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PROJECT DESIGN REPORT – UNIVERSITY OF MAINE

Clean Snowmobile - Chassis

Design and Modification of a
Compressed Natural Gas Snowmobile Chassis

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DESIGN AND MODIFICATION OF A COMPRESSED NATURAL GAS SNOWMOBILE CHASSIS

Abstract

This engineering design paper will discuss the process to improve the handling of a 2013 Arctic Cat XF1100 LXR snowmobile that is fueled by compressed natural gas. The vehicle dynamics of the snowmobile are improved by way of a new aluminum tube-tunnel, air silencer redesign, compressed natural gas fitting redesign, and suspension tuning. The changes allow the snowmobile to have handling characteristics comparable to a standard gasoline-powered equivalent.

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1.0 Introduction

The use of compressed-natural gas (CNG) as a reliable automotive fuel source is becoming more common. Although its use is spreading through a number of large vehicles, it remains largely absent in the small engine field.

Due to the increased weight and size of a CNG tank needed, several issues come about on a smaller vehicle that would otherwise be nominal for a larger vehicle such as a car or bus. The snowmobile conversion to compressed natural gas seeks to show that CNG is an effective fuel source that is both cost effective and cleaner burning while also keeping the same, or higher, level of performance and handling.

For a smaller vehicle like a snowmobile, weight distribution is critical to the handling and performance of the machine. A large, heavy CNG tank is needed to keep the same travel length requirements of the stock machine, which severely limits the handling when using the stock suspension setup.

1.1 Purpose of Clean Snowmobile Chassis Redesign

The snowmobile required redesign because of the poor handling that was a result of the addition of a compressed natural gas tank. The CNG tank, which weighs 130 pounds when full (as opposed to 64.37 pounds for a full gasoline tank), negatively changed the snowmobile's center of gravity and removed important weight from the front skis. The loss of weight on the skis made turning difficult because the skis were much more prone to sliding in the snow. The additional weight on the back of the snowmobile also dramatically increased its mass moment of inertia, again making it harder to turn the sled. When the snowmobile was tested, it handled poorly during turning which was a direct result of the change in weight distribution.

1.2 Overall Design Goals

The overall goals of the Chassis Team are to improve the handling of the snowmobile through several avenues. The first goal is to move the CNG tank towards the front of the snowmobile as much as possible. To accomplish this goal, two separate goals were also created; one, to significantly alter the air silencer to make it smaller, and two, to rearrange the filters, fittings, and heater that the natural gas runs through on the way to the engine. The final goal is to adjust the rear suspension of the snowmobile so that it can accommodate the additional weight that the CNG tank adds.

1.2.1 Design Goals Summary

The goal of the Chassis team this year is to modify and adjust the CNG snowmobile so that it has handling characteristics comparable to that of the machine in stock form. This goal is completed by addressing four key areas: rear suspension, tunnel, air silencer, and tank placement.

1.2.2 Overall Mission Details

The mission of the team is to finish the total CNG snowmobile conversion so that the snowmobile not only runs on compressed natural gas, but also drives and handles effectively with the required changes.

2.0 Previous Design Description

2.1 Design Overview

At the beginning of the year, the Chassis team was given the task of improving the handling of a snowmobile with a 130 pound compressed-natural gas tank mounted on the back. The first job was to assess the situation left to us by last year's team. A picture of the sled left to us by last year's team can be seen below in Figure 2, and the original stock sled they received is located in figure 1.

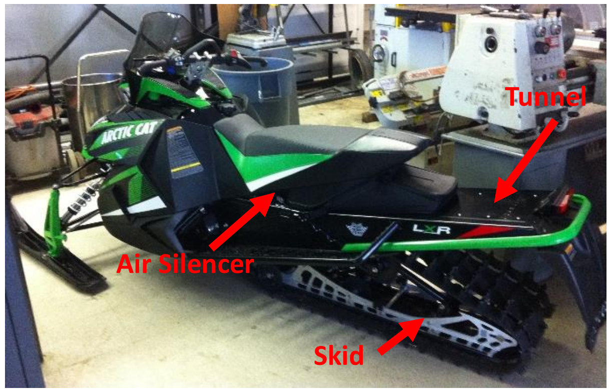

Figure 1: Stock Sled with Basic Chassis Components Labeled

Figure 2: Sled by the Last Year's Team

2.1 Rear Suspension

The rear suspension is designed for a track with a total length of 141 inches. The suspension is composed of two large pieces of aluminum, called rails, which are held together by steel pieces that make up the moving parts of the suspension. The rear suspension has a front shock and a rear shock within the suspension skid. The front shock is much smaller than the rear shock and is close to the front of the suspension skid. The rear shock is larger and located towards the center of the suspension skid. Please see Appendix A for a complete diagram of the rear suspension with measurements included.

2.2 Tunnel

The tunnel of last year's team consisted of three pieces all made of aluminum plate. The stock tunnel is made of two pieces of aluminum that are riveted together to make up the tunnel. To accommodate the length of the CNG tank, last year's team needed to create a third piece to the tunnel to extend its overall length. The first two pieces found on the snowmobile in stock form are 1/16th inch thick aluminum plate bent into the shape of the tunnel. The tunnel extension fabricated previously exists of a 1/8th inch thick aluminum plate bent to the shape of the tunnel that adds three feet of length to the overall machine.

2.3 Tank Placement

The tank is a Type 3 CNG tank composed of an aluminum structure wrapped in carbon fiber. The tank weighs 107 pounds when empty and 130 pounds when full. The tank is six feet long and holds 131 liters of CNG. When full, the tank has the same amount of energy as a ten gallon gasoline tank. The compressed natural gas is under 3600 pounds per square inch of pressure when full.

When the snowmobile was received at the start of the year, the tank was located 12 additional inches toward the back of the snowmobile compared to its current position after modifications.

2.4 Air Silencer

The original air silencer was 15 inches long which significantly interfered with the ability to move the tank forward as desired. This air silencer can be seen in Figure 3:

Figure 3: Stock Air Silencer

3.0 Concept Design Process

The modifications and additions made to the snowmobile produce a light, strong, and space saving tunnel that can accommodate the weight and volume of the tank, while keeping the snowmobile's handling characteristics as close as possible to stock. The finished snowmobile chassis consists of modified stock parts, and parts fabricated by the Chassis team. Modified parts include the air silencer, the skid/suspension, and the plastic bodywork. New / fabricated parts include the aluminum tube tunnel, the CNG fittings and bracket, and the Hygear suspension kit.

3.1 Chassis Components

The chassis redesign focuses on the four main areas mentioned previously: rear suspension, tunnel, air silencer, and tank location. Several chassis components must be understood for a full picture of how each modification works.

The rear suspension is often referred to as the suspension "skid" and is what is surrounded by the rubber snowmobile track. A picture of the rear suspension found in the stock snowmobile can be seen back in Figure 1.

The tunnel is the portion of the snowmobile that encloses the rear suspension and track. The tunnel serves as a crucial point in the structural integrity of the machine. The tunnel on a conventional snowmobile is made of one to two pieces of about 1/16th inch aluminum plate. The tunnel makes up a large portion of the chassis of the snowmobile. The stock tunnel can be seen in Figure 1.

The air silencer is a portion of the air intake system. The air silencer serves to quiet the engine volume by reducing the noise of the air going into the engine. The air silencer is positioned directly after the airbox of the snowmobile in the air intake system. In this way, the air is collected in the airbox, then goes through the air silencer which works with acoustics to lower the sound level of the entire snowmobile. The location of the air silencer on a stock sled can be seen in Figure 1.

3.2 Rear Suspension Redesign

The rear suspension design focuses on how to tune the suspension to better handle the weight. The stock suspension found on the Arctic Cat XF-model sleds is designed to keep weight off the front skis as much as possible, for better performance in deep snow. For a snowmobile designed to ride trails, a suspension setup is needed that puts weight forward onto the skis so that they can grip during cornering in snow. This setup is referred to as a “coupled suspension”, while the suspension found on the XF is “uncoupled”.

The challenge with the rear suspension design is to maintain a balance between strength and weight. The weight of the CNG tank places a lot of extra work on the suspension that caused the suspension to be completely compressed before modification. The difficulty is to provide a stiffer suspension setup without making it so heavy that the solution is ineffective in improving the handling. It is also important that the suspension be strong enough so that it does not fail under any normal circumstances. In doing research, it was discovered that a conversion kit made by the company Hygear can turn the stock uncoupled suspension into a pseudo-coupled suspension (reference 1). The new coupled suspension setup keeps the front skis down, and stiffens the rear suspension. The updated suspension design is now much more favorable for trail riding.

The stock suspension and modified suspension were both modeled with the computer program SolidWorks. The drawing package for the new suspension components can be seen in Appendix A.

3.3 Tunnel Redesign

The tunnel redesign was deemed necessary after it was noted that the previously fabricated tunnel extension on the sled was attached to a structurally weak member of the sled. While moving the sled, part of the tunnel failed under the weight of the compressed natural gas tank, making a redesign necessary. This gave the opportunity to design a new tunnel that was lighter, stronger, and shorter than the original design.

The difficulty in the tunnel design was the decision to find the best combination of low weight and high strength. It was decided that round bar (tube) would be the chosen material since it is regarded as the strongest method of chassis in the snowmobile industry. Aluminum and steel were both options for material. Aluminum presents a much lighter option, but it is also weaker than steel and more difficult to weld.

The decision to use aluminum was made after consulting with several people with knowledge of welding, as well as using a finite element analysis (FEA) computer program to analyze the maximum deflection of several different material and dimensions. The maximum deflection would show how the material would bend under each load. A factor of safety of 4 was accounted for, for each case. The analysis replicated a weight being applied directly down on the tunnel. It also took into account pulling strength in case a sled was attached to the back of the snowmobile. The results of this analysis can be seen below in Table 1. The yellow-colored row is the final selection for tunnel material.

Steel	150lb	300lb	600lb	150lb w 1600lb pull load
1” od	-.005in	-.011in	-.022in	-.095in
1.125”	-.004in	-.007in	-.015in	-.062in
1.5”	-.003in	-.005in	-.011in	-.045in
Alum	150lb	300lb	600lb	150lb w 1600lb pull load
1” od	-.014in	-.029in	-.057in	-.248in
1.125” od	-.012in	-.025in	-.05in	-.215in
1.25” od	-.011in	-.022in	-.044in	-.189in

Table 1: Rear Bumper Vertical Deflection Analysis Data for Various Tank Weights

A Solidworks rendering of the completed tunnel design can be seen below in Figure 4, and the complete tube-tunnel drawing package can be seen in Appendix B.

Figure 4: Tube Tunnel Render

3.4 Air Silencer Redesign

Before beginning fabrication of the tunnel, the air silencer and CNG fittings needed to be modified to determine the exact allowable length of the tunnel and the position of the tank. The purpose of the air silencer is to lower the volume level of the air going into the engine. The air silencer is designed for acoustics to direct the sound waves. It is necessary to significantly alter the size and shape of the air silencer to accommodate the tank placement change. However, doing this means that the acoustic design of the air silencer will be altered.

After consulting with several Arctic Cat representatives, it was determined that the silencer could in fact be shortened without a noticeable change in sound. The air silencer was altered so that it had less impedance on the newly altered tunnel. The final air silencer was shortened by 12 inches so that it is now only three inches wide. The lower three-inch portion of the air silencer was also removed, dramatically reducing its size and allowing enough room for the CNG tank to be moved significantly forward on the snowmobile. The CNG fittings, filters, and heater were moved to better make use of space. The space saved by these alterations allowed the tank to be moved forward 12 inches.

3.5 Tank Placement

The largest issue associated with the snowmobile is the large tank needed to hold compressed natural gas. The original tank location was behind the seat and extended about six feet along the tunnel extension fabricated in the previous year. This can be seen back in Figure 2 and in Figure 5 below. The weight and location of the tank yielded many problems for the performance of the snowmobile.

Figure 5: Suspension travel and CG Comparison between the Stock and Last Year's Sled

The rear suspension on the snowmobile was not stiff enough to support the weight of the tank. Because of this, the rear suspension was almost fully compressed while the sled was at rest, and the front skis of the sled had very little weight on them. This can be seen compared to what the stock suspension should look like in Figure 5. While watching videos of last year's team driving the sled, it was apparent that the sled had trouble turning as a result of the modified weight distribution caused by the tank weight. The purpose of the tank placement is to get the sled to handle like it did in the original unmodified stock form. Changing the tank placement brings about a way to fix the weight distribution so that our sled would handle like an unmodified one.

To move the tank forward as desired, several components must be moved or modified including the battery, the air silencer, and the fittings for the CNG tank. The new tunnel also allowed for accurate placement of the tank in the desired location.

4.0 Design Fabrication

4.1 Rear Suspension Fabrication

The rear suspension work consists of the installation of a Hygear suspension linkage system. The basic idea is to change the number of pivot points in the suspension from four to three to change the suspension ratio.

The suspension that came with the snowmobile is a falling rate motion which means that the larger the bump the snowmobile hits, the softer the suspension gets. This works well for deep snow riding that the machine was designed for since it allows the skis to lift easily. The standard for a trail sled is a rising rate suspension where the suspension acts stiffer as it is compressed more. This prevents the suspension from “bottoming out”, or compressing completely.

The difference between last year’s suspension and suspension with Hygear components can be seen in Figure 6a and Figure 6b respectively:

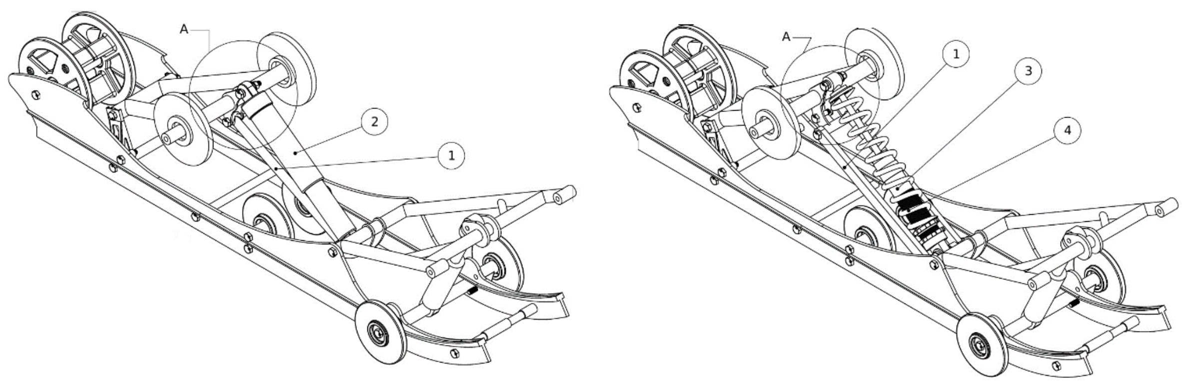

Figure 6a and 6b: Suspension without Hygear Components and Suspension with Hygear Components

Since the suspension modification involves pre-manufactured parts, the installation was completed by simply unbolting the previous suspension setup and bolting in the new setup, following the directions given.

4.2 Tunnel Fabrication

The tunnel fabrication involved a great deal of pipe-bending, welding, and cutting of metal. The first step was to cut the pipes used in the construction to the correct length. This was done using the JET saw.

After cutting each pipe to size, the pipe was then bent to form each of the shapes needed to construct the tube portion of the tunnel. Most of the angles were between nine to twelve degrees, but the rear bumper portion needed two ninety degree bends to fit properly.

Several of the pipes then needed to be “notched” to fit correctly with the rest of the tunnel. A pipe-notcher was used to remove material at a specified angle so that the pipe ends would fit flush with each other.

Following the completion of each of the tube pieces, the tube-portion was assembled with tape to hold the correct shape for welding. The various tube pieces were then welded together using a TIG welder to complete the tube portion of the tunnel.

Next, several pieces of aluminum plate were needed to cover up the track to stop snow from hitting the driver and prevent injury from the rotating track. 1/8th inch thick aluminum plate was chosen to cover the top of the tunnel and a portion of the sides of the tunnel. After being cut, these pieces were welded onto the tunnel in the same method that the tunnel was put together. 1/4 inch aluminum was then used in the two locations where the tank mounts are positioned to offer extra support for the tank.

Finally, the tunnel was cleaned and scuffed up so that it could be painted. Two coats of etching primer paint were used to provide a good base. Three more coats of semi-gloss black paint were used to provide a strong finish that matches that of the rest of the snowmobile.

4.3 Air Silencer Modification

In order to move the tank forward to its new location, the air silencer had to be shortened. The first step in modification was to purchase a stock air silencer from the snowmobile dealer. Once the air silencer was purchased it was measured and cut to make room for the tank. The modified air silencer seen in Figure 7 was then resealed with a piece of Plexiglas and epoxy. The air silencer had to be large enough for the air to move through freely, but short enough for the tank to fit.

Figure 7: Modified Air Silencer

4.4 Tank Relocation

The modifications described in 4.1, 4.2, and 4.3 made the tank location possible. The ideal tank location was found using SolidWorks as well as several calculations done by hand. The positioning of the tank mounts used for the tank were aligned and incorporated to the new tunnel. The fabrication portion of the tank relocation was then simply to install the tank on the new tunnel in its new location.

5.0 Testing

5.1 Center of Gravity of the Previous Team's Sled

To find the center of gravity location, four scales were used to measure the weight of the sled at four different locations with the sled lying flat, and then at a known angle. The scales were positioned at known distances from each other at the four "corners" of the machine. A picture of this setup can be seen in Figure 8. With this data, we were able to determine the location of the center of gravity using a simple equation derived by hand. This equation can be seen below as Equation 1. The location of the center of gravity at the beginning of the year was as expected: further back along the sled than it should be. This data can be seen in Table 2. The center of gravity was eight inches further towards the back of the machine than it was in stock form.

Figure 8: Setup to Measure the CG

$$X = \frac{L}{\frac{A+B}{C+D} + 1}$$

Equation 1: Equation for the Front to Back Center of Gravity

Where:

X is the distance of the CG from the front skis.
L is the distance between the front skis and the rear measuring point.
A, B, C, and D, are the front left, front right, rear left, and rear right weights respectively.

Weight Data for the Snowmobile with the Initial CNG Tank Location				
	Front Left Ski	Front Right Ski	Rear Right	Rear Left
Trial 1 Weights	115 lb	127 lb	250 lb	265 lb
Trial 2 Weights	123 lb	133 lb	258 lb	246 lb
Initial CG data compared with Stock				
	Total weight	Distance of the cg from front skis		
Last Year's Sled Data	758 lb	48.5 inches		
Stock Sled Data	575 lb	32 inches		

Table 2: Weight and CG Data for Last Year's Sled

5.2 Center of Gravity of our Sled

After completing all modifications described in this report, the center of gravity test was again completed using the same methods and hardware. The center of gravity location was significantly improved by making the modifications. As can be seen in Table 3, the center of gravity is now moved forward 5 inches.

Weight Data for the Snowmobile with Modifications				
	Front Left	Front Right	Rear Right	Rear Left
Trial 1 Weights	151 lb	130 lb	215 lb	230 lb
Final CG data compared with Stock				
	Total weight	Distance of the cg from front skis		
Last Year's Sled Data	758 lb	48.5 inches		
Modified Sled Data	726 lb	43.5 inches		

Table 3: Weight and CG Data for Our Sled

5.3 Vehicle Dynamics Test

The second test focuses on the vehicle dynamics of the snowmobile with the addition of the CNG tank. A gyro Arduino IMU and GPS Arduino are the two data acquisition devices used for the second test.

The physical test involves testing a 2004 Arctic Cat T660 snowmobile. This snowmobile is used to represent a stock, unmodified snowmobile. A weight analysis was conducted on this machine to find its center of gravity as well. After the weight analysis was completed, it allowed for the center of gravity of the 2004 Arctic Cat to be matched to the center of gravity of the CNG Arctic Cat by using a weight positioned at different locations along the machine.

This weight design allows for the snowmobile to be tested with a variety of different center of gravity locations. The goal of the trial is to test with the center of gravity at the same location that it would be with the CNG tank in its original location, and then with the center of gravity at the new location which is five inches closer to the front of the machine.

This testing gives a quantitative look into the handling of the machine and the effects of the center of gravity location. While it is known qualitatively that the handling is much worse with the CNG tank, the test serves to show which areas are most greatly affected.

We were unable to complete the second test because of time constraints. In order for the test to be completed, the IMU had to be assembled using many components purchased online. The assembly turned out to be very difficult and time consuming and unfortunately it was not finished before the snow melted.

6.0 Conclusions

6.1 Overall Project Conclusions

The chassis team was successful in returning the center of gravity near to stock location and improving the structural strength of the snowmobile. The suspension modification was able to support the increased load without being fully compressed under normal conditions. The redesigned chassis allowed for the tank to be placed 12" forward and removed 30 lbs. from the overall snowmobile. The new chassis is not only lighter, but is also stronger than the previous design. The final design can be seen as a render and photo below in Figures 9 and 10 below:

Figure 10: Final Tunnel Render

Figure 9: Final Design Photo

The suspension modification along with the redesigned tunnel moved the center of gravity forward 5" and added 38 pounds of weight to the front skis. The weight addition is a 13% weight increase, which should improve ski grip during cornering. When compared in person to the previous snowmobile, it is clear that the new CNG snowmobile has a stronger suspension and chassis.

6.2 Recommendations for Future Design

The new tunnel design significantly improves the overall handling by moving the center of gravity to a much more respectable position when compared to stock. The improved tunnel design and rear suspension work increased the travel from none at all to about 8 inches of travel. Due to the time schedule, the new design was never tested in real conditions on snow. Based on all of the results gathered for the machine, the handling will be greatly improved, although it can't be tested until next winter. This means that the following group may have to make additional suspension changes to achieve the desired handling results. These changes would be as small as tightening the rear shock spring to increase preload or as large as re-valving the shock and changing the shock spring.

The main focus for future chassis designs will shift to efficiency and sound levels related to the chassis. The most significant areas for improvement come with the track and exhaust. The team added two idler wheels to the rear suspension which helps reduce wear on the suspension and track components and also reduces track noise. The design of the rear suspension will allow for the addition of two to four more wheels which will significantly reduce the noise volume similar to snowmobiles done by the team previously. The new tunnel design leaves a number of possibilities for reducing noise levels in the track - something that is highly encourage for the Clean Snowmobile Competition. The current snow flap on the snowmobile is too short to be effective since it does not touch the ground when a rider is on the machine. A more effective design would have a longer flap to deflect snow coming from the track. This would again work to reduce the noise of the track spinning.

Another noise-reduction option lies with the exhaust. The addition of a catalytic converter is proven technology with the University of Maine Snowmobile Team from past projects. The catalytic converter significantly reduced the noise and emissions when placed on the 2004 Arctic Cat 4-stroke, so it would prove similar results on the 2013 machine.

List of Sponsors and References

Sponsors

Cat Trax

4788 Bennoch Rd, Lagrange, ME 04453

(207) 943-7903

References

[1] "HYGEAR Suspension for Arctic Cat XF." *HYGEAR Suspension for Arctic Cat XF*. Hygear Suspension, n.d. Web. 18 April 2015.

Appendices

Appendix A: Suspension Drawing Package

Appendix B: Tube Tunnel Drawing Package