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University at Buffalo
UB Approach to an Environmentally Friendly Snowmobile

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ABSTRACT

The concern over the environmental impact of snowmobiles on the surrounding environment has become a growing concern for environmentalists and those who use them. To produce an environmentally "clean" snowmobile a new motor and chassis were selected. The implementation of the four stroke engine into snowmobiles plays a key role in reducing emissions and improving fuel economy. The UB Clean Snowmobile Team has chosen to implement the Weber MPE 750cc four stroke engine and a closed loop Bosch fuel injection system. This motor will replace the original Polaris Liberty 800cc two stroke engine. The required subsystems necessary to support engine management are: the fuel delivery systems, oil system, and electrical system. In an effort to reduce noise and emissions a three way catalyst and a reactive muffler were utilized. The implementation of these technologies results in a snowmobile that is not only fun to ride but also environmentally friendly.

INTRODUCTION

Due to the increasing regulations on exhaust and noise emissions on modern snowmobiles, there is an ever-growing need for further development of new technologies that assist in making snowmobiles cleaner and quieter. The Clean Snowmobile Challenge (CSC) is a collegiate design competition for student members of the Society of Automotive Engineers (SAE). "The intent of the competition is to develop a snowmobile that is acceptable for use in environmentally sensitive areas. The modified snowmobiles are expected to be quiet, emit significantly less unburned hydrocarbons and carbon monoxide than conventional snowmobiles, without significantly increasing oxides of nitrogen emissions. The modified snowmobiles are also expected to be cost effective. The intent of the competition is to design a touring snowmobile that will primarily be ridden on groomed snowmobile trails. The use of unreliable and expensive solutions is strongly discouraged" [1]. Guidelines for the 2006 SAE Clean Snowmobile Competition state that this years entries into the competition must beat the 2012 emissions standards just as the manufacturers must do. Additionally, entries must pass the Snowmobile Industry noise test, just as manufacturers would have to.

PROBLEMS WITH TODAY'S SNOWMOBILES

EMISSIONS PROBLEM

The predominant use of hydrogen and carbon based fuels in snowmobiles leads to hazardous emissions from the combustion process. Hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) are the most harmful of the exhaust molecules and must be minimized. In order to create a solution to the emissions problem, the cause of the formation of the particles must first be understood.

Hydrocarbons are formed by five modes: incomplete combustion, flame quenching, crevice volume, absorption of fuel vapor, and high equivalence ratio. Incomplete combustion normally occurs during the expansion stroke, when the cylinder pressure drops, causing the unburned gas temperature to drop. This temperature drop causes a decrease in the burn rate. Flame quenching can be attributed to the relatively cold walls of the cylinder. The cooler walls form a boundary layer where the flame cannot penetrate, hence leaving some unburned HC molecules. Crevice volumes, such as the area between the piston and cylinder wall, can once again trap hydrocarbons in a region where the flame cannot enter. The mode of absorption of fuel vapor into the thin oil layer occurs during the compression stroke. Once the pressure gets to a certain level, the fuel vapor can be absorbed into the oil layer. Upon expansion, the fuel vapors containing unburned HC are emitted from the oil layer and exit out through the exhaust. Hydrocarbons are also known to be sensitive to the equivalence ratio, ϕ. When ϕ is greater than one, the fuel is rich and consequently HC emissions are high, conversely when ϕ is less than one, the fuel is lean and the HC emissions drop down.

Carbon monoxide formation is mainly a function of the equivalence ratio. Similar to hydrocarbon formation, CO emissions will increase with a rich fuel mixture, and decrease with a lean fuel mixture (see Figure 14 in the appendix)[3]. The CO is formed when there is not enough oxygen present to form CO_2. Therefore, poor mixing and incomplete combustion also play a factor in increasing CO emissions [3]. Normally, CO emissions range from 0.2% to 5% in the exhaust of an spark ingnition engine[4].

The formation of oxides of nitrogen are caused mostly by high temperatures and large oxygen concentrations in the combustion chamber. The high temperatures cause the nitrogen to dissociate, and NO/NO_2 forms if there is oxygen present [4]. The main engine parameters that will then influence NOx production are spark timing and equivalence ratio. Spark timing closer to TDC causes lower peak cylinder pressure [3]. These lower pressures cause lower cylinder temperatures, which reduce NOx emissions. Advancing spark timing has the opposite effect. Equivalence ratio affects both oxygen content and temperature. Maximum temperature occurs at an equivalence ratio of 1.1, but oxygen concentration decreases as equivalence ratio rises, and is too low at $\phi=1.1$. The maximum amount of NOx emissions has been empirically found to be at approximately $\phi=0.9$ [3].

UB SOLUTION

The University at Buffalo 2006 CSC Team concept is to focus on the problem areas encountered by manufacturers in making environmentally friendly snowmobiles.

The areas of focus for the 2006 team include:

- Noise Reduction
- Emissions Reduction
- Improved Fuel Economy
- Maintain/Improve performance
- Reliability
- Rider safety and comfort

PERFORMANCE

ENGINE OPTION EVALUATION

Selecting a motor for the CSC is one of the most important aspects in the design of an environmentally conscious snowmobile. First, the engine must be within specifications set forward by competition rules. This consists of engine types and displacement sizes. We must chose from the selection of rotary, two-stroke, four-stroke gasoline engines or diesel engines. The displacement of these engines is mandated with maximum limits. With these options in mind, the team must pick an engine which is suitable for designing an innovative snowmobile to revolutionize the snowmobiles of the future.

Due to the importance of emissions in the competition, our team first chose to select a four-stroke power plant. Our biggest design constraint was overall size and weight of the engine. Limited space is available in the bulkhead of a snowmobile. A compromise of displacement size of the engine, power of engine, dimensions, and crankshaft configuration had to be taken into consideration when choosing the engine for the 2006 Clean Snowmobile Competition.

ENGINE SELECTION

The UB CSC team selected a 2006 Weber MPE 750 motor to be used. This motor has previously been used in watercrafts, small import cars, all-terrain vehicles, and airplanes before making its snowmobile debut for the 2006 Polaris FS and FST snowmobiles. The MPE 750 is a 750 cc engine that produces 85 hp and 55 Nm max torque with its current setup (Naturally Aspirated). The engine weighs in at 50 Kg and has dimensions of 36 by 41 by 31 cm. The dimensions of the Weber motor allow it to be very suitable for the use in a snowmobile chassis with modification.

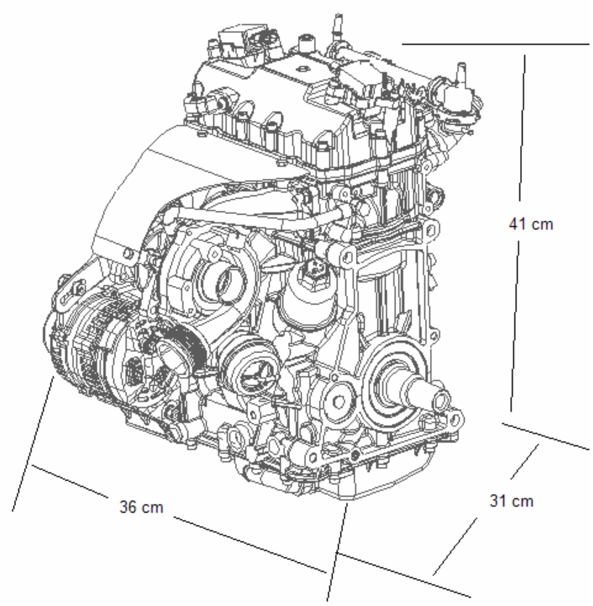


Figure 1: The Weber MPE 750 motor.

This engine was chosen over a vast array of four-stroke engines because of its dimensions, flexibility, environmental friendliness, and efficiency. This engine is smaller than most four-strokes of its size because it is a dry sump oil application. This locates the oil outside the block and eliminates the space of an oil pan. Additionally dimensions are smaller compared to competitors because of the patented head design. Weber designed the MPE 750 to be used in many applications and because of this the intake and exhaust ports can be located on either side of the engine which would allow us to mount the engine in a suitable position for snowmobile applications. The dry sump oil system not only decreases overall dimensions of the engine, but it allows us to configure the engine at angles that could not be achieved with other four-stroke engines. Due to the high efficiency of power to displacement, this engine consumes 20% less gasoline than four cylinder four-strokes, while being 60% cleaner than two-strokes. Lastly this motor is equipped with a 30mm 10-1 tapered output shaft which is what must be used for current snowmobile central variable transmission's (CVT). This cone geometry will mesh with any modern Polaris snowmobile clutch. Another advantage is that no internal or external modifications will be needed to adapt this engine for snowmobile use and placement into a 2001 Polaris Edge Chassis. [2]

FUEL DELIVERY SYSTEM

The fuel system that is being implemented into the 2005-2006 clean snowmobile consists of:

- An inline fuel pump. The fuel pump is regulated by the ECU with a ground wire.
- A fuel filter.
- A 3.5 Bar fuel regulator which is intended to control pressure to the injectors.
- #20 fuel injectors
- A gas tank
- A fuel rail

Fuel Pump

The size of the fuel pump must be large enough to provide adequate fuel to meet the maximum demand of the engine. If the pump is too large the fuel may become heated as the excess fuel is bypassed through the regulator. Our team chose to use an external automotive style fuel pump. This external system is ideal for our application because it takes up virtually no volume in the bulkhead head and it is easy to maintain and to make adjustments to the system.

Fuel Pressure Regulator

A 3.5 Bar regulator was implemented over the standard 3.0 Bar regulator. Our system allows the versatility to change regulators during fuel delivery tuning. This will assure that the engine is getting the proper amount of fuel.

Fuel Injectors

When selecting fuel injectors it must be kept in mind that the injector must be sized large enough to be able to supply fuel for the engine's needs. The injector cannot be too large because then it will not be able to send smaller amounts of fuel accurately to idle. We found that the present fuel injectors from the motors original application would be suitable.

Gas Tank

The stock gas tank that came with the 2001 Polaris Chassis was designed for a carburetor and has no fuel return line. The fuel delivery system that is being implemented requires a return fuel line to the gas tank. This ultimately left the design team with to options: modify the tank or design a new one. The stock tank has a capacity of 11.8 gallons. This gas tank is much larger than needed for our intended purposes. During the course of the competition the maximum distance that the snowmobile must travel is 100 miles during the endurance run. The weight of the 11.8 gallon tank with fuel tank when filled with gas is approximately 73.16 lbs.

The team decided to design a new fuel tank. The advantages of this approach is that weight can be reduced by decreasing capacity and improving fuel economy, and since the new tank will be manufactured from aluminum it ensures a leak free design. The new tank has a volume of 7 gallons and will have a weight of 43.4 lbs when filled with gas. Overall this new tank will produce a weight savings of 29.76 lbs. Additionally, the tank was designed to fit under the stock plastic cover. This was done to maintain the stock appearance of the 2005-2006 UB Clean Snowmobile.

Fuel Rail

The fuel rail that was provided with the Weber MPE 750 motor was manufactured from plastic. This configuration is not desired for our application in which we are going to be using it. The plastic rail does not provide secure leak-free fittings for the fuel lines. To ensure 3.5 bar of fuel can be provided and eliminating the use of hose clamps, a fuel rail will be produced from stainless steel.

The fuel regulator will be relocated off of the fuel rail to a remote location in order to limit the extra amount of necessary fuel lines.

ENGINE MANAGEMENT SYSTEM

The fuel injection system was supplied by Bosch Technologies. It is the Bosch Motronic Fuel Injection System that is based off of the Polaris Frontier Engine. This system is suitable because it contains:

- A configuration for a parallel twin application (MPE 750)
- Alpha-N style controller (TPS/RPM dependent Maps)
- Ambient Temperature Compensation
- Closed Loop (Lambda Sensor)
- Mature Cold Start Routines
- Battery Voltage Compensation
- Programming Capabilities [4]

Throttle position (alpha) and engine RPMs (N) are used with calibrations to estimate airflow and the Engine Control Unit (ECU) determines the fuel delivery requirements by programmed tables and interpolations of calibrated intervals. The ECU also has inputs of intake air temperature, engine temperature, and exhaust oxygen to further refine and fine tune the fuel requirements. Our system is closed loop because it utilizes the Lambda Sensor (O_2). This sensor measures the oxygen content of the exhaust and gives the computer an indication of the fuel/air ratio.

The ECU is the engine's computer. It manages the ignition timing (spark) and fuel control. The ECU constantly samples inputs and gives corresponding outputs from the lookup tables that are originally set up with an Alpha-N configuration. The computer must be programmed for many situations of running. These concerns are:

- **Engine Start**- extra fuel supplied for ignition at low RPM's
- **Warm up**- Extra fuel is supplied which acts like the choke on a carburetor.
- **Acceleration**- Extra fuel is supplied to increase performance
- **Decelerating**- Reduces fuel to reduce emissions
- **Overheating**- Extra fuel and ignition retard to cool engine or shutdown
- **Rev-Limiter**- Ignition shut off to protect engine from damage
- **Voltage Compensation**- Voltage determines injection firing length. When low voltage is present the ECU keeps injectors open longer to provide needed fuel.

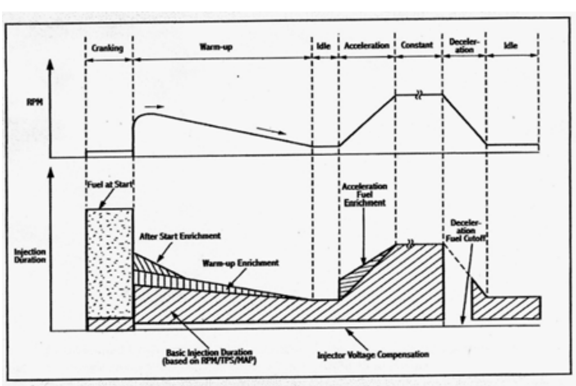
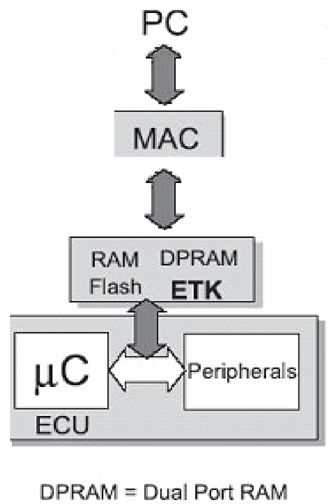


Figure 8: Graphic Representation of ECU Situations [5]

In order to program a fuel management an ETAS MAC 2 control unit and an ETAS ETK 3.1 were incorporated with the Bosch ECU to allow us to adjust fuel curves, ignition and monitor engine diagnostics, while setting up the engine configurations with INCA software. The MAC 2 is an interface so that INCA can communicate with the Bosch ECU. In order for the MAC 2 to make real time changes the information must be saved in the ETK's memory. The purpose of the ETK is to have added memory and an add-on computer for the ECU. This additional Ram (DPRAM) is made up of a working and reading page memory. All changes are made to the working page and then flashed or burned to the reading page of the ECU. The additional memory allows the ECU's processor to not become overburdened by engine management and also present the calibrations.



[6]

Figure 9: Diagram of how the system works

The general approach to programming an Alpha- N fuel injection system is by building fuel maps at desired intervals. This will set the programmed tables so that the ECU can interpolate in between the calibrated intervals. After testing is done the maps can be redefined in areas of concern. The fuel maps are based on throttle position vs. rpm vs. fuel.

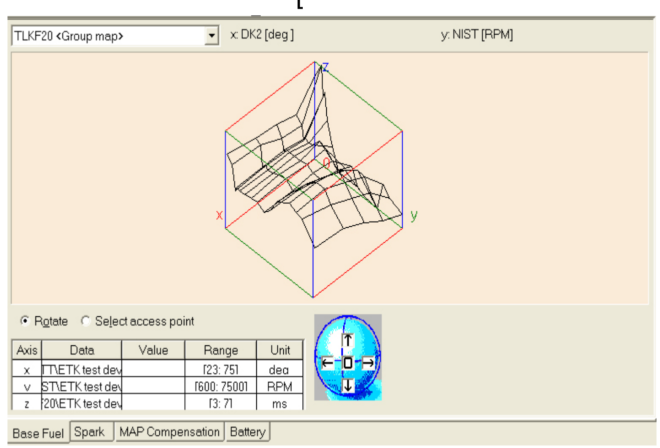


Figure 10: This is a sample of the maps that are created. The x axis is the throttle position; the y axis is the RPM; and the z axis the time in which the injectors stay open. [6]

INTAKE DESIGN

Since the 750 Motor was set up with the intake ports facing the rider, we designed our intake system to collect air above the gas tank in front of the driver. This intake design eliminates sharp turns to decrease pressure loss. Air moves through two high flow air filters and into two equally sized intake tubes through the throttle body and into the intake runners. The pressure loss in the intake system was calculated through the use of flow through tube equations and by modeling the intercooler at a tube bank. The overall pressure loss was calculated to be less than 1 psi.

By calculating the pressure loss in the intake charge tube and the intercooler we were able to estimate a loss .04 psi.

Calculations for pressure loss:

<u>Intake charge tube pressure loss;</u>

$$\Delta P = f * \frac{\rho Um^2}{2D} * (X_2 - X_1)$$

Um= max air velocity, max volumetric airflow=90 CFM, with the diameter of pipe equal to 3 inches Um= 97.6 m/s

D= diameter of pipe= 3 inches=. 0762 m

(X2-X1)= length of pipe= 12 inches= .3048 m

Density=. 913 (kg/m^3) at max intake temp of 383 K

f is found by solving for the Reynolds number in the pipe

$f = (.790 * \ln \text{Re} - 1.64)^{-2}$, for turbulent flow

$$\text{Re} = \frac{4\dot{m}}{\pi * D * \mu},$$

$$\mu = 222.67 * 10^{-7}\, Ns/m^2, \dot{m} = .102 kg/s$$

Re=76540 so we have turbulent flow in the pipe

f =. 019

After placing the above numbers into the equation for the change in pressure we calculated a pressure drop of 330.487 pa, which equals <u>.04 psi.</u>

.04 psi is a reasonable estimate for the pressure loss in the intake tube. Short equal length intake tubes allowed for nearly no loss in pressure.

ELECTRIACAL SYSTEM

The electrical system of the 2006 UB Clean Snowmobile will integrate three different electrical systems along with sensors from various manufactures. The wiring system consists of three separate wiring harnesses integrated together. The three wiring systems are from a 2004 Polaris Frontier snowmobile, the M-7 Bosch system (Weber MPE 750), and the Bosch Motronic Fuel Injection System (an adaptation of the 2004 Polaris Frontier Snowmobile). The main power distribution circuit is powered by a 12 V battery and supplies power to the starter, chassis harness, and engine wiring harness. The Bosch Fuel Injection System is its own independent circuit running directly from the battery with an ignition wire running from the key. The Frontier Chassis harness not only supplies the power to the Bosch harness, but also controls the hand warmers, headlights, tail lights, starter, and solenoid. Additional monitoring gauges from EGT INC. were added to sense and monitor the exhaust temperature and coolant temperatures.

Our electrical system will incorporate the original sensors from the M7 System, Bosch Specific sensors, and Mikuni sensors with our Bosch Motronic Engine Management System. The crank sensor, coolant sensor, ignition coils, throttle position sensor, and fuel injectors were used from the original M7 Pressure based system that was developed for this engine. Sensors that were not incorporated from the Bosch M7 EFI System were the cam position sensor, intake pressure sensor, and lambda (O_2) sensor. The Bosch Motronic system uses and unheated O_2 sensor which was used from the Frontier snowmobile. The engine harness which was built to couple these sensors and control the fuel management are in charge of powering the sensors, transmitting data, regulating voltage, communicating with the computer, and diagnosing the engine.

The Bosch Engine Control Unit (ECU) can utilize thirty-two inputs and outputs. This means up to thirty-two parameters are constantly monitored by the ECU. In our design twenty-five inputs and outputs will be controlled by the computer and must be integrated into the wiring harness.

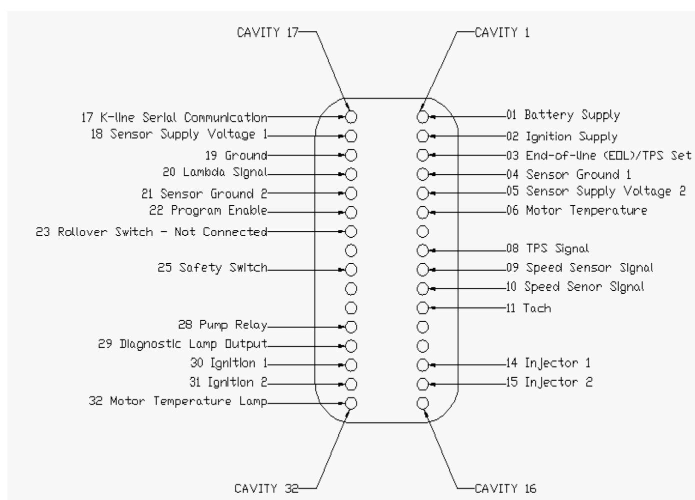


Figure 11: Schematic of the ECU with the 25 inputs and outputs to be controlled by the computer.

The battery will be located under the seat of the snowmobile to provide extra space in the engine compartment while also distributing weight to the rear of the snowmobile. A plastic sealed battery box made from Lexan was built to provide a sturdy nonconductive and hazardous containing container to relocate it under the seat. In order to indicate the engine's RPM the existing Polaris gauge will be used in conjunction with the wiring harness. RPM is read with an output by the computer to the gauge.

The additional gauges added supplied by EGT were installed to monitor actual exhaust and engine temperatures rather then just an over-temp warning sensor which the Bosch system alarms with. Liquid thermocouples were integrated into the oil and water lines to read the temperature. By incorporating these thermocouples into the electrical system we can now diagnose problems before malfunction occurs. For a complete wiring scheme see-"Appendix A."

ENGINE COOLING SYSTEM

The specifications for the stock cooling system for the 800cc two-stroke engine are nearly identical to those of the 750cc four-stroke engine, and using this information the cooling system already present on the chassis will be used with no foreseeable problems.

OIL SYSTEM

The Weber MPE 750 oil system is a dry sump application where a separate reservoir of oil is used and not reservoir of oil is located in the engine case. The delivery of oil to the engine is done by gravity to an internal oil pump. The implementation of 16 mm line will be used to eliminate pinching with vibrations and to prevent kinking around tight areas. The use of an oil container with baffles is needed to control the aeration of the oil due to an aggressive pump. The team initially wanted to design a custom oil container but later learned that the container provided by Polaris had to been specifically designed for this application. In addition to baffles, an oil-air separator is used. This separator sends oil back to the external tank and sends air to the intake manifold. The air is not released to the atmosphere because it contains hydrocarbons. The location for the oil box was chosen to be placed in the rear of the engine well near the chain case. The last stipulation of the oil system is to use an oil cooler. The oil cooler is required to have a cooling performance of 8 kW. This will keep the oil temperature at under the max temperature of 120 degrees Celsius. The oil cooler was purchased and is a water to oil style oil cooler. This utilizes the engines cooling system to cool the oil.

OIL SYSTEM SCEMATIC

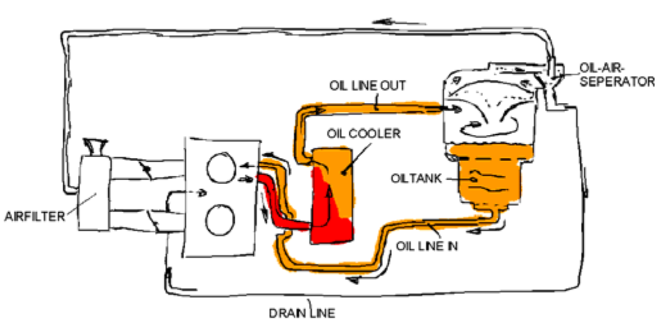


Figure 6: Schematic of how a dry sump oil system works.

CHASSIS SELECTION

The 2001 Polaris Edge chassis was chosen for the 2006 competition because of the various suspension setup it allows and it is lightweight. The chassis that we used is that of a stock 800 cc Cross Country Special (XC SP), we chose the 800 chassis because of its large open bulkhead which would allow for different engines and drive train configurations. The Edge chassis has over ten inches of travel in the front and depending on the rear suspension setup you can achieve almost fourteen inches of travel.

SUSPENSION

The front suspension used this year is that of a stock Polaris edge chassis. This suspension gives us one key advantage over a race chassis and that is the addition of a sway bar connected to both trailing arms through the chassis. The sway bar allows for less body roll when cornering and less effort for the driver. In the front suspension the stock Ryde FX shocks were re-built and re-valved for a heavy trail touring sled. The springs used on the front suspension are firmer than stock compensating for weight issues with a four stroke engine. The stock rear suspension from the 2001 chassis was the typical edge suspension, for this year an M-10 suspension by Fast was chosen to replace the stock rear suspension. The M-10 suspension uses the droop to fill in little bumps and acts like a normal suspension with larger bumps. The droop is caused by the rider sitting on the suspension and preloading the suspension so when the sled crosses over a smaller bump the droop goes into the bump leaving the driver unmoved and comfortable. The M-10 suspension also allows for more adjustability than the edge suspension allowing the driver to dial the suspension to their specific need. The only draw back to using the M-10 is the extreme angles used in the suspension can cause a minor loss in efficiency.

EXHAUST SYSTEM

EMISSIONS

An important aspect of an environmentally friendly snowmobile is low emissions. One of the criteria for the competition in March 2006 is to have a snowmobile that achieves or exceeds 2012 EPA emissions standards. Our goal, as previously stated, is to beat these standards by 20%.

Specifications to beat for 2012 Emissions Standards:

Specs for Snowmobiles in (g/kW-hr)

HC	HC+NOX	CO	HC	HC+NOX	CO
75	-----	----	150	165	400

The predominant use of hydrogen and carbon based fuels in snowmobiles leads to hazardous emissions from the combustion process. Hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) are the most harmful of the exhaust molecules and must be minimized. These emissions can be reduced in several ways. First, poor mixing and incomplete combustion play a big factor in increasing CO emissions. Hence, a lean fuel mixture is necessary to reduce CO emissions.

Since CO is formed when there is not enough oxygen present to form CO_2, One of the most important technologies for reducing exhaust emissions is the oxygen sensor. The oxygen sensor monitors the level of oxygen (O_2) in the exhaust so our ECU can regulate the air/fuel mixture to reduce emissions. Fuel mapping will also be created to help achieve a lean fuel mixture to minimize emissions and to help the catalytic converter operate at peak efficiency which is necessary to reduce hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOX) levels even further. [7]

In order to obtain complete combustion to eliminate these harmful emissions, a complete mixing and combustion reaction must occur. This reaction is:

$$C_8H_{18} + 12.5\ O_2 + 47\ N_2 \rightarrow 8\ CO_2 + 9\ H_2O + 47\ N_2$$

The other method of reducing emissions is by using a catalyst in the exhaust. A catalyst is a special material that facilitates the reaction of oxygen and hydrogen. The catalyst takes the harmful gases and forces the ions apart where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule (H_2O). A three-way catalyst has the ability to convert hydrocarbons, carbon monoxide, and nitrogen oxides into water, carbon dioxide and nitrogen gas. [8]

CATALYST

The three main criteria for the selection of the catalyst were the surface area in the monolith, the backpressure produced, and it had to be a three-way catalyst. In the these conditions the three-way catalyst has the ability to convert hydrocarbons, carbon monoxide and nitrogen oxides into water, carbon dioxide and nitrogen gas. In conjunction with Lubrizol, the most efficient three-way catalyst was selected based upon the following engine intake airflow (SCFM). Flowrate can be approximated by:

$$\text{Engine Intake Airflow (SCFM)} \cong \frac{EngineDisplacement \times RPM \times V_E}{14.16 \times EngineCycle}.$$

A value of .85 was substituted for V_E because the engine is a normally aspirated four stroke engine. The RPM used is that of the maximum RPM (8000) for the engine. Engine cycle is 4 because of the four stroke engine. From these values the engine intake airflow was calculated to be 90 SCFM. Once the airflow was determined, the correct size catalyst could be selected from Lubrizol. The dimensions (reference Figure 1) used for the catalytic converter are A= 1.75 in, B= 4.25 in, C=10 in and D= 1 in.

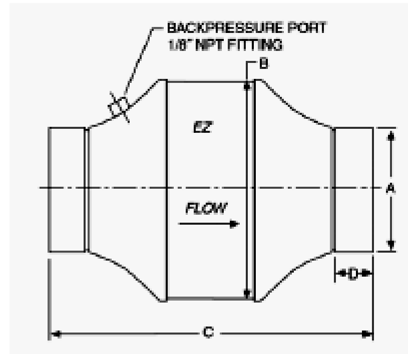


Figure 1

MUFFLER

To control the noise emitted from the engine exhaust, a muffler would be used. The muffler was from Honda. The muffler functions as a reactive muffler designed to dissipate sound waves. The muffler is designed to act as a broadband attenuator. This type of muffler is effective because the exhaust noise is composed of many different frequencies. A broadband attenuator reduces the amplitude of the frequencies with the highest peaks across the entire range of noise produced. Its construction involves three reactive chambers connected by pipes of various sizes. There is also a glass pack around the internal pip where it is perforated and is surrounded by an outer shell containing sound absorbing fiberglass fill. The muffler's body is three layers: an outer shell, a perforated inner shell, and sound absorbing fill in-between. Together they inhibit sound waves from exiting through the muffler shell by creating a barrier and making them travel through the chambers. Finally, the slim oval design fits well in the exhaust section of the chassis.

We were able to keep the muffler internals as purchased because the reduced overall SCFM made was calculated and the tubing size was adequate. Using some formula's from "Engineering Noise Control: Theory and practice" by David A. Bies and Colin H. Hansen for pressure drop in a duct we figured we were gaining roughly 1.1 inches of water. We estimated that with our new SCFM ratings the catalyst would produce 3 inches less of water, more than making up our increased pressure from the muffler.

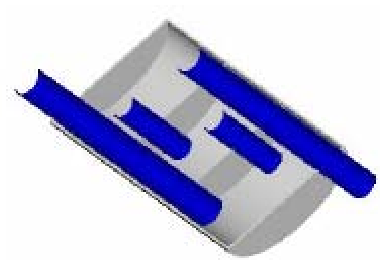


Figure 2: Cross Section of muffler

NOISE

HOOD DESIGN

A new hood was necessary because the stock Polaris hood proved to be inadequate in a few areas. The change from a two-stroke engine to a four-stroke engine meant a significant change in necessary clearances, so this issue had to be addressed. Also, the stock hood did not provide adequate noise reduction; this can be attributed to the thin plastic and hood vents. The new hood was designed to provide adequate space for the new engine and also to keep weight and noise to a minimum. To create this new hood a plug had to be made to create a fiberglass rendition of our design. The stock hood was placed on the sled, and the necessary clearances for the engine were measured. With these clearances in mind, long plastic strips 3” wide were placed along the bottom of the stock hood and attached using a two part epoxy. These strips raised the hood up away from the engine. After the strips were attached to the bottom, the stock vent holes and headlight hole were sealed to allow less noise to escape from the engine compartment. Once completed, the plug was used to form a mold. From the mold the new hood was made. Instead of using the inadequate plastic of the stock hood, fiberglass enhanced with PDP was chosen because of its weight and noise reduction capabilities. The fiberglass hood produced a 5 lb. reduction in weight from the stock hood. PDP is a constrained layer damping foil for laminating into fiberglass panels to improve sound transmission loss and absorb structural acoustic energy [10]. It interacts with the structure of the composite material to dampen sound waves. To further reduce noise, acoustic melamine was added to the underside of the hood. The particular melamine we used is called Hushcloth Melamine and was chosen for its light weight, excellent sound absorption, and high heat resistance. The high heat resistance is particularly important because the lack of hood vents leads to extremely high under-hood temperatures; and even if the melamine’s maximum temperature is reached, it will char rather than burn. Other types of sound absorbing foams are much more flammable and would create a fire hazard. While other materials have higher sound absorption coefficients (figure 1), the Hushcloth Melamine is the best foam for fire resistance and absorbs sound better than other fire resistant materials, like fiberglass. It also works the best in the 1 kHz to 4 kHz range, which is the most common weighted frequency in the dBA scale with our engine setup.

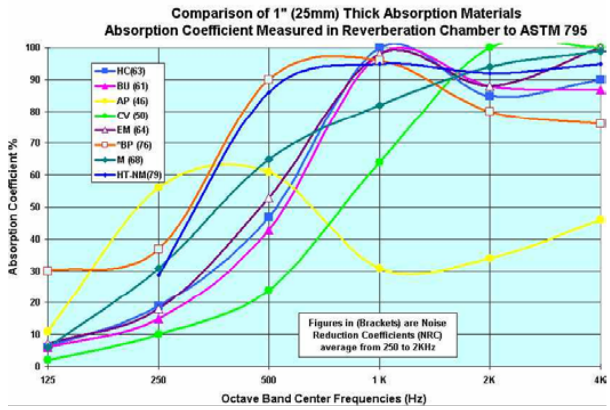


Figure 1: Sound transmission through various commercially available sound absorbing materials. Melamine foam (M) (dark green) is used in the snowmobile hood.

SOUND REDUCTION APPROACH

The reduction of noise was a large concern for the UB team this year. To tackle this challenge, a number of cutting edge materials from American Acoustical Products were used. A vinyl based matting called VE was used to reduce resonating frequencies coming from areas within the snowmobile. VE is used to lower noise heard from a resonating structure, which is perfect for the underside of a snowmobile tunnel. Noise from the moving track and rear suspension components are trapped in this cavity and resonate. With the use of VE on the interior of the tunnel, this will help to absorb unwanted frequencies and reduce audible noise. Two other materials that were used to reduce noise are Millennium Metal and the aforementioned Hushcloth Melamine. Millennium Metal is an aluminum honeycomb that is used to absorb low frequency noises, and its performance increases when used in conjunction with Hushcloth Melamine. Beneath the running boards of our machine are sheets of Hushcloth Melamine encased in Millennium Metal, the combination of these two will greatly reduce the unwanted noise from the moving components at the rear of the sled. The other main source of noise from a snowmobile is the engine; the steps taken to reduce noise from here was mention in the “Hood” section of the paper.

PACKAGING

ENGINE MOUNTS

<u>Design Considerations:</u>

Our main goal in designing the engine mount is that it must withstand the forces of the Weber MPE 750 motor (assuming a maximum engine output of 85 ft-lbs) and allowing for engine vibration isolation. It must be stiff enough to hold weight of the engine and not deflect when the clutch engages. The mount must be made out of a material such that its yield strength must be substantially greater than the stresses caused by the Weber MPE 750 motor.

Another design consideration of the mounts is selecting how the engine will attach to the mount itself. The mounts must be designed to allow for adjustability of clutch alignment and so that a standard belt size can be used. Lastly, proper rubber isolators must be chosen for a suitable compromise of dampening and stiffness to reduce engine vibration.

Design Chosen:

Our team decided to develop a cradle system for mounting. With this one piece mount, the motor was chosen to be mounted in a nearly vertical position to allow for versatility in intake and exhaust designs. The mounting points were chosen by utilizing existing engine mounting locations of the previous engine that was in the 2001 Polaris Edge chassis. The existing motor mounting holes were also utilized on the Weber MPE 750 engine.

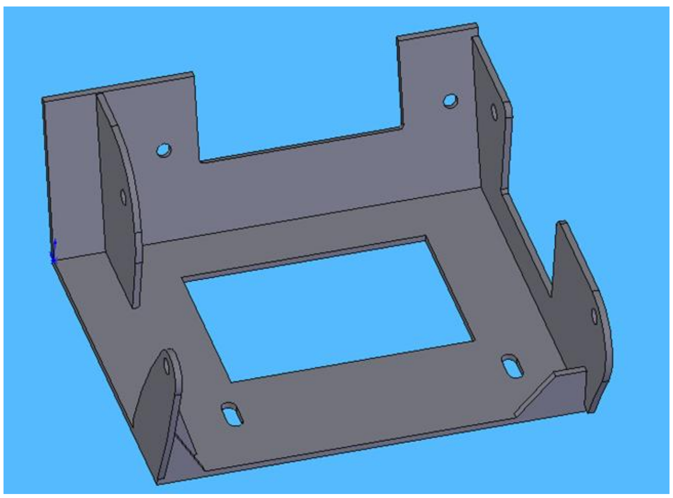


Figure 3: A solid model of the initial concept for the motor mounts.

Motor Mount Material:

Initially a prototype was created out of A36 3/16" steel. The prototype was created initially to mount the engine so the rest of the product could begin. After further analysis it was realized that this design was over engineered and a better solution could be created. The final design material for the mount was chosen to be 3/16" 5052 Aluminum plate (cold-rolled). This material has yield strength (S_y) of 27 kpsi. 3/16" thick aluminum was chosen mainly for weight reduction. Aluminum was chosen as the motor mount material based upon the calculations below.

Motor Mount Calculations:

The maximum forces that the engine mounts have to withstand is the force created when the clutch engages. For safety, the maximum engine output of 85 ft-lbs is assumed to be the torque when the clutch engages. This is a factor of safety of 1.4 over what the engine currently produces. However, because of our cradle design it is a statically indeterminate problem, therefore we assumed that F proportional to d. Therefore, the overall forces that the mounts are subjected to can be calculated by:

T= F1*d1 - F2*d2

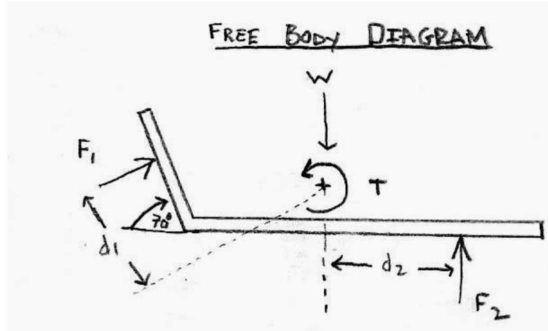


Figure 4: A free body diagram of the forces acting on the motor mounts.

Force Equations:

$\sum F = 0 = F1 (\sin 70) - F2 - 100$

$F2 = 100 - F1 (\sin 70)$

T= F1*d1 - F2*d2

85= F1(.324) – (100 – F1 (sin 70)) (.285)

Where F is the Force, d is the distance from center, and T is the torque from the engine. The value obtained for the front mounts is 191.8 lbs upward and the value for the rear mount is 80.12 lbs upward. These were calculated using Force Equations and the above torque formula.

Stress on the mount:

Front of the mount:

Using a .39" bolt (10mm), the area of contact between the bolt and one of the plates is 0.230 in^2. Since the max force on the front of the mount is 191.8 lbs, the force seen by each bolt is 95.9 lbs. The stress on the plate is seen to be .834 kpsi from:

$\sigma = F/A$

With the maximum strength allowed being 27 kpsi, the force seen is much less than this which means failure will not occur.

The bolts used are 8.8 metric class bolts which carry a yield strength of 95.8 kpsi (660 MPa), again well below the present stress, and therefore suitable to be used.

Back of the Mount:

The area of contact between the bolt and one of the plates is 0.14625 in^2. Since the max force on the rear of the mount is 80.12 lbs, the force seen by each bolt is 40.6 lbs. The stress on the plate is.277 kpsi. Since, the maximum force is .555 kpsi, it is well below the yield strength of the chosen aluminum.

Organizing the Engine Well

One of the concerns of designing a snowmobile is how the implementation of different technology affects the overall performance of the sled. The ideal snowmobile would have low center of gravity and a distribution of mass in the center axis of the snowmobile. Our team tried to take this into consideration when designing the layout of the engine compartment. Constraints that could not be changed were the location of the secondary clutch and chain case. The motor is the largest component that affects the center of mass because of its size and location. It must be located toward the right side of the bulkhead because of the CVT. To compensate the unbalanced weight distribution, other components were spaced towards the left side of the snowmobile. We assumed that the snowmobile chassis has a symmetrical distribution when it was empty. Then dimension were taken of the chassis and components. With these dimensions we assumed the center of mass of each component to be a point mass at the middle of each item. The vertical center of mass can not be estimated as easily because the vertical mass distribution is much more complicated.

The computations were done by:

$$\overline{X} = \frac{\sum_i m_i \overline{x}_i}{m_i} = 18.72" \qquad \overline{Y} = \frac{\sum_i m_i \overline{y}_i}{m_i} = 30.83"$$

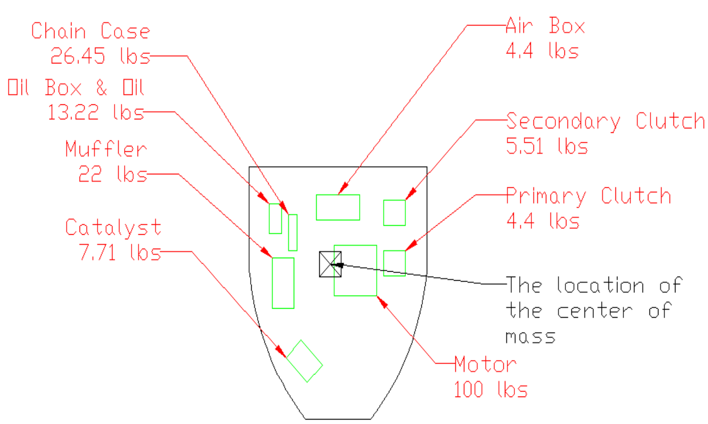


Figure 7: The location of the center of mass

CONSUMER ACCEPTABILITY/APPROVAL

COST

The additional cost of implementing the Weber MPE 750 Engine with a 2001 Polaris Edge Chassis is not much more than the four-stroke snowmobiles that are presently in production. Our Snowmobile was designed so that it is very feasible to

COMFORT/RIDE QUALITY

The ride and drive of the snowmobile is a major deciding factor when purchasing a snowmobile. For the 2006 competition; special attention was put towards the comfort and ride quality of the snowmobile. The improvements over last year's sled are the gauges, windshield, hood, and suspension. For this year the gauges are mounted in an easier to see location and are similar to those on a stock snowmobile. There are also more gauges to read so the consumer knows more of what is going on with the snowmobile. The hood for this year's snowmobile can be easily removed with no cables attaching it to the chassis. The hood is also modeled after a stock edge hood to give the sled a cleaner appearance. The windshield for this year is taller and covers the driver more exclusively making for a warmer environment. The suspension under the sled has been upgraded and retuned to create a better ride for the driver under touring conditions.

CONCLUSION

The concept of reducing the noise and emissions of a snowmobile with out greatly affecting performance is a complex task. For reducing the emissions the strategy chosen was a four-stroke engine accompanied with a three-way catalyst. With these changes implemented the emissions from the setup are significantly less than that from a conventional two-stroke snowmobile. With the Weber engine and the catalyst implemented into the snowmobile the emissions should have lower emissions than that of most stock snowmobiles. The strategy for noise control was a modified the implementation of various types of sound dampening/barrier materials. Through testing and analysis it is clear that the steps taken to reduce noise were effective. By decreasing the backpressure from the muffler, and increasing the engine intake charge and an intercooler the performance is still comparable to that of a commercial trail riding snowmobile. The UB 2006 CSC Team's design shows the potential for future snowmobiles to be cleaner, quieter, and environmentally friendly, while still being entertaining.

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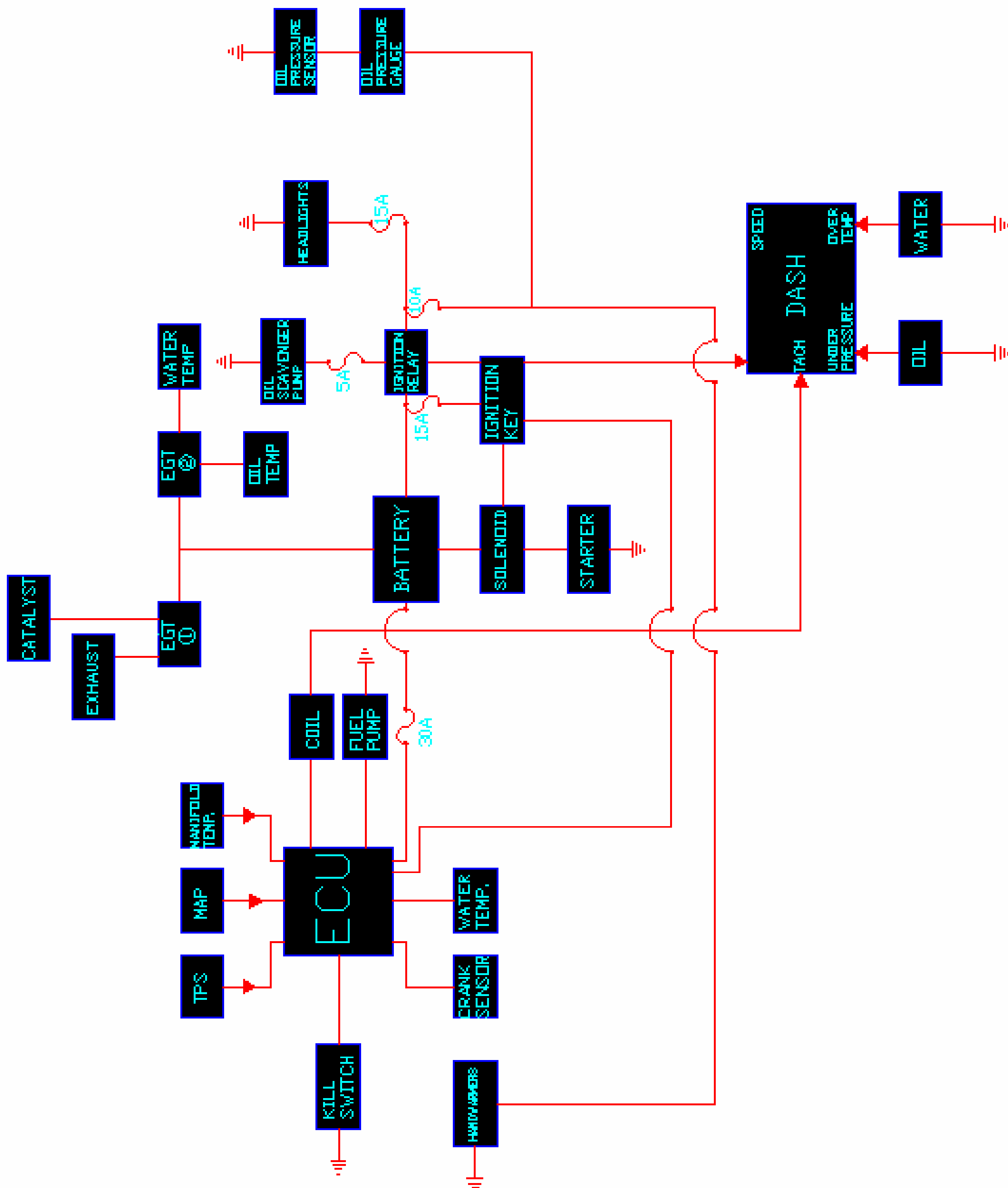
Appendix A


OIL PRESSURE SENSOR
OIL PRESSURE GAUGE
HEADLIGHTS
15A
10A
DASH
SPEED
TACH
OVER TEMP
UNDER PRESSURE
WATER
OIL
WATER TEMP
OIL SCAVENGER PUMP
5A
IGNITION RELAY
IGNITION KEY
15A
EGT ②
OIL TEMP
BATTERY
SOLENOID
STARTER
CATALYST
EXHAUST
EGT ①
COIL
FUEL PUMP
30A
MANIFOLD TEMP.
MAP
TPS
ECU
WATER TEMP.
CRANK SENSOR
KILL SWITCH