Snowmobile Design and Snowmobile Sound Basics

Author: Jason R. Blough, Ph.D.
Michigan Technological University
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What is a snowmobile?

A picture of a modern snowmobile is shown in the picture below. Key design features of a modern snowmobile include a long travel front and rear suspension to allow a very comfortable ride over a largely varying type of terrain, whether it be a trail or off-trail. The snowmobile is driven over the snow through a track which wraps around the rear suspension and is driven by a set of drive cogs on a driveshaft. The front of the snowmobile is supported by two skis to keep the nose of the snowmobile above the snow. The rider sits in a mostly upright position and steers through a pair of handlebars which includes a throttle on the right hand side, a brake on the left hand side, an emergency kill switch, as well as various rider comfort controls such as hand and thumb warmers and low and high headlamp controls. All snowmobiles also have a rider tether, which when disconnected causes the engine of the snowmobile to shut down immediately. A snowmobile typically has a gas tank between 7 and 11 gallons (26 – 42 liters) in size and can travel in excess of 100 miles (161 km) over even the most rigorous terrain. The weight of a typical snowmobile ranges from approximately 450 pounds to 650 pounds (204 – 295 kg) depending on the application it was designed for.

Snowmobile Designs:
Snowmobile designs vary greatly based on the desired use by a particular rider. Youth riders generally require a smaller machine with lower power. Dedicated trail riders desire a shorter track with short lugs for ride comfort and cornering. Dedicated off-trail riders desire a longer track with long lugs for maintaining traction in deep snow. Many riders enjoy a combination of trail riding and off-trail riding and they desire a machine with a medium length track with medium length lugs. Riders that travel in pairs on a single snowmobile generally have machines with longer tracks and shorter lugs for a smoother ride while having room for a second seat behind the operator.

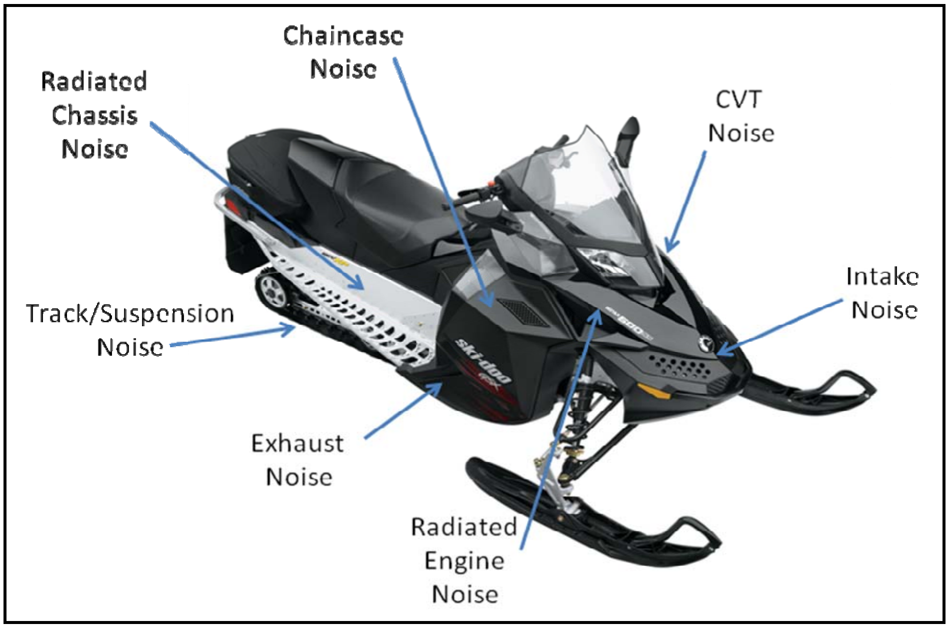
Engine Types:
Snowmobiles are manufactured with both 4-stroke and 2-stroke engine technology. Engine sizes used range from 120 cc to over 1000 cc ranging in power output of 3.7-135 kW (5-180 HP) for production machines. Historically, snowmobiles were almost exclusively 2-stroke designs due to their greater power to weight ratio. Weight is a huge concern for snowmobilers and the 2-stroke engine keeps the overall weight of the machine low while maintaining good power output. 4-stroke technology has been adopted by many of the manufacturers primarily to meet exhaust emission requirements, although modern fuel injection 2-strokes also have reduced emissions. Most riders choose an engine size based on their desired riding styles and ability level. Higher power engines generally result in higher top speeds, faster vehicle response and typically a higher cost to the rider.

Track Types:
Depending on the type of riding desired, there are a number of different types of track designs available. Track sizes range from 3.07-4.14 m (121-163 inches) for adult snowmobiles. Long tracks with long lugs allow a rider to travel in powder snow more easily. Longer tracks are needed for less pressure where no base exists like in powder snow. The longer lugs provide more lift and acceleration where the snow is not packed. Short tracks with short lugs allow a rider to travel on groomed trails more easily. The shorter lugs offer better traction on a groomed surface as it allows for more contact surface area. A cross-over design typically consists of a medium length track with medium length lugs. This track design is a trade-off between the previous two designs. A machine with this type of track has the ability to travel off-trail in more areas than the short track, but also offers better control on the groomed trail as compared to the long track.

Continuously Variable Transmission:
Snowmobiles are designed with a continuously variable transmission. The basic design consists of a reinforced rubber belt and two friction clutches. A primary clutch is attached to the crankshaft of the engine and the secondary shaft is attached to the track drive axle through a chain case with a fixed gear reduction. Both the primary and secondary clutches function in a similar way by changing their geometry depending on their angular velocity and required drive torque. Varying the dynamics of the clutches can change the response at low speeds and the vehicle’s top speed. In general, the clutches are setup such that the engine operates at peak power output for most operating conditions.

Snowmobile Noise Sources:

Potential snowmobile noise sources are many and include nearly any and all moving parts of the snowmobile. These parts include the following components whose approximate location on a snowmobile is shown in the figure below:



- **Radiated engine noise** – Radiated engine noise is the noise which radiates from the engine block and directly mounted components, due to surface vibration, into the air. This noise propagates to the rider and the surroundings through the hood vents as well as any air gaps or unsealed seams around the engine compartment. Hood vents are openings in the hood and/or side panels that are required to evacuate the heat produced by the engine, the exhaust system, and the CVT transmission as well as to cool down brakes in some configurations. The noise can have enough energy associated with it to actually cause the hood and surrounding panels of the snowmobile to vibrate which causes those panels to radiate noise. Radiated engine noise can be very expensive and difficult to reduce as solutions may require a complete re-design of the engine block as well as significant engine covers which may compromise engine cooling, add weight and cost, and be difficult to package in the limited space available around an engine in a snowmobile.

- **Intake noise** – Intake noise is the noise from the engine which is related to and directly from the air flow intake to the combustion chambers of the engine. In many cases the intake noise on many snowmobiles has been significantly reduced in the recent past. Controlling intake noise is done through the design of the air intake silencer as well as the intake manifold and plenum. Recent designs have become larger, more complicated, costly, and heavy to reduce the intake noise. Snowmobiles in many cases are nearing the limit as to what can be done to further reduce intake noise due to a lack of volume available in the engine compartment. Any substantial intake system requires a certain amount of volume based on the principles of physics which can be incorporated into these systems including quarter wave tuners, Helmholtz resonators, and expansion chambers. The size may also be constrained because the intake system is an integral part of the combustion tuning for emissions, noise, efficiency, and power.

- **Exhaust noise –** Exhaust noise has long been considered to be the primary noise source on a snowmobile. Historically most snowmobiles have been powered by 2 stroke engines which require a tuned exhaust to produce maximum power. This tuned exhaust is composed of a tuned expansion chamber and a “can” or muffler. In the past, the muffler was not always designed to provide significant noise attenuation. However, in the last 5-8 years modern snowmobiles have significantly modified this approach to their exhaust system designs. Many snowmobiles are now powered by 4 stroke engines which do not require a tuned expansion chamber to produce maximum power, leaving the muffler as the only exhaust system component besides the requisite downpipes and piping. The newer 2 stroke snowmobiles still require the tuned expansion chamber however they are now fitted with a very significant muffler, like the 4 stroke snowmobiles, which provides a very significant reduction in exhaust noise. These advances in the reduction of the exhaust noise can clearly be heard on the modern snowmobiles. In many cases, under many operating conditions the dominant noise source now appears to be the track system. These new mufflers are much larger and both weigh and cost considerably more than the older generation mufflers. Again, one limitation as to how much a snowmobile’s exhaust noise can be reduced is the volume available for the muffler. In some cases the newer mufflers also introduce significant back pressure to the exhaust system and hence reduce the power output of the engine. The weight of the new mufflers is high enough that aftermarket exhaust companies regularly advertise weight savings of as much as 20 lbs. (9.1 kg) if a snowmobiler purchases their muffler, however the noise will increase significantly with these aftermarket lightweight mufflers. Aftermarket exhaust system manufacturers also advertise significant power gains, again at the expense of noise.

- **Intake and exhaust system sidewall radiation -** The intake and exhaust silencers are made of relatively thin polymers (3mm to 6mm) or sheet metal (1mm to 2mm). The material thickness is limited by the manufacturing process (molding or stamping), weight constraints, and required shape to use maximum volume to increase their efficiency. The small thickness of those components translates into lower structural stiffness and increases their ability to be excited by acoustic pressure waves. This causes a high level of surface vibration to be generated which then radiates noise. Since the acoustic pressure is very high in these systems, the sidewall and overall shape design is extremely important to minimize this source. These components could also be excited by vibration and then radiate noise since they are attached to the vibrating engine.

- **CVT / Clutch –** The power produced by the engine of the snowmobile is transmitted to the rest of the drivetrain by a crankshaft mounted clutch, the drive clutch, which is part of a continuous variable transmission (CVT) which also contains an output or driven clutch. The drive/driven clutches are connected by a rubber belt. This CVT system is ideal for a snowmobile because, as the snow conditions are constantly and very often rapidly changing, the load on the engine changes accordingly. The CVT is a relatively lightweight transmission which functions very well in this environment. While the CVT works well from a performance standpoint, it is not as quiet a transmission as some other types because it is not enclosed in a casing of any type. The CVT system is not enclosed because it is air cooled and given that it is transmitting up to, and sometimes in excess of 180 Hp (134 kW), it must be cooled with air flowing over it or the rubber drive belts and clutch shivs will get too hot and a failure will occur. The noise generated by the CVT passes through the required hood vents and into the surrounding environment. To make the CVT quieter would require significant investment in engineering and potentially manufacturing costs as there is NO other similar application of this type of transmission given the horsepower levels transmitted. It is envisioned that a quieter clutch would have to be more aerodynamic and that the belts would have to be able to withstand significantly higher temperatures.

- **Chaincase –** The driven clutch of the snowmobile typically connects to a jack shaft, which transmits the engine torque across the snowmobile and acts as the input shaft to the chaincase. A modern snowmobile chaincase contains two chain sprockets, a chain tensioner, and a "quiet" chain similar to those used in front wheel drive automotive transmissions. This type of chain drive system has been optimized for noise over the last 7-8 years and now relies very heavily on the same noise reduction technologies that the automotive industry uses. There are no remaining easy to apply or engineer noise reduction strategies available for the chaincase which would not add significant weight and/or cost. The one technology that might be applicable is the addition of a damping treatment to the chaincase itself however, on most snowmobiles the chaincase is adjacent to the exhaust muffler which generates too much heat to allow most damping treatments to be used, hence removing this approach as a potential solution without significant material engineering costs.

- **Track / Suspension –** The track of the snowmobile, which like the CVT implementation, is specific to a snowmobile generates a large percentage of the noise heard on a modern snowmobile. The track generates noise due to its design and intended purpose which is to effectively provide traction on the snow. To provide this traction the track must have "lugs" which bite into the snow and provide resistance to the track slipping across the top of the snow. These lugs also act as a large fan when they are not embedded in the snow and hence generate airborne noise. The track is driven by a pair of drive cogs which interface to the track either by placing a tooth through a hole in the track or through pushing on a set of rubber bumps or knobs on the inside of the track. For the drive cogs to be able to push on the track without deforming it the track must act stiff at the cog/track interface locations in the longitudinal direction, along the direction they are pushing. The track is designed to handle this load by placing rods, typically a type of fiberglass rod, equally spaced in the track. These rods cause the track to be stiff in the vertical direction at their respective locations since they displace the softer rubber that otherwise would have been there. The presence of these rods then generates a spike of energy into the rear suspension every time they pass under or over an idler wheel. The idler wheels are a required part of the suspension for low snow conditions. There has been considerable work to lower the noise generated by the track and rear suspension through drive cog redesign, idler and support wheel placement, suspension geometry, and track design itself. In many cases, the track/suspension system may actually be the dominant noise source on a modern snowmobile if the snowmobile has a well designed factory supplied intake an exhaust system installed on it.

- **Radiated chassis noise –** The last major noise source on a snowmobile is the chassis itself. The chassis radiates or re-radiates noise generated by the noise or vibration input into the chassis from the engine, drivetrain components, and the suspensions. Reduction of this noise has been and is a continuing concern and plays a pivotal part in the design of each new chassis which is developed. Over the last 5-6 years the snowmobile industry has adopted many of the automotive design and analysis principles to reduce the noise including finite element modeling of prototype or concept chassis, transfer path analysis of prototype chassis, materials selection, and an understanding of how to design and optimize engine and powertrain mounting systems to reduce radiated noise and chassis vibration. All of the manufacturers now use these technologies very effectively and have made a large investment in time and money to become proficient in their use. Prior to the last 5-6 years none of these technologies was used on a widespread basis to optimize and understand potential designs. The continued reduction in radiated chassis noise will happen as the snowmobile manufacturers gain an even better understanding of the dynamic behavior of their chassis, however in many cases it will come with the cost of added weight and potentially much higher costs as exotic materials may be required to keep the weight of the snowmobiles at an acceptable level.

Current Snowmobile Noise Technology:

As is presented above the snowmobile manufacturers are employing nearly all of the state of the art noise reduction technologies that the automotive and heavy equipment manufacturers use. The snowmobile industry has spent a large sum of money over the last 7-8 years to modernize and upgrade both the facilities and software capability to deploy these technologies throughout the design and manufacturing of their snowmobiles. They use finite element analysis, rigid body dynamics, boundary element analysis, modal analysis, transfer path analysis, sound intensity and nearfield acoustic holography to optimize their designs. In every new product release by the snowmobile manufacturers the snowmobiles have been heavily optimized and tested for noise and in many cases hard decisions have to be made between weight, cost, performance, and noise. Upon listening to a new snowmobile it is very evident that in the tradeoff situations, noise has become much more important and driven the final design decisions much more often than in the past designs.

Sound Basics:

- **Sound Pressure Level:**
  Sound or noise is measured with a microphone and is the sound pressure generated and radiated from a noise source to a receiving microphone. The typical units of sound measurements are sound pressure level or SPL. The SI unit for sound pressure is the

pascal. However, the level of sound is typically presented and discussed in terms of decibels, dB, which is a log-scale unit defined in the equation below.

- $$dB = 20 \times \log_{10}\left(\frac{x}{x_{ref}}\right)$$

where: x_{ref} is $20e^{-6}$ for sound pressure.

x = energy measured by the microphone

The ramifications of using dB to describe sound is that a 3 dB decrease in the sound pressure level is actually a halving of x which is the energy measured by the microphone. This is to say that if something is 3 dB quieter than it actually only radiates half of the acoustic energy of something which has a 3 dB higher sound pressure level. Clearly, then to make a snowmobile which currently has a sound pressure level of 78 dBA measure only 75 dBA is a significant effort as half of the radiated noise must be attenuated or removed.

- **Sound Power:**
  The other unit that is typically used to describe the sound associated with a particular machine is sound power. Sound power is a measure of the acoustic power per second generated by a machine, not the sound radiated by a machine and received at a microphone as sound pressure is. Sound power is a property of a machine while sound pressure is dependent not only on the acoustic energy generated by a machine but also the location of the microphone used to measure it. The ramifications of the difference between sound power and sound pressure are that sound power of a machine never changes while the sound pressure measured will change based on the environment and distance from the machine where the sound pressure is measured. Sound power is not considered the optimal sound measurement for snowmobiles because it does not include any information or effects due to sound radiation which are very important for snowmobiles. Nearly all snowmobile noise complaints are reported by bystanders or persons not in the very near vicinity of the snowmobiles themselves; hence what they hear is influenced by the environment they are in. The environment which a snowmobile is typically operated in, moderate to deep snow (0.5m-2+m), has a very large impact on the sound radiation of the snowmobile and as such these effects should be included in the snowmobile sound measurement. Sound power measurements are also typically an average level of a stationary or slow moving vehicle, the most significant noise a snowmobile generates is typically under full acceleration, as in the SAE J-192 test, and hence is not a near stationary operating condition. Motorcycles are sound tested using this philosophy as well using SAE J-47 and SAE J-331. The human ear is sensitive to sound pressure, hence the reason that something sounds quieter the further away it is from the ear.

- **A weighting:**
  Typically both sound pressure and sound power are presented with the unit of dBA which means that the numbers are the dB level of the sound after it has been weighted by the A-weighting curve. The A-weighting curve is a frequency dependent amplification/attenuation curve which was generated and adopted as a standard to

roughly simulate the way in which the human ear perceives the sound pressure level of different frequencies. An A-weighted sound pressure level is then meant to be representative of the response of the human ear from a pressure, not power, perspective relative to the frequencies present in the sound.

- **Sound Quality vs. Sound Pressure Level:**
  The other important aspect of sound is the quality of the sound with respect to the perception by a person. While sound pressure level is an absolute number related strictly to amplitude, sound quality is typically represented by a broad range of sound metrics which have been developed to mimic the way in which people perceive the quality of a sound. Examples of sound quality metrics are: tonality, loudness, roughness, fluctuation strength, sharpness, and annoyance as well as many others. These metrics are developed through the use of sound jurors who listen to sound recordings and are asked very specific questions as to their perceptions of the sounds. From this juror feedback and various digital signal processing which is performed on the sounds, a correlation can be developed to allow a sound engineer to process a recorded noise and estimate how a person would respond to it. This field also includes a field called "Psychoacoustics."

  Typically, the goal of using sound quality tools is to determine when a sound is most pleasing or conveys positive information about a machine. What this positive information is, depends entirely on the machine being produced, for instance studies have shown that a house vacuum cleaner that is too quiet is perceived as not having much suction and hence not having the ability to clean a carpet well. The market has shown that even though this vacuum cleaner may be more powerful, because it is quieter, people will not buy it as it is perceived as too quiet to be able to perform its intended function. The other aspect of sound quality is that a sound may appear to a bystander to be quieter, but actually measure louder when using a microphone and a sound level meter measuring "A-weighted" sound pressure level that does not perfectly replicate what a person hears.

Over time, the manufacturers may be able to develop meaningful sound quality metrics for snowmobiles. Presently such metrics are not sufficiently well developed to be suitable for regulatory purposes.

Future Snowmobile Noise Technologies:

To produce a quieter snowmobile than is on the marketplace today without compromising its weight, cost, and performance will require new technologies to reduce the noise generated by the components of the snowmobile.

The track of the snowmobile must be re-designed or somehow improved to make the snowmobiles quieter, it is one of the major noise sources and hence to make a quieter snowmobile, the track must get quieter. A major hurdle in the track noise issue is that all of the snowmobile manufacturers purchase their tracks from the same company which in some ways limits the number of options available to them with respect to low noise track designs. The manufacturers themselves spend significant effort assisting the track manufacturer understand the noise issues. However, they do not manufacture the track and do this in addition to working to quiet the other snowmobile noise sources. While there are most likely some things that can be done to make a track quieter, there are also aspects of the track which will be very difficult to make quiet. The track must have significant lugs to grip the snow surface and these same lugs act as fan blades generating air movement and noise when they are not interfaced to the snow. This is an interesting and difficult problem to solve. The other aspect of the current tracks which leads to noise is the use of the cross-rods for stiffness. With significant effort and both design and materials engineering this problem maybe solvable in the future, 3-5 years, if a track noise engineer were working on it full time.

A quiet CVT may be possible with a cooperative effort between the snowmobile manufacturers and drive belt manufactures as many solutions to this problem may lead to higher belt temperatures and hence more belt failures which is not acceptable. Quieting the CVT will most likely require new belt material formulations, again a snowmobile supplier issue, as well as a new, possibly electronic and more expensive, clutch design. There has been some work done on an electronic clutch to optimize efficiency and power transfer but it is not known how quiet this clutch is as the company researching the clutch has had considerable durability issues. As with this research, any new clutch and or belt will have to undergo expensive and lengthy durability testing. There is also a very real possibility that any new solution will be both heavier and more costly than the current system.

A low noise radiating chassis is possible at the expense of weight and cost as there are "quiet" materials such as Quiet Steel that could be used to make several of the major chassis components. However, these materials are significantly heavier and more costly than the currently used materials; the manufacturers have been working very hard to reduce both the cost and weight, and in reducing weight potentially improving efficiency due to the state of the worldwide economy and rising fuel prices. This has become an important area of competition and brand/model differentiation in the marketplace.

The final major component which must incorporate significantly different characteristics to quiet a snowmobile down is the exhaust system. In general it is possible to make the exhaust of a snowmobile quieter however it will require the addition of weight, cost, and a way to increase the volume of space which can be allocated to the exhaust system. Exhaust systems can be made very quiet but this requires more volume than is typically available on a snowmobile. Increasing the size of a snowmobile is not possible for many markets as it will increase cost and weight and in some cases there are legal weight and width restrictions on a snowmobile which would restrict this option. As discussed above, adding weight to the snowmobile is not desired for many reasons.

In general, to make a snowmobile significantly quieter will require several new unproven technologies, two of which (track, CVT drive belt) must be developed by suppliers to the snowmobile industry. The snowmobile manufacturers are currently using the latest methods and technologies to design, analyze, build, and test their snowmobiles, with time the snowmobiles will get quieter but there are no simple or easy solutions left to make them quieter.