Sound and Snow

John Krouse, Consultant, Concord, Ohio

The thrill of the ride is enhanced with NVH technology at snowmobile manufacturer Arctic Cat. This article looks at Arctic Cat's commitment to NVH, while several sidebars highlight specific technologies and applications.

Anybody can bolt an engine and sled together to build a snowmobile and then stuff it with insulation so the vehicle squeaks by government noise regulations. At Arctic Cat, however, sound is not an attribute merely to be damped out by trial and error – rather, it is tuned during design to contribute to the overall riding experience. The goal is an Arctic Cat specific sound when the engine is revved up – a sound that adds to the thrill of the ride, yet a vehicle so quiet you can talk to fellow riders when the engine is idling.

A major challenge is delivering the sound riders want to hear while staying within strict noise regulations. Compounding the problem is that testing snowmobiles under real-life conditions is difficult because the process depends entirely on weather conditions. Arctic Cat is meeting these daunting challenges by investing in some of the most advanced NVH technology available and a state-of-the art testing facility that leads the industry. This allows them to proactively shape the sound they know riders want to hear.

The company designs, engineers, manufacturers and markets snowmobiles and All-Terrain Vehicles (ATVs) as well as related parts, garments and accessories. The Arctic Cat brand name has existed for more than 30 years and is among the most widely recognized and respected names in the snowmobile industry.

Arctic Cat knows its customers and their tastes, which is why they are among the leaders in the snowmobile industry. The company reported fiscal sales over $577 million in 2003 and a gain of 2.7 points in share of the U.S. market. Their newest model, the F7 Firecat (Figure 1), became the number-one selling snowmobile in North America in 2003.

Sound as a Key Product Attribute

Arctic Cat knows what its customers want to hear and feel when they ride a snowmobile. "Sound quality is critical to our product," says Arctic Cat CEO Chris Twomey. "It defines our brand value and together with performance and handling it is a distinguishing feature that sets us apart from the rest of the market. Most customers buy a snowmobile not just to get from one place to another but to enjoy the sport. The sound of the vehicle is a big part of that overall experience and our goal is to give them the consistent sound they want. At Arctic Cat, sound is a critical product attribute."

Tugging in the other direction of this drive for the right sound is a strict set of sound-level standards required by numerous governmental agencies limiting levels of noise emissions. The industry regulates itself and each year certifies through independent auditors that each model meets or beats the sound level requirements. Complying with these regulations is a top priority in the snowmobile industry and a major issue as new models are being designed.

When a snowmobile is under development, prototype vehicles typically are run through pass-by tests with microphones set up at a particular location to capture the sound level as the snowmobile passes. This outdoor method of testing noise emissions is particularly challenging for snowmobile manufacturers, since their window of opportunity for outdoor pass-by testing is limited to four months out of the year when snow is on the ground and in the right condition. Even then, measurements are affected by variations in snow conditions, temperature, humidity, background noise and wind direction. Readings can vary greatly, even with the same vehicle on the same day. Tests are also time-consuming, often taking days of travel to locations with satisfactory weather conditions.

Figure 1. Arctic Cat F7 Firecat.

Figure 2. Arctic Cat 900 Engine.

Investing in NVH

To overcome these limitations, Arctic Cat has taken a bold step in a traditionally frugal and conservative industry – they are the first snowmobile manufacturer to build a state-of-the-art NVH facility with the technology and equipment not unlike those found in the automotive industry.

The 3,500 ft^2 facility has a chassis dynamometer from AVL Inc. capable of simulating trail and high-performance riding conditions, a semi-anechoic sound chamber from Eckel Industries Inc. that eliminates outside noise and provides a stable testing environment, a modal bay to accurately test vehicles for excessive vibration, and a sound-quality room that provides conditions for evaluating various vehicle sound recordings played back for a jury of engineers for evaluation. The sound quality room also provides the capability for simulating sounds, allowing engineers to shape snowmobile noise to various profiles.

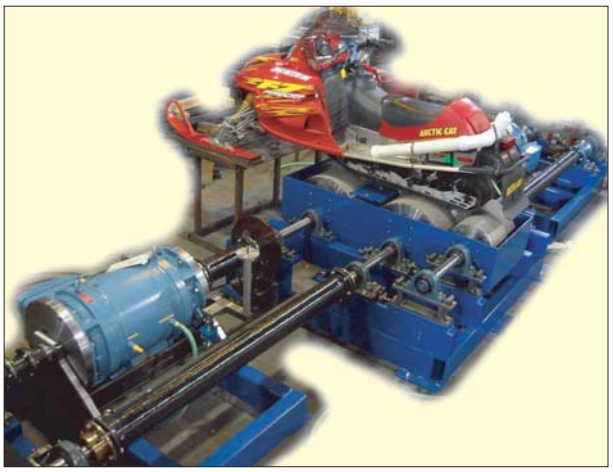
The facility houses some of the most advanced testing software and systems available. At the heart of the setup is LMS Test.Lab for acoustic and vibration testing. LMS Test.Lab is a multichannel data-acquisition package with a suite of integrated testing, analysis and e-report generation tools. In addition to NVH testing, Arctic Cat also has the capability to predict sound emissions and vibrations from components and assembles as well as full vehicles with LMS SYSNOISE, which is valuable in evaluating and optimizing design concepts early in vehicle development.

Bala Holalkere, NVH Engineering Design Manager, is in charge of setting up this system and making it work. "The new NVH facility will allow us to perform year-round testing in a controlled environment where we can gather more accurate data," says Holalkere. "This enables us to ensure our models comply with pass-by noise regulations while having the sound profile that will delight customers."

Holalkere explains that the process of shaping the sound of a snowmobile begins by comparing prototype test data with a target-sound signature. "We are aiming for a specific tone that

Chassis Dynamometer for Continuous Track Vehicles

Ken Barnes, AVL North America



Developed and built by AVL North America, the chassis dynamometer in the new Arctic Cat NVH facility is capable of testing a snowmobile under full road-load and inertia simulation conditions. The machine is designed to allow wide open throttle acceleration and speeds up to 140 MPH (225 km/hr) with 100 HP (75 kW) continuous power absorption. The dynamometer is also capable of steady-state full power performance and durability testing.

There are several challenges associated with the design of a chassis dynamometer for testing continuous track vehicles, particularly those that must exhibit low noise levels suitable for conducting sound drive-by tests. The AVL machine is installed in an anechoic chamber and utilizes dual water-cooled AC dynamometers and special water containment and sound attenuation systems to meet the unique demands of snowmobile testing. The target for the sound characteristics of the chassis dynamometer when operating at 100 km/hr measured 1 m above the roller assembly was 70 dBA – measured performance is significantly lower.

To provide a ground plane to the snowmobile track similar to that encountered in the snow, the ideal dynamometer would present a flat continuous track. However, in view of the noise-sensitive conditions required for NVH testing, a dynamometer track based on a flat belt was not technically viable. AVL developed a split-staggered roll assembly, which presents the maximum track contact while at the same time limiting the amount of unsupported snowmobile track. The amount of track contact and the load, which holds the sled on the roll assembly, are critical to maintaining traction under dynamic conditions. Wide open throttle acceleration of a 600 lb snowmobile at 1g will require a downward load of 600 divided by the coefficient of friction, which is typically about 700 lbs. This load includes the sled weight plus the rider and the remaining force can be provided from a special vehicle pull-down system, which is part of the AVL design.

The control system and mechanical dynamic characteristics of the machine are designed under similar guidelines to those required of passenger car exhaust emission chassis dynamometers. This means that the response of the system must be fast enough for accurate and repeatable inertia and road load simulation. The AVL design utilizes two state-of-the-art AC, flux vector controller motor/absorption dynamometers. When combined, they provide the necessary tractive effort for full simulation. This arrangement keeps the size of the motors small enough to be located beneath the test cell floor and splits the tractive effort in half, consequently reducing the full-scale error accordingly.

The motoring capability of the dynamometer provides Arctic Cat the ability to drive the sled track, transmission and non-firing engine at full speed while measuring component noise characteristics, previously unavailable without background noise.

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is not corrupted by mechanical clanging or other secondary noise," he says. A frequency analysis allows the NVH engineers to see the influence of the overall sound of various subsystems including the intake, exhaust, engine, tracks and chassis resonance. Using LMS SYSNOISE as a basis for predicting sound emissions, engineers try various what-if concepts in modifying components and configurations to muffle unwanted noises and attenuate the desired sounds.

The goal, says Holalkere, is an overall linearity in loudness, with amplitude increasing steadily as a function of engine speed. This feedback sound is pleasing for riders but is often difficult to achieve with snowmobiles, which often exhibit fluctuations in loudness at various speeds. And of course, sound level must stay within strict noise regulations.

"There are multiple requirements to satisfy in our work," explains Holalkere. "To meet these challenges, we are using the most advanced NVH technology available. In addition to the facility and NVH technology here, we have assembled a team of NVH experts from the automotive and other industries – top people in their field. This investment makes Arctic Cat the world-class leader in NVH for the snowmobile industry, and LMS technology is at the heart of our NVH work. It allows us to leverage the expertise of our superb NVH team in both testing and predicting NVH characteristics."

Working with Sound and Vibration

One of the NVH engineers brought on board is Mark Christensen, who explains "The vehicle must have outstanding performance in terms of acceleration and hill-climbing capacity as well as nimble handling. And it must be lightweight. The challenge is to balance these attributes with the right overall sound and feel obtained from the combined noise and vibration of all the various parts, assemblies and subsystems that comprise a snowmobile: engine, drivetrain, exhaust, suspension and chassis. The key is accentuating the desired sound and damping out unwanted mechanical noises such as gear whine. And for a smooth ride, we need to minimize mechanical vibration transferred through the chassis. That means a considerable amount of testing is needed, on individual subsystems as well as complete vehicles – ours and competitors'."

Christensen explains that LMS Test.Lab is particularly useful in efficiently running repeated tests. "Because the whole test setup and required signal processing tasks only need to be defined once, after which they are saved in a dedicated template. The whole procedure is done automatically, we can run tests over and over again with highly consistent results. The same test can be performed time and time again on different snowmobiles, or we can test the same model numerous times to measure the effects of changing the configuration slightly. Because the environment is controlled, the tests are highly repeatable and consistent, allowing us to build up a knowledge base of sound signatures from various snowmobile models and different part configurations. This information is extremely useful in comparing results and working with designers in optimizing the way the vehicle behaves."

According to Christensen, this knowledge base of data obtained from NVH testing is extremely useful in giving designers recommendations on the configuration of exhaust systems or intake boxes, for example, to minimize unwanted resonances

Noise Prediction Measurements

LMS North America

For its NVH work, Arctic Cat uses a range of software from LMS International including Test.Lab for multi-channel data-acquisition, CADA-X for acoustic and vibration testing, SYSNOISE for predicting and visualizing sound envelops, and general utility programs FMON and TMON to correlate data and perform a variety of comparative studies.

LMS Test.Lab is a multi-channel data-acquisition package with a suite of integrated testing, analysis, and e-report generation tools, all integrated in a single familiar, networkable environment. A workflow-based interface facilitates ease-of-use, productivity and data consistency. The system is geared toward fast set-up and testing as well as better communication of results. It features superb on-line graphics, an easy interactivity for users to react and change a configuration on-line if necessary, and productivity tools to perform tasks efficiently. The 24-bit system is expandable from four channels to over a thousand and can function either in the lab or as a battery-powered mobile unit. The Test-Lab hardware platform integrates the latest multi-processor PCs and laptops with the Scadas measurement frames and signal conditioning modules. LMS Test. Lab incorporates the feedback of a wide user community and is backed by ISO 9001 certified quality procedures for product development, maintenance and support.

LMS CADA-X is a platform for test-based acoustic and vibration engineering. The system is based on a selection of multichannel measurement front-ends, runs on PCs and workstations, and has all the standards and hooks to connect to a variety of dedicated testing hardware including smart sensors, laser vibrometers, remote-controlled microphone arrays and chassis dynamometers. The modular software ranges from general-purpose multichannel data acquisition and DSP (LMS Fourier Monitor – FMON, and LMS Time Data Processing Monitor – TMON), through basic and advanced acoustics, signature testing and operational analysis, structural testing and modal analysis. The system can be customized to add extra functionality or analysis procedures and is flexible to meet the most sophisticated of engineering tasks and scalable to the operational needs of test technicians, development engineers, or structural analysts.

LMS SYSNOISE is a solution aimed at vibro-acoustic design, troubleshooting and optimization. From predicting the sound inside a cavity to estimating the sound field around the structure, or even calculating the structural response to an acoustic load, SYSNOISE helps optimize vibro-acoustic performance of products. Over the years, SYSNOISE has evolved to meet the requirements of a substantial user community and has been used and validated in a wide range of vibro-acoustic design applications. It is ideal for interior acoustic analysis of passenger compartments, acoustic radiation prediction of engine/powertrains, back-scattering analysis of underwater vessels, and acoustic transmission analysis of wall partitions, doors and seals.

For more information on LMS products and technology, visit the company website www.lmsintl.com.

and noises. "Developing a snowmobile is a collaborative effort between design, NVH and manufacturing," says Christensen. "The information we obtain from the LMS system allows us to know how to avoid problems at the outset. Otherwise, it is just a hit-or-miss guesswork. The LMS system gives us the information we need to proceed in the right direction during development."

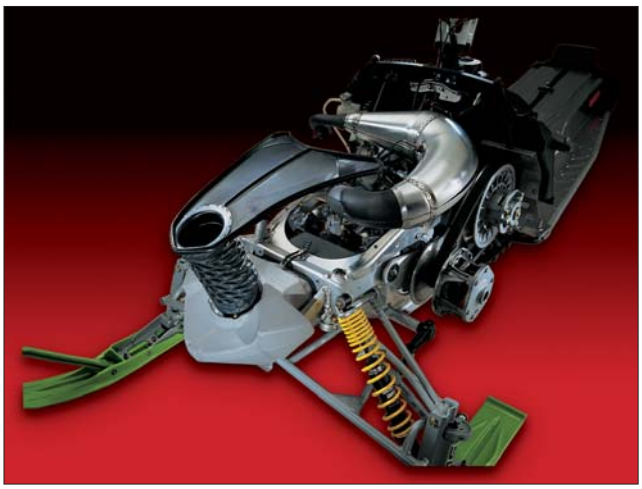

Figure 3. Forced air induction system.

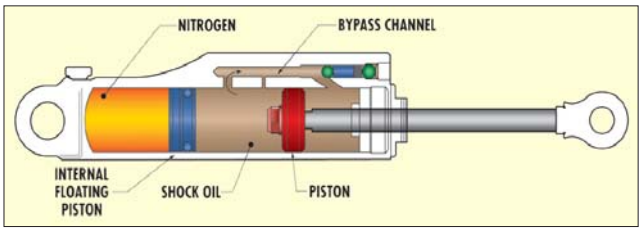

Figure 4. Position sensitive shock absorber.

Figure 5. Arctic Cat Pantera.

Product Development and Business Strategy

Roger Skime, Vice President of Snowmobile Engineering, confirms that considerable collaboration between NVH and design is necessary in the product development process. "The NVH group is involved in development as early as possible," says Skime. "That way, we can take advantage of the real power of NVH technology in helping guide the design, not just troubleshoot problems right before product launch."

Skime says that the NVH knowledge base of past vehicle and subsystem tests is highly useful in indicating to designers what to do, and what not to do on new models. "LMS SYSNOISE is especially useful in predicting sound envelopes around new, never-built configurations," says Skime. "This predictive capability enables our engineers to change the design up-front early in development to achieve the right sound, before any hardware is built. That capability not only saves us time and money in development, but also lets us deliver the required performance, sound and feel that the market demands. The predictive capability of LMS SYSNOISE is where the future lies in NVH, to utilize the technology as much as possible in the early conceptual stages of development when changes are most easily made to refine and optimize designs early on instead of making last-minute changes downstream."

CEO Chris Twomey describes the significance of NVH at the company. "With the considerable investment we have made in

Hemi-Anechoic Sound Chamber

Alan Eckel, Eckel Industries Inc.

The hemi-anechoic sound chamber designed, engineered and installed by Eckel Industries, Inc. at the Arctic Cat NVH Facility utilizes the EMW (Eckel Metallic Wedge) design for the chamber's acoustical treatment or lining. The EMW wedge for the chamber has an overall depth of 27.25 in. with a designed low frequency cut-off of 120 Hz. The two-peak arrangement on a 2 ft × 2 ft base is constructed of perforated metal with 52% open area. The wedge units are factory finished in white enamel and were mounted to the walls of the chamber using Eckel's track mounting system.

A double-walled attenuating structure was designed to house the chamber. The outer walled structure was 12 in. thick with staggered studs and two layers of sheet rock on each face. The walls of the two rooms were separated with a 32 in. air space lined with sound absorbing panels. The inner chamber walls were constructed of 12 in. thick concrete block, with all blocks completely filled with mortar or grout for maximum noise reduction and to achieve the specified NC 15 interior ambient noise level.

The pit to house the dynamometer was lined with acoustical panels, so it would not become a resonant cavity once the dynamometer was installed. The entire chamber is constructed on a vibration isolated floor system. A 5000 CFM silenced ventilation system provides the room with ample airflow through roof-mounted silencers and vertical corner inlet and exhaust passages incorporating perforated acoustical treatment.

Two in-swinging wedge cage doors with radius wedges and two out-swinging STC 52 sound doors provide access to the chamber interior working area. Interior dimensions of the chamber are 27 ft 4 in. × 31 ft 4 in. × 15 ft high wedge tip to wedge tip. Exterior dimensions are 32 ft × 38 ft × 18 ft high.

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people, processes and technology, NVH technology is now an integral part of our product development process and a key component in our long-term business strategy," he says. "We want to do more than just comply with industry noise standards. We want to give customers the thrilling ride they want – and naturally expect – from an Arctic Cat snowmobile." SV

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