E85 Fuel System & Tank Design
MEE 488 Senior Design
University of Maine

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1.0 Introduction

1.1 Project Background

In the University of Maine’s clean snowmobile project, mechanical engineering students can apply their skills to improve the environment. The clean snowmobile team is mostly made up of seniors, for whom the project is their capstone, but underclassmen have been members as well. Each year, the goal has been to modify a production snowmobile to reduce emissions, improve fuel efficiency, and lessen noise, all while maintaining the machine’s performance.

The team has entered a snowmobile in the Society of Automotive Engineer’s Clean Snowmobile Challenge (CSC) since 2004. Their initial entry won third place and provided the team with real-world feedback on their design. Last year, the team won second place overall.

This year’s team chose to work on a new snowmobile, a 2007 Yamaha Phazer, instead of refining last year’s sled. The team’s overall design goal was to produce a snowmobile that was both clean and attractive to the majority of snowmobile buyers. In other words, the sled had to be powerful, visually attractive, quiet, and clean. To accomplish this, the team was divided into three groups. This paper presents the efforts and results of the E85 group.

1.2 2008 Design Goals: E85 Group

Internal combustion snowmobiles participating in the 2008 CSC were required to use E85 or B10 as fuel. UMaine chose E85 because of its growing popularity across the country. The E85 group’s goals were to modify or replace any parts of the Phazer’s existing fuel system that were not compatible with ethanol. In addition, a larger fuel tank had to be constructed to ensure the snowmobile could make the 100-mile endurance run at the CSC with ethanol fuel, which yields lower fuel economy than gasoline.

1.3 Specific Targets for Improvement

- Fuel system (pump, regulator, lines, etc.) chemically compatible with E85
- Flex-Fuel vehicle (not required for CSC, but is a great feature on a biofuel sled)
- Variable fuel pressure for customizable fuel flow through injectors
- Hot spark plugs (aids in cold-start)
- Larger battery capacity (aids in cold-start)
- 10+ gallon fuel capacity
- Brake rotor shield (required for CSC 2008 rules)
1.4 Why Ethanol?

In the United States, the majority of ethanol used in formulating E85 fuel comes from corn. When E85 is burned in an internal combustion engine, the carbon dioxide that is released is later absorbed by this corn, which can then be processed into ethanol for more E85. From this perspective, E85 is a clean, 85% carbon neutral fuel. However, when the considerable use of fossil fuels in the production of ethanol is factored in, the environmental benefits of using E85 dwindle [1]. Still, with the development of new farming practices and manufacturing technologies, it may be possible to drastically reduce the amount of fossil fuels used in the production of ethanol, eventually leading to a widely available form of E85 that is greatly beneficial to the environment. Because of this potential to reduce our dependence on oil, as well as the fact that E85 vehicles produce less non-methane hydrocarbons and nitrogen oxides than their gas counterparts [2], it is worthwhile to demonstrate the conversion of a snowmobile to run on E85.
2.0 Fuel System

2.1 Overview

The problem with the Phazer’s stock fuel system was that no documentation existed on its compatibility with E85. Most of the components, like the fuel fittings and lines, were made of unidentifiable plastics and rubbers. Since many plastics and rubbers can be damaged by ethanol, the team decided to replace most of the components with aftermarket solutions that were rated for use with ethanol fuels.

Any aftermarket components that contained rubber or plastic were only considered for use in the new fuel system if they had a statement from the manufacturer proving ethanol compatibility. When an ethanol-compatible metal component was required, the team made sure to use only nickel-plated, anodized aluminum, or stainless steel materials, which are all impervious to ethanol [3]. Figure 1 shows the original layout of the fuel system.

![Figure 1. 2007 Yamaha Phazer fuel system](image)

Even though it was not a requirement of the 2008 competition, the team decided to make the Phazer a flex-fuel vehicle. This was done by installing a dielectric flex-fuel sensor in the fuel system, which detects the percentage of alcohol in the fuel and relays it to the engine control unit (ECU). Flex-fuel vehicles can operate on varying mixtures of gasoline and ethanol, from straight gas to E85. Thus, the Phazer’s rider would have much more freedom at gas stations than a rider of a snowmobile designed to simply meet the CSC 2008’s E85 requirement.
The final fuel system layout is shown in Figure 2. One difference between the new system and the old is the fuel routing, which is explained in section 2.5 by the change in fuel pressure regulator. Also, the new system uses an inline fuel pump and filter instead of in-tank units. It also has an alcohol sensor for flex-fuel capability and a pressure transducer for fuel pressure monitoring. See Appendix B for a detailed list of the components used to create the new system.

Figure 2. Modified fuel system

2.2 Lines

The team replaced the fuel lines with 3/8-inch inner diameter Goodyear EFI hose. The Hypalon material this hose is made of is rated as having excellent ethanol resistance [4]. The 3/8-inch size of the lines was necessary to connect to the fuel pump’s fittings.

2.3 Pump

The team replaced the in-tank fuel pump, which was contained in a plastic housing of unknown material characteristics, with an in-line Edelbrock EFI unit. The new pump, which was designed for racing applications and can operate with alcohol fuel, was the smallest model available that met the ethanol compatibility requirements. It can deliver up to 57 gal/hr of fuel, and can provide between 35 and 90 PSI of fuel pressure. The Phazer’s 80 horsepower engine requires only 12 gal/hr of fuel when running on E85, and less for gasoline (due to gasoline’s higher energy content per volume). See Appendix A for fuel flow calculations.

2.4 Fittings

The team used nickel-plated brass fittings for the tank’s fuel line connections. For the connection to the fuel rail, the stock plastic quick connect was used, but only after testing the plastic for ethanol compatibility via immersion. A new fitting wasn’t used here.
because the stock connector was a proprietary part designed for use with Yamaha’s fuel rail, which the team decided to keep (see section 2.7).

2.5 Pressure Regulator

An Edelbrock ethanol-rated fuel pressure regulator was chosen to match the fuel pump. This regulator was designed for in-line use before the fuel rail, so some modification of the rail was required (see 2.7). The regulator is fully adjustable from 35 to 90 PSI, which was desirable because the team wanted the ability to adjust fuel system pressure during tuning. Specifically, the team realized a higher fuel pressure than the stock 45 PSI would be needed to force enough ethanol through the injectors at full throttle. The new regulator is capable of handling 180 gal/hr of fuel flow at 75 PSI, which exceeds the Phazer’s requirement of 12 gal/hr. A Cyberdyne digital fuel pressure gage was installed in-line to complement the pressure regulator.

2.6 Filter

The fuel filter selected was a JEGS 40 micron in-line filter. The filter is ethanol compatible, as the filter element is made of stainless steel. This filter is suitable for 130 gal/hr of flow at 75 PSI, which exceeds the Phazer’s need of 12 gal/hr.

2.7 Rail/Injectors

To save on costs and time, the team used the stock fuel rail and fuel injectors. Research done by the controls group in online tuning forums revealed that the stock injectors could support the increased fuel demand of an engine running on ethanol as long as the fuel system pressure was raised. However, there was no information regarding the Phazer’s specific fuel injectors and ethanol. Since immersion testing of the injectors in ethanol wasn’t an option (there is no way to judge the effects of the fuel on the inside of the injectors because the injector’s internals are not visible), the team went with the general consensus of mechanics who have experience with ethanol-powered engines. From what these individuals had seen, fuel injectors themselves are rarely damaged by ethanol, but they can become clogged from particles released by ethanol’s corrosion and cleansing effect on the fuel system before the injectors. Based on this observation, the team decided it was safe to use the stock injectors as long as the rest of the fuel system would not corrode in the presence of ethanol.

The stock fuel rail could be tested because it was made of a uniform material inside and out. Figure 3 shows an immersion test of the fuel rail, along with an O-ring that sealed the stock fuel pressure regulator to end of the rail. The parts were submerged in denatured alcohol (90% ethanol, 10% methanol) for three days. No noticeable swelling of the O-ring or softening of the fuel rail occurred.
The new fuel pressure regulator from Edelbrock was designed to be placed in the fuel path before the fuel rail. This arrangement means that excess fuel bypasses the fuel rail and flows from the regulator back to the tank. However, the stock fuel pressure regulator bolted to the end of the fuel rail. Excess fuel flowed through the rail, through the regulator, and back to the tank. Once the old regulator was removed and the new one installed, the open end of the stock fuel rail needed to be plugged.

This was accomplished by machining a plug out of stainless steel, shown in Figure 4. This plug uses the stock Yamaha O-ring from the old pressure regulator attachment (the same O-ring as in Figure 3) to create a seal inside the fuel rail.
2.8 Flex-Fuel

The E85 group worked with the controls group to make the flex-fuel Phazer a reality. The controls group had selected the MegaSquirt programmable ECU to control the engine’s operation. The MegaSquirt is capable of adjusting engine parameters based on fuel mixture as long as it is given real-time fuel composition data. To provide the ECU with the necessary information about fuel composition, the E85 group installed a General Motors flex-fuel sensor, shown in Figure 5. This dielectric sensor is the same one as used in current GM flex-fuel vehicles. Located directly in the fuel path, the sensor samples the fuel flowing through it and relays the information to the MegaSquirt ECU.

Figure 5. GM Flex-Fuel sensor
3.0 Composite Fuel Tank

3.1 Overview

For the CSC 2008, all snowmobiles had to complete a 100 mile endurance run on a single tank of fuel to prove the functionality of the sled’s design. This would be an easy task for a gasoline snowmobile to accomplish because most new snowmobiles can go at least 100 miles on a tank of gas. However, to meet the competition requirements, UMaine’s Phazer was designed to use E85 fuel, which has a lower energy density than gasoline [2]. The consequence is that more fuel is required to go a certain distance.

A stock 2007 Phazer has an 8.1 gallon fuel tank, meaning that the vehicle would have to average 12.3 miles per gallon to go 100 miles. A stock Phazer averages about 16 miles per gallon, depending on riding style. However, E85 has approximately 70% the energy density of gasoline [2]. Thus, a rough estimate of the Phazer’s fuel economy when using ethanol as fuel is:

\[
\frac{.7 \times 16 \text{ miles}}{\text{gallon}} = 11.2 \frac{\text{miles}}{\text{gallon}}
\]

To ensure the completion of the 100 mile endurance run, a new, larger tank would be required. The team decided a minimum of three gallons would need to be added to the Phazer’s existing fuel capacity. If this was achieved, the 11.1 gallon capacity would yield a maximum range of 125 miles. The resulting 25% buffer zone should be enough to compensate for possible drops in engine efficiency due to problems with tuning the ECU for E85.

3.2 Tank Material Selection

Three possibilities for the tank’s material were considered: composites, metal, and plastic. Fiberglass composite was eventually selected, because the manufacturing of a composite tank could be done on campus. The lab was not equipped for the injection molding process of plastic tanks, and none of the team members had enough metalworking experience to make an aesthetically pleasing metal tank. By using composites, the team would be able to form complex shapes that matched the Phazer’s styling. The resulting tank would also be relatively lightweight. Although the lightest possible tank could have been made with carbon fiber, fiberglass was chosen as the reinforcement material because of its low cost.

The use of composite tanks for ethanol fuel is not recommended or used in standard practice because ethanol chemically breaks down the epoxy matrix that holds the fiberglass reinforcement in place. This results in soft spots and eventual delamination of the tank. Therefore, the team had to decide whether to use an ethanol-safe chemical coating or an ethanol-safe fuel bladder to protect the tank. The final decision was to use a chemical coating, because these were available for small fuel tanks while physical fuel bladders were not.
3.3 Composite Manufacturing Overview

There are three steps to making a composite part. The first is to create a plug, which is an object of the same physical dimensions as the desired part. The next step is to lay fiberglass on the plug to create a mold, which is a negative contour of the part. The final step is to lay up fiberglass in the mold to create the part. Since the mold is usually two pieces, the two halves of the final part will need to be combined.

3.4 Plug

A stock fuel tank for a 2007 Yamaha Phazer was used as the basis for the plug. Foam insulation was added to the top and sides of the plug, creating a shape with a larger volume than the stock tank, as shown in Figure 6. The bottom and front of the plug were left bare (i.e. the stock plastic tank was not covered in these areas), thus preserving the intricate details of the tank’s mounting surfaces. The team was careful to keep the tank reasonably dimensioned so that it wouldn’t interfere with the snowmobile’s new cowlings or with the operation of the vehicle.

Figure 6. Initial buildup of plug from existing gas tank
Once the plug had a roughly adequate shape, it was covered with body filler to fill in the gaps between the foam. Sequential applications of body filler allowed the shape to be refined. When the final layer of body filler hardened, the plug was sanded smooth and its corners rounded, as shown in Figure 7.

Figure 7. Final plug shape and size
The sanding process took many weeks, but was necessary to ensure that the fiberglass mold matched the Phazer’s aggressive looks. The smooth surface would also be critical when it came time to make the mold, because imperfections in the surface would cause the mold to stick, resulting in a difficult job of separating the mold from the plug. Once the plug was completely sanded, it was primed and painted with a high gloss paint, which helped to fill in any microscopic pits that the mold could stick to (Figure 8).

![Figure 8. Finished plug being painted](image)

3.5 Mold

The mold could be made once the plug was complete, but first the plug’s surface needed to be prepared. This entailed applying three coats of bowling alley wax and one coat of PVA release film to ensure that the fiberglass mold would release from the plug. Once the plug was prepped, one layer of a fine woven fiberglass was saturated with West System epoxy and laid on the plug, followed by two layers of a heavier boat glass that would give the mold strength. The fine woven fiberglass was a necessary first layer, because it would form the mold’s smooth inner surface (as opposed to the thick, coarse boat glass). When the time came to lay the tank sections up inside the mold, the mold’s smooth inner surface would help keep the tank from sticking.
The mold was made in two parts. The bottom and front of the plug were encompassed by the lower half of the mold, while the top and sides of the plug were encompassed by the top half, as seen in Figure 9. Once the mold cured, it was separated from the plug. Due to the intricate shape of the plug, the mold pieces were difficult to separate, even though the plug had been waxed and sprayed with PVA. The team found that if hot water was poured between the plug and the mold, the PVA release film would soften and the mold would become slightly pliable, thus allowing for a clean release.

Figure 9. The final mold halves sitting on the plug
3.6 The Tank Halves

To create the part from the mold, it was necessary to prep the mold in the same way as the plug to ensure the part would release. Two layers of the same fine woven fiberglass were then laid on the mold, followed by two layers of thicker boat glass to give the tank strength. In this case, the fine woven fiberglass was used to give the tank a smooth, aesthetically pleasing surface. (Note: To add a bid of visual flair to the final tank, a single layer of carbon fiber was laid against part of the top mold). A recessed spot was made for the gas cap by using a piece of round steel the same size as the gas cap on the inside of the mold (Figure 10), thus creating an indent for the gas cap in the tank. The steel was covered in packing tape, which has a smooth surface that will not stick to the curing epoxy-fiberglass composite.

Figure 10. Metal ring used to produce indent in tank for gas cap
Once the epoxy-saturated fiberglass was laid on the mold, it was placed in a vacuum bag to cure, as shown in Figure 11. The purpose of the vacuum was to allow the atmosphere to press bleeder material (located inside the vacuum bag) evenly against the tank as it cured, thus drawing excess epoxy resin from the tank pieces to minimize weight. Once cured, the part was released from the mold in the same fashion that the mold was removed from the plug.

Figure 11. Top half of tank (laid up on the mold) being vacuum bagged
3.7 Finishing the Tank

Once the two halves of the tank were ready, the holes for the intake and return lines were drilled and the fittings installed. The fittings, as shown in Figure 12, were AN-6 to right angle 3/8-inch hose barb, made from ethanol-safe anodized aluminum.

![Fitting for the pickup line](image)

Figure 12. Fitting for the pickup line

The gas cap was then placed in its recessed pocket in the top of the tank and mounted flush with the top. Once in place, all of the fittings and the gas cap were glued to the tank using a chopped fiberglass/West System epoxy mix to ensure there would be no leaks.

Once all of the fittings were installed, both halves of the tank were coated with the highly chemical resistant Novalac epoxy from Caswell Inc. Since there was little time until competition, the team could not test the Novolac and was forced to trust the manufacturer’s assurance that the product was ethanol-proof. Once the Novolac coating cured, the tank halves were combined by laying a fiberglass strip along the outside of the seam. This strip, made with the same West System epoxy resin as the tank, contained one layer of thick boat glass and an outer layer of fine woven glass to maintain the tank’s smooth outer surface.
After the tank was together and the seam had cured, two coatings of the Novalac epoxy were run around the inner seam of the tank to ensure the entire tank would be ethanol resistant. In addition, a layer of Novolac was applied to the top of the tank to prevent against fuel spills. Then, as per the manufacturer’s instructions, the tank was allowed to cure at the elevated temperature of 85°F for three days before it was filled with fuel. Once cured, the tank was filled with water to measure its volume, which turned out to be 13.1 gallons. Figure 13 shows the finished tank.

Figure 13. Complete tank
The tank was then turned over to the team’s mechanic and body specialist, Nicholas Beers, for a final coat of body filler to be applied (thus covering the seam). The tank was then primed and painted to match the rest of the sled’s cowlings. The finished tank is shown in Figure 14.

Figure 14. Finished tank
4.0 Other Work

4.1 Brake Rotor Cover

4.1.1 Overview

The 2008 CSC rules state that a brake rotor cover is required to protect people from a failure of the rotor. However, the rules did not call for any engineering principals to be used in the cover’s design. Despite this, the team decided to try to engineer the cover properly.

After researching the fields of ballistics and projectile physics, the team realized that accurately modeling the forces of projectiles against metal plate is very difficult, because even today the interaction between the projectile and target is not well understood. Since the general practice in the ballistics field is to use energy-method experimental data for design purposes, the team began searching for an experimental correlation.

Data from Sandia National Laboratories (Figure D. in Appendix A) relating the kinetic energy of armor piercing rounds to penetration depth in 2024-T4 armor plate was used to design the Phazer’s brake rotor cover [5]. Since the correlation used a stronger form of aluminum than the easily-weldable 6061-T6 available for use in the lab, and because the correlation was for bullets of known diameters instead of oddly-shaped brake rotor fragments, the team realized that a design based off the correlation would be a rough approximation.

4.1.2 Design

In the end, the team used more of a gut feeling than the correlation to design the cover, which resulted in a shield made from .190- inch thick 6061T6 aluminum plate. The procedure for the brake rotor’s design, as well as the problems encountered, is presented in Appendix A. The primary part of the cover was a large section of the aluminum plate, which guarded the face of the rotor. Smaller sections of plate were welded to this piece at right angles to provide radial protection around the cover. The underside of the rotor was left unshielded, because any fragments from a rotor failure passing through this region would strike the ground. The rotor cover was also designed to include a mount for the Phazer’s battery and fuses.

4.2 Battery

The original battery provided 200 cold cranking amps and twelve amp-hours of capacity. This was fine for the engine running off gasoline, but because ethanol-based fuels have a lower vapor pressure, there is less flammable vapor mixed in with the air charge in the cylinders upon starting. This means the starter has to draw more electricity to cold start an engine with E85. To compensate, a larger battery with 350 cold cranking amps and twenty-one amp-hours of capacity was purchased. This was the most powerful battery available that had the same slim profile as the stock battery. This 4-inch thick profile
allowed the new cowling to stay as close to the sled as possible, thus preserving the Phazer’s looks. The new battery is a sealed AGM type, so no battery acid can escape.

4.3 Hot Spark Plugs

After noticing the difficulties the Phazer had during cold-start conditions with gasoline, the team installed a pair of NGK CR7EKB spark plugs, which run slightly hotter than the stock Yamaha plugs. This was done because the higher temperatures of the plugs’ tips would help to ignite the fuel mixture faster in cold conditions. Since E85 has a higher octane rating than gasoline (105 vs. 91), installing slightly hotter plugs would not cause detonation when running E85.
5.0 Results

5.1 Overview

The purpose of the E85 group’s work was to modify the Phazer’s fuel system for ethanol compatibility and flex-fuel operation, and to create a larger fuel tank for E85 use. For this work to be considered successful, the snowmobile must be able to operate on varying mixtures of gasoline and ethanol without suffering damage to its fuel system. The structural integrity of the new fuel tank must also show no signs of weakening.

Since the team worked over the course of the year to complete the snowmobile for the Clean Snowmobile Competition, a further consideration for successful results is that the Phazer should have satisfied all of the above criteria as of March 10, 2008, which was the start of the competition.

5.2 Competition Overview

The CSC was held in Houghton, Michigan from March 10 to 15, 2008. The team’s standings were hurt due to the failure of the fiberglass fuel tank, but on-site repairs kept the team from having to withdraw.

5.2.1 Tank Failure

Prior to the competition, the Phazer had ethanol fuel in its new tank only for a few days, during which the controls group tuned the snowmobile with an approximate mixture of E85 created in the lab. During this time, the snowmobile was operated on the dynamometer and outside in a field. There were no signs of tank failure.

The tank started leaking on the second day of competition, just before the 100-mile endurance run. It appeared that it had delaminated near the seam sometime during the night, and the ethanol had seeped between fiberglass layers to the tank’s bottom, where it broke through the thin layer of paint. On the same day, a small hole formed in the top of the tank by the fuel cap, apparently from a fuel spill. Since the team had coated the outer surface of the tank with Novolac to prevent against spills, they decided that two independent failures of the coating warranted the resealing of the tank with a different compound. The decision was made to withdraw from the endurance run for safety reasons. The team then procured a stock Yamaha tank in order to complete the make-up endurance run the next day and to compete in future events.

5.2.2 Tank Repair

In an effort to repair the Phazer’s fiberglass tank for the remainder of the competition, a chemical fuel tank lining kit made by Northern was obtained from a local auto supply store. The tank was drained, cleaned of fuel residues, and dried out with the Methyl Ethyl Ketone from the kit. Once dry, Northern Fuel Tank Liner was sloshed around the inside of the tank, as per the manufacturer’s instructions. According to the manufacturer,
this product is similar to the Novolac epoxy in that it is unaffected by ethanol. There were only two foreseeable problems. The first was that, unlike the Novolac, the Northern Tank Liner was not intended for use with fiberglass tanks. The second was that the new liner might not adhere to the previously cured Novolac on the inside of the tank, since the Novolac is a chemically resistant coating that repels foreign substances.

The team constructed a makeshift oven out of building insulation and used a heat lamp to cure the tank at 115 °F for two days. When the new coating was dry, the tank was filled with E85. As of the writing of this report, the tank has held E85 for over a month with no signs of leaking. The noise, vibration, and harshness group took the snowmobile out for sound testing and reported no problems during use.

5.2.3 Competition Results

The Phazer finished ninth out of twelve in the internal combustion category, which was disappointing considering last year’s second place finish with an Artic Cat 660. If the fuel tank had not failed, and if the team had had more data about the snowmobile’s emissions and noise characteristics, they would have finished higher. Still, the Phazer earned third place in the noise category and was one of five internal combustion snowmobiles that succeeded in the cold start event (out of 13 vehicles). This last success was probably due in part to the powerful battery and hot spark plugs that were installed.

5.3 Functional Fuel System

So far, the fuel system has performed well with E85, and although the flex-fuel system still needs to be refined, the snowmobile’s MegaSquirt ECU has processed the signal from the flex-fuel sensor and adjusted engine settings to run successfully on the team’s homemade E85 and the competition’s E85 test fuel. There have been no signs of corrosion or damage to any of the fuel system’s components, and the modified fuel rail has not failed at the system pressure of 62 PSI. The Edelbrock fuel pump performed flawlessly throughout the competition and has continued to work during outdoor riding and indoor dynamometer tuning.

5.4 Tank

The fiberglass fuel tank holds 13.1 gallons of fuel, as compared to the 8.1 gallon capacity of the stock tank. The % improvement is:

\[
\frac{13.1 - 8.1}{8.1} \times 100\% = 61.7\%
\]

The team believes the tank, with its coating of Northern Fuel Tank Liner, has done well to withstand the E85 inside it, especially considering the fact that the repairs were done off-campus and under a tight timetable. However, no final judgments should be made until the snowmobile can be ridden hard over rough trails. Only under these conditions,
with chassis flex and fuel slosh coming into play, can an educated decision be made about the tank’s structural integrity.
6.0 Conclusions and Future Recommendations

6.1 Conclusions

The Phazer went from a virtually stock machine in September 2007 to a functional flex-fuel vehicle in March 2008. Tuning and optimization will need to be done next year, but the Phazer’s ethanol-compatible fuel system is operating as expected. The new fuel pump, pressure regulator, filter, and lines have not shown signs of deteriorating performance, and the modified fuel rail has yet to leak where it was capped. The only goal that was not met was having a functional fuel tank by competition.

The 13.1 gallon fiberglass fuel tank has performed well since CSC 2008, with the Northern Fuel Tank Liner as the protection against ethanol fuel. The original Novolac epoxy, obtained from Caswell Inc., might have been the cause for failure at competition. Another possibility is that the Novolac, which is a highly viscous substance, failed to cover a small section of the tank’s interior seam during the sloshing method of application. However, since the team coated the top of the tank to prevent against ethanol spills and the tank failed there as well, the current theory is that the Novolac chemically failed. Since Caswell Inc. has laboratory test results detailing their product’s performance with ethanol fuels, it may be that the quantity of Novolac epoxy purchased by the team was from a defective batch. Currently, the team is investigating the methods of possible failure for the fuel tank. The results of this analysis will be attached to this report when complete as an appendix.

6.2 Recommendations

For next year, the Jegs inline fuel filter should be removed and checked for residue or other build up. Ethanol has a cleansing effect on fuel systems that have seen use with gasoline, and the particles it dislodges from the fuel system will accumulate in the fuel filter. The filter element can be replaced if necessary.

Since a mold exists for the Phazer’s fuel tank, it would be a good idea to make a new tank. This should be possible to do within two weeks, assuming no damage occurs to the mold while in storage. The reason for a new tank is because the current tank’s structural integrity is questionable, given its history of failure. If it fails next year, a spare tank would allow the team to still go to competition. The mechanical laboratory report attached to this paper will make a recommendation as to which ethanol-proofing product to use (Caswell’s Novolac or Northern’s Tank Liner).

It would also be prudent to have solid engineering data behind the design of the Phazer’s brake rotor cover. As explained in Appendix A, the current brake rotor cover’s design was based off of a very arbitrary procedure. Since a force-based analysis would be difficult (due to complicated material interactions between rotor fragments and the cover), and energy analysis is still the best option. A better correlation might allow for the same procedure described in the appendix to be used, although laboratory testing might be the most accurate design approach in this case.
References


4. Isolator Gloves Hypalon Chemical Compatibility Page. 6 Nov. 2007 <http://www.isolatorgloves.com/Chemical%20Compatibility%20Hypalon.doc>

Appendix A: Calculations

Fuel Flow Calculations

The following calculation was performed as a check to ensure that the new fuel pump could provide enough fuel flow during E85 operation. It should be noted that the pump will operate successfully on winter blend fuel used at the CSC, because winter blend has a higher energy density than E85, meaning less flow rate is required. The pump will also operate successfully on gasoline, because gasoline has a higher energy density than any ethanol-gas fuel mixture.

Ethanol Energy Density = \(22 \frac{MJ}{L}\)

Gasoline Energy Density = \(34.6 \frac{MJ}{L}\)

E85 composition = 85% ethanol and 15% gasoline by volume.

\[\text{E85 Energy Density} = 0.85(22 \frac{MJ}{L}) + 0.15(34.6 \frac{MJ}{L}) = 23.8 \frac{MJ}{L}\]

Phazer Target Horsepower = 80 HP

\[80 HP = 0.06 \frac{MJ}{Sec} = 216 \frac{MJ}{Hr}\]

Assuming a Conservative Engine Efficiency of 20%

\[\frac{216 \frac{MJ}{Hr}}{0.20} = 23.89 \frac{MJ}{L} \times \text{FlowRate} \frac{L}{Hr}\]

\[\text{FlowRate} = 45.21 \frac{L}{Hr}\]

\[\text{PumpCapacity} = 215 \frac{L}{Hr}\]

Demand on pump = 21% of full capacity.

Although this is an approximate estimation (the engine efficiency was assumed to be 20%), there is no question that the pump, which was designed for automotive use, will provide enough fuel flow for the snowmobile.
Brake Rotor Design

Figure D at the end of this appendix is the energy-based correlation from Sandia National Laboratories that was used to help size the thickness of the brake rotor cover. Although the correlation was for 2024-T4 aluminum, 6061-T6 aluminum was chosen as the cover material because it is easily wieldable.

The first step was to calculate the maximum kinetic energy of the brake rotor. The brake rotor is driven off the secondary clutch, so it shares the clutch’s rotational velocity. This velocity reaches a maximum whenever the Phazer’s engine is operating at its top speed of 11, 500 RPM. In order to calculate the brake rotor’s speed, the drivetrain’s gear ratios were used.

\[
\text{MaxEngineRPM} = 11,500 \\
\text{RotorSpeed} = 11500 \times \frac{7}{10} \times \frac{1}{.95} = 8475 \text{ RPM}
\]

In radians per second:
The brake rotor’s kinetic energy also depends on its moment of inertia. The rotor itself is made of steel, with the majority of the material making up the braking surface. A small hub and light-weight spokes make up the central part of the rotor. Since the mass that translates into high moments of inertia on a cylinder are located towards the cylinder’s outer diameter, the moment of inertia calculation was simplified by ignoring the central hub and spokes. The rotor was modeled by hand and checked in SolidWorks as a hollow cylinder made of steel. The SolidWorks model is shown in Figure B.

\[
8475 \frac{\text{rev}}{\text{min}} \times \frac{1}{60} \frac{\text{min}}{\text{sec}} \times 2\pi \frac{\text{rad}}{\text{rev}} = 877.05 \frac{\text{rad}}{\text{s}}
\]

From the SolidWorks analysis, the moment of inertia is:

\[
I_{zz} = .00326 \text{ kg} \cdot \text{m}^2
\]

\[
\text{KE} = \frac{1}{2} I W^2
\]

\[
= \frac{1}{2} \times .00326 \times (887.05)^2 = 1.3 KJ
\]

Upon failure, the brake rotor would likely disintegrate into fragments, which would strike the cover in different locations. Since the brake rotor cover doesn’t shield the underside of the rotor, some fragments would travel downward into the ground. Without having
experimental data on how brake rotors disintegrate, it was difficult to estimate how much of the brake rotor’s energy would be dissipated in the cover.

In the end, the team assumed that 5-10% of the brake rotor’s kinetic energy would impact the brake rotor cover at any single point. However, the problem with the experimental correlation from Sandia (Figure D) was that penetration distance was a function of kinetic energy divided by the bullet diameter squared. The team was unable to find any information on how to convert a chunk of brake rotor into a bullet diameter, so a guess at an equivalent diameter was made, based off of 5% of the surface area of the rotor. This yielded a plate thickness of approximately 3/8 of an inch from the correlation. The team used .190 inch 6061-T6 for the brake rotor cover.

The specifics of this portion of the design have been intentionally left out of this appendix, because the team views much of the method as completely arbitrary. The problems with the method are:

- Correlation projectiles are armor-piercing bullets, not brake rotor fragments.
- Correlation target is 2024-T4 aluminum, not 6061-T6
- Correlation does not take into account the possibility for multiple projectile impacts in the same area of target material

Because of these issues, the design of the Phazer’s brake rotor cover cannot be justified. As mentioned in section 4.1, the alternative method of designing using forces would have been just as difficult, because the impact force of a bullet is subject to many properties of the materials in question as well as geometry. Since next year’s clean snowmobile team will have less work to do on the Phazer’s fuel system, a more detailed brake rotor cover design should be attempted. If the forces of impact can be determined, then SolidWorks can be used to model the plate’s failure, as shown in Figure C for an arbitrary force. If not, then perhaps a testing rig should be built to simulate a brake rotor fragment impact against aluminum plate.
Figure C. Sample SolidWorks brake rotor analysis: arbitrary point force, cover welded (left side)
Figure D. Penetration depth of ballistics rounds into aluminum plates as a function of projectile kinetic energy and projectile diameter [5].
Appendix B: Ethanol Fuel System

Parts List

<table>
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<tr>
<th>Component</th>
<th>Manufacturer</th>
<th>Model/Part Number</th>
<th>Quantity</th>
<th>Cost</th>
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</table>

$1,011.59
Mechanical Laboratory 3: Testing Ethanol and Fiberglass

MEE 443  
University of Maine  
Crosby Laboratory

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May 03, 2008
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Introduction

Purpose of Ethanol Testing

The Clean Snowmobile Team chose Caswell’s Phenol Novolac Epoxy to protect the Phazer’s new fiberglass fuel tank because it was certified for total immersion in ethanol as well as gasoline. Due to the tank’s failure at the competition, the team decided to test the Novolac epoxy to determine if it was the reason the tank failed. When deciding how to go about the testing procedure, the team realized the necessity to test not only the coating itself but the method in which it was applied.

Overview of Testing Theory

The effects of ethanol fuel on fiberglass fuel tanks are well-documented. Fiberglass tanks made with standard epoxy resins soften when exposed to ethanol and eventually fail. The purpose of chemical-resistant fuel tank linings like Caswell’s Novolac Epoxy is to act as a barrier between the inside of the fiberglass tank and the fuel. Thus, a tank protected with an effective coating will not show any signs of softening or leakage.

The team created nine fiberglass bowls using the same West System epoxy resin that was used to create the fiberglass tank for the snowmobile. The principle behind the testing procedure was that these bowls, once coated with the Novolac Epoxy and filled with E85, would remain rigid if the coating held but would soften and/or leak if the coating failed. In addition to testing Caswell’s Novolac Epoxy, the decision was made to test Northern’s Fuel Tank Liner, which was used as a last-minute fix for the leaking tank at the competition. In the two months since, the tank has shown no signs of failure.

Since the Phazer’s new tank failed in an area close to the seam, the ethanol testing needed to address the issue of how the chemical-resistant coatings behaved around a seam. Thus, four bowls were constructed in two parts, so that the halves could be joined with a seam. These bowls were tested with both coatings, and with two different application methods for the coatings.
Testing Apparatus & Description

Figure 1 shows the primary testing apparatus. It is a plywood stand that holds eight of the bowls suspended over filter paper. Once filled with E85, any of the bowls that develop leaks could be identified by inspecting the filter paper for wet spots. A separate stand was created for the ninth bowl, which was the uncoated control. Since it was known this bowl would leak heavily, the separate stand ensured that excessive amounts of fuel wouldn’t saturate the filter paper under the primary apparatus.

![Diagram of Primary Testing Apparatus]

Figure 1. Primary testing apparatus.
Discussion of Test Bowls

Bowl Identification:

A:  Novolac, 1 coating  
B:  Novolac, 2 coatings  
C:  Novolac, seamed bowl, 1 coating after bowl was combined  
D:  Novolac, seamed bowl, bowl halves coated, combined, then coated again  
E:  Northern, 1 coating  
F:  Northern, 2 coatings  
G:  Northern, seamed bowl, 1 coating after bowl was combined  
H:  Northern, seamed bowl, bowl halves coated, combined, then coated again

Bowls A and E serve to test the effectiveness of a single coating of tank liner, and bowls B and F serve to test the effectiveness of a double coat of tank liner. However, none of these bowls are an effective simulation of the Phazer’s actual tank, because the tank has a seam. Thus, bowls C, D, G, and H were created in halves. The halves were joined together by a strip of fiberglass on the outside of the bowl, just like the Phazer’s tank.

Bowls D and H were prepared the same way as the tank. This means the two halves were coated with the ethanol-resistant product and allowed to dry before being unified. The resulting bowl was then coated with the ethanol-resistant product, with emphasis being placed on sloshing the coating over the internal seam. Thus, the bowl halves effectively received two coatings and the seam one.

After the Phazer’s tank failed, the team suspected the failure might have been caused by improper adhesion of the Novolac epoxy to itself at the seam’s edges. The basis for this assumption is that the tank halves, having been previously coated with the chemical-resistant Novolac, repelled the fresh coat of Novolac when it was applied to the seam area. Thus, bowls C and G were unified and then coated with a single coat of ethanol-resistant product. The idea here is that the coating would bond equally with all parts of the bowl.

A Note about Bowl Coatings

Both the Novolac and Northern coatings are applied to fuel tanks by a sloshing method (this is stated in the manufacturer’s instructions). This means dumping the product inside the tank, sealing it, and then rotating the tank to coat all surfaces. The bowls used in this test were coated in the same manner, and allowed to cure for the recommended amount of time before being filled with fuel (1 week).

During the coating, the team noticed that the Novolac quickly becomes very viscous after its two components are mixed together. The Northern, which is a single-component substance that requires no mixing, remained very runny for a few minutes, which allowed it to coat the fiberglass bowls much quicker. The Novolac’s viscosity caused difficulties in completely coating the bowl’s surfaces.
After coating bowl C with Novolac, the team noticed that the coating had missed a spot of the bowl up near the bowl’s lip. This defect is shown in Figure 2. Although this defect was too high up on the bowl to be submerged in ethanol for the test, something like this could easily cause fuel tank failure, especially considering it would be difficult to see an uncoated spot by peering inside a fuel tank’s filler opening. The Novolac also seemed to trap a lot of air bubbles beneath the coating.

Figure 2. Air Bubbles / Uncoated Section of Novolac Bowl
Test Procedure

The bowls were filled on April 17, 2008 with the fuel that was used during CSC 2008. This fuel, a winter blend version of E85 containing approximately 75% ethanol and 25% gasoline, was provided by Gage Fuels. The fuel was dyed with food coloring in a manner such that no two adjacent bowls contained the same color fuel. The purpose of the food coloring was to make it easier to detect leaks by looking at the filter paper below the bowls. It also ensured that a leak from one bowl wouldn’t accidentally be associated with a different bowl.

The bowls were periodically checked for failure, with failure being considered a visible softening of the bowl or leakage (which would be detectable on the paper under the bowls). Figure 3 is a picture of the filled bowls.
Results

The first failure of one of the test bowls was documented on April 21. As shown in Figure 4, the bowl that failed is bowl B, the 2-coating Novolac bowl.

Figure 4. Failure of Bowl B. Taken 4/21/2008 2:09 PM.
The second failure was documented on April 22, and is shown in Figure 5. This bowl is the control. Since the leak was very small, an enhanced version of the photograph with a more visible leak is presented in Figure 6. The control was allowed to leak for another day, which resulted in significant failure and softening of the bowl’s bottom. This is shown in Figure 7. After the bowl was emptied, the team noticed that its bottom felt soft in some places. This is a typical symptom of failure for uncoated fiberglass fuel tanks.

Figure 5. Failure of Control. Taken 4/22/2008 12:38 PM.
Figure 6. Failure of Control (enhanced). Taken 4/22/2008 12:38 PM.
Figure 7. Advanced Failure of Control. Taken 4/23/08 3:54 PM.
The rest of the bowls showed no conclusive signs of failure until the experiment’s conclusion on May 2. Figure 8 shows the final state of the test apparatus. Inspection of the bowls after the test was complete showed no obvious holes, even in the control or bowl B.

Figure 8. Final state of test apparatus (combined from two photographs).
Discussion

After the experience with the Phazer’s fuel tank, it was expected that one or more of the Novolac bowls would fail. Of the four bowls coated with this product, bowl B should have been the most resistant to E85 because of its two coatings. However, bowl B failed first, even before the control (although the control’s failure came only a day later and ended up being more massive than that of bowl B). Since the inspection of the bowl’s bottom revealed no visible defects, the bowl B likely failed from a tiny hole.

Since the three other Novolac bowls didn’t fail, it seems that the Novolac coating is somewhat successful in protecting fiberglass parts from ethanol. As previously noted, the Novolac is a much more viscous substance than the Northern, and thus it takes more sloshing effort to achieve a uniform coating of a surface. As shown in Figure 2, the Novolac’s viscosity can cause it to miss a section of the surface, resulting in a small unprotected area. In the case of bowl B, irregularities in the fiberglass surface probably caused both coatings of Novolac to pool around an irregularity instead of flow over it.

In contrast, the Northern bowls all held ethanol for the duration of the sixteen day experiment. Since the Northern coating has an initial low viscosity, it runs easily over the irregular surface of fiberglass parts. The fact that it is dyed blue also helps the person applying it to see uncoated surfaces.
Conclusion

The Northern Fuel Tank Liner is the better product to use when coating fiberglass fuel tanks when compared to Caswell Inc.’s Phenol Novolac Epoxy. The Novolac epoxy is so viscous that it can miss coating sections of the fiberglass surface, even when two coats are applied, resulting in fuel tank failure. It should be noted that Northern claims their product does not adhere to fiberglass fuel tanks. From what has been shown in this lab experiment, and from the fact that the Phazer’s fuel tank has been working well with the Northern coating for two months, it seems the coating does work with fiberglass parts. Perhaps the Northern company is referring to a long-term issue.