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# University of Maine's Tuned, Flex-Fuel Capable Four-Stroke Snowmobile

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## ABSTRACT

The University of Maine's submission to the 2009 Clean Snowmobile Challenge (CSC) is a second-generation, tuned four-stroke powered snowmobile, a 2007 Yamaha Phazer. An aftermarket engine control unit (ECU), Microsquirt, is used to improve fuel economy while decreasing exhaust emissions and maintaining the stock engine configuration power output. Engine and clutch noise is reduced using sound-absorbing materials. Track noise is reduced using additional idler wheels, and exhaust noise is reduced by the addition of a second muffler. The UMaine altered Phazer meets the 2012 EPA snowmobile emissions standards and is flex-fuel capable, fuel efficient and powerful.

## INTRODUCTION

Snowmobiles provide adventurers a much-needed escape during the winter months, but do so with harsh consequences. Snowmobiles can be extremely noisy with poor fuel economy and emissions, limiting the areas in which they can be ridden. When the National Park Association (NPA) banned snowmobiles from national parks in the year 2000, the Society of Automotive Engineers (SAE) developed the Clean Snowmobile Challenge (CSC) to promote new technology. The challenge invites college students to use an original equipment manufacturer's (OEM) design and adapt it to reduce unburned hydrocarbon (HC), carbon monoxide (CO) and noise emissions without substantially increasing nitrous oxide ($NO_x$) emissions. The 2009 Clean Snowmobile Competition also challenges teams to develop flex-fuel snowmobiles, capable of running E10 to E85 ethanol-based fuels.

DESIGN GOALS – The first goal for competition is to reduce exhaust emissions of HC and CO without substantial change in $NO_x$ emissions. Based on the Southwest Research Institute (SwRI) study, the five-mode test cycle is used to determine the Phazer's assigned Environmental Protection Agency (EPA) emissions score.[1] Table 1 outlines the modes, associated speed, and weighting factors for determining average emissions.

**Table 1:** SwRI Five-Mode Snowmobile Dynamometer Test Cycle

| Mode | Engine Speed, % | Torque, % | Weight, % |
|---|---|---|---|
| 1 | 100 | 100 | 12 |
| 2 | 85 | 51 | 27 |
| 3 | 75 | 33 | 25 |
| 4 | 65 | 19 | 31 |
| 5 | Idle | 0 | 5 |

As of 2012, the EPA will require snowmobile manufacturers to achieve EPA scores of greater than 100, with CO and HC average levels no higher than 275 g/kW-hr and 90 g/kW-hr respectively. EPA emissions scores are determined using the weighted average found using the SwRI five-mode test according to Equation 1.[2]

$$E = \left[1 - \frac{(HC+NO_x)-15}{150}\right] * 100 + \left[1 - \frac{CO}{400}\right] * 100 \qquad (1)$$

At competition, emissions testing will use the five-mode test procedure with a Dynomite engine dynamometer. The University of Maine team uses a track dynamometer with an eddy-current brake for laboratory testing. Because of the continuously variable transmission (CVT) clutch system, the team was unable to produce the necessary power and torque curves for the Phazer, so a series of constant load tests was used for emissions testing. A 32% of maximum eddy-current brake was applied to the track to allow the snowmobile to operate at wide open throttle (WOT) without hitting the set rev limit. Differences in testing are expected to result in lower emissions values at competition than those reported, since increasing load increases emissions.[7] Points will be awarded for achieving EPA scores greater than 100 with additional points awarded for EPA scores higher than 100.

The second goal for competition is to adapt the snowmobile for ethanol-based fuels. The corrosive properties of ethanol require replacement of a number of components in the fuel system. In addition, a larger gas tank is necessary due to the lower energy density of ethanol.[3]

The third goal for competition is to reduce the snowmobile's noise emission. Snowmobiles are required to have noise emissions below 78 dBA, the standard determined by the International Snowmobile Manufacturer's Association. Teams that have quieter snowmobiles receive additional points. Sound levels are measured using SAE J-192 pass-by test procedure. [4]

The final goal for competition is to find a cost-effective solution to the above design requirements. Teams are awarded points based upon the overall value of the designed sled.

## UMAINE DESIGN

THE BASELINE SLED – The 2007 Yamaha Phazer was chosen for its lightweight design, four-stroke engine, and acceleration and handling characteristics. In its stock configuration, the 2007 Phazer has an 8.1-gallon fuel tank and is capable of running E10. Sled specifications are given in Table 2.

**Table 2:** 2007 Yamaha Phazer Manufacturer's Specifications

| | |
|---|---|
| Engine Type | Four-stroke |
| Cooling Method | Liquid |
| Cylinders | 2 |
| Displacement | 499 cc |
| Compression Ratio | 12.4:1 |
| Maximum Crank Power | 80 hp |
| Dry Weight | 454 lbs |

IMPROVING EMISSIONS – The University of Maine team chose to improve emissions through two methods, mechanical and electrical.

Mechanical Solution – The mechanical solution includes the addition of a three-way catalyst, designed for and used in automotive applications. A three-way catalyst was chosen for its ability to reduce HC, CO and $NO_x$ emissions through oxidation.[5] The converter chosen is a Walker universal catalytic converter, featuring two-inch inlet and outlet diameters, with an overall length of 13.25 inches. Figure 1 shows the catalyst mounted below the seat on the Phazer, just before the stock muffler.

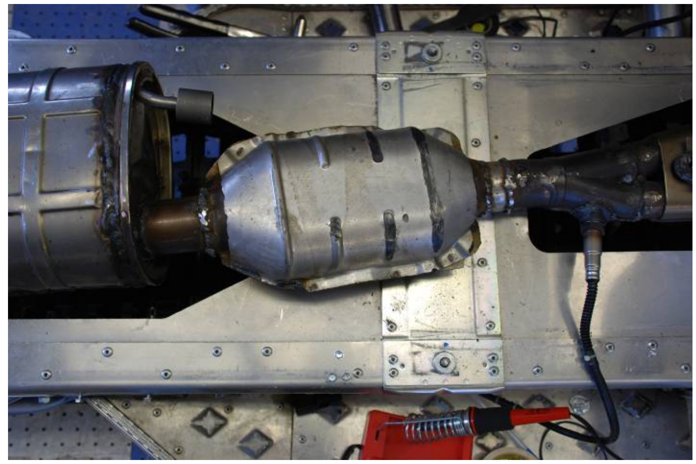


**Figure 1:** Catalytic converter mounted in the Phazer's exhaust system

Electrical Solution – The major alteration in the baseline snowmobile is evident in the electrical solution to emissions. The team replaced the stock engine control unit (ECU) with an aftermarket ECU, allowing the team to optimize ignition and fuel delivery parameters for the best balance of fuel economy, emissions and performance. The decision to completely replace the stock ECU was a significant departure from the 2008 team's use of the Bowling & Grippo Megasquirt, which was not compatible with coil-on-plug ignition and required an additional ignition system, introducing a 9300 RPM rev limit, crippling the Phazer's power output.

To replace the stock ECU, the Bowling & Grippo Microsquirt was chosen due to compatibility with stock sensors, programmability and low cost. The Microsquirt is also compatible with coil-on-plug ignition; allows complete control of spark, fuel, and air; and provides access to forums for troubleshooting.[6] Other models considered were Bowling & Grippo's Megasquirt, Motec, and Simple Digital.

The ability to vary spark, fuel, and air allows the team to determine the best combination for fuel efficiency and emissions. Increasing spark advance can allow the engine to achieve maximum power and have good fuel economy without harmful detonation.[7] Fuel delivery control with the measured air pressure allows the most useful mixture to be chosen, generally around stoichiometric for best efficiency in the catalytic converter.[5] If too rich a mixture is used, the sled will lose power, exhaust black smoke and have sluggish throttle response. If too lean a mixture is chosen, the sled will lose power and backfire in addition to possible detonation in the engine.[7]

The addition of the Microsquirt ECU required the addition of a new manifold absolute pressure (MAP) sensor because the twin stock MAP sensors were incompatible with Microsquirt. The General Motors 3-bar MAP sensor was chosen for this application because of the robust design and existing occurrence with Microsquirt. A single, wide-band oxygen sensor was also added to allow closed-loop control of the fuel and air mixtures for most accurate tuning.

Wiring – The manufacturers suggest wiring the power and ground circuits to Microsquirt first, then wiring each additional circuit one at a time to check their functionality.[8] The team followed these instructions, providing power to first the ECU, then each of the following sensors: the throttle position sensor (TPS), intake air temperature (IAT), coolant temperature (CLT), MAP sensor, and oxygen sensor. Next, the fuel pump and injectors circuits were completed using the stock relay to provide power to the fuel pump and injectors only when the signal from the Microsquirt indicates that the engine is running. Finally, the ignition input and output circuits were wired, including the camshaft position sensor, the crankshaft position sensor, and the ignition coils.

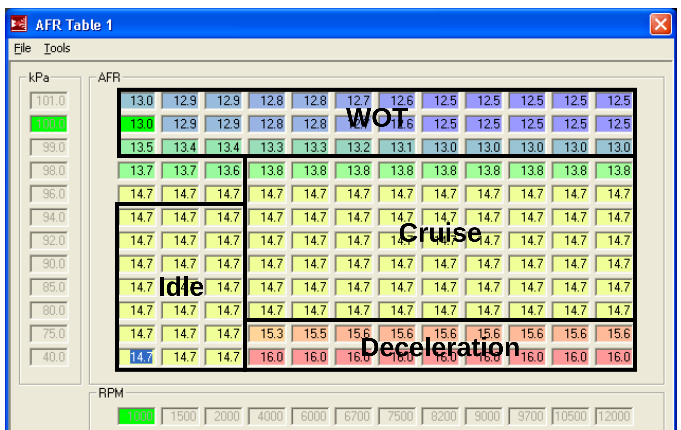
Calibration – Once installed, Microsquirt interfaces with Megatune, a downloadable program available from both distributers and Bowling & Grippo.[6] Sensors were calibrated using the calibration wizards included in the program and the sensors' supporting documentation. Each sensor was tested following calibration to ensure proper outputs were received by Microsquirt.

Initial Settings – Megatune allows users to provide initial information about the engine and the associated systems. This information is then used to determine ignition signals, fuel requirements, and acceptable operating ranges. Though some of the necessary inputs are pre-programmed into Megatune, the team still needed to provide Megatune with the engine displacement, injector flow, revolution limits, max cranking RPMs, and ignition settings. Once these were determined, the software required that only seven parameters be tuned in order for the engine to run: cranking pulse widths; warm-up enrichment; after-start enrichment; acceleration enrichment; and volumetric efficiency (VE), air/fuel ratio (AFR), and spark advance tables.

Tuning for E10 – To get the engine running, it was first necessary to tune the cranking pulse widths. According to the manufacturer's configuration instructions, the cranking pulse widths should first be estimated by determining the fuel injected into the engine.[6] This calculation is done automatically by the software, using the engine displacement, number of cylinders, injector flow rate, and desired air/fuel ratio. To calculate injector flow, the team used the calculator provided in the Megatune Manual to determine the Phazer's injector flow rate, taking into account the increased pressure.[7] The stock flow rate was determined to be 24.7lbm/hr, and the new flow rate was determined to be 27.1lbm/hr. The required fuel value used by Megatune was then determined to be 5.7. The cranking pulse widths are defined as 88% of required fuel for the cold cranking pulse width and 23% of the required fuel for the hot cranking pulse width. These values were tried first, using 5.0 ms for the cold pulse width and 1.3 ms for the hot pulse width. The trial and error method was employed, varying the hot and cold pulse widths and the injector open time, until the engine would start. It was determined that the injector open time necessary to avoid flooding the engine was lower than the pre-programmed value of 1.0 ms at 0.7 ms. The cranking pulse widths are 4.8 ms and 1.0 ms at this value.

Once the engine started, the team began tuning the warm-up and after start enrichments. After start enrichment was needed if the engine starts but dies quickly and warm-up enrichment needs tuning if the engine starts and runs but dies after a few minutes. Since the Phazer was located inside at a minimum 70°F, tuning the warm-up enrichments required only slight variations over the pre-programmed values. The after start enrichments were determined through a trial and error process in which the team varied the idle-air screw and the settings until the Phazer would start and hold idle with each turn of the key.

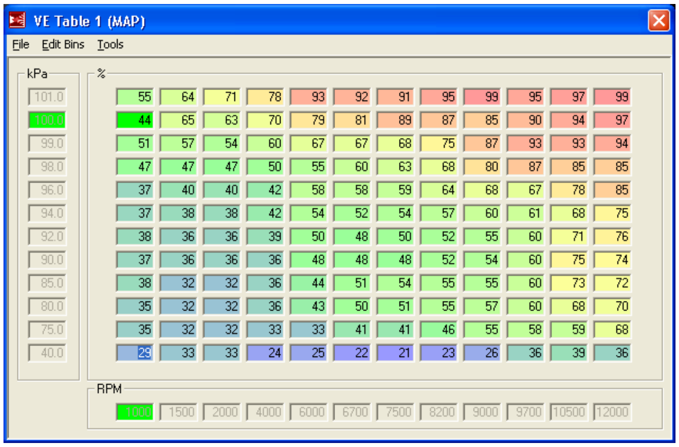
With the engine starting and idling well, the team moved on to tuning the volumetric efficiency and air-fuel tables. The AFR table is the basis for which the VE table is tuned. The goal is to tune VE such that the corresponding cell in the AFR table is achieved. [6] The team created a rough air-fuel table that used a 14.7:1 AFR at idle, 16.0 AFR during deceleration, and 12.5:1-13.8:1 AFR at wide-open throttle (WOT). The cruise AFR ranged from 13.8:1 to 14.7:1 to provide a smooth transition between idle, WOT, and deceleration. Figure 2 shows the initial AFR table with each zone of use (idle, WOT, cruise and deceleration) outlined.




| kPa \ RPM | 1000 | 1500 | 2000 | 4000 | 6000 | 6700 | 7500 | 8200 | 9000 | 9700 | 10500 | 12000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101.0 | 13.0 | 12.9 | 12.9 | 12.8 | 12.8 | 12.7 | 12.6 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| 100.0 | 13.0 | 12.9 | 12.9 | 12.8 | 12.8 | [illegible] | [illegible] | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| 99.0 | 13.5 | 13.4 | 13.4 | 13.3 | 13.3 | 13.2 | 13.1 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| 98.0 | 13.7 | 13.7 | 13.6 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| 96.0 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 |
| 94.0 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 |
| 92.0 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | [illegible] | [illegible] | 14.7 | 14.7 | 14.7 | 14.7 |
| 90.0 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 |
| 85.0 | 14.7 | [illegible] | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 |
| 80.0 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 |
| 75.0 | 14.7 | 14.7 | 14.7 | 15.3 | 15.5 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 |
| 40.0 | 14.7 | 14.7 | 14.7 | 16.0 | 16.0 | 16.0 | [illegible] | [illegible] | [illegible] | 16.0 | 16.0 | 16.0 |

**Figure 2:** Initial AFR Table for the Phazer

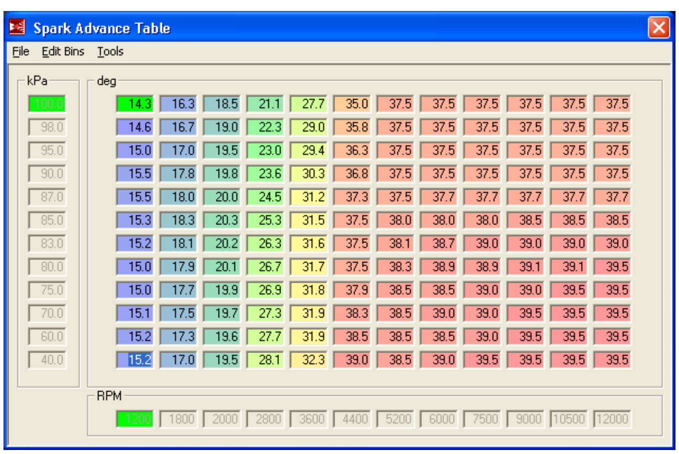
The initial volumetric efficiency table was created from a sample table included in the Megatune documentation. This table was tuned to the AFR table by allowing the EGO sensor control in the program. The Phazer was mounted to the team's dynamometer and was run in as many of the table entries as possible while datalogging with the Megatune program. Controller authority was initially set to 30%, which allowed it to change cells in the VE table by as much as 30% in order to achieve the desired AFR in its corresponding cell. Using MegaLogViewer, a program for viewing datalogs taken with Megatune, the data taken during the previous dynamometer run was used to adjust values in the VE table. With each run, the controller authority was lessened, allowing the table to come to a completed tune after only a few hours on the dynamometer. Figure 3 shows the tuned VE table.




| kPa \ RPM | 1000 | 1500 | 2000 | 4000 | 6000 | 6700 | 7500 | 8200 | 9000 | 9700 | 10500 | 12000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101.0 | 55 | 64 | 71 | 78 | 93 | 92 | 91 | 95 | 99 | 95 | 97 | 99 |
| 100.0 | 44 | 65 | 63 | 70 | 79 | 81 | 89 | 87 | 85 | 90 | 94 | 97 |
| 99.0 | 51 | 57 | 54 | 60 | 67 | 67 | 68 | 75 | 87 | 93 | 93 | 94 |
| 98.0 | 47 | 47 | 47 | 50 | 55 | 60 | 63 | 68 | 80 | 87 | 85 | 85 |
| 96.0 | 37 | 40 | 40 | 42 | 58 | 58 | 59 | 64 | 68 | 67 | 78 | 85 |
| 94.0 | 37 | 38 | 38 | 42 | 54 | 52 | 54 | 57 | 60 | 61 | 68 | 75 |
| 92.0 | 38 | 36 | 36 | 39 | 50 | 48 | 50 | 52 | 55 | 60 | 71 | 76 |
| 90.0 | 37 | 36 | 36 | 36 | 48 | 48 | 48 | 52 | 54 | 60 | 75 | 74 |
| 85.0 | 38 | 32 | 32 | 36 | 44 | 51 | 54 | 55 | 55 | 60 | 73 | 72 |
| 80.0 | 35 | 32 | 32 | 36 | 43 | 50 | 51 | 55 | 57 | 60 | 68 | 70 |
| 75.0 | 35 | 32 | 32 | 33 | 33 | 41 | 41 | 46 | 55 | 58 | 59 | 68 |
| 40.0 | 29 | 33 | 33 | 24 | 25 | 22 | 21 | 23 | 26 | 36 | 39 | 36 |

**Figure 3:** Tuned VE table for the Phazer

During tuning of the VE table, the exhaust was extremely hot, glowing red prior to entering the catalytic converter after only a few seconds of running. Exhaust overheating is a symptom of spark that is too retarded. Microsquirt does not have an input for a knock sensor, so the stock knock sensor hooked to an oscilloscope was used to read the voltage out of the sensor. At idle, the sensor output 0.5V, a reasonable signal output for the sensor at normal running conditions. In subsequent runs on the dynamometer, a richened fuel mixture and increased spark advance was used to find the onset of knock based on the oscilloscope signal. At the end of the process, the spark advance was 12 degrees further advanced at the high RPMs and three or four degrees further advanced at the low RPMs. Figure 4 shows the tuned spark advance table.

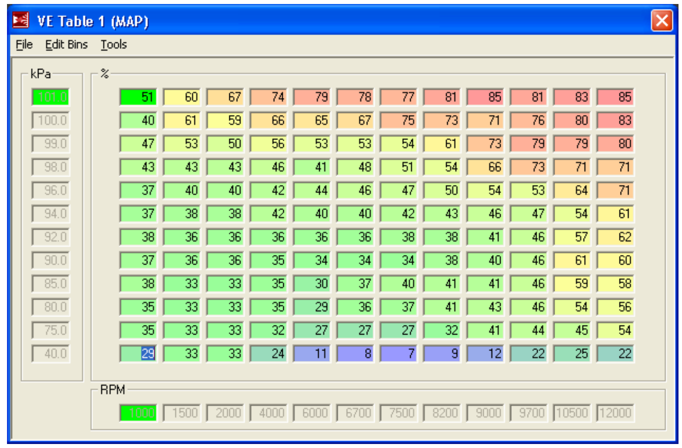



| kPa \ RPM | 1200 | 1800 | 2000 | 2800 | 3600 | 4400 | 5200 | 6000 | 7500 | 9000 | 10500 | 12000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100.0 | 14.3 | 16.3 | 18.5 | 21.1 | 27.7 | 35.0 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| 98.0 | 14.6 | 16.7 | 19.0 | 22.3 | 29.0 | 35.8 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| 95.0 | 15.0 | 17.0 | 19.5 | 23.0 | 29.4 | 36.3 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| 90.0 | 15.5 | 17.8 | 19.8 | 23.6 | 30.3 | 36.8 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| 87.0 | 15.5 | 18.0 | 20.0 | 24.5 | 31.2 | 37.3 | 37.5 | 37.7 | 37.7 | 37.7 | 37.7 | 37.7 |
| 85.0 | 15.3 | 18.3 | 20.3 | 25.3 | 31.5 | 37.5 | 38.0 | 38.0 | 38.0 | 38.5 | 38.5 | 38.5 |
| 83.0 | 15.2 | 18.1 | 20.2 | 26.3 | 31.6 | 37.5 | 38.1 | 38.7 | 39.0 | 39.0 | 39.0 | 39.0 |
| 80.0 | 15.0 | 17.9 | 20.1 | 26.7 | 31.7 | 37.5 | 38.3 | 38.9 | 38.9 | 39.1 | 39.1 | 39.5 |
| 75.0 | 15.0 | 17.7 | 19.9 | 26.9 | 31.8 | 37.9 | 38.5 | 38.5 | 39.0 | 39.0 | 39.5 | 39.5 |
| 70.0 | 15.1 | 17.5 | 19.7 | 27.3 | 31.9 | 38.3 | 38.5 | 39.0 | 39.0 | 39.5 | 39.5 | 39.5 |
| 60.0 | 15.2 | 17.3 | 19.6 | 27.7 | 31.9 | 38.5 | 38.5 | 38.5 | 39.0 | 39.5 | 39.5 | 39.5 |
| 40.0 | 15.2 | 17.0 | 19.5 | 28.1 | 32.3 | 39.0 | 38.5 | 39.0 | 39.5 | 39.5 | 39.5 | 39.5 |

**Figure 4:** Tuned spark advance table

With initial values for the AFR, VE, and spark advance tables, the team could then tune the snowmobile for best emissions possible following the five-mode dynamometer test cycle outlined above. For more information about the tests performed, please see the EMISSIONS TESTING section.

Tuning for E85 – Once the Phazer was adequately tuned for E10, winter blend E85 was obtained from a gas station in Massachusetts and the flex-fuel sensor was put to the test. Once E85 was added to the fuel tank and the engine was started and running, the flex-fuel gauge read 67% ethanol, deemed acceptable for winter blend E85. The flex-fuel sensor's interface with Microsquirt provides the ECU with a percentage of ethanol, adding additional fuel and retarding spark to compensate for percentage of ethanol fuel in the system. Because of the structure, the AFR gauge still reads as though gasoline flows through the system, meaning stoichiometric remains 14.7:1. While using the dynamometer to test the output of the Phazer on E85, the AFR gauge dropped extremely low, below 11:1, indicated that the VE table required re-tuning due to the addition of ethanol. The re-tuned VE table is shown in Figure 5.




| kPa \ RPM | 1000 | 1500 | 2000 | 4000 | 6000 | 6700 | 7500 | 8200 | 9000 | 9700 | 10500 | 12000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101.0 | 51 | 60 | 67 | 74 | 79 | 78 | 77 | 81 | 85 | 81 | 83 | 85 |
| 100.0 | 40 | 61 | 59 | 66 | 65 | 67 | 75 | 73 | 71 | 76 | 80 | 83 |
| 99.0 | 47 | 53 | 50 | 56 | 53 | 53 | 54 | 61 | 73 | 79 | 79 | 80 |
| 98.0 | 43 | 43 | 43 | 46 | 41 | 48 | 51 | 54 | 66 | 73 | 71 | 71 |
| 96.0 | 37 | 40 | 40 | 42 | 44 | 46 | 47 | 50 | 54 | 53 | 64 | 71 |
| 94.0 | 37 | 38 | 38 | 42 | 40 | 40 | 42 | 43 | 46 | 47 | 54 | 61 |
| 92.0 | 38 | 36 | 36 | 36 | 36 | 36 | 38 | 38 | 41 | 46 | 57 | 62 |
| 90.0 | 37 | 36 | 36 | 35 | 34 | 34 | 34 | 38 | 40 | 46 | 61 | 60 |
| 85.0 | 38 | 33 | 33 | 35 | 30 | 37 | 40 | 41 | 41 | 46 | 59 | 58 |
| 80.0 | 35 | 33 | 33 | 35 | 29 | 36 | 37 | 41 | 43 | 46 | 54 | 56 |
| 75.0 | 35 | 33 | 33 | 32 | 27 | 27 | 27 | 32 | 41 | 44 | 45 | 54 |
| 40.0 | 29 | 33 | 33 | 24 | 11 | 8 | 7 | 9 | 12 | 22 | 25 | 22 |

**Figure 5:** Tuned E85 VE table for the Phazer

The team added gasoline to the E85 to obtain E45 and used the above table to determine its compatibility with the lower percentage of ethanol. Though the AFR was slightly different, dangerously lean conditions did not appear, indicating that the E85 tune would work for mid-range blends of ethanol fuel.

ETHANOL COMPATIBILITY – Since the Phazer was also used in CSC 2008, much of the work to make the Phazer ethanol compatible was done by the 2008 team. The 2009 team checked the previous process thoroughly and made alterations where necessary. What follows is the product of the work from both years.

To adapt for alcohol-based fuels, the 2008 and 2009 teams tested the fuel components with ethanol immersion and adapted the fuel system accordingly. The stock fuel pump, located in the fuel tank, could not be adapted to provide a fuel flow measurement during emissions testing, which is necessary for competition. In addition, its resistance to ethanol was unknown. A Walbro FGA-3 inline fuel pump was chosen, capable of providing approximately 76 L/hr and requiring only 4 A of current. In order to account for the lower energy density of ethanol, the Edelbrock EFI fuel pressure regulator, capable of 35 to 90 psi, was also installed to increase fuel pressure from the stock 40 psi. A JEGS Compact Billet in-line stainless steel filter, capable of 130 gph at

75 psi, was also added. Due to the barb sizes on the new fuel components, Goodyear Hypalon EFI hose was chosen for its pressure rating and permeation resistance to ethanol.[9]

The remaining components, the stock fuel rail and associated O-ring, were immersion tested in ethanol for three days to determine their compatibility. Neither component showed signs of swelling or softening, signs which usually show after only 24 hours of immersion.[3]

Additionally, the new components required re-routing fuel through the fuel system to allow the fuel to enter the fuel pressure regulator before entering the fuel rail, as required by the aftermarket manufacturer. To do so, it was necessary to modify the fuel rail by plugging the end of the rail that had housed the stock fuel pressure regulator. A plug, shown in Figure 6 below, was machined from stainless steel and sealed using a stock Yamaha O-ring which was immersion tested for E85 compatibility.

**Figure 6:** Machined plug for the stock fuel rail

For CSC 2009, all snowmobiles are required to be flex-fuel capable, meaning snowmobiles must be capable of running on any mixture of ethanol and gas. To achieve this, a General Motors flex-fuel sensor was installed on the return line to the fuel tank. Figure 7 shows the General Motors flex-fuel sensor installed on the UMaine snowmobile.

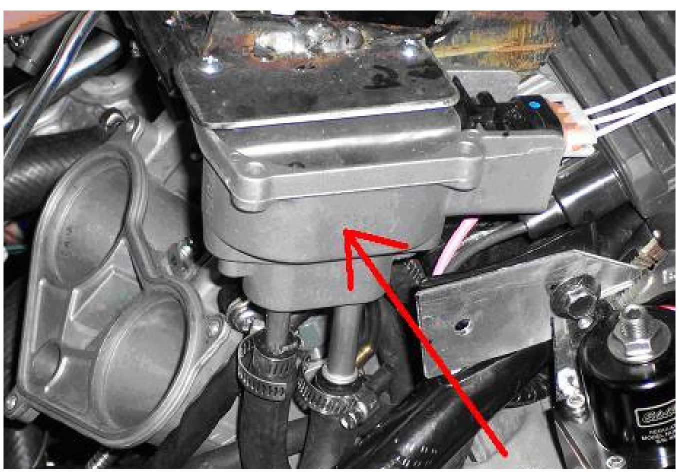


**Figure 7:** General Motors flex-fuel sensor installed on the Phazer

FUEL TANK MODIFICATION – The stock Phazer fuel tank capacity of 8.1 gallons would not be sufficient for the competition endurance event. At competition, the possibility of higher ethanol blend fuel exists and due to ethanol's lower energy density, the stock tank would be too small. To improve the Phazer's range, the team used a stock Phazer tank with pieces of foam added to shape the exterior of the tank to create a plug for a new tank. Body filler was applied to fill the gaps before the plug was prepared for molding. Once sanded, painted and waxed, the team sprayed a PVA release agent onto the plug and laid it with fiberglass. The thin fiberglass mold was removed from the plug in two pieces, and the two tank halves were laid up inside the mold halves and vacuum bagged to withdraw excess resin and reduce weight. Anodized aluminum fuel fittings were installed and the tank halves were coated with an ethanol-resistant Caswell Novolac epoxy. The two parts of the tank were then combined and sealed with a fiberglass strip around the seam.

After CSC 2008, the tank was left filled with E85 for the duration of the summer months. Upon return in the fall, the team discovered that the tank had developed another leak. A section of the tank containing the tank's cap was removed and four layers of 2 oz fabric soaked with a chemical resistant resin by Dow Chemicals, D.E.R. 331, was added to the interior. An additional coat of the chemical resistant resin was applied to the entire inside of the tank to provide an additional layer of ethanol protection. The final coat of resin was left to gel, then post-cured at 200°F for 2 hours and 300°F for 2 hours to allow the coating to reach maximum chemical resistance.[10] A 5 gallon aluminum fuel cell from JEGS was purchased. The top of the cell was then used to replace the portion of the tank that was cut away.

REDUCING NOISE – The 2009 University of Maine team focused on four areas to reduce the overall noise output of the Phazer snowmobile, the snowmobile's cowlings, the exhaust system, the aluminum tunnel, and the rear suspension's idler wheels.

During the SAE CSC noise testing events, the sound pressure measured is weighted on the A-scale. The A-scale ranges from approximately 20Hz to 20kHz, which closely mimics the threshold of the human ear. The standard A contour filter is shown in Figure 8, and showing how low frequencies are reduced in amplitude in the test weighting.

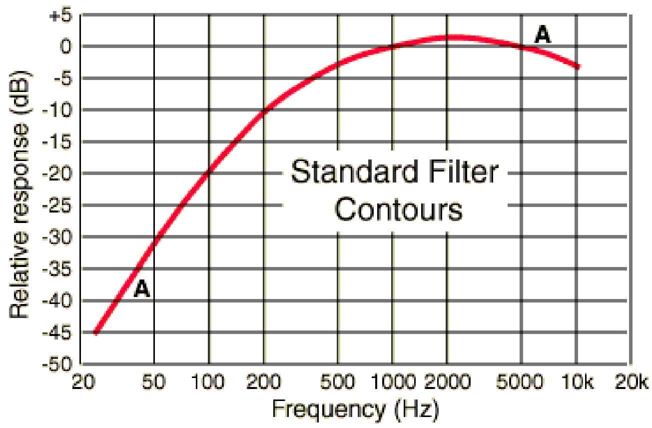



**Figure 8:** A-weight standard contour filter [14]

Cowlings - The main focus for reducing the noise output of the snowmobile was to improve the cowlings previously created for the snowmobile. The Phazer was originally equipped with eight small plastic pieces, which did not contain any sound deadening material, and also would not be acceptable for competition due to the number of pieces. The stock configuration left portions of the engine and clutching system unshrouded.

To better enclose the snowmobile's power train, multiple plastic pieces were eliminated in favor of three larger cowling pieces. These larger components better enclose the engine and drive system and increase the surface area on which sound-deadening material can be fixed. The basic cowlings parts used in the plug for the new fairings were from a Yamaha Venture Lite and were modified to fit the Phazer chassis. The plastic Venture Lite cowlings were then reshaped using an automotive body filler and spray foam to improve both internal clearances and aesthetics. A vacuum bagging process was then used to create female fiberglass molds from these redesigned plastic cowlings. The vacuum bagging process was again employed to create the final cowling pieces from the female molds using layers of a lightweight fiberglass, and is depicted in Figure 9. The fiberglass used added minimal weight, yet was strong enough to withstand the abuse that it will endure during snowmobile operation.

**Figure 9:** Finished vacuum bagged fiberglass side panel

Sound testing of a variety of materials was conducted to determine which material would be best suited for application in the snowmobile. Criteria for selecting the best material included noise level reduction, weight addition, ease of application and cost. To test the noise level reduction of the various sound deadening materials, a sonic tube test apparatus was employed. The apparatus consisted of a PVC pipe, approximately 4 feet in length and 6 inches in diameter, a speaker sealed to one end of the PVC pipe, a function generator wired to the speaker to produce a range of frequencies. At the other end, a shorter piece of PVC pipe with foam to seal the test sample in place with a sound pressure level meter to measure the relative acoustic transmissibility of each sample piece. A schematic of the apparatus is shown Figure 10.

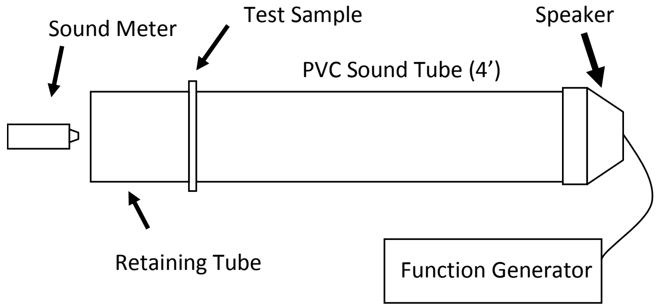



**Figure 10:** Schematic of noise level reduction test apparatus

Fiberglass discs were constructed for each of the sound dampening materials tested, and a fiberglass disc without any sound dampening material was used as a control. The same procedure was repeated using several spray-on materials applied to aluminum discs. This was to test the effectiveness of sound dampening materials that could be applied to the tunnel and other metal parts of the snowmobile.

After completing the material property tests, the team chose to use a combination of two different materials, both used in the automotive audio industry. Both the Dynamat Xtreme and QuietCar materials were very effective at reducing the noise level around 1000 Hz, the peak frequency of noise emitted by the snowmobile. The Dynamat Xtreme provided 5 dB at 1000 Hz, using only 2 coats. The materials were also very effective at reducing the noise levels across a broad range of frequencies, not just the 1000 Hz frequency band which is of primary interest. The results of testing are shown in Figures 11 and 12.

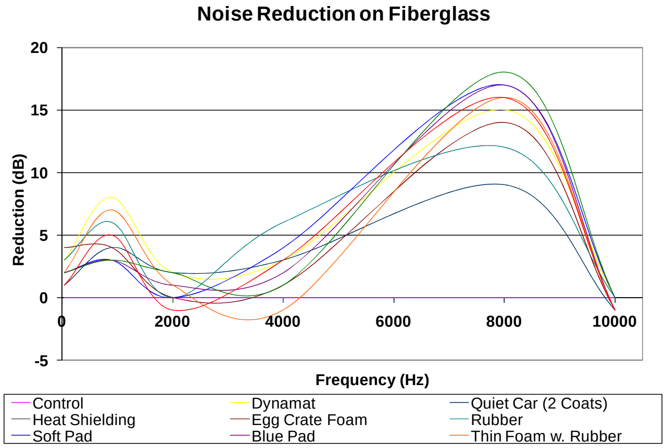



**Figure 11:** Noise reduction on fiberglass

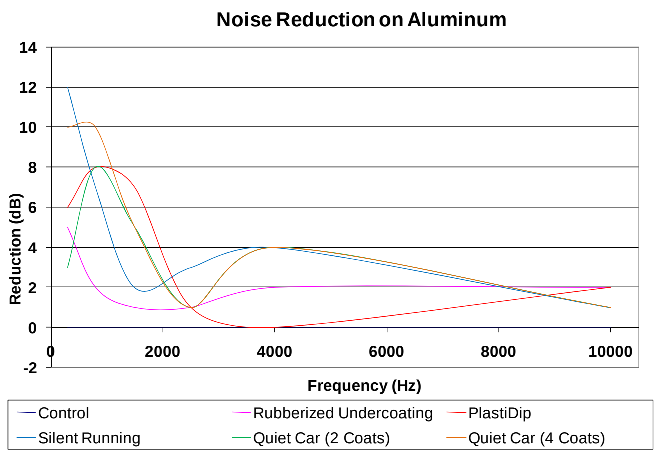



**Figure 12:** Noise reduction on aluminum

In addition, the weight addition per square foot for each material is shown in Figures 13 and 14.

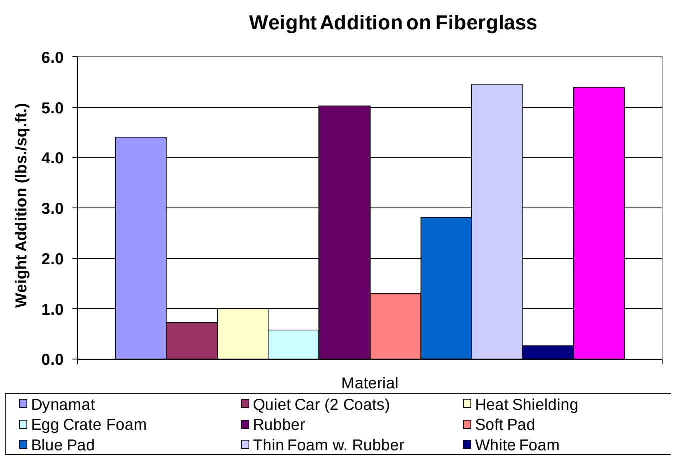



**Figure 13:** Weight addition on fiberglass

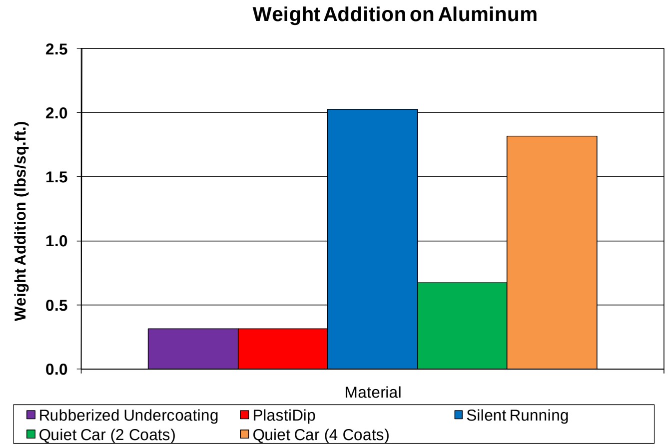



**Figure 14:** Weight addition on aluminum

The first layer of material used was Dynamat Xtreme, a mat type material consisting of a black butyl core with a 4 mil. aluminum constrain layer. During our testing, the Dynamat was one of the top performers in noise level reduction. It is also easy to apply with a self-adhesive backing. The overall cost of adding Dynamat was not significantly different from the other sound dampening materials that were tested. Dynamat performs best at temperatures between 14°F and 140°F, but the material is designed for temperatures ranging from -65°F to 300°F, which makes it compatible for use on the snowmobile cowlings.[11]

The second material chosen was QuietCar, a viscoelastic polymer material that can be applied by brushing or spraying.[12] This material also performed well in the noise level reduction testing, and the weight addition was minimal. The QuietCar was applied on top of the Dynamat to produce additional noise reduction, to reduce vibration of the cowlings. QuietCar was also used to fill voids in the complex cowling shapes where the Dynamat could not be used and to keep the Dynamat adhered to the cowlings.

Upon completion of the ECU installation and tuning, the snowmobile was tested in the field using the procedure outlined by the SAE J192 specification.[4] Here, the snowmobile was driven for 150 feet in a direction perpendicular to a sound meter located 50 feet away from the sled. To pass the test at competition, the snowmobile's noise level must be lower than 78 dB at full throttle.[4] The results of the field-testing showed that the Phazer produced a noise level of 87 dB when measured on the left (clutch side), and 84 dB when measured on the right side of the snowmobile. It was also observed during testing that the snowmobile was approximately 5 dB louder when moving away from the sound meter when compared to its noise level while approaching. Noise level measurements taken from the front and rear of the sled at idle also confirmed the 5 dB difference between the front and rear of the snowmobile. Based on this data, an aftermarket muffler was selected, which initial evaluations suggest will be sufficient to meet the required noise specifications at competition.

Exhaust - The original exhaust, while having a pleasing tone, was louder than necessary. The stock muffler case was opened up by the previous team, and additional fiberglass packing was added to help to further suppress the exhaust noise from the Phazer, depicted in the diagram in Figure 15.

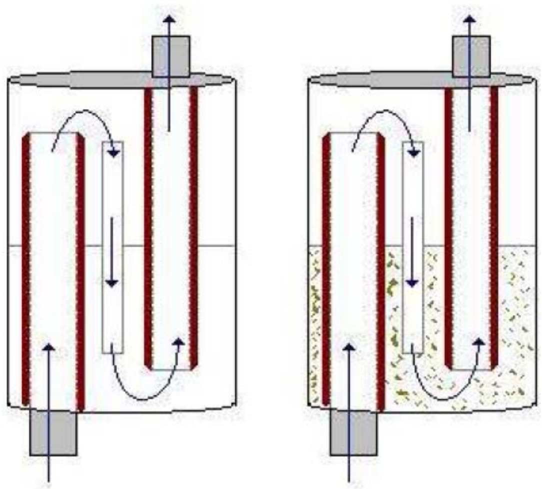


**Figure 15:** Stock muffler diagram, before and after additional fiberglass packing

A hole was also cut in the rear of the tunnel that houses the snowmobile's suspension system, and a tip was added to the stock muffler to direct the exhaust downward toward the snow. The mounting helped to direct the exhaust noises away from bystanders. This also provided an appropriate mounting for the emissions testing equipment.

The snowmobile passed noise testing with this configuration in the 2008 competition, but the engine was limited to 9300 RPM, due to the ECU configuration. The new ECU configuration increased the engine's RPM limit, now 11250 RPM, so further exhaust noise suppression was required, a second muffler placed after the modified stock muffler. The tip of the stock muffler was removed, and replaced by a 90° bend routed through the hole in the tunnel. A Hushpower ATV silencer (5" O.D., 18" case length) was then mounted in the tunnel, and connected to the 90° bend. A 10" tail pipe with a 180° bend was connected to the exit of the muffler to route the exhaust gases back towards the rear of the sled, and to provide maximum noise reduction.[13] A schematic of the exhaust layout can be seen in Figure 16.

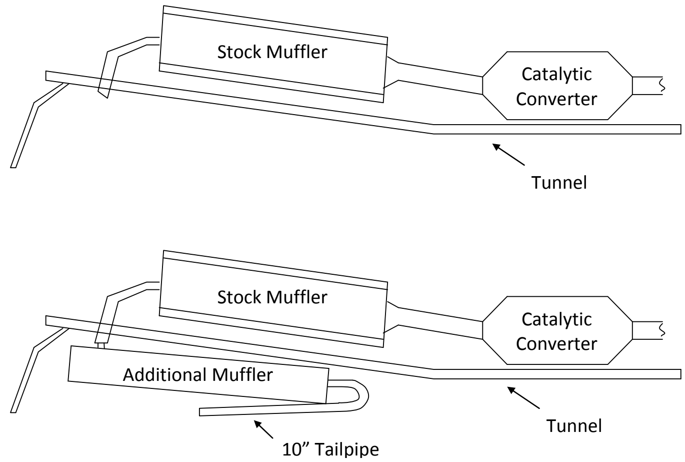



**Figure 16:** Schematic of existing exhaust system, and system with additional Hushpower muffler

Tunnel – It was also necessary to address mechanical vibration that is transferred through the tunnel and radiated to the surrounding area. The approach to reducing sound radiation from the tunnel of the snowmobile was to damp the vibrations in the tunnel. The Dynamat used for reducing noise transmission through the cowlings could not be used in the tunnel due to the extreme environment. As an alternative, several spray-on or brush-on materials were tested. These materials were designed to reduce vibration and would be compatible for use in the snowmobile's tunnel.

From the sound testing procedure previously described, QuietCar was again the top performing material on aluminum test samples. QuietCar was used to coat the inside of the tunnel, underside of the running boards, as well as other metal surfaces that may produce noise from vibrations, shown in Figure 17. In addition to noise reduction, reduced vibrations in the tunnel and running boards also increases rider comfort by reducing fatigue felt by the rider.

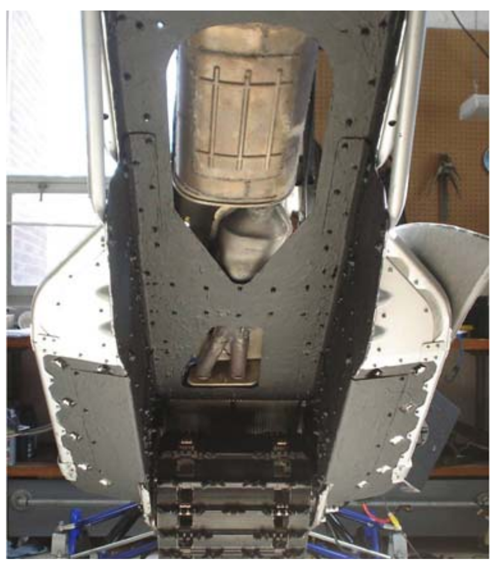


**Figure 17:** Finished Quietcar application to tunnel and running boards

A triangular shaped skirt was also fabricated from rubber and attached to each side of the tunnel. The skirts were positioned toward the rear portion of the tunnel to further reduce the amount of exhaust noise and mechanical track noise emitted to the surroundings. By reducing the amount of radiated exhaust and track noise in this manner, the amount of noise experienced by bystanders in pass-by situations will be greatly reduced. Figure 18 shows the rubber side skirt on the Phazer.

**Figure 18:** Side skirts attached to the snowmobile's tunnel

Idler Wheels - A fourth area of focus in reducing the noise output of the Phazer was in the rear suspension and track area. During higher speed operation, especially on hard pack snow conditions, noise from the track is a significant contributor to overall sound levels. The noise was of particular concern because the frequency content is in part due to the track rubbing on the sliders of the rear suspension. In order to reduce this noise, additional idler wheels were added to the rear suspension of the snowmobile to reduce the contact area between the sliders and the track. Two idler wheels were added to the outside of the suspension rails on each side. Idler wheels used were from a 2007 Yamaha Venture Lite, that are a bolt on application for the Phazer. The two snowmobiles share the same suspension rail profile, so no major modifications were required to the idler wheel mounts or the suspension rails. Two sets of smaller idler wheels from an Arctic Cat 660 rear skid were also added to the inside of the slide rails, which again required no major modifications to the Phazer's suspension. The idler wheel set up on the suspension can be seen in Figure 19. The reduction of contact area also has additional benefits. It is expected that the life of the sliders on the rear suspension will be increased as well as improved fuel economy by reducing rolling resistance.

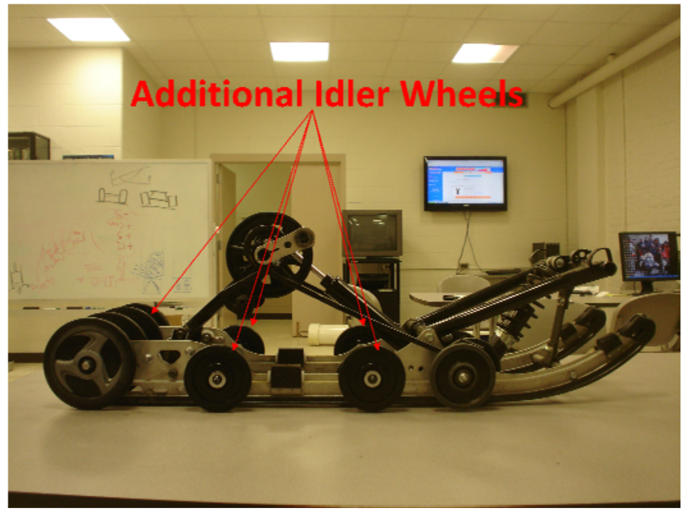



**Figure 19:** Suspension idler wheel set-up

COLD START – To improve the Phazer's cold starting performance, the stock battery with 200 cold cranking amps and 12 amp-hours of capacity was replaced. The new larger battery has 350 cold cranking amps and 21 amp-hours of capacity. This battery was approximately the same cost as the stock battery for the Phazer. The team also used the tuning parameters for cold cranking pulse widths and warm-up enrichment over the course of several days of cold starts to ensure the Phazer's ability to cold start.

SAFETY COMPONENTS – In order to compete in competition, a clutch cover and brake rotor cover were necessary for safety reasons in the case of a clutch and/or brake rotor failure. As per the competition rules, the clutch cover for the Phazer was constructed out of 0.090 inch 6060 T6 and covered with Kevlar belting.[4] The brake rotor cover was constructed from 0.190 inch 6060 T6 aluminum and machined such that the battery could be placed along the outside of the cover.

## EMISSIONS TESTING

TUNING FOR 95% GASOLINE, 5% ETHANOL – With the rough tuning for gasoline complete, the team began to tune the snowmobile for the best possible emissions determined by the approximated five-mode test cycle while taking into account the changes in output power. With the Phazer tuned for stoichiometric AFR at idle and cruising, the sled was tested on the dynamometer to determine output power. Due to the CVT clutch system and the available dynamometer, output could only be obtained using track speed rather than engine speed. The team expected a power loss of around 50% from the crank to the track, and the Phazer produced 40 hp (29.8 kW). Due to the type of dynamometer available, the team will be unable to understand until competition how the changes made in the laboratory affect the power output of the snowmobile.

During emissions testing, the team followed the procedure outlined in the paragraph above, using a 32% load for each testing speed. A WOT run, at approximately 11000 RPM was completed first, during which the Phazer was allowed to achieve steady state before readings were obtained. After the run, the Phazer was decelerated to idle and allowed to idle until steady state was achieved. The Phazer was then shut off and the dynamometer brake given time to cool before the test was repeated for subsequent runs of 9350 RPM, 8200 RPM and 7150 RPM. The readings taken at idle for each of the above runs were compared to determine consistency. Though the procedure is very different from that used at competition, the team expects to match or improve the results obtained.

Because the team did not have baseline data for the Phazer other than the certified emissions of 12 g/kW-hr HC and 240 g/kW-hr CO listed by Yamaha, the data taken in the laboratory was compared to the data taken at CSC 2007 for UMaine's modified Arctic Cat snowmobile and the data taken at CSC 2008 for UMaine's previous generation Phazer. The CSC 2007 emissions data for the Arctic Cat is shown in Table 3. Table 4 shows the CSC 2008 emissions data for the Phazer.

**Table 3:** CSC 2007 Emissions data for UMaine's Arctic Cat snowmobile running 90% gasoline 10% ethanol

| Mode | HC | CO | $NO_x$ |
|---|---|---|---|
| | *ppm* | *%* | *ppm* |
| 1 | 1054.68 | 4.82 | 613.53 |
| 2 | 54.68 | 0.04 | 361.31 |
| 3 | -7.56 | 0.02 | 510.99 |
| 4 | -16.45 | 0.02 | 104.13 |
| 5 | 2380.63 | 1.51 | -14.51 |

**Table 4:** CSC 2008 Emissions data for UMaine's Phazer snowmobile running 15% gasoline 85% ethanol

| Mode | HC | CO | $NO_x$ |
|---|---|---|---|
| | *ppm* | *%* | *ppm* |
| 1 | 225.71 | 1.07 | 574.85 |
| 2 | 581.31 | 3.39 | 11.49 |
| 3 | 1758.14 | 5.76 | -4.05 |
| 4 | 2356.54 | 5.81 | -8.39 |
| 5 | 1632.70 | 3.67 | -13.83 |

Even with the high HC and CO levels shown in Table 4 for the Phazer in 2008, the EPA score was 138, though the CO maximum level was very close to the 275 g/kW-hr limit. The Arctic Cat's EPA score at CSC 2007 was 190, with both HC and CO maximum levels safely below the 90 g/kW-hr and 275 g/kW-hr limits. From these tables, the team determined that though $NO_x$ values play a role in determine EPA number, the main focus should be in reducing HC and CO below the levels recorded for the Phazer at CSC 2008.

The first set of data taken used a VE table that was 2% leaner than the table shown in Figure 3 at all mode points except point 1. The data obtained for gasoline with 5% ethanol is shown in Table 5.

**Table 5:** 2009 Emissions data for 95% gasoline 5% ethanol, with a 12.5:1 AFR at WOT, and 14.7:1 AFR at each other location

| Mode | HC | CO | $NO_x$ |
|---|---|---|---|
| | *ppm* | *%* | *ppm* |
| 1 | 87.65 | 5.12 | 885.66 |
| 2 | 34.53 | 1.10 | 1524.30 |
| 3 | 19.73 | 0.48 | 1376.60 |
| 4 | 24.09 | 0.46 | 818.10 |
| 5 | 104.34 | 2.93 | 96.27 |

When comparing to last year's emissions testing data from competition, the HC levels were significantly improved, but the CO and $NO_x$ levels were worse, due to the difference in test fuels.

The team also gathered emissions data using the VE table shown in Figure 3, which is 2% richer at idle and cruise. A WOT run was not done because the values were unchanged. This data is shown in Table 6.

**Table 6:** 2009 Emissions data for 95% gasoline 5% ethanol, with a 14.4:1 AFR at modes 1, 2, 3 and 4

| Mode | HC | CO | $NO_x$ |
|---|---|---|---|
| | *ppm* | *%* | *ppm* |
| 2 | 22.39 | 0.58 | 1313.10 |
| 3 | 50.28 | 2.33 | 776.63 |
| 4 | 27.78 | 1.65 | 458.71 |
| 5 | 62.77 | 0.08 | 0.00 |

Richening the mixture at idle and cruise decreased the $NO_x$ levels, but increased the CO levels at modes 2 and 3. The HC levels were also slightly changed, but still in the same range as the previous run. This tune was chosen as an acceptable level for gasoline.

TUNING FOR 15% GASOLINE, 85% ETHANOL – Once emissions for gasoline were known, emissions testing for winter blend E85 began. The emissions procedure outlined above was performed again using the VE table tuned for E85 shown in Figure 5. The data collected for the E85 tune is shown in Table 7. The HC levels for modes 1, 2, 3 and 4 were below measurable levels (BML).

**Table 7:** Emissions data for 15% gasoline 85% ethanol

| Mode | HC | CO | $NO_x$ |
|---|---|---|---|
| | *ppm* | *%* | *ppm* |
| 1 | BML | 2.55 | 220 |
| 2 | BML | 4.29 | 53 |
| 3 | BML | 0.19 | 167 |
| 4 | BML | 0.18 | 120 |
| 5 | 25.70 | 0.91 | 8 |

The emissions data collected in the laboratory indicate that UMaine's Phazer will perform extremely well at CSC 2009. The emissions levels are a vast improvement from the 2008 CSC entry and will allow the Phazer to be very competitive in the emissions competition.

## COST

The University of Maine's modified 2007 Yamaha Phazer has an MSRP of $9443.49. The price increase is largely due to the addition of an onboard computer with heated touch screen monitor, which allows for user tuning out on the snow. Though costly, this addition allows the interface with Microsquirt to reach its full potential, and allows for the possibility of additional applications for the snowmobile made possible by an on-board computer. If the monitor were eliminated and a new gauge display constructed, the MSRP of the Phazer would be approximately $8400. The addition of the sound-dampening materials and the fabrication of the cowlings only minimally increases the cost of the Phazer over the stock configuration.

## CONCLUSION

The University of Maine entry into the 2009 Clean Snowmobile Challenge is a tuned, four-stroke snowmobile capable of running on any blend of ethanol fuel. The interface with the ECU allows more advanced users the possibility of additional tuning for power and torque or emissions. The design produces 40 hp (29.8 kW) at the track and drastically improves the emissions over the 2008 CSC design. The stock configuration produces roughly 87 dBA of noise, expected to be significantly improved by the addition of a second muffler and sound and vibration-damping materials by the start of competition. The lightweight, fabricated, fiberglass cowlings maintain the stock power-to-weight ratio, allowing responsive handling and aggressive acceleration.

## ACKNOWLEDGMENTS

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