSE THAN MOST CARBS OUT THERE FOR THE RECREATIONAL RIDER. AWESOME GAINS FOR JUST A BOLT ON KIT!	Direct Bolt on More power $700 Prejetted Dual Carbs Complete intake

http://www.highlifter.com/p-1312-jky350b.aspx
8/27/12

Increased power and fuel efficiency! That's what we're all looking for. A DynoJet Jet Kit can take care of the problem. Looking for an inexpensive mod that can make a big difference? A jet kit will increase your power and smoothness throughout the entire power-band. At the same time, a jet kit will keep your engine running at the right fuel-air mixture so that you receive the most benefit and optimum fuel efficiency. A DynoJet Jet Kit includes comprehensive instructions which show step-by-step installation and testing procedures to ensure a perfect setup every time. DynoJet and High Lifter work together to develop jet kits for new applications…and jet kits are available for most makes and models. In many cases, there are several jet kits and main jets to fit specific needs and carburetion problems. HELPFUL TIP: If you've recently installed snorkels…and something just isn't quite right? You'll want to look at the jetting of your machine to see if a minor change could help you out!

Direct Bolt on
More power
Fuel Efficiency
Very cheap (under $100)
For stock carbs
Just jets

http://www.jegs.com/p/FAST/Fast-Racing-EZ-EFI-Carburetor-to-EFI-Conversion-Kits/1216664/10002/-1
8/28/12

Direct Bolt on
Self tuning
Complete kit
$2136
Easy to use

With the EZ-EFI from FAST, you don't need a laptop or tuning experience - it does the work for you. In the past, carburetor-to-EFI conversion was no picnic. At the very least, you would need a laptop and significant tuning experience. But thanks to FAST engineers, those days are over. With the new EZ-EFI Self Tuning Fuel Injection System, you get patent-pending EFI technology that does all the work for you. Simply hook up EZ EFT, answer the basic setup Wizard questions on the included hand-held display, and the system tunes itself as you drive!

EZ EFI Features & Benefits:

- Speed Density Based
- Self-tuning system - NO tuning experience or laptop needed
- Complete system includes mini ECU, wide-band O2 sensor, wiring harness, injectors, fuel pump kit & 4150 throttle body
- 4150 throttle body works with original carb-style linkage & accepts all OEM sensors
- Bolts on to any engine under 600 hp, regardless of brand or size; the perfect choice for street rods & muscle cars
- Easy-to-use setup Wizard provides a comprehensive walk-through & system tunes itself

http://www.hotrod.com/howto/113_0504_standalone_efi_systems/viewall.html
8/28/12

Let's just get this out of the way up front. For the average street machine, EFI isn't about making more horsepower. It's not about simplicity or saving money either. The good ol' carburetor has had that covered for more than a century. Even those of us who've picked our knuckles up off the ground would agree. To top it all off, the ugliness of errant wires and sensors requires innovative solutions on the OE level--like slapping on engine covers. So why go EFI?

Despite its higher initial cost of entry and reputation for fussiness, once EFI is set up properly, no Dominator or Q-jet can come close to the drivability, reliability, lack of maintenance and consistent performance EFI delivers. EFI also offers reduced emissions and improved gas mileage (for those of you who care about that sort of thing). Whether you're looking to trade in your carb for a computer, want to step up from a factory PCM to a standalone, or just train your stock computer to play nice with big cams and blowers, the options are many, and getting started isn't as hard as you may think.

Since consumer intimidation is inversely proportional to profits, the aftermarket has taken great measures to make the transition from carb to EFI as painless and simple as possible. Here's a look at some of the more popular EFI systems on the market plus some tips on how to get started.

Drivability
Reliability
Lack of maintenance
Consistent Performance
Reduced Emission
Better MPG

APPENDIX B – SURVEY RESULTS

EFI SYSTEM ON YAMAHA BANSHEE
CUSTOMER SURVEY

This survey will be used to evaluate the importance of difference feature for an electronic fuel injection (EFI) bolt-on conversion kit for a Yamaha Banshee, a 347cc twin cylinder two-stroke ATV. The results will be used to ensure best design of a bolt-on EFI system for both current and future Yamaha Banshee owners.

How important is each feature to you in the design of an EFI system for a Yamaha Banshee?

Please circle the appropriate answer. 1 = low importance 5 = high importance

							AVE
Reliability	1	2	3	4(10)	5(20)	N/A	4.67
Durability	1	2(2)	3(3)	4(7)	5(18)	N/A	4.37
Ease of Installation	1(2)	2(10)	3(5)	4(5)	5(8)	N/A	3.23
Verifiable Results							
Power	1	2	3(2)	4(10)	5(18)	N/A	4.53
Fuel Economy	1(8)	2(5)	3(4)	4(5)	5(8)	N/A	3.27
Precision	1	2(3)	3(7)	4(10)	5(10)	N/A	3.90
Ease of Maintenance	1	2(2)	3(8)	4(15)	5(5)	N/A	3.77
Appearance	1(7)	2(6)	3(6)	4(7)	5(4)	N/A	2.83
Ease of Programming	1	2	3(3)	4(9)	5(18)	N/A	4.50
Ease of Operation	1	2(3)	3(7)	4(10)	5(10)	N/A	3.90
Resistance to Environmental Factors	1	2(2)	3(6)	4(8)	5(14)	N/A	4.13
Ease of Adjustment	1	2(1)	3(8)	4(8)	5(13)	N/A	4.10

How much would you be willing to pay for an EFI system for your Yamaha Banshee?

$1501-$1750 (8) $1751-$2000 (6) $2001-$2500 (4) $2501-$3000 (6) $3001+ (6)

Thank you for your time.

APPENDIX C – QFD

Nick Strickland
EFI Conversion Kit
9 = Strong
3 = Moderate
1 = Weak

	Size	Reduced number of components	Weight	Material	Color	Fuel Pump	Injectors	Geometry of Manufacturability	Throttle Body	ECU	USB adaptor for laptop connection	Battery	Stainless Steel bolts and nuts	Sensors	Customer importance	Designer's Multiplier	Modified Importance	Relative weight	Relative weight %
Reliability						3	3	1	3	9		3		9	4.7	1.04	4.9	0.10	10%
Durability	1	3	3	9		3	1	3	3	3		3	9		4.4	1.04	4.5	0.09	9%
Ease of installation	3	9	9	3		3	1	3	3	3	1	3	3	1	3.2	1	3.2	0.07	7%
Verifiable Results (power)	1					3	3	1	3	9	1			9	4.5	1	4.5	0.09	9%
Verifiable Results (mpg)	1					3	3	1	3	9	1			9	3.3	1.1	3.6	0.07	7%
Precision	1					3	3	1	3	9	3			9	3.9	1	3.9	0.08	8%
Ease of Maintenance	3	3	1			3	1	1	3	3		1	1	3	3.8	1	3.8	0.08	8%
Appearance	1	1		9	9	3		3	1	1		1	9	1	2.8	0.95	2.7	0.06	6%
Ease of Programming							1		1	9	9			3	4.5	1.05	4.7	0.10	10%
Ease of Operation		1				1	1		3	1				1	3.9	1	3.9	0.08	8%
Resistance to Environmental Factors				9	3					1			3	1	4.1	1	4.1	0.09	9%
Ease of Adjustment		3					1		1	3			1	1	4.1	1	4.1	0.09	9%
Abs. importance	0.84	1.52	0.97	2.33	0.76	2.03	1.56	1.08	2.26	5.26	1.37	0.92	1.98	4.08	27.0		48.0	1.0	
Rel. importance	0.03	0.06	0.04	0.09	0.03	0.08	0.06	0.04	0.08	0.19	0.05	0.03	0.07	0.15					

APPENDIX D – PRODUCT OBJECTIVES

EFI Kit for a 2-stroke Gas Engine

The following is a list of product objectives and how they will be obtained or measured to ensure that the goal of the project was met. The product objectives will focus on an Electric Fuel Injection kit for a Yamaha Banshee. The 2-stroke gas engine that is selected currently utilizes a carbureted fuel system.

Ease of Installation:

1) Any special tools will be included in the kit.
2) Less than 3 hours to uninstall carbureted system and install EFI system.
3) Less than 20 steps will be needed to install EFI kit.
4) No welding will be required by installer.
5) Kit will include all new hardware.
6) All electrical plug connections in the wiring harness will use a male/female plug connection.

Ease of Programming:

1) Programming will be done on a laptop via a USB cord.
2) Software for programming will be provided as a CD and filmware can be downloaded online.
3) Basic knowledge of spreadsheet is required.
4) Less than 2 hours to adjust fuel and ignition charts from preset settings to desired settings.

Ease of Operation:

1) Thumb throttle will take less applied force to open the throttle body than the current carbureted system and will meet standards for human ergonomics.
2) On/Off switch and key switch will take less force to select a setting than the standards for human ergonomics.
3) Clutch lever will take less force to disengage than the standard for human ergonomics.

Ease of Maintenance:

1) Fuel injector cleaner will be poured in gas tank to clean injectors.
2) Throttle body cleaner will be used to clean throttle body.
3) Replacement of individual worn out parts with new parts will take less than hour.
4) Outerwear on filter eliminates need to clean and re-oil air filter, just need to clean outerwear and let dry.

Ease of Adjustment:

1) Changing of throttle body will take less than 30 minutes.
2) Changing of injectors will take less than 45 minutes.
3) Changing of air filter will take less than 15 minutes.

Durability:

1) Proper grade bolts will be used in the kit, calculations will be done to select proper grade. Stainless steel bolts will be used because of looks.
2) Mechanical assembly will follow allowable torques of mechanical fasteners.
3) Loc-Tite will be used to keep all bolts from vibrating loose.

Reliability:

1) All electrical connections will be soldered and then covered with heat wrap as to assure of no loose connections or bare wires.
2) Reliability of the kit measured by component life and proper design criteria specified in the following spec sheets:
   -Battery Spec Sheet
   -Injector Spec Sheet
   -Fuel pump Spec Sheet
   -All sensors spec sheets

Verifiable Results:

1) EFI kit's power curve will be greater than the current carbureted system by 1%.
2) EFI kit will increase fuel economy by 10% over carbureted system.

Resistance to Environmental Factors:

1) All parts in the EFI kit will be able to work in a temperature range of -30°F to 120°F.
2) Heat from exhaust will not affect the EFI kit's ability to operate during a normal riding weekend of 8 hours a day for 3 days.
3) Kit will be able to be pressure washed.
4) All visible metal parts will be powder coated or anodized to inhibit rust.
5) Dialectical grease will be used in all electric plugs to keep water out.

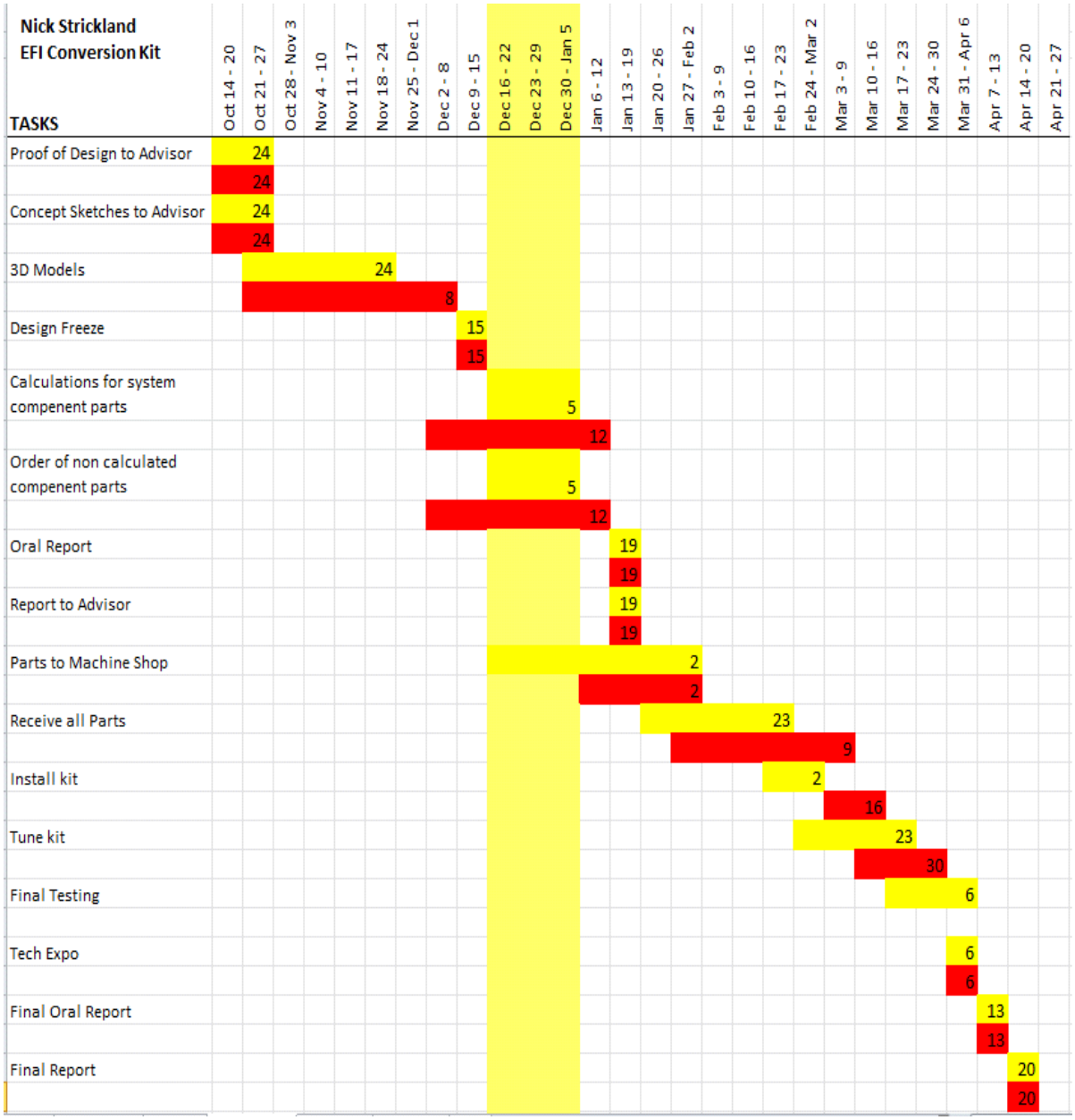
Precision:

1) The kit will hold the user selected air fuel ratio settings within 1% during a normal riding weekend of 8 hours a day for 3 days.

Appearance:

1) All visible bolts will be stainless steel Allen heads.
2) No external sharp edges.
3) All visible metal parts will be powder coated or anodized to user's desired color.
4) No exposed wiring.

APPENDIX E – SCHEDULE



APPENDIX F – BUDGET

Budget for EFI Conversion Kit

Assembly	Component	Desription	Vender	Projected Cost	Actual Cost	Retail Price
DC Conversion	High Watt Stator	300watt, floating ground	GT Stators	150	0	80
	Battery	12v, SLA, 8aH	eBay	50	25	20
	Recifier	12v, 200w+, 1-phase	Tympanium	75	50	50
	Battery Box	Custom	SCSS	50	0	20
Elecontrics	ECU	PE-ECU-3-SP	PE	1200	800	800
	TPS	Throttle Body Sensor	Extrudabody	50	0	Came with TB
	Wideband Sensor	O2 sensor with digital gauge	AEM	200	57	114
	Injectors	370cc/min, low impendence	Rceng	150	0	177
	AIT Sensor	Air Intake Temp Sensor	AEM	30	30	59
	Wiring Harness	34pin, custom harness	PE	100	200	200
	Ignition Coils	Smart Induction Coil	AEM	200	84	167
	MAP Sensor	1 Bar, Brass	AEM	150	33	66
	Flywheel	Stock Modified 36-1 Wheel	Custom	100	0	50
Intake	Manifold	Custom Y Manifold	Custom	400	0	300
	Throttle Body	45/50 Taper Bore	Extrudabody	200	288	288
	Air Filter	5* angle with Outerware	K&N	75	54	54
Fuel	Fuel Pump	LTR450 fuel Pump	Suzuki	150	90	90
	Fuel Lines	3/8" Rubber Lines	Dayco	30	25	25
	Fuel Rail	6" Universal	Ross Machine	15	10	10
	Fuel Fittings	3/8 NPT to 3/8" Barb	Mr. Gasket	50	50	50
	Fuel Pressure Re	0-140PSI, black	Mr. Gasket	50	23	23
Tools	Hardware	SS bolts and nuts	AlloyBoltz	50	25	25
	Tools	Flywheel Puller	Yamaha	100	25	25
	Extra Parts			250	50	50
Total				3875	1919	2743

APPENDIX G – PE-ECU-3

PE3 ECU SERIES
BY **PERFORMANCE ELECTRONICS, Ltd.**

Performance Electronics, Ltd.
www.pe-ltd.com • info@pe-ltd.com
Phone: (513) 777–5233
Fax: (513) 777-2042

The ***PE3*** engine control unit is a compact, adjustable system that handles fuel and ignition responsibilities for almost any engine. The long features list, ease of use and small size make it a great addition to any vehicle, on or off-road.

General System Features

- Completely adjustable via a laptop.
- *Plug-and-Play* versions available for some applications.
- Lightweight and compact with a waterproof option (4.25"x 4.80" x 1.00" and less than 1 lb).
- *Dedicated CAN bus* that allows communication with external devices.
- *Standard 1MB of on-board data logging* for engine parameters and external inputs (Approx 5 hrs of data with 10 channels at 20 Hz).
- 25,000+ max RPM.
- Adjustable rev limits including Primary, Secondary and Boost limits.
- Password protected access.
- Fast and reliable communication via *Ethernet*. Allows for easy *wireless tuning* with routers.
- Real-time tuning.
- Extensive error and diagnostic functions.
- Save and load tuning files, or parts of tuning files, to and from disk.
- Primary/Secondary main fuel and ignition tables.

Plastic, Waterproof Enclosure

Aluminum Enclosure

Fuel Specific Control

- *25x26 Main fuel table* with adjustable indices and an option to reduce table size to 13x13.
- Barometric Pressure, Acceleration, Deceleration, Battery, Air Temp, Coolant Temp and Starting compensations.
- Individual cylinder trims.
- Closed loop control with adaptive learning.
- Sequential, batch or semi-sequential injector firing.
- Adjustable injection timing control.
- Saturated or peak-and-hold injector drivers.
- Adjustable peak current and adjustable hold current for low impedance injectors.
- Staged injection.

Ignition Specific Control

- Coil-on-plug, wasted spark or distributor based ignition.
- *No external igniters required.* Inductive igniters are built in the ECU.
- *25x26 Main Ignition table* with adjustable indices and an option to reduce table size to 13x13.
- Starting, Air Temp, Coolant Temp and Barometric Pressure compensations.
- Individual cylinder trims.
- Adjustable dwell as a function of Battery Voltage.

System Inputs

- MAP, TPS, Barometric Pressure, Air Temp, Coolant Temp, Battery Voltage, Crank, Cam, Thermistors, EGO.
- Up to *8 generic analog inputs* that can be used to modify fuel, modify timing, cut fuel, cut timing or simply be logged.
- 2 additional thermistor inputs.
- Up to *7 user configurable digital inputs* that can stop fuel, stop ignition, measure speeds, initiate secondary rev limit, start/stop data logging, etc.

System Outputs

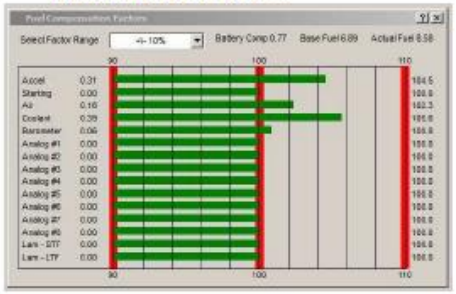
- Fuel pump driver.
- *8 peak-and-hold or saturated injector drivers.*
- *4 ignition coil drivers with internal igniters.*
- Dedicated tachometer driver.
- Idle air stepper motor driver.
- *Up to 10 user configurable digital outputs.*
- *Up to 8 Pulse Width Modulated outputs* with adjustable duty cycles based on 3-D tables.

PE reserves the right to change the specifications without notice. 10/24/11

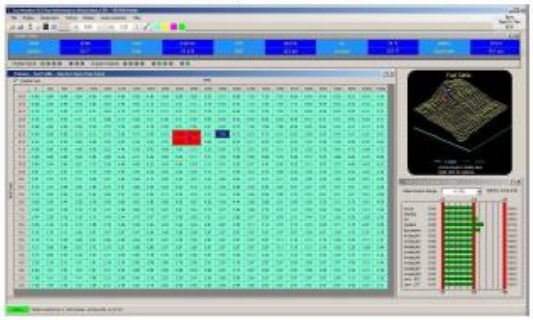
Advanced Tuning Software

- All features are completely adjustable using the advanced software that communicates to the ECU via an Ethernet connection.

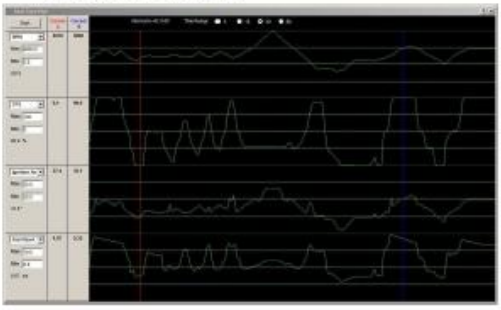
- While tuning, individual compensation terms are represented in an easy to view bar graph. This allows instant identification of which factors are influencing fuel and ignition.



- Huge *25x26 main fuel and ignition tables* provide ample resolution for even the most difficult to tune engine. User adjustable RPM and Load indices make the system even more versatile.

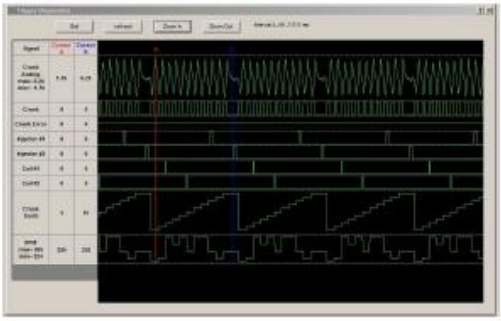


- *Real-time plotting and internal data logging are included with every system.* 1 MB of data can be stored in the ECU as the engine runs. Engine parameters, as well as generic analog and digital inputs, can be logged.



- In addition to the large fuel and ignition tables, the ***PE3*** allows you to adjust all fuel and ignition compensation terms real time.

- *Advanced diagnostic features,* like error logging and crank/cam trigger scope displays, allow for easy troubleshooting.



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