Development of an Application Specific Electric Snowmobile Using Advanced Powertrain Modeling and Simulation

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ABSTRACT

This paper addresses the question: can an electric snowmobile be a cost effective solution for use as a utility snowmobile?

In addressing this question the performance limitations of current electric snowmobile prototypes are investigated and it is shown that, unless a huge leap is seen in current battery technology energy density, electric snowmobiles cannot perform on par with gasoline snowmobile on both range and performance simultaneously.

Despite this, electric snowmobiles do have a certain number of niche applications where they can be useful.

This paper suggests that electric snowmobile powetrain modeling and simulation for these niche applications can potentially help overcome some of the challenges that exist in implanting such a vehicle for regular use. A complete, virtual electric snowmobile model was built and validated using actual electric snowmobile on-snow test data.

Given the current cost of electric powertrain components, in order to be cost effective solutions for use as utility snowmobiles, electric snowmobiles cannot afford to have oversized powertrain components. The powertrain modeling and simulation methodology presented in this paper enables one to ensure that a proposed electric snowmobile powertrain can meet the need of a given application without being needlessly oversized. The end result is a rapidly obtained custom powertrain design at the lowest possible cost for a given application.

INTRODUCTION

Worldwide, an extensive amount of research and development is being performed with the goal of reducing emissions and energy consumption associated with transportation. One of the areas receiving the most attention is the passenger car sector. This research brought to market the use of electronic fuel injection and catalytic converters. Both technologies have now been widely implemented in passenger cars for many years. This widespread implementation has yielded great improvements in emissions and energy consumption in passenger cars. Lately, the use of battery electric technology has been under strong investigation as a means of further improving passenger car emissions and energy consumption.

Snowmobiles have not received as much global research interest as passenger cars and it is only recently that snowmobile manufacturers started to implement 4-stroke engine technology and electronic fuel injection on multiple snowmobile models. As far as one can tell from the press releases, unlike the auto industry, none of the major snowmobile manufacturers has the use of electric technology as a mean to improve snowmobiles on its agenda. While lower global research interest is possibly one of the factors in this reality, it most likely isn't the only one. The reality of consumer expectations on the performance and cost of snowmobiles, regardless of how extreme the terrain and conditions are, plays a non-negligible role in this apparent lag in snowmobile technology when compared to passenger cars.

SNOWMOBILE DESCRIPTION - The definition of a snowmobile is fairly broad. It says that a snowmobile is "a motor vehicle with a revolving tread in the rear and steerable skis in the front, for traveling over snow"[i].

The first attempts at building a vehicle that would move over snow on runners happened over 70 years ago. In 1935, a snowmobile was built with skis in front and a sprocket wheel and track system in back. It carried 12 people. Family doctors, veterinarians, ambulance and taxi drivers were first in line to purchase one[ii]. Nowadays, most North Americans, when hearing the word "snowmobile", picture a small, open chassis, track propelled and ski steered vehicle, which can be straddled by a driver (and sometimes one or two passengers). Such a vehicle can be seen in Figure 1 below.

Figure 1: Snowmobile with Utility Cargo Box in the Rear

Today, the majority of snowmobiles in the world are manufactured by the four members of the International Snowmobile Manufacturer Association (ISMA): Arctic Cat, BRP, Polaris, Yamaha. These vehicles are powered by gasoline internal combustion engines. The engine's power is usually transferred to the track via a V-belt continuously variable transmission (CVT) and a step-down secondary ratio. The CVT, which also houses a centrifugal clutch, allows the snowmobile to seamlessly go from idling mode to various motoring ratio modes with nothing more than driver pressure on a handle bar mounted "throttle" lever.

Today's snowmobiles are one of the simplest and fastest ways to transport people and cargo on snow covered ground and frozen bodies of water.

The following statistical information regarding the snowmobile industry comes from the ISMA's online snowmobile fact book[iii]:

- In 2008 there were 163,753 snowmobiles sold worldwide; 79,552 were sold in the U.S. and 50,556 were sold in Canada. Worldwide sales have generally been declining since 1998 (257,936 units).
- There are approximately 1.62 million registered snowmobiles in the US and 708,490 registered snowmobiles in Canada.
- Approximately 80% of snowmobilers use their snowmobile for trail riding and touring on marked and groomed trails. 20% of snowmobilers use their snowmobile for work, ice fishing or transportation.
- Average snowmobilers ride their snowmobile 1674 km (1040 miles) per year. They average 22 days snowmobiling per year. (i.e. over 75km per day on average when calculated based on the above numbers)
- The average suggested retail price of a new snowmobile sold in North America in 2008 was $9,324.00.

The snowmobile industry, like many other transportation industries, has, in recent years, been criticized for some of its perceived negative environmental impacts. Areas of criticism include:

- Noise
- Emissions
- Effects on wildlife
- Energy consumption
- Effects on snow, water and soil
- Effects on plants and crops

There is some debate between a number of organizations and individuals on many of these perceived issues. That being said, the current reality of some snowmobile applications has prompted some snowmobile users to look for a type of snowmobile not currently offered by the four members of the ISMA: an electric snowmobile.

One of the first to come forward was the scientific community who was looking for a zero-emissions on-snow utility vehicle to decrease contamination risk of samples taken in remote locations. Following them, some snowmobile tour operators in both North America and Europe started to show interest in electric snowmobiles.

The North Americans saw a way for their customers to better appreciate the environment which they are visiting and thus they believed that the electric snowmobile could provide a plus value to their short range tours. The Europeans (currently located in the French Alps) saw a potential way to try and expand or simply keep their business in operation given the recent ban on snowmobiles in France.

Lastly, winter sports resort operators started to come forward in order to see if their operations could benefit from the use of electric snowmobiles. Two pilot projects (one in Quebec with Mont St-Sauveur International at its Mont St-Sauveur and Avila winter resort and one in France with Val d'Isere ski town while it was hosting the 2009 FIS World Alpine Ski Championships) have demonstrated that electric snowmobiles can better meet the needs of some winter resort applications than their gasoline snowmobile counterparts.

So, if there are applications out there where electric snowmobiles can shine, why are we not seeing more electric snowmobiles being used on a regular basis?

The answer is short: cost.

Electric snowmobiles can do wonderful things as prototypes… but when it comes time to move from the "prototype world" to the "real world", the cost factor becomes a major obstacle.

The scientific community has found a short term solution around the cost problem:

> Sponsor a student competition where students are asked, among other things, to design the electric snowmobile with:
>
> - The most possible range
> - The most possible towing capacity
> - The maximum possible speed and acceleration
> - The best possible handling
> - The lowest possible noise
>
> The scientific community then "rewards" the top finishers by using their snowmobile(s) for remote location environmental research.

The format of the competition encourages the quest for maximum performance at all levels without compromising anything for cost. This however is not an issue for the scientific community since their "cost" for whatever vehicle comes out on top is fixed: it is the amount of their direct and indirect contribution to the competition and its competitors as part of their pre-established sponsorship agreement. So in the end the scientific community currently "gambles" a fixed amount yearly and receives a "variable" product in return from year to year.

While this is a great short term solution for the scientific community in order to have somewhat cost effective access to one or two electric snowmobiles, this approach has likely reached it maximum production capacity. It is very unlikely that other applications which could benefit from electric snowmobiles can acquire them in this manner.

Thus, one may ask: In the short term, is there a way for these other applications to benefit from electric snowmobiles at a viable cost? If so, how?

Dedicated mass production of electric snowmobiles to bring down the cost is very unlikely. Electric snowmobiles will for the foreseeable future be limited in how much range and power then can simultaneously offer when compared to what current user have become accustomed to. Thus it is unlikely that a single electric snowmobile model can meet the needs of enough applications to enable cost reduction via mass production.

Instead, this paper proposes that the custom design, using advanced computer modeling and simulation, of application specific powertrains to be retro fitted in currently mass produced snowmobile chassis, is the most promising way for these “pro-electric” applications to benefit from electric snowmobiles at a viable cost.

This paper is divided into four main sections:

The first section investigates the main physical and technological obstacles facing the design of an electric snowmobile.

The second section presents a proposed electric snowmobile design methodology using advanced powertrain modeling and simulation. It also presents the early results obtained with this methodology in a somewhat controlled environment.

The third section shows a case study example of the proposed methodology applied to the needs of Canadian Snowmobile Adventures, a large snowmobile tour operator based in Whistler B.C..

Lastly the fourth section provides some information on the electric snowmobile McGill University will be presenting at the 2009 SAE CSC.

THE CHALLENGES OF MAKING (AND SELLING!) AN ELECTRIC SNOWMOBILE

Why is the design of a practical electric snowmobile such a challenge? Why can’t electric snowmobiles aspire to replace the majority of current gasoline powered snowmobiles?

The short, two word, answer to the above questions is: **energy density**.

The more detailed answer is: because current energy storage systems (ex. batteries) have very low energy density when compared to currently permissible alternatives. (i.e. gasoline for snowmobiles in North America).

Let us look at electric and gasoline snowmobiles in more detail to see why energy density is a tremendous obstacle to overcome for electric snowmobiles and thus why it greatly limits the number of potential applications which could see their needs be fulfilled by electric snowmobiles.

ENERGY DENSITY - Using a value of 8760 Wh/l[iv] as the energy available in gasoline and looking at the size of the fuel tanks offered by the four main snowmobile manufacturers on one of their small utility snowmobile models, Table 1 shows that, on average, their utility snowmobiles carry 355,875 Wh of energy on-board.

Table 1: On-Board Energy of 2008 Model Year Gasoline Powered Utility Snowmobiles

Vehicle	Fuel Volume (l)	Energy On Board (Wh)
Arctic Cat Bear Cat 570 [v]	49.2	430,992
Polaris 340 LX [vi]	44.6	390,696
Ski-Doo Skandic Tundra [vii]	34	297,840
Yamaha Venture Multi-Purpose [viii]	36	315,360
Average	40.95	358,722

Using a mass of 0.73 kg/l [ix] as the specific mass of gasoline, the weight of the average 355,875 Wh of energy carried on-board those snowmobiles is 29.66kg.

In order to compare battery energy density with gasoline, Table 2 looks at the energy density of four of the main battery technologies mature enough for use in electric snowmobiles: lead acid (PbA), Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lithium-Ion (Li-ion).

Table 2: Energy Density of Common Battery Technologies

Battery Technology	Gravimetric Energy Density (Wh/kg)	Volumetric Energy Density (Wh/l)
PbA [x]	33.5	76.2
NiCd [xi]	54	95
NiMH [xii]	60	155
Li-ion [xiii]	105	284

It is clear from Table 2 that none of the common battery technologies have energy densities approaching the 12,000Wh/kg and 8760Wh/l of gasoline. Nevertheless, in Table 3, all four battery technologies and gasoline are compared head-to-head on weight and volume basis in the case where they would be installed in a common utility snowmobile.

Table 3 answers the following three questions:

If one was to use a Ski-Doo Skandic Tundra snowmobile with 297,840Wh of energy on board (as seen in Table 1), for different energy carriers, what would be

- the energy carrier (EC) volume ?
- the energy carrier (EC) weight ?
- the ratio of energy carrier (EC) weight to vehicle dry weight?

Table 3: Head-to-Head Comparison of Raw Energy Density of Common Battery Technologies and Gasoline in a Snowmobile

Energy Carrier (EC)	Gasoline	Batteries			
		Li-ion	NiMH	NiCd	PbA
Vehicle	Ski-Doo Tundra				
Dry Weight	172 kg				
Energy On-Board	297,840 Wh				
EC Volume	34 (l)	1049 (l)	1292 (l)	3136 (l)	3910 (l)
EC Weight	24.8 (kg)	2837 (kg)	4965 (kg)	5516 (kg)	8892 (kg)
Ratio: EC Weight / Vehicle Dry Weight	0.144	16.5	28.9	32	51.7

As Table 2 has shown, the “raw” energy density of battery technologies is nowhere near the “raw” energy density of gasoline. Consequently, as shown in Table 3, unrealistically large amounts of batteries would have to be used to equate the on-board energy of a standard gasoline snowmobile.

Why is the term “raw” energy density being used?

The term “raw” energy density is used since the values in Table 2 only consider the energy density of the batteries themselves. For a more accurate comparison between the energy density of batteries and gasoline, one should also account for the weight and volume of the containment chamber or other means of holding the gasoline and batteries on board. To this, one must add the difference in weight and volume, of energy transfer systems (i.e. fuel pump and tube vs. battery management system and wires). Lastly, the reduction in battery energy density related to cold temperature and high discharge rates should be taken into account for a true comparison between battery technology and gasoline.

Taking all these factors into account can be termed the “net” energy density comparison. In general, the “net” energy density comparison will make the difference between the energy density of gasoline and battery technologies even greater than the “raw” energy density comparison.

In a best case scenario, (see Table 3), in order to have as much energy on-board an electric snowmobile as on a gasoline powered snowmobile, one would have to carry over 2800kg (6173lbs) of batteries. In a utility snowmobile such as Ski-Doo's Skandic Tundra weighting 172kg (379lbs) (dry weight)[xiv], this represents a “fuel” weight 16.5 times larger than the weight of the vehicle itself! Furthermore, unlike liquid fuels, the mass of the batteries will not diminish as energy is consumed. It is clear that such a vehicle to fuel weight ratio is not suitable for a snowmobile.

It has been established that a large energy density difference between gasoline and battery technology exists and that, given this large difference, with current technology, it is impractical for one to have as much energy as a standard gasoline snowmobile on-board an electric snowmobile.

Next, we investigate if this energy density difference can be compensated by the difference in energy efficiency between gasoline powered technology and electrically powered technology.

ENERGY EFFICIENCY - To see if energy efficiency can offset the energy density difference between gasoline and batteries, we investigate a theoretical best case scenario for the battery technology. For this best case scenario the following steps and assumptions are used:

- Two identical snowmobiles with the same weight distribution and drive characteristics are used
- One is given 24.8 kg of gasoline, the other 24.8 kg of the best battery technology as listed in Table 2 (Li-ion)
- The amount of available energy on-board is calculated using “raw” energy density (Table 2)
- The electric snowmobile is assumed to have maximal theoretical efficiency. (i.e. All the energy in the battery is transferred to the ground without any losses).

Based on all of the above, the efficiency value of the gasoline snowmobile powertrain required for the gasoline snowmobile to have exactly the same performance as the electric snowmobile is calculated.

Table 4 below summarizes this procedure and its result.

Table 4: Comparison of Required Theoretical Efficiencies for Equivalent Vehicle Performance

Energy Carrier (EC)	Gasoline	Batteries (Li-ion)
Vehicle	Ski-Doo Tundra	
Dry Weight	172 kg	
Energy Carrier Weight	24.8 kg	
Energy On-Board	297,840 Wh	2,604 Wh
Theoretical Efficiency for Equivalent Performances	0.87%	100%
Energy Used to Propel the Snowmobile	2,604 Wh	

Table 4 shows that even using "raw" energy density values and assuming a theoretical electric snowmobile drive system efficiency of 100%, the gasoline powered snowmobile's drive system would only have to be less than 1% efficient for the two vehicles to be equal in terms of range and performance with the same mass of energy carrier (EC) on-board.

Calculations based on results from the SAE Clean Snowmobile Challenge results[xv] indicate that snowmobile engine efficiencies generally tend to range in between 17 and 24 % (depending on operating point) with some specific operating points on some specific engines sometimes achieving up to 28% efficiency.

It is clear from this exercise that electric snowmobiles cannot compete with gasoline snowmobiles on both range and performance simultaneously. The gap in energy density between battery technology and gasoline is so large that, even when using an ideal theoretical scenario when factoring in energy efficiency, one cannot fully compensate for this fundamental difference.

However, not all applications require all the range and performance modern gasoline utility snowmobiles can offer. Some applications require only a limited range and/or limited power.

Potentially, electric snowmobiles could be used in such applications. Also, some applications exclude the use of current gasoline snowmobiles since they cannot be used due to their exhaust emissions. In such cases, an electric snowmobile can be a very interesting solution.

OBSTACLE TO ELECTRIC SNOWMOBILE COMMERCIALIZATION - Is the energy density issue the main obstacle to the use of electric snowmobiles in day to day operations? Not exactly. Cost is the main issue.

There are a number of applications that could see their needs satisfied by snowmobiles with low energy density. However, based on our work with various commercial snowmobile operators (tour operators and winter sport resort operators), there are currently almost no applications where the snowmobile owners are willing to spend substantially more on an electric snowmobile than on a gasoline powered snowmobile to meet their needs.

The exact amount one might be willing to spend on an electric snowmobile varies a lot based on the application. For example, some tour operators have certain routes or packages on which they net much more profit then others. After discussing with them, without much surprise, these tour operators felt they were able to spend more on an electric snowmobile that could meet the needs of the product with the biggest profit margin than the product with a lower profit margin.

However, more than the cost of the electric snowmobile itself, what interests most owners is its cost relative to other alternatives. Once known, the relative costs can be weighted along with the advantages and disadvantages of each alternative to see which option they will choose. This is nothing new. The exact same decision process is currently happening within the gasoline snowmobile world when these operators are faced with the choice between 2-stroke vs. 4-stroke.

So when will these commercial snowmobile operators start to not only pick between "2-stroke vs. 4-stroke" but rather "2-stroke vs. 4-stroke vs. electric"?

Believe it or not, the first steps of this process have already started in Western Canada, Eastern Canada and in Europe.

Based on our conversations with commercial snowmobile operators, figuring out the relative cost between gasoline snowmobile is mostly based the vehicle price tag. Some look at the fuel savings and in some cases a more thorough investigation might include cost of oil and/or coolant as well as specific maintenance cost related to a specific engine. However, in many cases the decisions are mainly made on upfront price tag and perceived advantages vs. disadvantages of the different gasoline powered options.

Adding the electric snowmobile to the list of possible options to pick from brings up 2 major questions which the commercial snowmobile operator needs an answer to before he can take an informed decision:

1. Can an electric snowmobile meet the needs of my application without too much of a compromise on vehicle weight (and thus still handle like a "snowmobile")?
2. At what cost can an electric snowmobile meet the needs of my application?

Given that there are currently no worldwide electric snowmobile distribution networks with a wide range of available models, being able to answer these 2 questions rapidly and precisely without actually designing, building and testing a complete electric snowmobile prototype to answer it is crucial. Otherwise simply the cost of answering these 2 questions would scare away potentially interested operators.

So, is there a way to answer these 2 questions rapidly, precisely and efficiently?

McGill University believes it has a solution.

After having been faced with this dilemma on more than one occasion, McGill University looked for a way to answer the questions of prospective electric snowmobile users. A quick peek into the automotive world showed that this industry was facing a very similar problem with all the new electric and hybrid technologies making their way into this industry. The solution the automotive world has been embracing is to rely more and more on advanced powertrain modeling and simulation to answer their questions.

Why wouldn't the snowmobiling industry rely on the same solution to answer their questions? Since no obvious answer to this question could be found, a first attempt at using advanced powertrain modeling and simulation for snowmobiles at McGill University was given the green light.

ELECTRIC SNOWMOBILE ADVANCED POWERTRAIN MODELING AND SIMULATION METHODOLOGY

Based on commercial snowmobile operator feedback, in applications where electric snowmobiles could potentially be implemented, the perceived cost/benefit ratio of implementing an electric snowmobile is by far the biggest obstacle to the implementation of these vehicles. Two previously introduced factors, are at the root of this issue and need to be addressed:

1. Performance - How can one ensure that a given electric snowmobile will meet the duty cycle requirements in a given application?

   Given the cost of an electric snowmobile, without the assurance that it can fulfill the requirements of the duty cycle, it is unlikely that an end user will be willing to purchase such a vehicle. Since a number of applications where electric snowmobiles can be implemented are in remote locations, an onsite trial and error methodology is in many cases an extremely costly option.

   Determining snowmobile performance without onsite testing is part of the solution.

2. Cost - Even in cases where it has been determined that an electric snowmobile can fully complete the duty cycle of a specific application, the initial cost of purchasing an electric snowmobile can be prohibitive.

   Minimizing vehicle cost and knowing this minimal vehicle cost prior to the decision process is crucial.

As a first step to try and overcome these obstacles, an electric snowmobile powertrain model was developed and a simulation was performed for a hypothetical application duty cycle. The reasoning behind this is:

1. Since applications where electric snowmobiles can perform the required duties adequately are limited, it is unlikely that mass production can be used to bring down the cost of a complete electric snowmobile.

2. Electric snowmobile powertrains are not mass produced powertrains. The relative cost difference of an electric snowmobile versus a gasoline powered snowmobiles comes from their powertrain.

3. Electric powertrain cost is closely linked to an electric snowmobile's performance. Thus, in minimizing an electric snowmobile's cost, one must be extremely careful and make sure that cost reduction measures do not affect the snowmobile's performance to the point where it doesn't meet the baseline performance criteria for a given application.

Given all three points above, electric snowmobile powertrain modeling and application duty cycle simulation were thought of as a means to try and minimize powertrain cost while simultaneously ensuring that the resultant design can fully satisfy the needs of the application's duty cycle. This methodology allows the virtual design of a snowmobile powertrain tailor-made for any given application without the high cost of full scale trial and error electric snowmobile prototyping and testing.

By having the possibility of rapidly and efficiently determining an optimal electric powertrain design for a given application, the cost of an electric snowmobile can be brought down to its lowest possible point for this application while ensuring the prospective commercial snowmobile operators that the electric snowmobile will meet their needs (i.e., ensure maximum benefit to the end user for the lowest possible cost).

SELECTION OF MODELING AND SIMULATION ENVIRONMENT

After some research on the subject, no standardized electric snowmobile powertrain modeling and simulation platform was found. The closest thing to such a platform that could be found was the work of Philip S. Auth from Idaho University[xvi]. In this work, computer simulation was used to investigate the feasibility of hybrid electric snowmobile design. For this, Auth used a gasoline powered snowmobile as a baseline to determine the snowmobile's power requirement in a given set of snow conditions at different vehicle speeds. The "backward facing" modeling environment ADVISOR was used to get a performance estimate for hybrid electric snowmobiles for various speeds. The results obtained by Auth give a general idea of what one might expect if one were to design a generic hybrid electric snowmobile. It seems however that the final results were not tested against a real-life hybrid electric snowmobile.

For the task under investigation in this paper, the electric snowmobile powertrain modeling and simulation goal is more specific than in Auth's work. The goal here is to create a method by which one can take an existing snowmobile application (terrain and expected speed trace) and run a virtual snowmobile on this terrain and at the corresponding driver input in such a way that the simulation can be used as an exact virtual model of the application with transient modeling capability. Then, for validation, this methodology is to be tested against the performances of a real-life electric snowmobile. Once validated, this methodology should enable the user to eliminate the need for on-location testing prior to implementing an electric snowmobile as well as enable powertrain optimization for cost and performance in a given application.

The only previous work in snowmobile advanced powertrain simulation used a backward facing modeling environment (ADVISOR). While "backward facing" models are generally simpler and faster to compute, the fact that they are static models limits some of the possibilities these types of models offer. For modeling activities where more detailed modeling than what "backward facing" models can offer is expected, "forward facing" models can be used.

How do they work?

The backward facing model takes as an input the vehicle's speed vs. time trace and simply "back-calculates" the drivetrain operating parameters based on the vehicle's speed at every time step.

The forward facing model is more complex but more realistic. It takes in a driver speed demand and calculates/predicts the vehicle speed and its drivetrain operating parameters.

It was found that standard "forward facing" advanced powertrain simulation software platforms are currently widely used in the automotive world. Given this, a methodology was implemented in order to try and use the automotive world's existing simulation capabilities and apply them to electric snowmobiles.

METHODOLOGY

The following methodology was followed in order to obtain an electric snowmobile model:

1. <u>Simulation platform selection</u> - The first step in creating an electric snowmobile model was to select a proper simulation platform since inherent platform constraints can influence the way one needs to construct its model. The selected platform was Argonne National Laboratory's Powertrain System Analysis Toolkit (PSAT) software (version 6.2 sp1).

2. <u>Drive cycle definition</u> - Usually, a drive cycle is a speed trace defined over time, which a given vehicle must follow. There are currently no public standard snowmobile drive cycles in widespread use. Thus, in order to perform a simulation, a drive cycle, specific to a moderately powered utility snowmobile application, was defined. Given the difficulty for a driver to replicate a speed trace cycle on a snowmobile in a real life environment, the drive cycle was defined as a modal cycle where each mode is defined by an accelerator lever position maintained by the driver for a given distance. In this case, the drive cycle is more of a "drive methodology" where driver behavior is fixed.

3. <u>On-snow data acquisition</u> - Three types of on-snow tests were used.

   i. The modal "drive methodology" from point 2 was performed and data logged. The results from this test were kept for use in the validation stage of the simulation.

   ii. Acceleration tests were performed. For these tests, the snowmobile was accelerated from stop to whatever speed it would attain with the accelerator lever in a fixed, predetermined position. This was done for different accelerator lever positions, back and forth, repeatedly, on the same straight line course. Since the "drive methodology" test (i) is modal and thus has little acceleration time, these acceleration specific tests allow one to better see the model's behavior under rapid changes in vehicle speed.

   iii. A coast down test was used in order to gather the data required to model the snowmobile chassis power dissipation. For this test the snowmobile was accelerated to a given speed and then it was turned off and left to coast down to a stop.

4. <u>Application duty cycle modeling</u> - To have a complete application duty cycle model on which to simulate the electric snowmobile model, speed **and grade** at each time step of the test are needed. Thus, a terrain model for the slope encountered by the snowmobile at any given point in time during on-snow data acquisition was constructed; it was then superimposed on the snowmobile's required speed trace to create an application duty cycle model.

5. <u>Bench test data acquisition</u> - Electric snowmobile sub-systems and components were removed from the chassis and bench tested. This ensured good sub-system and component data independent from the on-snow data acquisition tests.

6. <u>Electric Snowmobile modeling</u> - Using the gathered data, snowmobile component models were built and then assembled into a complete electric snowmobile model.

7. <u>Simulation</u> – Proper simulation parameters for an electric snowmobile were introduced in PSAT and the electric snowmobile model was run through the previously defined application duty cycles (one with the modal "drive methodology" and one with the acceleration tests).

8. <u>Validation</u> - Results from the on-snow data acquisition (step 3) were retrieved and compared to the simulation results.

RESULTS - In this section, the performance of the electric snowmobile model is evaluated on 3 points:

1. Ability to follow the speed trace
2. Instantaneous power use
3. Overall energy use

Points 1 and 2 will be evaluated using both:

- the main application duty cycle (derived from the modal "drive methodology")
- the acceleration test (with the assumption that is was performed on a flat surface)

Point 3 (Overall energy use), given the very short duration of the acceleration test, will only be reviewed using the main application duty cycle.

Ability to Follow the Speed Trace - In both cases, the main application duty cycle and the acceleration test, the model accurately followed the speed trace.

For the main application duty cycle, the electric snowmobile model was never off the target speed trace by more than 3.2km/h (0.89m/s).

The Figure 2 below shows the target speed and the simulated model speed overlap.

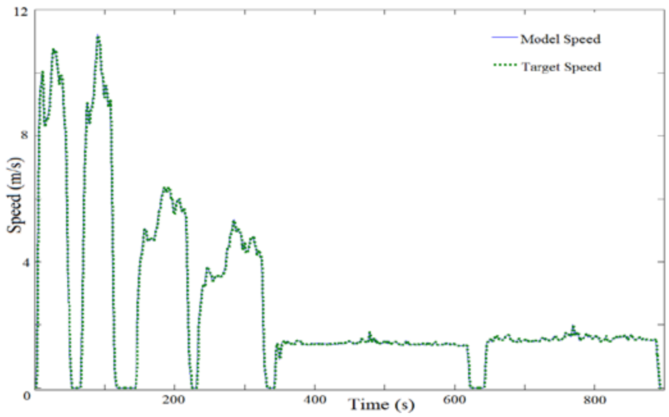

Figure 2: Target Speed Trace Overlapping Electric Snowmobile Model Speed Trace on the Main Application Duty Cycle

For the acceleration test, the electric snowmobiles model was off the target speed trace by more than 3.2km/h (0.89m/s) for only 2.1 seconds over the total duration of the test.

The Figure 3 shows that, once again in this case, the target speed and the simulated model speed overlap nicely throughout the simulation.

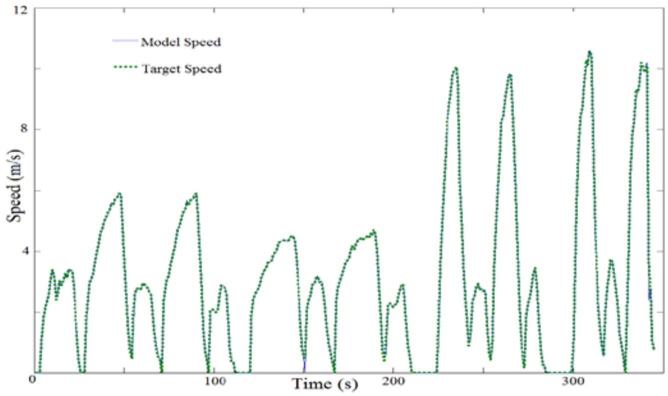

Figure 3: Target Speed Trace Overlapping Electric Snowmobile Model Speed Trace on Acceleration Test

Instantaneous Power Use - The power used at each time step by the electric snowmobile model is plotted along with the data gathered from the actual electric snowmobile for both the application duty cycle and the acceleration test. Figure 4 below shows the results for the main application duty cycle.

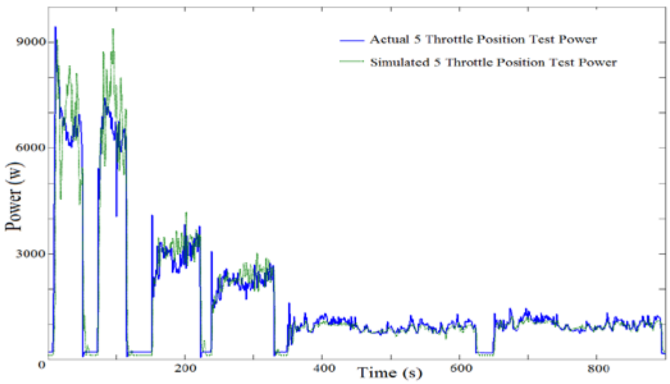

Figure 4: Electric Snowmobile Model Simulation Power Use Results and Actual Electric Snowmobile Power Use Data for the Main Application Duty Cycle

Correlation at low speeds is very good; unfortunately, simulated power at high speed is noisy. A smoothing 10 point moving average was thus applied to the results from the application duty cycle simulation. This can be seen in Figure 5 below.

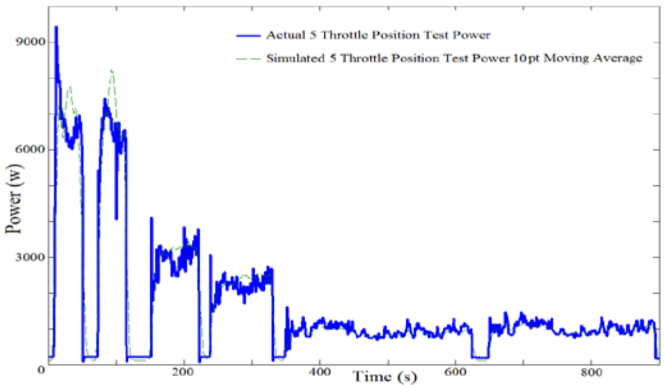

Figure 5: Model Simulation Power Use Results (10pt moving average) and Actual Electric Snowmobile Power Use Data for the Main Application Duty Cycle

Figure 5 shows good correlation between the actual electric snowmobile data and the simulation results. Detailed analysis of the results suggests that the lower fidelity of the power model at higher speeds is in part due to the combined effect of an underestimation of slope in the test circuit and a linear approximation of the snowmobile's chassis power dissipation model. However, since the vehicle is performing on a closed loop, and thus completes its circuit at the same elevation as it has started, the overall energy consumption is not greatly affected by the slope based (dominant) component of the discrepancy.

Figure 6 below shows the power results for the acceleration test.

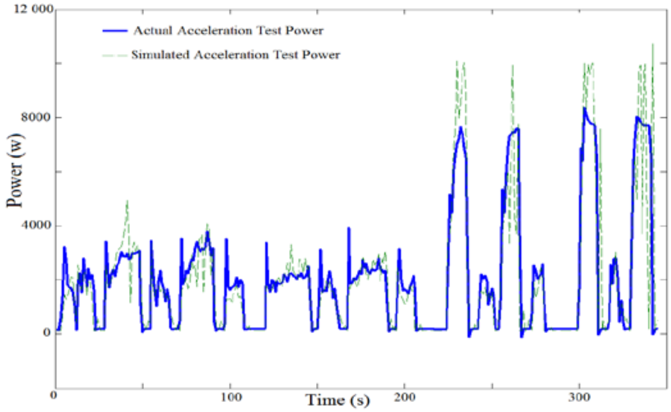

Figure 6: Electric Snowmobile Model Simulation Power Use Results and Actual Electric Snowmobile Power Use Data for Acceleration Test

The results in the acceleration test are similar to those of the application duty cycle test. Satisfactory correlation is obtained at low power levels but higher powers have substantial noise associated with them.

Applying a 5point moving average to the simulation results of the acceleration test reveals some interesting information. Figure 7 below shows this result.

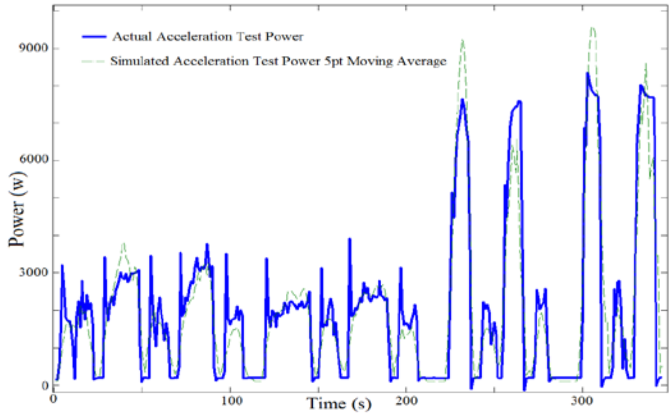

Figure 7: Electric Snowmobile Model Simulation Power Use Results (5pt moving average) and Actual Electric Snowmobile Power Use Data for Acceleration Test

It can be seen from Figure 7 that the model alternately overshoots and undershoots the acceleration run results. Given the way this test was performed, this is most likely due to the assumption that the test run was flat. Based on this result, most likely the test run had a small inclination which caused this phenomenon.

Another interesting piece of information is that the model constantly undershoots the "turnaround" of the snowmobile between acceleration runs. This could indicate that a compensation factor might be needed in future simulation in order to compensate for a possible supplemental load during turns.

Overall Energy Consumption - Below, Figure 8 compares the energy consumption simulation results with the data obtained during the main application duty cycle testing.

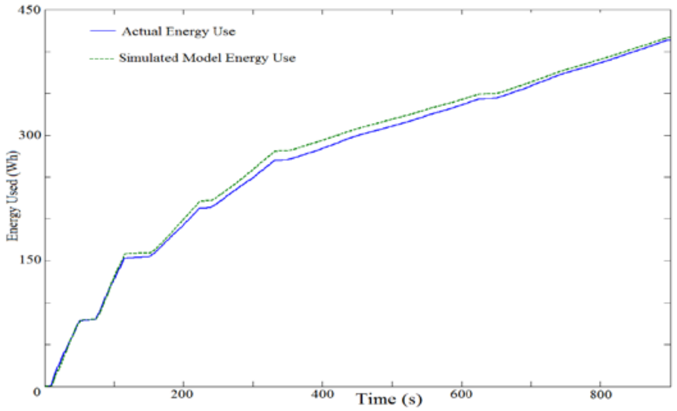

Figure 8: Electric Snowmobile Model Simulation Cumulative Energy Use Results and Actual Electric Snowmobile Cumulative Energy Use Data

Figure 8 shows that the model accurately predicts energy consumption. The maximum error is 11.25Wh. The final error at the end of the drive cycle is only 3.25Wh (approximately 0.8% of the total energy used).

CONCLUSION - The goal of this exercise was to see if it was possible, using a standard powertrain simulation software platform, to create an electric snowmobile model which could be used to predict snowmobile performance for a given duty cycle in a potential application. The idea behind this is to enable designers to rapidly, and cost efficiently meet the needs of commercial snowmobile operators by determining electric snowmobile performance and cost options for their specific application.

Even though the model obtained in this first attempt is not a high fidelity model, the data obtained shows that such a simulation does yield results which should ensure an end user that the electric snowmobile will adequately perform on a specific application's duty cycle. At the same time, the modular approach used by simulating with PSAT is perfectly suited to fine tune motor power and battery pack energy to a specific application duty cycle without having to go to remote locations in order to do full scale trials on site. Furthermore, this approach is not limited to electric snowmobiles. It can be applied to gasoline, diesel or even hybrid snowmobiles.

Given the promising results of this first test, a full scale case study with a commercial snowmobile operator was scheduled.

WHISTLER / FITZSIMMONS CREEK CASE STUDY

Canadian Snowmobile Adventures (CSA), one of Canada's largest all season motorized tour operators, located in

Whistler B.C., was one of the first commercial snowmobile operators to seriously consider the integration of electric snowmobiles in its products.

Given the ease of access to terrain data, their Fitzsimmons Creek Cruise tour was the selected site for the case study. CSA describes the run as follows:

“Journey into the pristine depths of the hidden valley nestled between Whistler and Blackcomb Mountains. Follow wide mountain trails along the Fitzsimmons Creek watershed on this ride designed for families and first timers, with a perfect mix of easy riding and spectacular scenery.”

In terms of electric snowmobile design, the terrain for the run is mainly divided into 3 sections:

1- It starts with a steep uphill. Close to 200m rise in approximately 1500m of horizontal travel.
2- It then levels off and becomes a very moderate uphill gaining less than 40m of height over more than 2km of horizontal travel
3- The trail ends in a moderate downhill that drops the snowmobile approximately 15m over a 250m span.

Once this trail has been done one way, the snowmobiles are turned around and the return trip is done on the same trail but in the reverse direction (and thus the uphill sections are now downhill sections and vice versa).

According to CSA tour guides, the speed on the tour varies depending on snow conditions and customers. However, in general, then tend to average approximately 20-30km/h. Maximum speed rarely goes over 40-45km/h.

GOAL – The goal of this case study was to demonstrate that a full scale and real life implementation of the previously defined methodology was possible.

For this, a detailed topographical map of the Fitzsimmons Creek trail was obtained and the previously constructed snowmobile model was used to get an idea of how the electric snowmobile used for initial modeling and simulation testing would perform in the Fitzsimmons Creek application.

Based on the input from CSA, various potential speed traces for the Fitzsimmons Creek Cruise were conceived.

The result for the various simulations clearly showed that, in terms of torque, speed and energy, the electric snowmobile used for initial modeling and simulation testing could adequately meet the needs of the Fitzsimmons Creek Cruise.

In order to validate the results and prove the usefulness of powertrain modeling and simulation, in the frame of this case study, the electric snowmobile was sent to Whistler B.C. to show what its actual performances were on the Fitzsimmons Creek trail.

Unfortunately, the only possible time frame for the trip was early to mid December 2008 and Whistler got hit by one of its worst late fall season in years in terms of snow cover. After having spent a week in Whistler things were not looking good. Not a trace of snow in the village. Fitzsimmons Creek trail, located at a slightly higher elevation, wasn’t faring much better. Thankfully, after waiting for 10 days, a few snowflakes came down on the village and luckily, given the micro-climate of the Fitzsimons Valley, a few more came down on the trail.

Snow coverage on the second and third section of the trail was far from perfect but it was sufficient to do some snowmobile runs. Unfortunately, most of the 1st section of the trail had insufficient snow coverage to operate a snowmobile on it.

Testing was thus done over only 70% of the terrain normally used by CSA for their Fitzsimmons Creek Cruise.

The speed data recorded on that run can be seen below in Figure 9 along with a smoothed fit to it (used as the simulation speed input).

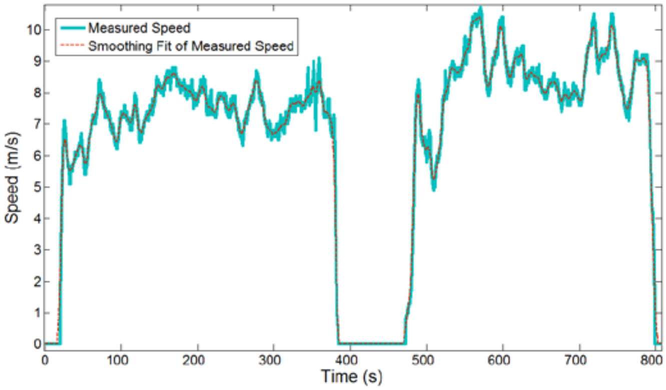

Figure 9: Measured Speed of Snowmobile Run on 70% of Fitzsimmons Creek Trail along with Smoothing Fit

Based on topographical map information of the trail and the speed of the vehicle at each time point, the grade presented in Figure 10, is what was calculated the vehicle encountered on this run.

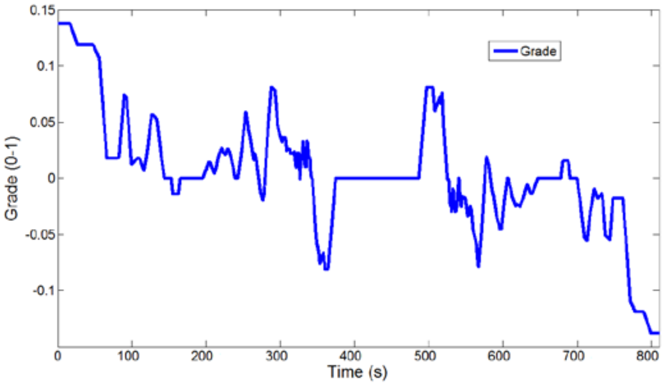

Figure 10: Grade vs. Time Plot of Snowmobile Run on 70% of Fitzsimmons Creek Trail

Figure 11 on the following page shows energy consumption for the actual run taken with the electric snowmobile on 70% of Fitzsimmons Creek trail. Superimposed over the actual energy consumption is the computer model prediction of energy consumption when running a simulation on 70% of Fitzsimmons Creek trail.

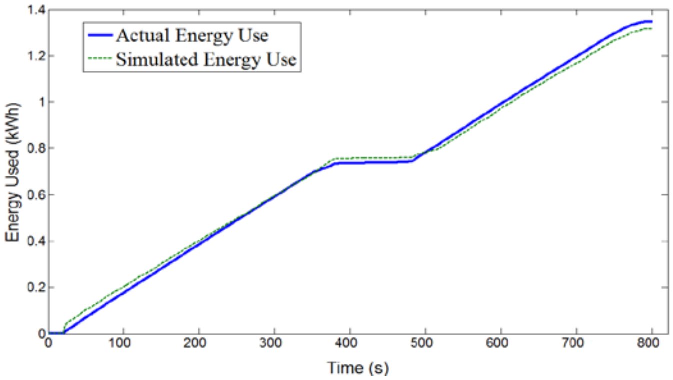

Figure 11: Electric Snowmobile Model Simulation Cumulative Energy Use Results and Actual Electric Snowmobile Cumulative Energy Use Data for 70% of Fitzsimmons Creek Cruise

Once again, just like in the first test, over a closed loop course the energy use predictions of the program are very precise. The maximum error is of 29Wh. The total amount of energy use predicted by the simulation has an error of 2% when compared to the actual energy used.

However, for the instantaneous power use of the vehicle it proved to be difficult for the computer model simulation to perfectly match the actual run on 70% of Fitzsimmons Creek trail. The main reason for this is believed to be actual terrain conditions. The computer received "macro-scale" terrain variations of grade as well a constant vehicle to snow interaction model as inputs. In reality, snow conditions were variable throughout the run and a number of small terrain variations not perceivable on a topographical map were encountered by the vehicle. As a result, without this "micro-scale" information available to it, the computer model often over-compensated speed changes by varying the snowmobile's power much more than it did in real life. It is believed that in the actual run, many of the speed changes were induced by "micro-scale" effects (i.e. changing terrain and surface conditions).

Figure 12 below shows the computer model predictions superimposed over the actual power draw recorded during the run.

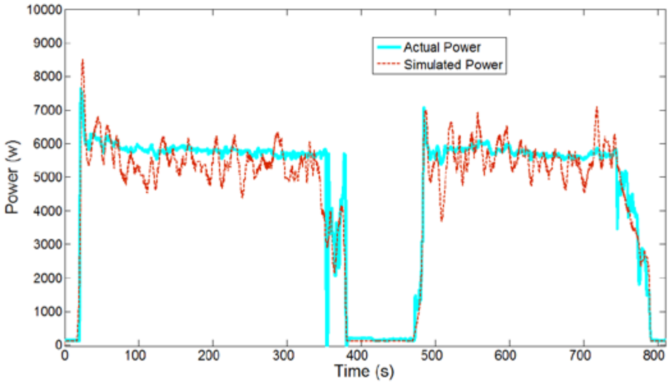

Figure 12: Electric Snowmobile Model Simulation Instantaneous Power Results superimposed on Actual Electric Snowmobile Instantaneous Power Data for 70% of Fitzsimmons Creek Cruise

While the simulation did not produce a perfect match on instantaneous power use, the results nonetheless follow the actual power trend within a reasonable range to enable vehicle designers to properly dimension the vehicle's powertrain for the application.

Overall the Whistler/Fitzsimmons Creek case study with CSA was deemed a success. New work is currently underway to simulate different electric snowmobile configurations on different CSA products. Given that most of CSA's products are on mountainous terrain, the aspect of vehicle and passenger/cargo weight and its effect on the design of an electric snowmobile is of particular interest. With gasoline snowmobiles, having multiple customers on a single snowmobile can substantially increases that snowmobile's revenue generation. However, the increased passenger weight in mountainous terrain can have a dramatic effect on an electric snowmobile's powertrain design and thus potentially send the vehicle's cost climbing faster than the additional revenue generated by the extra passenger(s).

This and many other questions are currently under investigation for CSA's application. With the success of the case study, CSA is no longer the sole commercial snowmobile operator seriously thinking of electric snowmobiles. Some interested commercial snowmobile operators from both ends of the North American continent as well as from Europe are currently in talks with McGill University to have their application investigated.

MCGILL UNIVERSITY ELECTRIC SNOWMOBILE ENTRY AT THE SAE CSC 2009

McGill believes that the current format of the Zero-Emissions category of the SAE CSC is somewhat similar to high end auto racing (ex. Formula 1). Despite the best of intentions to try and keep costs under control, its format rewards vehicles with the most funds invested in them. Just like high end auto racing, it can potentially serve as a proving ground for some future technology which can maybe eventually become affordable; however it is unlikely that a commercially viable electric snowmobile will fare very well unless the rest of the field is all composed of commercially viable products.

Nevertheless, McGill has decided that for SAE CSC 2009, it would present a snowmobile platform which it believes, if combined with commercial application modeling and simulation, can be a commercially viable product in some applications.

Thus, the 2009 McGill electric snowmobile has not been designed with the SAE CSC events in mind. It was designed as an easily modifiable platform which can hopefully suit a wide range of commercial and utility snowmobile applications simply by having 3 components (motor, controller, battery) selected based on the application. Vehicle layout has been optimized to enable different versions of these components to be used in the vehicle.

In order to present the vehicle, the different dynamic events of the CSC will be looked at and some predictions will be made as to how this snowmobile will behave in each of them.

NOISE (300pts combined) – The most important criteria for Zero-Emissions snowmobiles at CSC 2009; the lower the noise the better.

As it has been seen in past events, almost all electric snowmobiles fall within a very narrow db range (often smaller than the error used in the industry standard!...). How will the McGill snowmobile do in this event? On an absolute scale if should be the same as in past years: too quiet for actual “real life” use.

After having been used in Whistler, Mont St-Sauveur, Mont Avila, Les 3 Vallees, and Val d’Isere (for the 2009 FIS World Alpine Ski Championships), one comment came back from all operators: this vehicle is too quiet for our application; we need to add some artificial noise. Nevertheless, since some commercial snowmobile applications may benefit from the lack of noise, the added noise source was given an interrupter switch. Given that this switch cannot be operated during CSC the snowmobile will be in “quiet” mode.

HANDLING (125 pts combined) – Good handling is a major requirement of many prospective electric snowmobile applications. In some of these applications ease of handling and high maneuverability and stability are needed to get the snowmobile from point A to point B in a crowded area (ex: ski hills). In other applications these same characteristics are being sought mainly because the drivers have little to no snowmobile experience (ex: snowmobile tours).

With that in mind, the baseline Ski-Doo Tundra snowmobile used had its front stance widened and a stabilizer bar was added to its front suspension system. A pre-studded track was also used instead of the stock track.

One of the keys to electric snowmobile handling is weight distribution. This electric snowmobile keeps almost the same weight distribution as the stock gasoline powered Tundra. Placement of the motor and battery pack at the lowest possible point in the vehicle also ensures a very low center of gravity (lower than the original Tundra).

Smooth operation of the snowmobile at low speed is also a factor which makes this electric snowmobile interesting for certain specific applications. The combination of an electric motor and a permanently engaged CVT allows the driver to take off without any jerks from the vehicle.

The snowmobile has proven its outstanding ease of handling and high maneuverability and stability earlier this winter when it was used for 15 days without any incident at the FIS World Alpine Ski Championships in Val d’Isere.

Why can one say that?

The snowmobile was operated on an extremely busy snow front where regular ski traffic from one of France’s biggest ski resorts gets funneled. But that’s not all. On top of regular ski traffic a crowd of over 200 000 spectators found its way to the snow front during the two weeks of the event. And to top it off… many of the drivers of the electric snowmobile (event volunteers) had never even touched a snowmobile before.

RANGE (100 pts) – Commercial snowmobile applications where electric snowmobiles can shine are the ones where a **known** maximum amount of range is required within a **known** time frame. This enables the snowmobile designer to optimize the amount of energy on-board and this in turns minimizes cost (battery cost can be the largest cost in an electric snowmobile).

The current format of the event goes it the exact opposite direction. Points are given on a relative basis based on who ever goes the furthest (regardless of energy on-board and the cost of this energy).

So how does one tailor a battery pack for a customer that asks for “More energy than other snowmobiles” but can’t tell you the amount of energy the other snowmobiles have? One can’t do it.

Thus, for SAE CSC 2009, the team decided to leave in the snowmobile the battery pack that was used during the FIS World Alpine Ski Championships in Val d’Isere.

A first snowmobile performance simulation was performed. With this battery pack, the simulation results predict that the electric snowmobile will travel just over 12km at a steady speed of 32km/h on hard flat snow. Past the 12km point (assuming all battery cells are perfectly equal at then all turn off at the same time), another 2.5 kilometers could be travelled at speeds below 32km/h before the battery turns off. Realistically given the age of the pack and the use and abuse these cells have endured in their lifetime, it is unlikely that all cells will start with their maximum name plate capacity and all discharge equally. As a result of this, the simulation data should be considered as a best case scenario to the given conditions. At this point the team considers that a 10-20% de-rating of the pack’s available energy would be more realistic. Running a second simulation with this de-rating yields a range of 10 km at 32 km/h.

WEIGHT (100 pts) – The weight of the vehicle is crucial in a number of commercial snowmobile applications. CSA’s application of snowmobile tours on Whistler Mountain and Blackcomb Mountain is a good example of this.

Thus the McGill electric snowmobile has been designed with a strong emphasis on minimizing vehicle weight.

Depending on whether or not competition organizers decide to include charger weight in the vehicle weight, the McGill entry could be the first electric snowmobile at the SAE CSC below the 227kg (500lbs) mark.

Minimizing weight starts with the use of one of the lightest snowmobile chassis available. Other key factors include minimizing the number of components on the vehicle and the choice of those components based on weight. Lastly a major contribution to weight has to do with component placement. Components placed in strategic locations inside the vehicle can greatly reduce overall weight by minimizing wire lengths and support bracket size and quantity.

One thing which must not be neglected is that weight feeds itself… in both directions! A heavier vehicle will require more energy and more power to move and this extra energy and power will themselves have an impact on weight. Conversely, less vehicle weight requires less power and energy to move over a given drive cycle. This is particularly true in mountainous applications. Furthermore, this effect can have a tremendous impact on vehicle cost since, combined, the energy and power sources for the vehicle can easily constitute 75% or more of the vehicle cost (as it is the case in the McGill CSC 2009 entry based on SAE CSC MSRP formula).

DRAW BAR PULL (100 pts) – Draw bar pull events from previous years have made it clear that, for any snowmobile with the slightest amount torque, this event is equivalent to measuring the vehicle's traction on a given surface.

There are mainly 2 ways of increasing a snowmobile's traction: improve is friction coefficient with the snow or increase the weight on its track.

Increasing vehicle weight is not considered to be a valid option (see WEIGHT subsection for more information). So what's left? Well putting you heaviest driver on the snowmobile is a start (and filling his pockets with lead could possibly further improve things...).

In terms of the snowmobile itself, increasing the weight over the track by changing the ski-track weight distribution would help. It turns out that, compared to some previous prototypes, the 2009 McGill electric snowmobile has more weight on the track. This is the result of strategic component placement in order to make the snowmobile an easily customizable platform as well as reducing weight. Nevertheless the change is minor and should have very little effect on the event.

What might have a positive effect on the McGill electric snowmobile performance is the use of a studded track. If the conditions of the test are hard packed snow or ice, the studs could increase the snowmobile's friction coefficient and thus substantially increase its towing capacity.

The use of a studded track is the result of driving the electric snowmobile down alpine ski slopes during some testing with local commercial snowmobile operators and experiencing the feeling of coming down the mountain with almost no speed control. This feeling of total lack of control on what was probably one of the most expensive "toboggan" in the world sparked the realization that studs may after all not just be for 200hp snowmobile trying to get a better hole shot...

A quick survey then showed that pre-studded tracks are being used more and more in alpine ski resorts since their slightly higher cost has almost immediate payback from the decrease in on slope vehicle accidents.

ACCELERATION (50 pts) – So far, no actual commercial electric snowmobile application has indicated that acceleration has a high importance. Thus, this area of performance has not received particular attention. However, given that acceleration is a combination of power to weight ratio and traction, the added traction of the studded track and the relatively low weight of the vehicle give it good potential for acceleration if a potential customer required it.

In order to have this substantial acceleration power for a given application, the vehicle's motor would have to be sized to the requirements of that application. The motor in the 2009 McGill SAE CSC entry has not been sized for amazing acceleration but rather for proper efficiency and power at minimal cost for use in a utility snowmobile application on the 2009 FIS World Alpine Ski Championships snowfront.

COLD START (50 pts) – In over five years of building electric snowmobiles, the McGill team has yet to have one not start because of the cold; they haven't started for various other reasons (usually human/design error), but cold was never the main factor.

Given that the 2009 electric snowmobile is almost all based on components which the team has successfully used for years in various applications from -40C to 40C ambient temperature; ambient temperature is not expected to be an issue.

MANUFACTURER'S SUGGESTED RETAIL PRICE (MSRP) (50 pts) – Based on the SAE CSC formula to calculate MSRP, the baseline cost of the McGill electric snowmobile entry for 2009 is 15 000$. Lower than all electric snowmobiles from the previous year. One would expect that it will fare well in this event. Unfortunately, given the format of the competition, this event, which is actually the most important criteria in electric snowmobile commercial viability, is worth less than 5% of the total points allotted at the SAE CSC.

One must also realize that, realistically speaking, it is extremely unlikely that one would produce 5000 units of the exact same electric snowmobile (the number used in the SAE CSC MSRP formula).

A single unit cost would better reflect the reality.

Based on this approach the McGill team considers that its snowmobile's true market MSRP would in real life be calculated as follows:

1. The cost of chassis and essential components. This cost is dependent on whether or not the prospective electric snowmobile buyer is providing a used chassis or if a completely new snowmobile needs to be purchased.

2. The cost of the motor and controller; which will in large part determine the maximum speed and acceleration of the vehicle. These should be selected based on the specific needs of the application.

3. The cost of the battery pack; which will in large part define the maximum available range of the vehicle between electrical outlets. This will in many cases represent at least 30% of the vehicle's value. This

percentage can easily go up to 80% in some applications.

This 3 step approach is the approach currently being used by McGill University in defining a suitable electric snowmobile for use by CSA during the 2010 Winter Olympics in Vancouver – Whistler.

This approach also eases the introduction of electric snowmobile in Canadian ski resorts since the Ski-Doo RF platform used for the McGill electric snowmobile is one of the most common platforms found on Canadian ski resorts. Thus, the possibility for the prospective electric snowmobile buyer to see the price tag come down substantially while simultaneously re-using chassis which had their original gasoline powertrain fail in any way can be a very interesting one. Current work is also underway to expand the success of the RF platform based electric snowmobile to the Yamaha Venture Lite chassis.

OTHER (0 pts) – One interesting feature of the McGill electric snowmobile is the fact that it has an on-board charger which can be used almost anywhere in the world. The charger is designed and sized in order to maximize the recharge speed of the batteries while ensuring that it doesn't trip common household breakers. Having an onboard charger is a must for numerous applications. In order to get the maximum use out of an electric snowmobile during a day, the best way to use it is to plug it in every time it is not in use. This way, if it is being used as a people/cargo mover within a fixed area (ex: ski resort) its daily mileage will likely be greatly superior to its single charge range.

The batteries in this snowmobile were in part chosen due to their ability to constantly accept charge without any issue regardless of their depth of discharge.

Another feature of the snowmobile is its ability to have a convenient removable cargo box added to the rear of its tunnel (see figure 1 on page 1). If the cargo box is not needed, the area can easily be fitted with a multi passenger seat extension.

Lastly, the track selected for the vehicle was selected based on its capacity to perform well under a vast array of snow conditions. Based on the current sample of potential end users, the applications which might benefit from an electric snowmobile will have to use it regardless of snow conditions and thus will benefit from such a track choice.

CONCLUSION

This paper has investigated the question: can an electric snowmobile be a cost effective solution for use as a utility snowmobile?

The proposed answer is yes. However in order for this to be true, an electric snowmobile must be properly sized for the target application.

Electric snowmobile will by no means take over the snowmobile world given the difference in energy density between gasoline and batteries. Nevertheless, McGill University has demonstrated with different successful projects that in applications where limited range and/or power is required, a electric snowmobile can potentially be successfully implemented.

In order to be a viable product, the end users must be willing to purchase electric snowmobiles at a price higher than the manufacturer's production cost. Unfortunately, mass production of electric snowmobiles is unlikely due to the relatively low number of suitable applications. Thus, other means of improving the end user's perceived cost/benefit ratio for electric snowmobiles must be investigated. It was proposed that electric snowmobile powertrain modeling and simulation can potentially improve the end user's perceived cost/benefit ratio in two ways:

1. By determining if an electric snowmobile design can perform adequately on a given duty cycle, thus ensuring the end users that the snowmobile will meet their needs without need for potentially expensive on-site trials

2. By being used as a tool to custom design electric snowmobiles for specific applications in order to limit costs associated with expensive energy storage and powertrain components.

A methodology for electric snowmobile powertrain modeling and simulation was proposed and validated. This methodology was then successfully applied to a real life case study with Canadian Snowmobile Adventures.

Following this success an easily configurable platform was conceived which can easily accept a number of powertrain configuration thus enabling the rapid implementation of an electric snowmobile in a given application.

Future work is currently being focused on further improving the use of advanced vehicle modeling and simulation for electric snowmobile commercialization. A number of North American and European partners have shown interest in using this approach in order to improve the services offered by their business via the use of electric snowmobiles.

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REFERENCES

---

[i] Dictionary.com [Aug 2008]
http://dictionary.reference.com/browse/snowmobile?r=14

ii International Snowmobile Manufacturer Association Snowmobiling Facts: History [Aug 2008]
http://www.snowmobile.org/facts_hist.asp

iii International Snowmobile Manufacturer Association Snowmobiling Facts: Snow Facts [Aug 2008]
http://www.snowmobile.org/facts_snfcts.asp

iv HyWeb, Zittel, Werner & Reinhold Wurster (Ludwig-Blkow-Systemtechnik). Hydrogen in the Energy Sector. Chapter 2: Physical Properties, [Aug 2008]
http://www.hydrogen.org/Knowledge/w-i-energiew-eng2.html

v Arctic Cat Snowmobile Specification Sheet [Feb 2007]
www.arcticcat.com/snow/sled.asp?id=776

vi Polaris Snowmobile Specification Sheet [Feb 2007]
www.polarisindustries.com/enus/Snowmobiles/2007Models/TrailLuxury/340LX/

vii BRP Ski-Doo Snowmobile Specification Sheet [Feb 2007]
www.ski-doo.com/en-US/Snowmobiles/Skandic/The.Basics/

viii Yamaha Snowmobile Specification Sheet [Feb 2007]
www.yamahamotor.ca/products/products.php?model=1991&section=td&group=S#contentTop

ix Calculated based on:
HyWeb, Zittel, Werner & Reinhold Wurster (Ludwig-Blkow-Systemtechnik). Hydrogen in the Energy Sector. Chapter 2: Physical Properties, [Aug 2008]
http://www.hydrogen.org/Knowledge/w-i-energiew-eng2.html

x Calculated based on:
Optima D34M Sealed Lead Acid Battery Specification Sheet [Feb 2007]
www.optimabatteries.com/publish/optima/americas0/en/config/product_info/marine/technical_specs.html

xi Calculated based on:
Saft STM Nickel Cadmium Battery Specification Sheet [Feb 2007]
www.saftbatteries.com/120-Techno/10-10_produit.asp?paramtechno=Nickel+systems&Intitule_Produit=STM

xii Calculated based on:
Cobasys Nickel Metal Hydride Battery Specification Sheet [Feb 2007]
www.cobasys.com/pdf/faq/faq.html

xiiiCalculated based on:
Lithium Technology Corp. 602050 Lithium Ion Cell Specification Sheet [Feb 2007]
www.lithiumtech.com/StandardCells.html

xiv BRP Ski-Doo Snowmobile Specification Sheet [Feb 2007]
www.ski-doo.com/en-US/Snowmobiles/Skandic/The.Basics/

xv SAE International, Collegiate Design Series, Clean Snowmobile Challenge [Jun 2007]
http://students.sae.org/competitions/snowmobile/results/

xvi Auth, P.S.; “Determining Hybrid Electric Snowmobile Feasibility Through Simulation”, M.S. Thesis, Mechanical Engineering, University of Idaho, Apr 2003.