Design Report

Electric ATV Conversion

Team 24
Andrew Shapiro
Richard Shapiro
Peter D'Urso
Carlo Spano

Presented to:
Prof. Peter Radziszewski
Prof. Rosaire Mongrain
Chris Prahacs

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Table of Contents

Executive Summary

The following report will guide you through the design process our group underwent while attempting to convert a gas-powered all-terrain vehicle (ATV) to an electric-powered ATV. The opportunity for this project arose when the Gault Nature Reserve (GNR) in Mont-Saint-Hilaire approached us with the task of helping them decrease their carbon footprint by providing them with a less environmentally-harmful electric ATV to perform their every day maintenance tasks.

Contrary to our belief when we took on this project, we were not provided with the actual ATV or with the necessary funds to buy the parts necessary for the conversion. Before the design could begin, it was necessary to acquire the ATV, because speculations about the mounting and installation of electric components would not suffice. With months of time and effort, we finally were able to convince Bombardier Recreational Products to donate an Outlander 800 MAX ATV to our team. We also acquired most of the necessary funds through our application to the McGill Sustainability Projects Fund.

The basic requirements that the GNR desired from the ATV, such as towing capacity, average daily use and passenger load, were supplied. We then performed multiple experiments and analyses on the motions of an ATV under different circumstances. Using the results of the experiments, we developed the power requirements that the ATV would need. These results helped us begin the process of selecting the right motor, controller and battery pack. To select the motor that could satisfy our requirements, it was necessary to perform another experiment to determine the RPM and speeds desired. Furthermore, we were able to determine the torque required by the motor. The result was the selection of the HPEV AC-15 72V AC motor.

Based on the motor we decided that we will use either a Curtis 1236 or 1238 controller. The decision depends mainly on the availability and price. The motor mentioned above will be run on either a 48V or 72V system, depending on the battery pack we acquire. We will not be ordering batteries for the moment as we need to be sure of the system before we do so, and thus we will first use test batteries to validate the functionality of the ATV. The other required components, however, such as the belt drive, throttle, battery charger and DC-DC converter have been selected.

Once concrete dimensions of the electrical components were determined, methods were developed to mount them to the ATV. Using the preexisting frame made this process challenging. Not only did each appropriate mounting mechanism need to be designed and

tested by finite element analysis, but each one needed to fit on the ATV frame as well as have plausible mounting points.

As mentioned, the report that follows will provide detailed explanations and calculations, accompanied by their complimentary graphs, charts or figures to help clarify each step of the design process of this project listed above.

Introduction

The Gault Nature Reserve (GNR) in Mont-Saint-Hilaire of McGill University is a private conservation reserve that protects the primeval forests of the St. Lawrence Valley. Its multitude of walking trails throughout the reserve is a year-round tourist attraction, receiving up to a few thousand visitors on a given day. As with many large land attractions and natural reserves, constant maintenance is vital for keeping the grounds pristine. Due to its large size, the daily maintenance on the GNR is mostly done by all-terrain vehicles (ATV's). These powerful 4-wheel vehicles are capable of transporting one or two passengers, as well as a trailer full of gear around the grounds, including up some of the hiking trails, to carry out the everyday upkeep.

The GNR wishes to promote its environmental awareness in all aspects on the reserve. They feel that a significant step in further reducing their carbon footprint is to use electrically powered vehicles for the maintenance of their grounds. The GNR already has electric golf carts for transportation purposes, and gas-powered ATV's for heavier duty tasks, but they are eager to switch the ATV's for more eco-friendly alternatives.

With the highly efficient batteries, motors and controllers on the market today, conversions of vehicles from gas-powered to electric are becoming much more prevalent. This report will outline the design process and embodiment for the conversion of a gas-powered ATV to an electric ATV.

Problem Definition

The goal of this project is to provide the GNR with a functioning converted electric ATV that is capable of performing the daily maintenance tasks year round. These tasks include hauling a lawnmower, collecting garbage, moving firewood to various locations on site, as well as many other daily maintenance tasks. Most of the tasks are accomplished by means of a detachable trailer at the reserve, and thus the converted ATV requires the proper trailer connection. It is also required that the ATV can haul a 300 pound trailer and handle the driver and a passenger. Determination of the power requirements of the ATV are done using topographical maps to estimate average daily power consumption, maximum power consumption, battery capacity in amp-hours, etc in order to properly size the batteries and motor that will effectively be able to carry out the demands of the user. The ATV will be charged each night, and thus the ultimate goal is for the ATV to be able to operate all day.

Original Vehicle Specifications

2008 BRP Outlander 800 MAX

This vehicle was generously donated by Bombardier Recreational Products thanks to the head of the ATV division, Steve Langlais.

The company showed great enthusiasm towards our project. Being environmentally friendly and respecting the environment are objectives that Bombardier takes very seriously.

Upon designing the prototype, it is important to keep in mind the original specifications of the ATV. Furthermore, the gas powered vehicle's specifications and capabilities must be maintained with the new electric prototype. In doing so, the project will effectively demonstrate that as battery and engine technology progresses, the demarcation between gas powered vehicles and electric vehicles is diminishing. The main challenge of the project is not only to create an electric prototype that meets a series of specifications, but to do so while conforming to a strict time schedule as well as to budget restrictions.

The Outlander is a 4x4 utility ATV with a removable second seat. The engine is coupled to a CVT transmission that is connected to a conventional gearbox with gears including park, high, low and neutral. The relevant specifications are found in the table below.

The 800 CC V-twin fuel injected engine produces ~60 hp at 6750 rpm and 73 N-m (53.83 lb-ft) of torque at 5500 rpm. It is equipped with the following accessories:

- Electric front mounted winch
- Power Steering
- 2 to 4 wheel drive actuator switch
- Front lights with high beam option and brake lights
- Thumb actuated throttle
- All accessories powered by an onboard 12 V lead acid battery

Vehicle Specifications		
Overall Length		2.39 m
Overall Width		1.17 m
Overall Height		1.14 m
Dry Weight		323 kg
Weight Distribution (F/R)		48/52
Rack Load	Front	45 kg
	Back	90 kg
Total Vehicle Load (Including driver and all other loads)		272 kg
Towing Capacity		590 kg

Evaluation Criteria

Upon request, the GNR provided an estimate of average daily usage requirements, summarized in the table below.

Time	Distance round trip (m)	Explanation	Trail to use for calculation (David Maneli)
8:30h	7000	Going up and down to Dieppe with two people to repair a vandalised sign (trailer and small tools)	Dieppe
11h	1400	Pavilion to Gault House for maintenance in the Research Bld. (trailer and small tools)	Hertel
12:15h	600	Pavilion to gate house replacement of staff (no trailer)	See Gatehouse Sheet
13h	1000	Pavilion to Chalet for maintenance	Hertel
15h	1800	Pavilion to Picnic area for garbage pickup (trailer)	Hertel
16h	1400	Pavilion to Gault House for maintenance in the Research Bld.	Hertel
17h	600	Pavilion to gate house replacement of staff (no trailer)	Hertel
19h	1800	Closing of the gate at the picnic area	Hertel

Table 1: Average Daily ATV Usage at GNR

Using these requirements, along with thorough discussions with the client, a QFD was developed in order to weigh the customer requirements against the engineering characteristics we developed, shown below. Each of the customer requirements was given a weight on 10 representing its relative importance (1 being the least, 10 being the most). Each customer requirement was compared with the engineering characteristics by designating the relationship as strong, medium or weak, which was in turn assigned numerical values of 5, 3 and 1 respectively. Summing the scores for each engineering characteristic delivers an absolute importance of each. Additionally, by multiplying the score of any given relationship by its customer requirement weight, then adding the sum and dividing by 100 (for easier comparison), we obtain the relative importance of each engineering characteristic. The higher the relative importance, the more that aspect should be considered in designing the ATV. A last grading assigned to each engineering characteristic is the technical difficulty. This is what we deemed the level of difficulty of each task to achieve on 5 (1 being the simplest, 5 being the most complex).

Weight (on 10)	Engineering Characteristics / Customer Requirements	Battery pack voltage	Maximum power output	Starting torque at wheels	Average power output	Regenerative braking	Number of driven wheels	Charge capacity of battery pack	Towing capacity	Number of motors	Sound level (pedestrian safety)	Low center of mass	Mass of battery pack	Emergency power kill
9	Ability for full day functioning	▲	■	■	▲	▲	●	▲	●	●	■	●	▲	■
5	Two-passenger accommodation	●	●	●	●	■	■	▲	▲	■	■	▲	●	●
10	Ability to climb the steepest slope	▲	▲	▲	●	■	▲	■	●	●	■	▲	■	■
8	Possibility to switch trailers	■	■	■	●	■	■	■	▲	■	■	■	●	■
8	Carry the desired loads (300lbs cargo + 2 passengers)	▲	▲	▲	▲	●	●	▲	▲	●	■	▲	▲	■
7	Able to travel at a sufficient speed (10 km/h)	▲	●	■	▲	▲	●	●	●	●	▲	▲	▲	■
9	Small turning radius	■	■	■	■	■	●	■	■	■	■	■	■	■
8	Reversing capabilities	■	■	■	■	■	●	■	■	●	▲	■	■	■
10	User friendly	●	●	●	●	■	■	●	●	■	▲	■	■	▲
8	Able to function in snow	●	▲	▲	●	■	▲	●	●	●	■	●	●	●
10	Fail safe	▲	■	■	■	■	■	■	■	▲	●	▲	■	▲
	Absolute Importance	37	28	27	33	21	29	29	33	27	25	35	29	23
	Relative Importance	2.74	2.3	1.9	2.7	1.44	2.46	1.48	2.64	1.92	2.12	2.86	2.54	1.98
	Technical Difficulty	1	4	3	3	5	1	3	4	1	1	4	4	1

Legend	
▲	Indicates a strong relationship (5)
●	Indicates a medium strength relationship (3)
■	Indicates a weak relationship (1)

Figure 1: QFD Based on Customer Requirements

The results of the tabulations indicate that based on both absolute importance and relative importance, the most crucial engineering characteristics are battery pack voltage, maximum and average power outputs, towing capacity, mass of the battery pack and a low center of mass. The max power output, the towing capacity, the mass of the battery pack and the low center of mass were deemed to be fairly technically difficult, and thus it is expected that we will need to devote much of our efforts in obtaining the desired results.

Design Embodiment

Power Requirements

In order to begin the design of the electric ATV that would satisfy the customer and engineering requirements, it was necessary to develop the initial power requirements. Our client at the GNR provided us with topographic data for each of the five major trails at the reserve, which consisted of the change in elevation up the trail per meter of trail travelled.

To develop the power requirements, some assumptions had to be made. The first was that a constant speed of 10 km/h was maintained. The second was that our calculations would be only for the uphill portion of the trip as this requires most of the power needs. To determine the energy required to maintain this constant speed, a force balance was developed. As the ATV moves up the hill, it needs to overcome rolling resistance and the component of gravity that acts to pull it down the hill. The component of gravity is easily obtained based on the weight of the ATV and the angle of the slope at each instant. This is shown in the 'Sample Calculations' section. In order to determine the coefficient of rolling resistance, an experiment needed to be performed, which is outlined in detail in appendix 'A'.

Constants				
Vehicle mass	712.09	lbs	323.00	kg
Driver(s)	200	lbs	90.72	kg
Trailer	300	lbs	136.08	kg
Total Mass			549.80	kg
Total Weight			5388.00	N
Tire rolling resistance coefficient, C_r			0.0724	
Drivetrain efficiency			0.7	
Speed			10	km/h
Pack Voltage			48	V
			(72)	V

Table 2: Constant Values Used in Power Calculations

	Dieppe	Rocky (Red)	Rocky (Blue)	Burned Hill	Lake Hertel
Total Distance, km	3.00	2.95	1.83	0.83	0.72
Total Time, s	1080.00	1062.00	657.00	297.00	260.64
Total Energy Consumed, W-h	886.58	751.40	528.68	339.48	211.32
Vehicle Efficiency, W-h/km	295.53	254.70	289.69	411.49	291.88
Average Power required, kW	2.96	2.55	2.90	4.11	2.92
Max Power required, kW	14.97	9.47	10.34	10.07	9.83
Average Current consumed, A	61.57 (41.05)	53.07 (35.38)	60.35 (40.23)	85.73 (57.15)	60.81 (40.54)
Max Current Consumed, A	311.95 (207.97)	197.37 (131.58)	215.49 (143.66)	209.89 (139.93)	204.71 (136.47)
Battery Pack capacity required, Ah	18.47 (12.31)	15.65 (10.44)	11.08 (7.34)	7.07 (4.72)	4.40 (2.94)

Table 3: Power Consumption Data for All Five Trails

In the table above, note that the total time is that required to travel the uphill distance at 10km/hr. Once the energy to maintain this constant speed was calculated (shown below in the 'Sample Calculations' section), the following are determined. Note that the battery pack voltage corresponds to a value of 48V and (72V) respectively. Being able to compare both results will ultimately make it easier to decide which configuration best suits the project's needs.

- Vehicle efficiency = (total energy consumed) / (total distance)
- Average power required (kW) = (total energy) / (total time) / 1000
- The maximum power required is the maximum power for any given point on the trail.
- Average current consumed (A) = (Average power x 1000) / (battery pack voltage)
- Maximum current consumed (A) = (Max power x 1000) / (battery pack voltage)
- Battery pack capacity required (A-h) = (Total energy consumed) / (battery pack voltage)

All of the necessary variables were determined using an Excel spreadsheet. Tabulating the above data and a few simple calculations gave rise to the following results, while sample power calculations can be seen in the following section.

Total Average Power Required	3.09	kW
Absolute Maximum Power Required	14.97	kW
Total Average Energy Consumed	543.49	W-h
Average Vehicle Efficiency	308.66	W-h/km
Total Average Current Consumed	64.30 (42.87)	A A
Absolute Maximum Current Consumed	311.95 (207.97)	A A
Average Battery Pack Capacity Required	11.32 (7.55)	A-h A-h

Table 4: Average Power Values

Note that the total average values in the table above were calculated from table 3, by taking an average of the total values from each of the five trails. The absolute maximum power and current is simply the maximum of the average values listed for each trail. Both maximum power and current happened to pertain to the Dieppe trail. Clearly, satisfying the capability to ascend this trail would imply similar capabilities on all other trails.

It was evident that our assumption of a constant 10 km/h speed up every trail would result in some discrepancies. For example, if a rapid incline were met along the trail, realistically, the ATV would decelerate slightly over that section as opposed to consume a large amount of current in order to maintain speed. To identify some of these situations, current versus time plots were developed for each trail in order to identify the outliers. The plot for one of these trails (Rockly blue) is shown in figure 2 below:

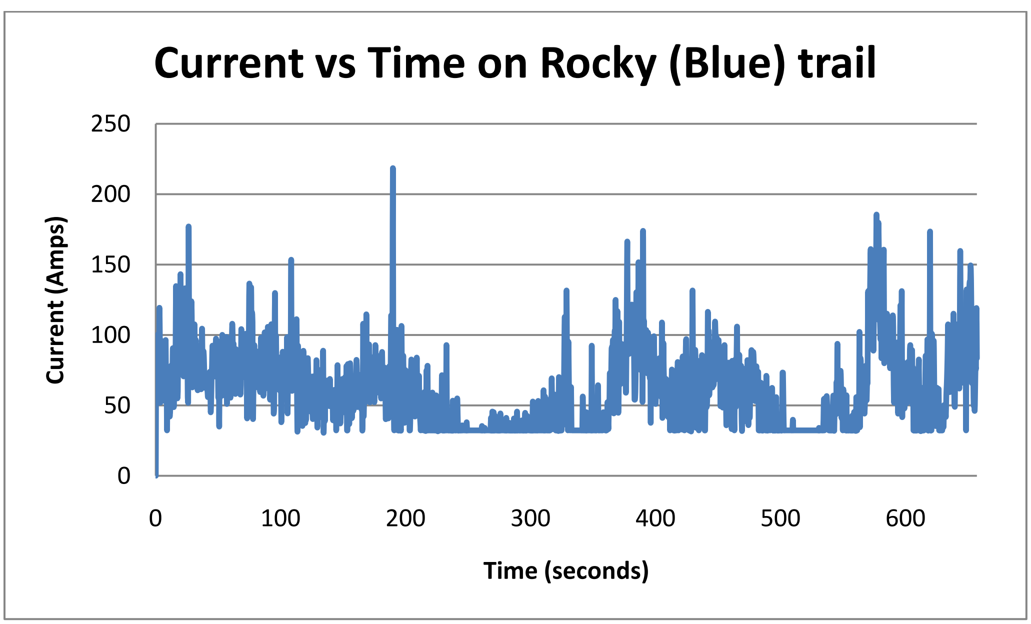


Figure 2: Current as a Function of Time for Rocky (Blue) Trail

It is evident from the above plot that there are instances where an excessive amount of current is consumed over a very short period of time. These instances correspond to the situation discussed above, where a short, rapid incline is met along the trail. It can be observed that a baseline value of approximately 40 amps is established in this graph. This is due to the formulas used to calculate the power requirements to travel uphill in the spreadsheet. Whenever a data point with a negative change in elevation was encountered, the direction of the weight of the ATV along that slope would change sign and aid the ATV in moving rather than opposing it.

$$\sum F_{on\ ATV} = -F_{rolling\ resistance} + F_{hill} = F_T$$

We are only interested in the force needed to travel uphill to keep the ATV from rolling backwards therefore; the hill force is set to 0 whenever this occurs. This in turn would mean that the minimum current drawn by the vehicle would be solely based on the rolling resistance force. The baseline of ~40 is understood when looking at the equation of the rolling resistance force and understanding that all changes in elevation on the trails are extremely small:

$$F_{rolling} = m_{ATV} g C_r \cos\theta \approx m_{ATV} g C_r$$

The above figure, however, is not very clear and as a result it was beneficial to develop power and current histograms in order to visualize the ranges of power and current being consumed over a given distance on the trails. Three plots for 48V and (72V) battery packs are shown below:

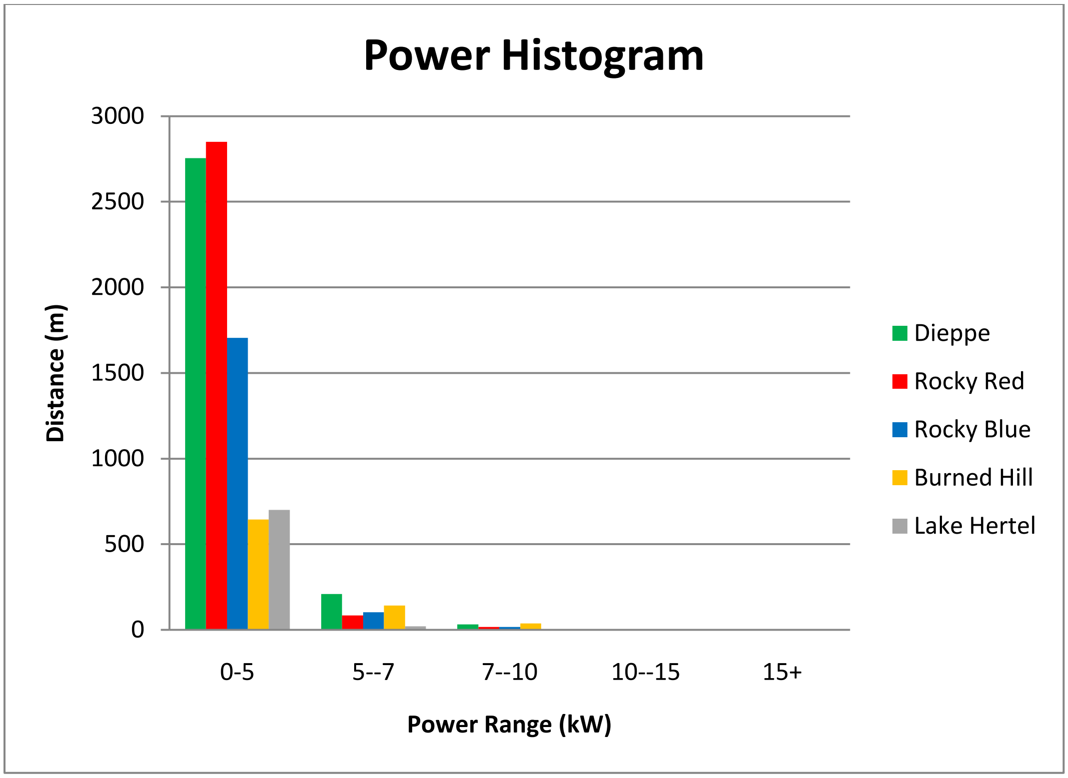


Figure 3: Power Histogram for the Five Trails regardless of battery pack

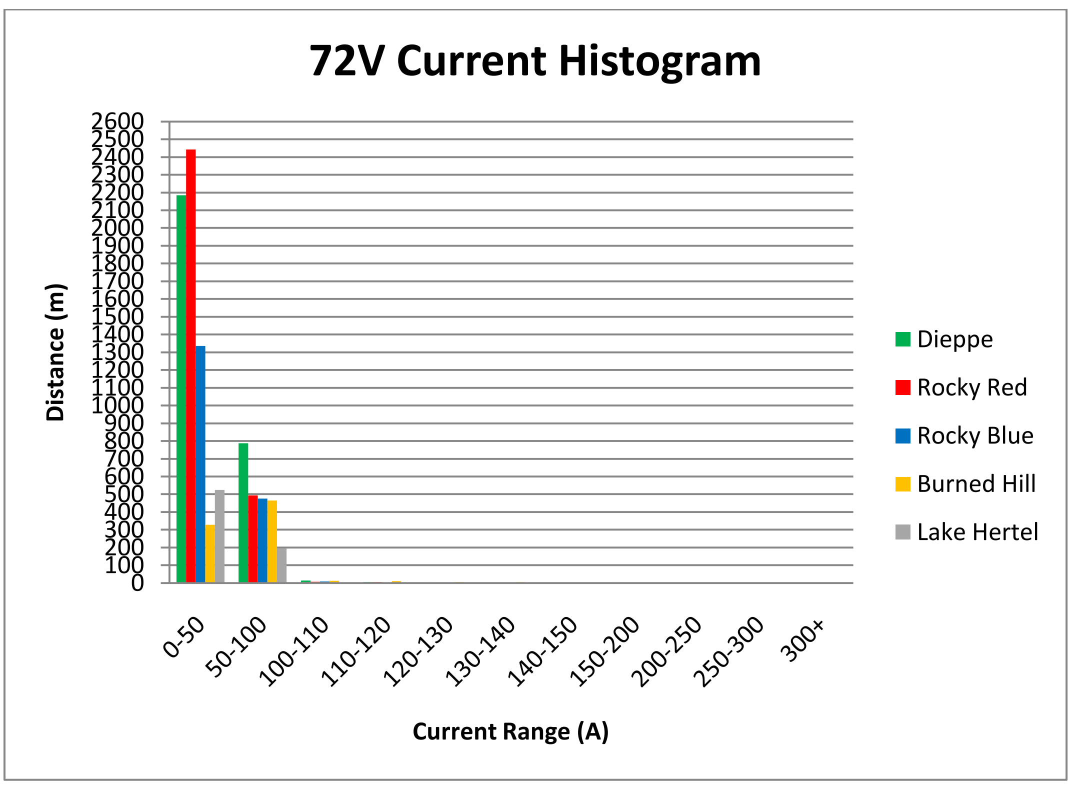


Figure 4: Current Histogram for the Five Trails with 48 V Battery Pack

According to the three plots above, the power consumption is mainly in the range of 0-5 kW, with a few instances where 5-7 kW is needed. Rarely does the power consumption climb above 7 kW. With regards to current consumption, most of the time, less than 200 amps are consumed with a pack voltage of 48V. When the calculations are repeated with the 72V pack, it is clear that there is a current drop and that disregarding several outliers, the current draw would never exceed 100 Amps.

Based on the daily usage requirements provided by the client at the GNR, the specific battery capacity in amp-hours was calculated for each of the daily tasks that the ATV is required to perform. Each trip was associated with a trail that best approximates the inclinations involved. The results of the calculations are shown in the table below. Details on how to obtain these specific battery capacities are shown in the sample calculations 'daily battery capacity used' section below.

Time	Distance round trip (m)	Explanation	Associated Trail	48V Battery Capacity (Ah)	72V Battery Capacity (Ah)
8:30h	7000	Going up and down to Dieppe with two people to repair a vandalized sign (trailer and small tools)	Dieppe	22.29	14.86
11h	1400	Pavilion to Gault House for maintenance in the Research Bld. (trailer and small tools)	Hertel	5.27	3.51
12:15h	600	Pavilion to gate house replacement of staff (no trailer)	See Gatehouse Sheet	2.05	1.36
13h	1000	Pavilion to Chalet for maintenance	Hertel	2.84	1.89
15h	1800	Pavilion to Picnic area for garbage pickup (trailer)	Hertel	6.78	4.51
16h	1400	Pavilion to Gault House for maintenance in the Research Bld.	Hertel	3.97	2.64
17h	600	Pavilion to gate house replacement of staff (no trailer)	Hertel	1.70	1.13
19h	1800	Closing of the gate at the picnic area	Hertel	5.10	3.39
Total	**15.6 km**	---	---	**53.68**	**33.29**

Table 5: Battery capacity based on daily usage

For the purposes of the calculations, one driver without a trailer was used unless the explanation explicitly called for a trailer and/or second driver. Illustrated in the table above, a majority of the trips used the data from Lake Hertel. The total amp-hours required for a typical day at GNR totaled to 53.68 Ah for the 48V pack and for the 33.29 Ah for the 72V pack. In order to provide the user with sufficient battery capacity for those instances where more usage is needed, it was determined that a battery pack capable of providing up to 100 Ah for the 48V and 60-70 Ah for the 72V pack.

The next step in the design was to convert a given motor rotation speed in revolutions per minute into an attainable ATV speed in km/h. In order to do this, the overall gear ratios for both high and low gears on the transmission needed to be determined, performed most accurately by means of experimentation.

This experiment consisted of rolling the loaded ATV (2 passengers) and counting the number of rotations of the transmission axle as one full tire revolution was made; the front left tire was marked, as was the transmission axle. Following such a procedure, a full revolution of the tire was made both in high gear and in low gear, and the number of revolutions of the transmission axle was 19 and 10 respectively. Note that this gear ratio is the product of the differential gear ratio and transmission gear ratio. It was also possible to record the effective circumference of the wheel by recording the distance travelled during one revolution. The effective wheel radius was determined to be 299.085 mm; this corresponds to a diameter of 23.5 inches significantly less than the unloaded 26 inch diameter.

Originally, the ATV was equipped with a CVT transmission. After determining that an AC electric motor would be used in the conversion, it was clear that with such a wide RPM range and high torque exhibited by the HPEV line of motors, there was no need for a CVT. This would not only eliminate a source of mechanical losses but would also simplify the design and thus reduce possible failure modes that were difficult to predict.

A fixed gear ratio timing belt system would be installed in its place. Using the clients input of travelling at average speeds of 5, 10 and 15 km/h and using the data provided by the McGill University Dyno testing of the HPEV AC-15 with a Curtis 1238 controller, we were able to determine a suitable gear ratio. The results of the dyno testing with a 72V battery pack are shown below:

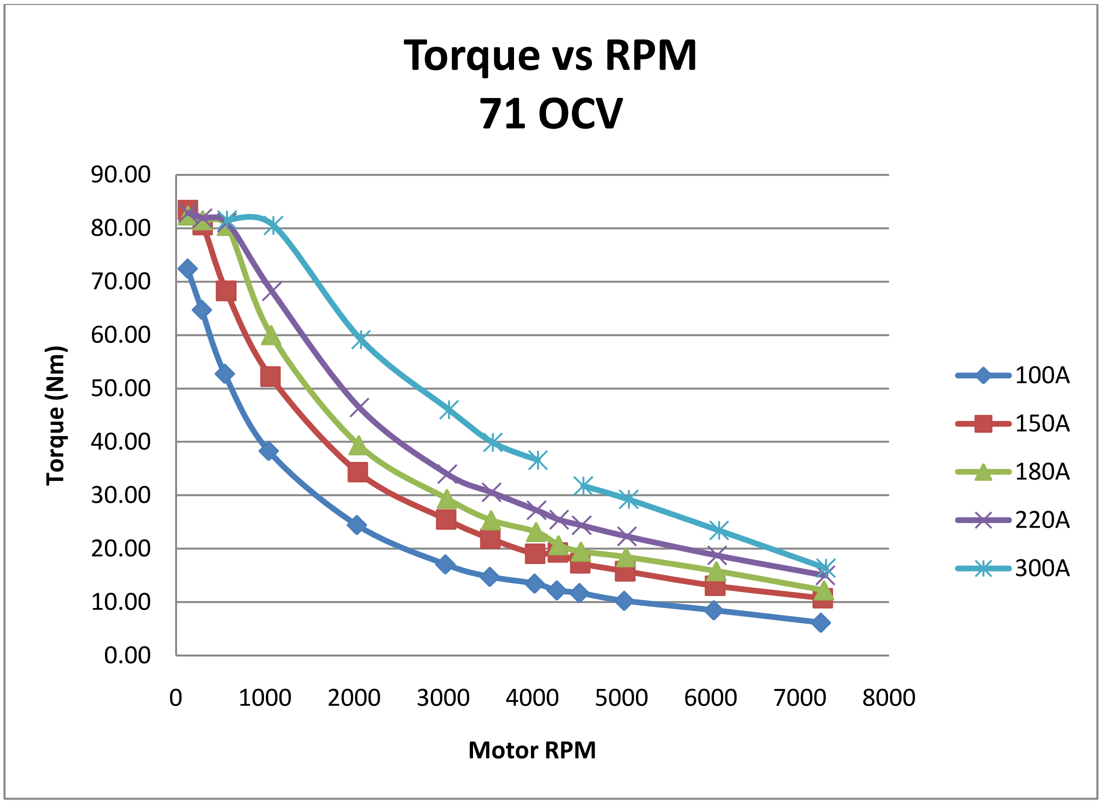


Figure 5: Torque vs. Motor RPM Dyno Testing Results with a 72V Battery Pack

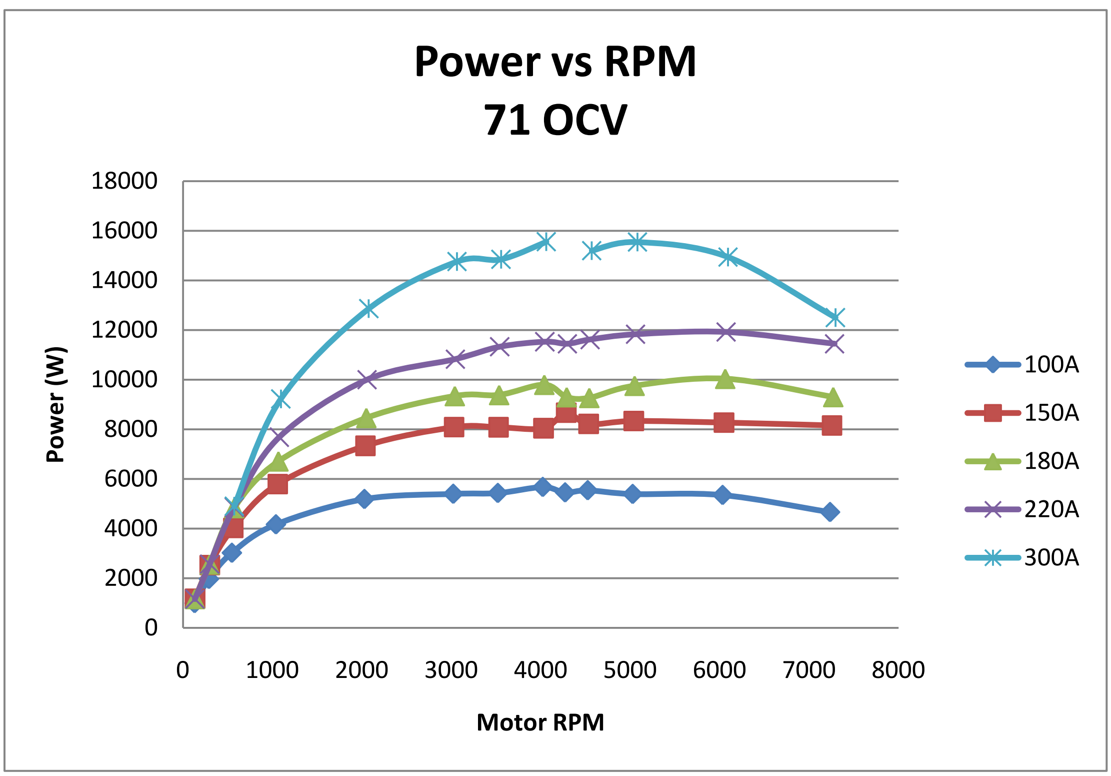


Figure 6: Power vs. Motor RPM Dyno Testing Results with a 72V Battery Pack

Assuming a final pack voltage of 72V with 60-70 Ah and a continuous discharge rate of 3C, the continuous current drawn from the battery pack is calculated as:

$$Continuous\ Current\ Drawn = 3C \cdot 60Ah - 70Ah = 180A - 210A$$

Thus, based on the above torque and power graphs, the functioning of the ATV will be associated with either the green (lower limit) or the purple (upper limit) curves. Most industry standard components are capable of handling currents in excess if 300 A, thus the difference between choosing the green and purple curves in terms of amperage is negligible. However, in our analysis, we will take the lower limit or the green curve, given that it represents a worst case scenario in terms of power and torque available.

It should be noted that in a real life scenario, it is highly unlikely that the motor-controller would accurately follow the data presented by the curves. Furthermore, in order to properly predict the actual results, it is safe to assume that the values for torque, horsepower and efficiency will likely lie somewhere under the green curve. Only when the throttle is engaged in situations where the ATV would require maximum acceleration would the system operate at maximum specifications for a given current limit.[1]

Using the data recorded from the dynamometer and the power required tables, it is confirmed that the AC-15 will with a battery pack capable of delivering between 180 and 220 A continuously would fulfill the power requirements of 5 -7 kW continuous for our application. Below is the efficiency graph based on the plots in figures 5 and 6:

[1] Quote from Simon Ouellette

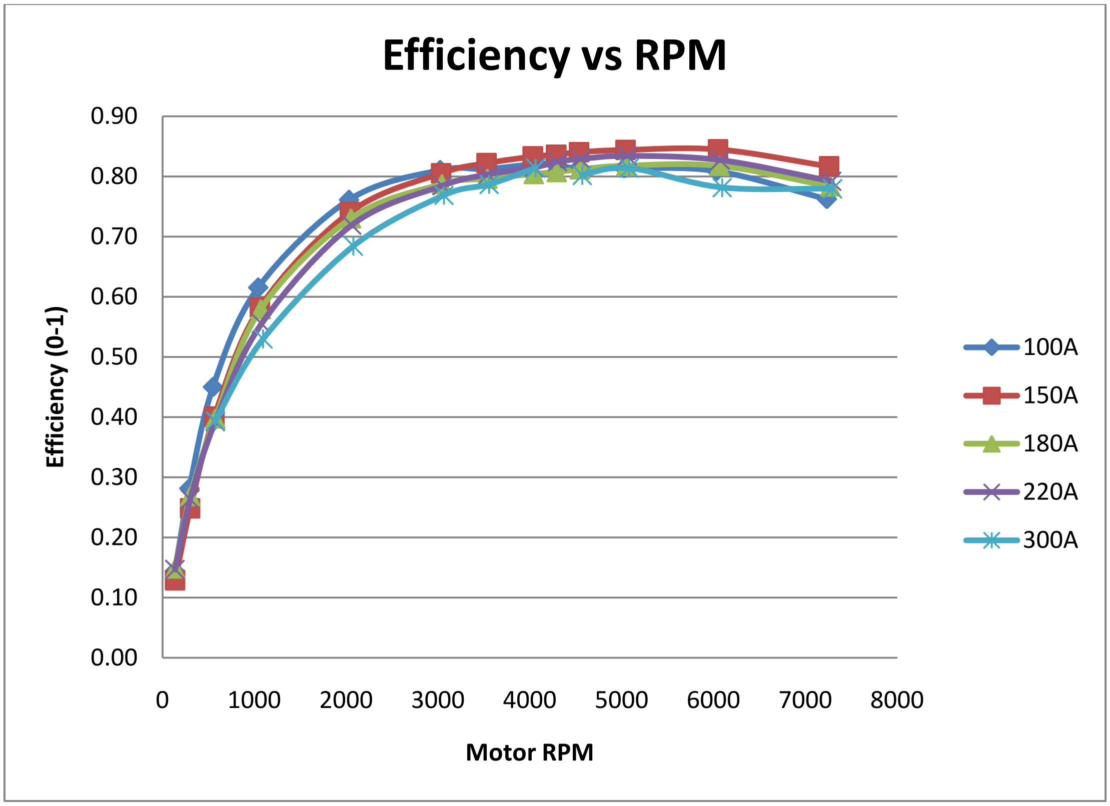


Figure 7: Efficiency vs. Motor RPM Dyno Testing Results with a 72V Battery Pack

The “Efficiency vs RPM” graph above reveals that in order to run as efficiently as possible, the motor should be operating above 4000 rpm. This would yield an efficiency of approximately 80%. Conversely, in order to take advantage of the majority of the AC-15’s torque, the motor should be operated between 1000 and 2000 rpm where the electric motor approximately matches the stock internal combustion engine’s max torque of 73 N-m.

Although it is difficult to put an exact limit on usable rpm range, a general rpm range that has the best combination of efficiency, power and torque must be identified. This rpm range must incorporate the 5, 10, 15 km/h and 25km/h coasting travel speeds as specified by the client. This data is critical for the selection of a gear ratio for the belt. The conclusions that can be drawn from the dynamometer results are that when towing a heavy load, the ATV’s electric motor should operate at low rpm and maintain desired cruising speeds at or above 4000 rpm to maximize efficiency. A gear ratio of 2.5:1 was selected as a compromise between torque and efficiency, allowing for the average travel speeds to correspond with an RPM range between 2500 and 4500 rpm in high gear. It is likely that an exact gear ratio of 2.5 will not be able to be achieved given availability and industry standard diameters of pulleys, therefore an acceptable range between 2.4 and 2.6 is acceptable. The following table summarizes the attainable speeds for a range of rpm with the selected gear ratio.

Engine RPM	Low Gear	High Gear
0	0.0	0.0
500	1.2	2.3
1000	2.4	4.5
1500	3.6	6.8
2000	4.7	9.0
2500	5.9	11.3
3000	7.1	13.5
3500	8.3	15.8
4000	9.5	18.0
4500	10.7	20.3
5000	11.9	22.5
5500	13.1	24.8
6000	14.2	27.1
6500	15.4	29.3
6750	16.0	30.4
7000	16.6	31.6
7500	17.8	33.8
8000	19.0	36.1

Table 6: Speed as a function of RPM for low and high gears

Sample Calculations

Power Requirements

The following sets of calculations are performed on the tenth set of data values on the "Dieppe" trail. This trail offers the longest ATV accessible terrain as well as a variety of ranges of slope gradients and was therefore the focus of these calculations. The calculations were performed over each meter of each path using the GIS data provided by David Maneli at the GNR. The data includes changes in elevation along interval distances of one meter for each of the five selected paths. For the purpose of dynamic calculations, a time interval between each data point was needed. Assuming a *constant* vehicle speed of 10 km/h at all intervals:

Change in elevation $\Delta z = z_2 - z_1 = 134.033 - 133.887 = 0.146\ m$

Time interval (@ 10km/h) $\Delta t = t_2 - t_1 = 2.88 - 2.52 = 0.36\ s$

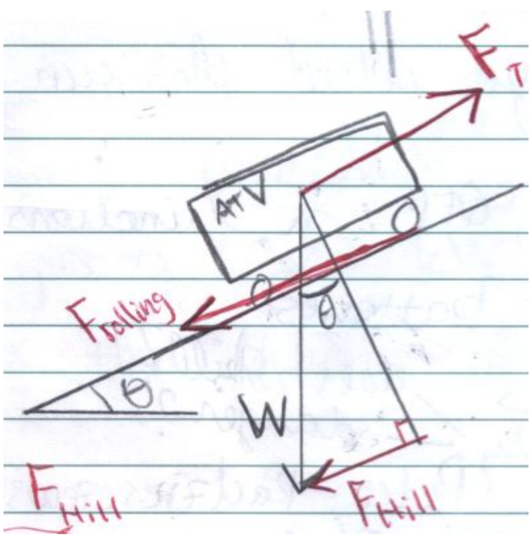
Slope Gradient $\theta = \sin^{-1}\frac{0.146}{1} = 8.395°$

- Note that for the slope gradient calculation, the hypotenuse corresponds to the distance travelled along the hill, or a uniform 1 meter.

In order to calculate the forces acting on the ATV at any given point on the trail, the mass of the ATV must be determined. For simplicity, the mass of the ATV is split between the ATV itself, the riders and the trailer as follows:

$$m_{vehicle} = 712.09lbs \quad m_{rider} = 200\ lbs \quad m_{trailer} = 300\ lbs$$
$$= 323.00kg \quad = 90.72kg \quad = 136.08kg$$
$$m_{ATV} = m_{vehicle} + m_{rider} + m_{trailer} = \mathbf{549.80}\ kg$$

The forces acting on the ATV included the rolling resistance originating from the tires as well as the force of the hill due to the weight of the vehicle. The force due to air resistance is negligible due to its minimal effect in comparison to the rolling resistance and weight. The following free body diagram illustrates the forces acting on the ATV at a given point on the trail. Note that the coefficient of rolling resistance, C_r, has been assumed linear with respect to the normal of the slope therefore the fore-aft weight distribution was not needed.



$$\theta = \sin^{-1}\frac{\Delta z}{\Delta d} = \sin^{-1}\frac{0.146}{1} = 8.395°$$

$$F_{rolling} = m_{ATV} g C_r \cos\theta$$
$$= 549.80 \times 9.8 \times 0.0724 \times \cos(8.395)$$
$$= \mathbf{385.91}N$$

$$F_{hill} = m_{ATV} \times g \times \frac{\Delta z}{\Delta d} = 549.80 \times 9.8 \times \frac{0.146}{1}$$
$$= \mathbf{786.65}N$$

$$F_T = F_{rolling} + F_{hill} = \mathbf{1172.56}N$$

Now, the energy and power required to maintain the ATV at constant speed can be calculated:

$$E_{\substack{to\ maintain\\ speed}} = \frac{(F_{rolling} + F_{hill}) \times \Delta d}{\eta_{drivetrain}} = \frac{(385.91 + 786.65) \times 1}{0.7} = \mathbf{1675.08}\ J$$

$$P_{\substack{to\ maintain\\ speed}} = \frac{E_{\substack{to\ maintain\\ speed}}}{\Delta t} = \frac{1675.08}{0.36} = 4653.12\ W = \mathbf{4.65}\ kW$$

Note that the coefficient of rolling resistance (C_r) and the drivetrain efficiency ($\eta_{drivetrain}$) are assumed constant. Justification for this is provided in the appendix.

An estimate of the total linear distance travelled by the ATV along each path can be estimated using the scale provided. The green trail "Dieppe" is estimated at about 2.8 km, but 200m is added to account for human error. The calculated distance accounts for the first 3000 data points provided for this trail and therefore:

$$d_{\substack{total \\ dieppe}} = n \times \Delta d = 3000 \times 1 = \mathbf{3}\ km$$

$$t_{\substack{total \\ dieppe}} = n \times \Delta t = 3000 \times 0.36 = \mathbf{1080}\ s$$

With the data for every point on the trail, the average and maximum values of the energy and power requirements can be determined. The results are summarized below:

$$E_{\substack{total \\ consumed}} = \sum E_{\substack{to\ maintain \\ speed}} \times \frac{1\ W-h}{3600\ J} = \frac{3191704.04}{3600} = \mathbf{886.58}\ W-h$$

$$\eta_{vehicle} = \frac{E_{total\ consumed}}{d_{total\ dieppe}} = \frac{886.58}{3} = \mathbf{295.53}\ W-h/km$$

$$P_{avg} = \frac{\sum E_{to\ maintain\ speed}}{t_{total\ dieppe}} = \frac{3191704.04}{1080} = 2955.28\ W = \mathbf{2.96}\ kW$$

$$P_{max} = \max_{0 \leq x \leq 3000} P_{\substack{to\ maintain \\ speed}} = \mathbf{14.97}\ kW$$

To incorporate the acceleration of the ATV at any point on the trail, a separate calculation is performed. The acceleration must be assumed, and for our purpose we chose to accelerate to 10 km/h over 2 seconds; equivalent to a final velocity of 2.78 m/s. The energy and power required to attain this speed, starting from a standstill, are calculated according to the following equations:

$$E_{\substack{required\ to \\ accelerate}} = \frac{1}{2} m_{ATV} (v_2 - v_1)^2 = \frac{1}{2} \times 549.80 \times (2.78 - 0)^2 = 2449.96\ J = 2.45\ kJ$$

$$P_{\substack{required\ to \\ accelerate}} = \frac{E_{\substack{required\ to \\ accelerate}}}{t} = \frac{2449.96}{2} = 1224.98\ W = \mathbf{1.22}\ kW$$

Here, rotational kinetic energy has been assumed negligible. This introduces a source of error.

Based on conversations with various McGill design teams, a proper approximation for overall continuous power would require a doubling of the calculated value. To ensure that the ATV will be powerful enough to perform on any of the trails, a motor that supplies the appropriate power must be chosen. This implies that a suitable motor will have the following minimum average and maximum power:

$$P_{\substack{avg\\motor}} \geq P_{\substack{avg\ to\\maintain\ speed}} + P_{\substack{required\ to\\accelerate}}$$
$$P_{\substack{max\\motor}} \geq P_{\substack{\max to\\maintain\ speed}} + P_{\substack{required\ to\\accelerate}}$$

The above inequalities depend on the power required to accelerate to 10km/h. However, it was verified in the calculations that the energy and power required to accelerate to 10km/h are not critical, merely serving for purposes of comparison. The calculations confirmed that the majority of the power output is due to travelling uphill, rather than sporadic straight line acceleration. The significance of this result lies in the specifics of the motor selection. Thus, for the purposes of the specific functioning of this ATV, $P_{\substack{required\ to\\accelerate}}$ is assumed negligible.

Now, calculating the average and maximum current consumed based on a 48V battery pack.

$$I_{\substack{avg\\consumed}} = \frac{P_{avg}}{V_{pack}} = \frac{2955.28}{48} = \mathbf{61.57}\ A$$
$$I_{\substack{max\\consumed}} = \frac{P_{max}}{V_{pack}} = \frac{14973.64}{48} = \mathbf{311.95}\ A$$
$$Battery\ Pack\ Capacity\ required = \frac{E_{\substack{total\\consumed}}}{V_{pack}} = \frac{886.58}{48} = \mathbf{18.47}\ A-h\ per\ climb$$

Daily Battery Capacity Used

Using the information provided in 'table 5' which outlines a typical day of ATV use at the GNR, trails of similar inclinations were associated with each trip. Then, using the excel power requirement spreadsheet for uphill and downhill travel, the amp hours for the trips individual trips were calculated as a ratio of the original trails. For example, trip 4 is associated with inclinations similar to the trail of 'Lake Hertel', however it is a trip that is 1000m in length. Thus, since the trip distances are not exactly equal to the trail distance, a ratio is used to relate the 'Lake Hertel' data to each individual trip. From the power requirement spreadsheet, the battery capacity associated with riding up and down the 'Lake Hertel' trail with one driver and no trailer was calculated to be 3.97 Ah. Then, the required battery capacity for the trip is calculated as follows:

$$Battery\ Capacity = \frac{1000}{1400} \cdot 3.97 = 2.84\ Ah$$

For the situation where a trailer is attached to the ATV, the total battery capacity to travel the 'Lake Hertel' trail increases to 5.27 Ah with one driver. Thus, the battery capacity for the trip is:

$$Battery\ Capacity = \frac{1000}{1400} \cdot 5.27 = 3.76\ Ah$$

Similar comparison methods were used to calculate the battery capacity for the other trips.

Speeds with Final Drive Ratio

In order to calculate the speed the ATV will be travelling in a certain gear, the following formula was used:

$$speed, s\ \left[\frac{km}{h}\right] = \frac{\left(RPM \cdot \frac{1\ min}{60\ sec} \cdot \pi(2 \cdot R_{\text{wheel}})\,\frac{mm}{rev} \cdot \frac{1\quad m}{1000mm} \cdot \frac{1\ \ km}{1000\ m} \cdot \frac{3600\ s}{1\quad hr}\right)}{Overall\ Gear\ Ratio}$$

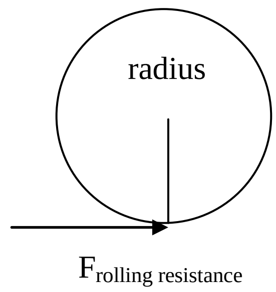
With an engine speed of 500 RPM in high gear (10:1 gear ratio)

$$s = \frac{\left(500\,\frac{rev}{min} \cdot \frac{1\ min}{60\ sec} \cdot \pi(2 \cdot 299.085)\,\frac{mm}{rev} \cdot \frac{1\quad m}{1000mm} \cdot \frac{1\ \ km}{1000\ m} \cdot \frac{3600\ s}{1\quad hr}\right)}{47.502} = 1.19\,\frac{km}{h}$$

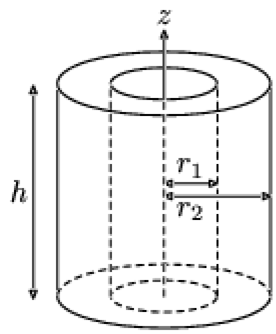
Note that the indicated gear ratio in this case assumes a direct drive between the motor and transmission through a belt and sprocket system.

Torque Required at the Wheels

The torque required at the wheels is a combination of the torque induced by the rolling resistance and the amount of torque need to turn the wheel about its axis.



$$T_r = F_{rr} \cdot radius = \ 1172.56N \cdot 0.299m = 350.60Nm$$



Next, we calculated the torque required to turn the wheel about its axis, which requires a calculation of the moment of inertia about the z-axis. Here, it is assumed that the weight distribution is centralized in the tire. Note that since the rear tires are larger than the front tires, the rear ones were used for the calculations as they represent the worst case scenario.

$$I_z = \frac{1}{2}m({r_1}^2 + {r_2}^2) = \frac{1}{2}\rho h\pi({r_2}^2 - {r_1}^2)({r_1}^2 + {r_2}^2)$$

$$I_z = \frac{1}{2} \cdot 1200\frac{kg}{m^3} \cdot 0.254m \cdot \pi \cdot [(0.299m)^2 - (0.165m)^2] \cdot [(0.165m)^2 + (0.299m)^2]$$

$$I_z = 3.47 \ kg \cdot m^2$$

The torque associated with the moment of inertia of the rear wheels is given by the equation below, where ⍰ = ⍰/⍰.

$$T_z = I_z\alpha = 3.47kg \cdot m^2 \cdot \frac{1.38\frac{m}{s^2}}{0.299m} = 4.62 \ Nm$$

Thus the total torque needed is:

$$T_{needed} = T_r + \ T_z = 350.60 \ Nm + 4.62 \ Nm = 355.22 \ Nm$$

$$T_{needed} = 355.22 \ Nm \cdot 0.74\frac{ft \cdot lbs}{Nm} = 262.0 \ ft \cdot lbs$$

The most torque required at the motor would be while driving in high gear. Thus the torque required at the motor is:

$$T_{motor} = \frac{262.0 \ ft \cdot lbs}{gear \ ratio} = \frac{262.0 \ ft \cdot lbs}{10} = 26.2 \ ft \cdot lbs$$

Summary

Based on the power calculations, the specific parameters that the electric components must meet in order to satisfy the daily usage requirements are seen in the table below:

Total Average Power Required	3.09	kW
Absolute Maximum Power Required	14.97	kW
Total Average Current Consumed	64.30 (42.87)	A A
Absolute Maximum Current Consumed	311.95 (207.97)	A A
Battery Pack Capacity Required	53.68 (33.29)	A-h A-h
Motor torque	26.2 35.52	ft-lbs N-m

Table 7: Average values for power requirements

It was determined that it is important to account for instances in which the ATV would require more power in a given day. For example, if the ATV were needed for an emergency or if a very heavy load were placed in the trailer, in addition to two passengers on the ATV. We thus decided that we would select components with more power than the specifications above.

Component Selection

Now that all of the power requirements have been determined, it is possible to begin the selection of our main electrical components. These include:

- Electric motor
- Controller
- Timing belt drive
- Electric throttle
- Charger/DC-DC converter
- Battery pack and associated battery management system.

Electric Motor and Controller:

Based on the power calculations, our first choice of motor was a 48V AC motor, outputting a current of 650 A, 26 HP (19.12 kW) and 90 ft-lbs. There is no doubt that the specifications of the motor satisfy our requirements in terms of torque and power, even going as far as over-compensating for the extreme scenarios, as has been mentioned in the previous section. However, further analysis demonstrated that for our particular use, this elevated current of 650 A would result in extremely high I^2R power losses. Thus, the solution was to go with a HPEV AC-15 72V AC motor, and run it at 72V or 48V depending on the battery pack acquired. This motor would be able to give us the same required power and torque while reducing the current and thus the power losses. Refer to excel graphs in the “Design Embodiment” section for power, torque and efficiency details and to Appendix C for detailed drawings.

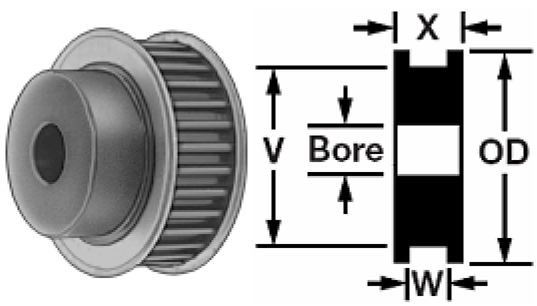
The controller selection is based on the motor. The Curtis 1236 and 1238 are the two controller offered for the HPEV line of motors. The 1236 model is smaller and less performance oriented, more likely to overheat in heavy duty applications. The 1238 model is larger and a higher end model geared towards an increased performance. It is also more dependable under continued use conditions. Thus, the 1238 Curtis controller would ideally be the preferred model. With a maximum current limit of 650 A, the controller would ensure that the limiting factor in the electric system would be the battery pack. Furthermore, if it a later date, the client wishes to purchase more efficient batteries that are more technologically advanced, there will be no worry or potential of overexerting the controller. Ultimately, the decision lies with availability and pricing through our contact, Simon Ouellette. If the 1236 controller becomes the only option and must be implemented, an efficient cooling method will have to be installed during use in order to reduce the risk of overheating. A plausible method for this is to use the fan that was removed from the ATV after receiving it, which served to cool the radiator. Refer to ‘Appendix D’ for a simplified mock up of the controller wiring diagram and for dimensions of the 1238 Curtis Controller.

Both models of the Curtis controller are compatible with any AC motor drive and have been implemented on all types of industrial applications from hydraulic pumps to tow tractors and Airport Ground Support Equipment (GSE).   They have integrated battery state-of-charge algorithms and short circuit protection on all outputs. The controllers are equipped with a thermal cutback, warning and automatic shutdown safeguards in order to protect the motor and controller. Curtis controllers are ruggedly sealed and their connectors meet IP65 standards. IP65 compliance is critical in an off road application such as an ATV, where electric wiring and components will be in continuous contact with the elements. In addition, the electric snowmobile and formula hybrid McGill design teams are very familiar with these controllers, having nothing but positive feedback to give and expressing a willingness to help in its installation and programming.

Timing Belt Drive:

In order to obtain the desired gear ratio of 2.5, two standard steel pulleys were selected from the ‘McMaster’ website. Upon comparing the two pitch diameters of 2.206” (motor) and 5.614” (transmission), a gear ratio of 2.5448 is obtained. All components are from the “HTD Series, Power Grip GT Series”.

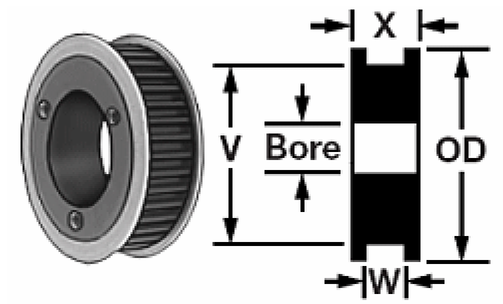
Motor Shaft Pulley:



Pulley Type	Drive Pulleys
For Belt Type	Timing Belt Pulleys
Timing Belt Series	HTD Series, Power Grip GT Series
Number of Teeth on Pulley	22
System of Measurement	Metric
For Timing Belt Width	20 mm
Outside Diameter	2.56"
Bore Type	Plain Bore
Bore Size (ID)	1/2" (Machinable to 1-3/16")
W-Dimension	7/8"
X-Dimension	1-1/8"
V-Dimension (Pitch Dia.)	2.206"
Pitch	8 mm
Pulley Material	Steel

This pulley (6497K111) will be mounted to the motor shaft by machining the inner diameter to match the motor shaft diameter of 7/8”. Additionally, a keyway will have to be machined in order to match the ¼” keyway in the motor shaft. The pulley and keyway will then be press-fit together.

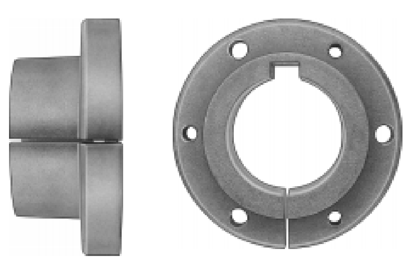
Transmission Shaft Pulley (6497K123):

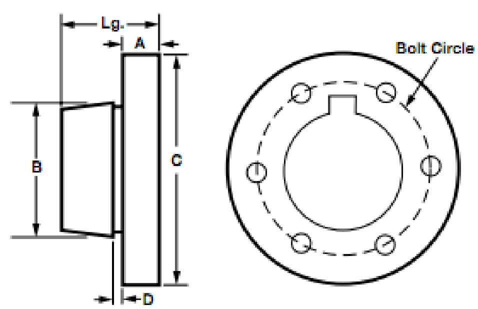


Pulley Type	Drive Pulleys
For Belt Type	Timing Belt Pulleys
Timing Belt Series	HTD Series, Power Grip GT Series
Number of Teeth on Pulley	56
System of Measurement	Metric
For Timing Belt Width	20 mm
Outside Diameter	5.95"
Bore Type	Bushing Bore
Bore Size (ID)	2.187"
W-Dimension	7/8"
X-Dimension	1-1/8"
V-Dimension (Pitch Dia.)	5.614"
Pitch	8 mm
Pulley Material	Steel
Bushing Type	SDS Style Quick-Disconnect Bushing
Bushing Part Number	6086K13

The transmission side will have a 5.95" outer diameter pulley that will be coupled with a quick disconnect bushing (shown in the following section). Both components will be of the SDS style. The SDS bushing includes three cap screws. As the cap screws are tightened, the bushing grips the shaft and pulls it into the pulley, thus preventing any slip from occurring.

Transmission Pulley Bushing:





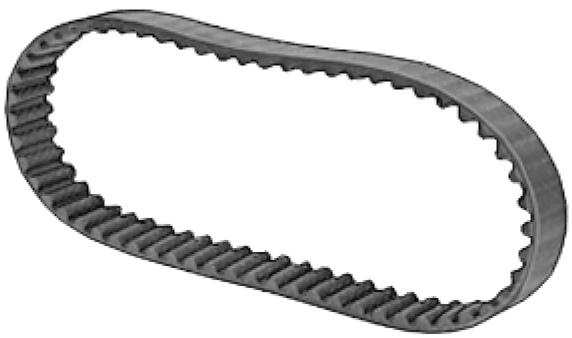
Style	Dimensions (Inches)						Cap Screws Included	
	(A)	(B)	(C)	(D)	Lg.	Bolt Circle	Qty.	Size
SDS	½"	2³⁄₁₆"	3³⁄₁₆"	⅛"	1⅜"	2¹¹⁄₁₆"	3	¼"-20x1⅜"

This bushing (6086K13) can be ordered in any bore size. A 21mm bore to match that of the transmission shaft will be ordered.

It should be noted that the same style would have been preferred on the motor side as well but in order to obtain the correct gear ratio and because of the limited selection of pulleys from the manufacture at that size, this was not possible. If time allows, the possibility of machining a similar bushing for the smaller pulley can be explored.

Timing Belt and Belt Guard:

The 800mm timing belt (6486K116) has curved tooth profiles which will allow for good surface contact between the pulleys and the belt. It will allow for a strong grip, quiet operation in comparison to a chain, and most importantly, high torque capacity. The belt has an 8mm pitch and is made of neoprene rubber with fiberglass cords.



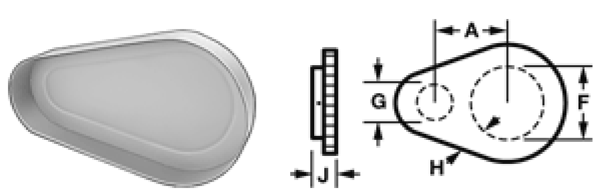
Form	Belts
Type	Timing Belts
Timing Belt Type	Single-Sided with Curved Teeth
Material	Neoprene
Cord Material	Fiberglass
Number of Teeth	100
Outer Circle	800 mm
Belt Width	20 mm
Timing Belt Series	HTD Series, Power Grip GT Series
Pitch	8 mm
Trade Size	800-8M
Color	Black

In order to protect the belt drive a belt cover or guard will be implemented. This will ensure that the belt and pulleys will not be damaged and protect the user from any moving parts on the drive itself. Again, a custom belt cover will be ordered from McMaster. Below are directions for sizing the custom belt guard.

Custom Guards

Similar to the guards above, but custom sizes.

To Order: Step 1: Choose the correct part number you need by determining your order size, which is found by adding the center-to-center distance of your sprockets (A) to the OD of your larger sprocket (F). Step 2: Please specify the actual center-to-center distance of your sprockets (A), large sprocket OD (F), small sprocket OD (G), clearance between sprocket and side of guard (H)—standard clearance is 2", and guard depth—largest sprocket width (J) plus 1".

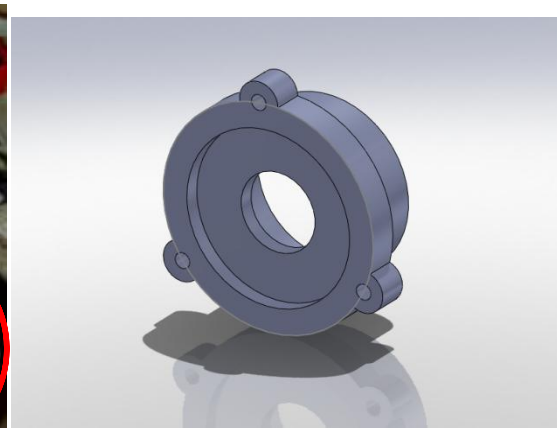


Custom Guard Dimensions

This cover will be mounted to a plate/support that will be bolted to the stock transmission bolt holes as well as holes in the motor mount. Obviously, the plate will have tabs with holes corresponding to those drilled in the custom guard cover.

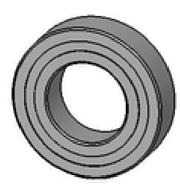
Front Axle Bearing Housing:

The two stock bearing housings are going to be kept in the final design of the electric ATV's power train. This allows for the least modification to the drive train and ensures that all pieces connected to the front axle (elbow joint and front differential) function as intended. It should be noted that the bearings located in the housings are exposed. They will be replaced with sealed equivalents in order to ensure that their internal components remain unobstructed by any small particles.

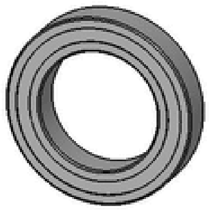


The two sealed equivalents have the following product numbers: 6661K18 and 5972K171. They will be press-fitted into their respective bearing housings.

Type	Ball Bearings
Ball Bearing Style	Double Shielded
Ball Bearing Type	General Purpose
System of Measurement	Metric
For Shaft Diameter	25 mm
Outside Diameter	47 mm
Width	12 mm
ABEC Precision Bearing Rating	ABEC-1
ABEC-1 Precision Rating	Precision Plus
Bearing Trade Number	6005
Dynamic Radial Load Capacity, lbs.	2,680
Maximum rpm	20,000
Temperature Range	+14° to +230° F
Bearing Material	Steel
Shield Material	Steel
Specifications Met	Not Rated
Note	Bearing comes greased. Designated as ABEC-1, these bearings are actually made to higher-precision ABEC-3 dimensional tolerance standards.



Type	Ball Bearings
Ball Bearing Style	Double Shielded
Ball Bearing Type	General Purpose
System of Measurement	Metric
For Shaft Diameter	30 mm
Outside Diameter	47 mm
Width	9 mm
ABEC Precision Bearing Rating	ABEC-1
ABEC-1 Precision Rating	Regular
Bearing Trade Number	6906
Dynamic Radial Load Capacity, lbs.	1,628
Maximum rpm	14,000
Temperature Range	-22° to +230° F
Bearing Material	Steel
Shield Material	Steel
Specifications Met	Not Rated
Note	Bearing comes greased.



Electric Throttle:

The process of selection of an electric throttle or potentiometer is quite simple. The two primary options are either a twist grip throttle, or a spring activated potentiometer operated with the thumb of the user. The twist grip, however, is not ideal for the use of the ATV at Gault given that there is potential for accidental acceleration when entering steep inclines or declines, proving to be extremely dangerous. Thus, a thumb actuated throttle will be used, showed in the image below:

The above Curtis PB-6 style box throttle are the industry standard for electric golf carts and electric automobiles. It is a two-wire box with a micro-switch, designed to be compatible with various controllers on both AC and DC vehicles. It is approximately 3.75 inches in height, 4 inches in width and 2 inches in depth.

Charger/DC-DC Converter:

A DC-DC converter is needed in order for the 12 volt accessories found on the electric ATV to run of a 48 or 72 volt battery pack. With the QuiQ-dci integrated charger/12V converter, the battery pack charger and converter have been combined into one concise package. This cuts the project's cost as well as saves critical space on the ATV. The unit also simplifies wiring because instead of having to connect the high voltage cables to two units found at different locations on the vehicle, there is now only one unit to incorporate into the high voltage line. The charger is fully programmable and compatible with most battery configurations. It will additionally come pre-programmed for our application from the manufacturer. An image of the DC-DC converter/charger is shown below:

The unit has built in reverse polarity and short circuit protection and other safety features that prevent the vehicle from being switched on if it detects that the charger's outlet is connected to the wall. The unit is IP66 rated. It is another component that the McGill teams are quite familiar with and are eager to recommend. Note, in addition, that the company supplying the unit, 'Delta-Q', has a very strong reputation, known to provide electrical components with only the highest quality and reliability to its customers. Refer to 'Appendix E' for dimensions.

Battery Pack and BMS (Battery Management System):

There are a number of factors to consider in the selection of the battery pack, as this is the most expensive component to be purchased. We were informed that once a battery pack has been shipped, it immediately loses a large percentage of its value, and thus when it is time to order it, we must be absolutely certain with our decision. This fact has led us to the decision to test the ATV with available batteries before buying our own. The test batteries belong to Jeff Turner and are Xellerion Ni-Zn Xell-20 cells. The complete specifications can be seen in' Appendix F'. Once we can validate the expected results based on the test batteries, we will then purchase our own battery pack.

During this 'proof of concept' stage, the team will have access to cells to make either a 79.2 V, 20 Ah pack or a 79.2 V, 40 Ah pack. The 20 Ah pack would have a discharge rate of approximately 90 A to 100 A. The 40 Ah pack would have a max discharge of approximately 180 A.[2] A proposed approach is to predict the performance for both the 100 A and 180 A cases. To do this, the 79.2V, 20 Ah would be implemented and tested in order to validate our calculations as well as to ensure that all systems function. Then, another string can be added in parallel combination, thus creating a 79.2V, 40Ah pack. This can be tested to validate the 180 A calculations. For the results of these tests, the ATV team can decide with a significantly elevated confidence level the energy capacity as well as the discharge limits that we will want. One this is decided, all that will be left to do is to size the battery pack accordingly. If however, we find that the performance at 180A is not adequate enough for application such as pulling heavy loads uphill, then we may consider looking into higher power battery packs as oppose to higher energy. In summary, if the vehicle is tested at both discharge rates, conclusions can be drawn based on the performance at each, allowing the battery chemistry, voltage and discharge current to be purchased at a later date with much greater certainty and confidence.

There are two options for the battery pack that we intend to purchase. The first option is a 48V, 100 Ah $LiFeMnPO_4$ battery pack from the company 'GBS', which includes a battery management system. The pack comprises of 16 individual cells packaged into groups of 4 cells. These are the first Chinese cells of this particular chemistry to have passed China's certification for on-road use. The complete specifications can be seen in Appendix G. This certificate requires that the batteries do not catch fire or explode when they are dropped, over-discharged, over-charged, baked, frozen, crushed or pierced with a steel rod. 'GBS' also offers a pack and battery management system rated at 80 V and 60 Ah.

[2] Information obtained from Simon Ouellette

The second option is a military grade 72V battery pack that could potentially purchase at a significant discount. These are an ideal choice because the pack would be smaller and lighter than the GBS option. On board space for components is scarce and size is always of great importance especially when dealing with the battery pack, one of the bigger and heavier components in the conversion project. These military grade LTC cells are approximately 60 mm in diameter and 232 mm in length. This pack is advantageous as it can be configured in almost any shape. In terms of power, the LTC units will deliver a 250 A discharge for a prolonged period of time, and even a 500 A discharge without adverse effects on the cell. As a result, in terms of meeting the power requirements of the vehicle, these cells are not an issue. The pack of LTC cells can be configured to any voltage between 43.2 V and 90 V in steps of 3.6 V. For the application of the electric ATV, the cells would come in 45 Ah modules. Thus, taking any voltage in the specified range, and multiplying it by either 45 Ah or 90 Ah (and so on) will give the available energy 'sizes' in Wh for the ATV. Military grade LTC cells are advantageous as they have undergone rigorous testing and certification and a great deal of data is available in terms of cell performance. This would guarantee that the pack would be of the highest quality and safety. Again, the McGill Design teams are quite familiar with this chemistry and have used them extensively for several years now.

Mounting and Installation

In order to install the electrical components onto the original frame of the vehicle, it was necessary to design custom mounting brackets and supports. The origin in 3-D space or the reference point for these custom parts is the transmission, which was separated from the motor and re-installed onto its original mounts. The front axle shaft that runs through the transmission was originally supported by the motor, and so the new ATV design requires new supports. Both the transmission and front axle shaft are shown in the figure below, with the transmission on the left (rear) and the front axle shaft emerging from it in the center.

Note that for each supporting component, two views will be given; one of the component alone, and another of the component as it will be installed onto the frame of the ATV.

Motor Plate

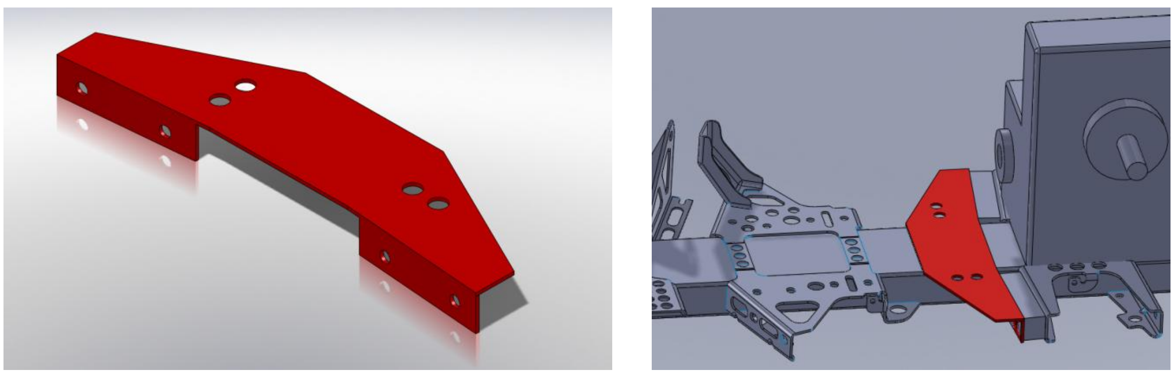


Figure 8: Motor Plate

In order to install a bulk of the component supports, a new plate was designed in order to serve as an additional mounting point. Once this plate is welded to the frame, the front axle shaft support could be bolted onto it (see below). This plate will be welded onto the frame as well as bolted to the existing footrest. There are four holes on the top face that will be used for later components.

Motor Mount

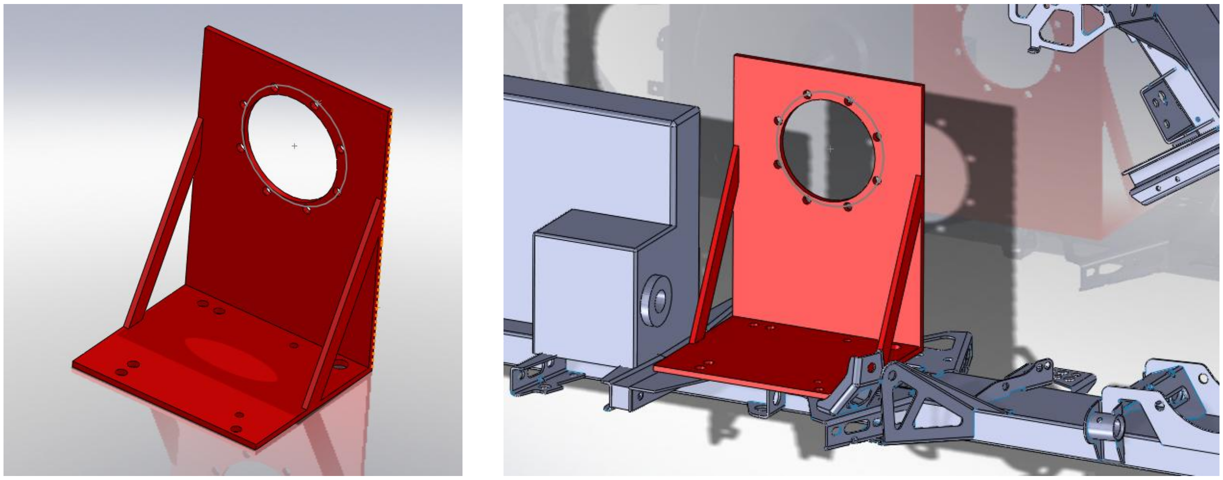


Figure 9: Motor Mount

There are eight equally spaced screw holes on its face that will be used as points of attachment. This mount will be in the shape of a large ‘L’ bracket, secured to the frame with two bolts at each of its four corners. Given the expected vibrations from the functioning of the motor, the motor mount will be reinforced by cross ties that are welded in place.

Bearing (front axle shaft) support (front & rear), Front axle casing

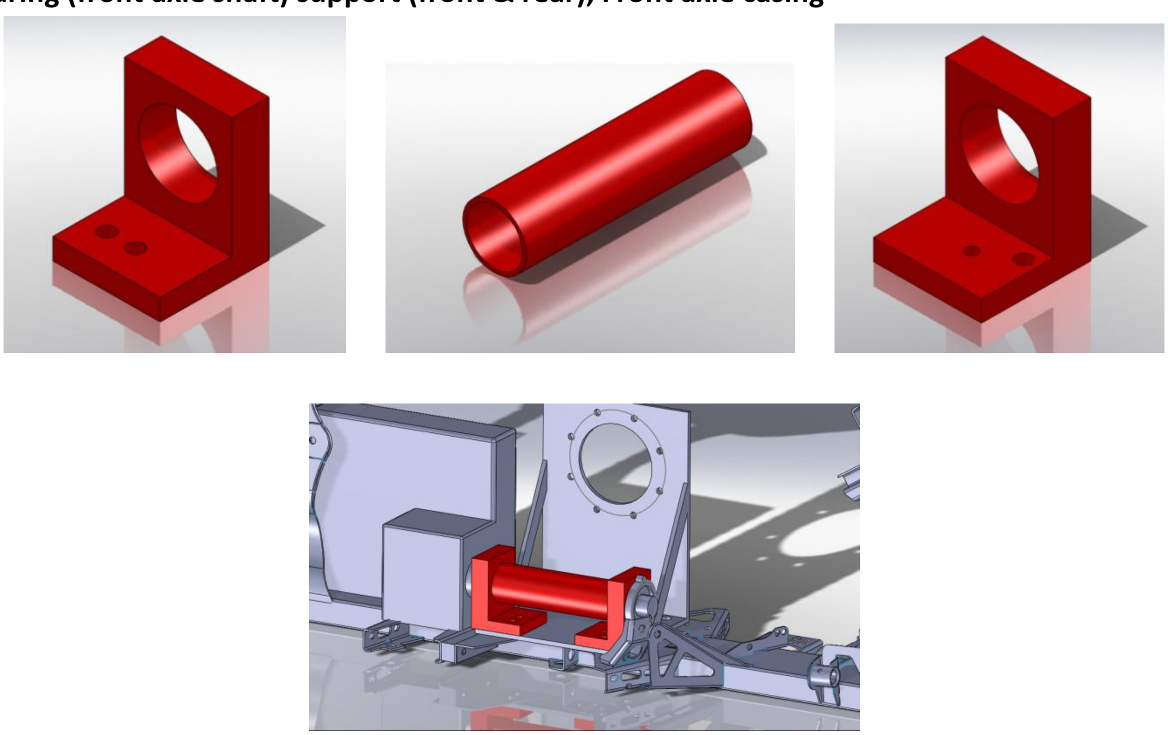


Figure 10: Front axle casing

It is essential that the front axle be parallel with the rest of the driveshaft in order to rotate efficiently. Mounting this component precisely and securely is therefore extremely important. This will be accomplished through the use of mounting brackets on each end. These will be machined together and separated afterwards in order to achieve perfect concentricity of the holes. These will be attached on top of the base of the motor mount which is secured to the frame. A hollow cylinder will serve both to protect the shaft as well as set the distance between the mounts.

Motor back support / Sheet metal engine support

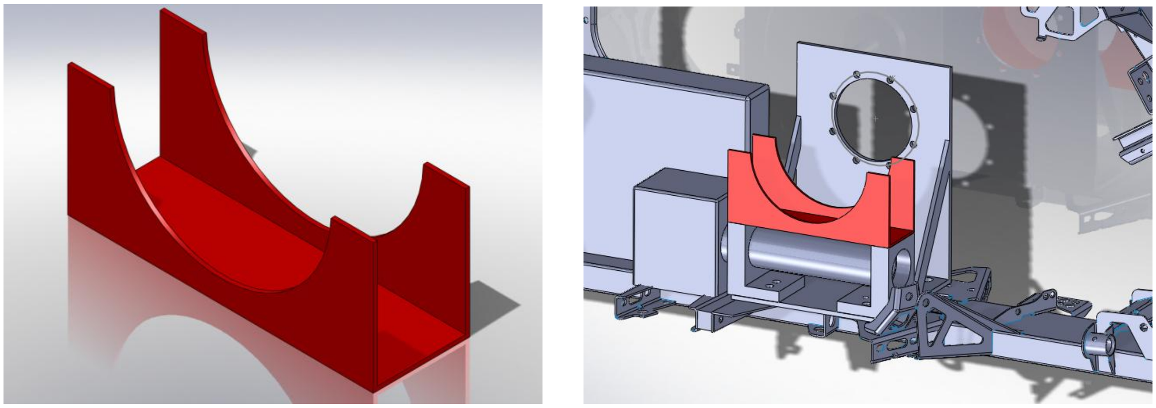


Figure 11: Motor back support

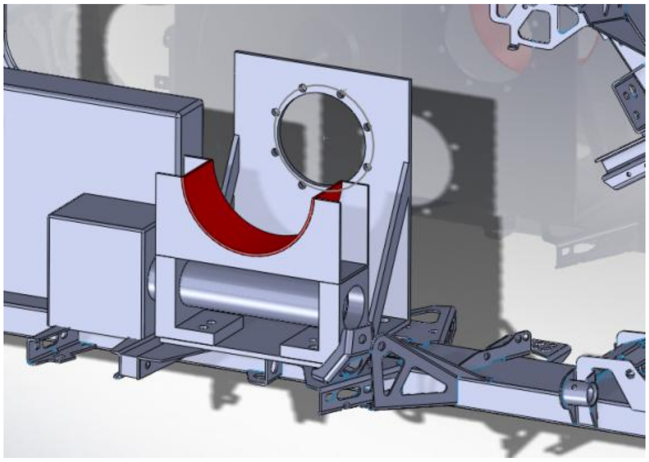


Figure 12: Sheet metal engine support

The motor will pass above the driveshaft, and so it will require additional support. A sheet metal plate will be cut out and bent into shape (shown in figure 11) in order to support the motor above the driveshaft. This component will be welded to the top of the driveshaft supports (bearing/front axle shaft supports), additionally helping to secure them in place.

Another section of sheet metal will be bent to sit directly below the motor (figure 12). This sheet will serve to distribute the stress of the support on the motor over a larger area rather than along two sharp lines. This sheet will be welded into place and used to tie down the motor with straps.

Belt drive linking the motor and transmission

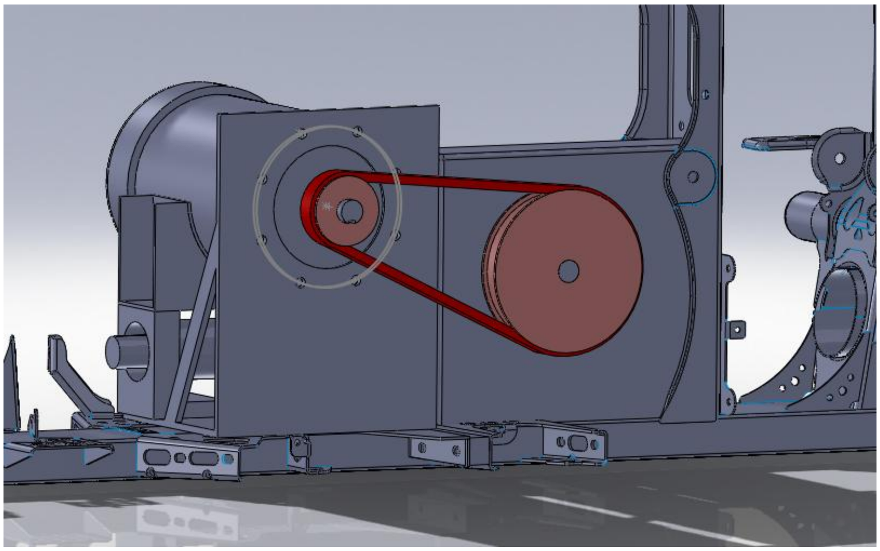


Figure 13: Linking of the Motor and transmission

The figure above is a view from the left side of the vehicle with the motor and transmission both mounted in place. The two components will be linked through a belt drive. These parts are all standard pulley belt drive parts from McMaster, and are chosen according to the center distance of the transmission and motor shafts. Based on our calculations, we will be using a gear ratio of 2.5:1, with the smaller gear being on the motor end in order to achieve our desired range of speeds.

Front axle driveshaft / Motor mounting

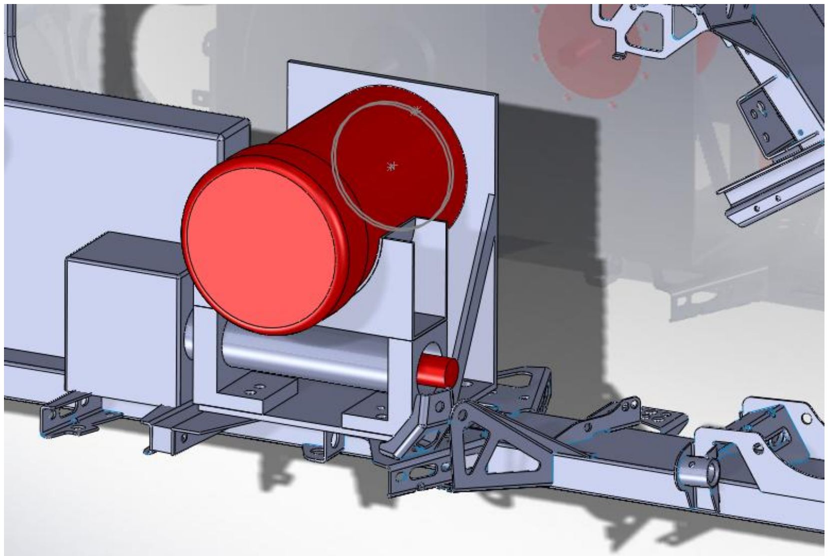


Figure 14: Front axle driveshaft / Motor mounting

Shown in the figure above, the motor will be screwed into the face plate while resting on the support and then strapped down. The front axle driveshaft will slide into the assembly from the front end, and the bearing casing will be used to hold it in place. Illustration of the bare front axle driveshaft and bearings is shown in the figure below. The shaft can then be reattached to the front wheels through the elbow joint, shown in the second image in the figure below.

Figure 15: Front axle driveshaft and elbow connections

Charger/DC-DC Converter and Controller Placement

The placement of the charger and controller on the ATV frame cannot be finalized due to the fact that the controller selection has not been determined. The difference in size between the Curtis 1236 and 1238 is significant. For this reason, two areas have been determined for the charger and controller assuming that a 1238 will be acquired. The charger and 1238 controller are almost identical in dimensions and would both fit in the areas shown below. The final decision will depend on the placement that corresponds to the most organized wiring option.

Area 1 – This is the ideal choice, since this area is shielded from impact in case of a front or rear collision and is also well shielded from the elements.

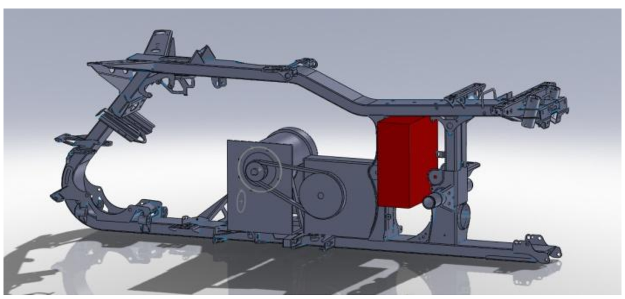


Figure 16: Controller placement 1

Area 2 – With the removal of the radiator and coolant system as well as the stock fuse box there is ample room in the front of the ATV. This area is ideal because it is completely sheltered from the elements by the front body panels and offers many simple mounting points for either of our two components.

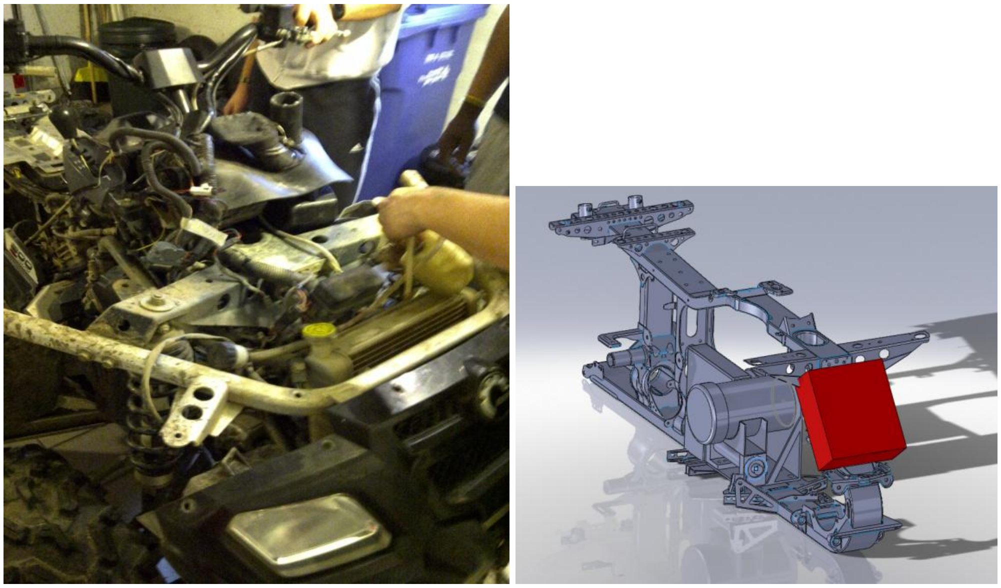


Figure 17: Controller placement 2

If the 1236 controller is used instead of the 1238 there are several areas that can be used to mount this smaller controller. This design would use Area 1 as space for the charger. It is likely that the controller would be placed where the 12v battery used to be on the back of the ATV (shown in the image below), right under the license plate using the stock brackets.

Figure 18: Area 1

FEA Analysis

A finite element analysis (FEA) was performed on the custom motor mount and axle case assembly in order to determine if our design would be able to withstand the expected applied loads and torques. An aluminum alloy was assumed as the material for the assembly. The value for torque applied on the face of the motor mount was 90 ft-lbs. All components were assumed to be bonded together except for contact points with the motor, such as to the motor back support and the motor face to the motor mount; these were assumed to be frictionless. The bolts were bonded to the motor holes and to the plate holes. The FEA analysis information is shown below.

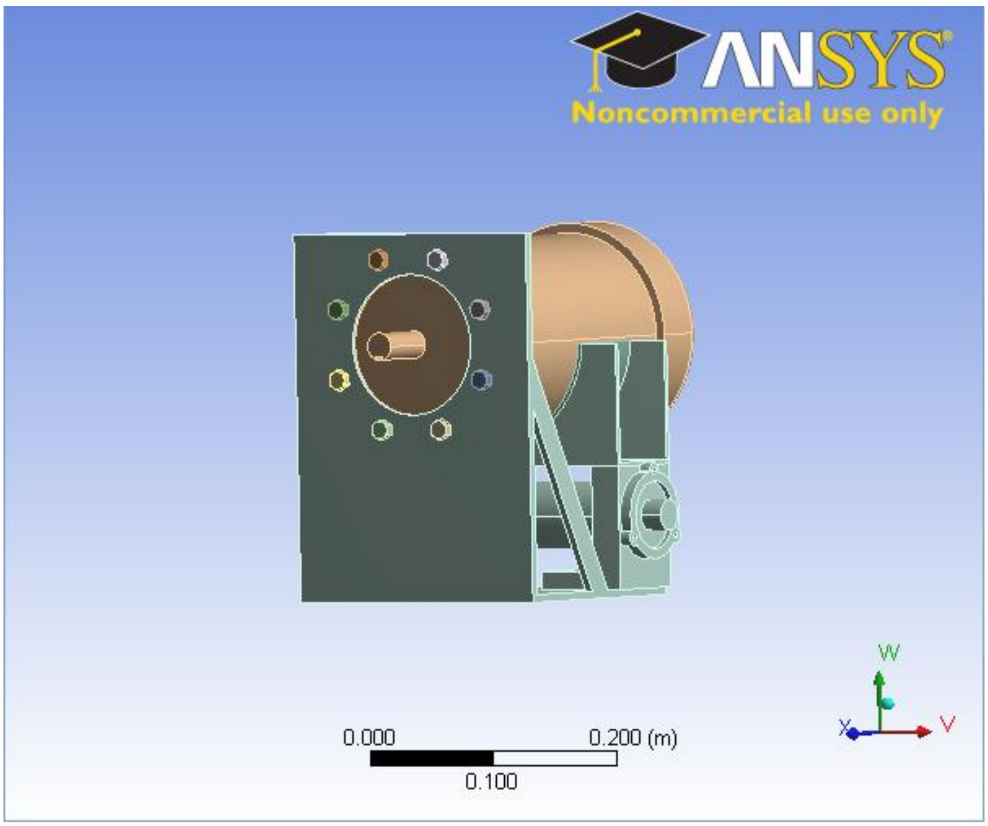


Figure 19: Assembly in ANSYS

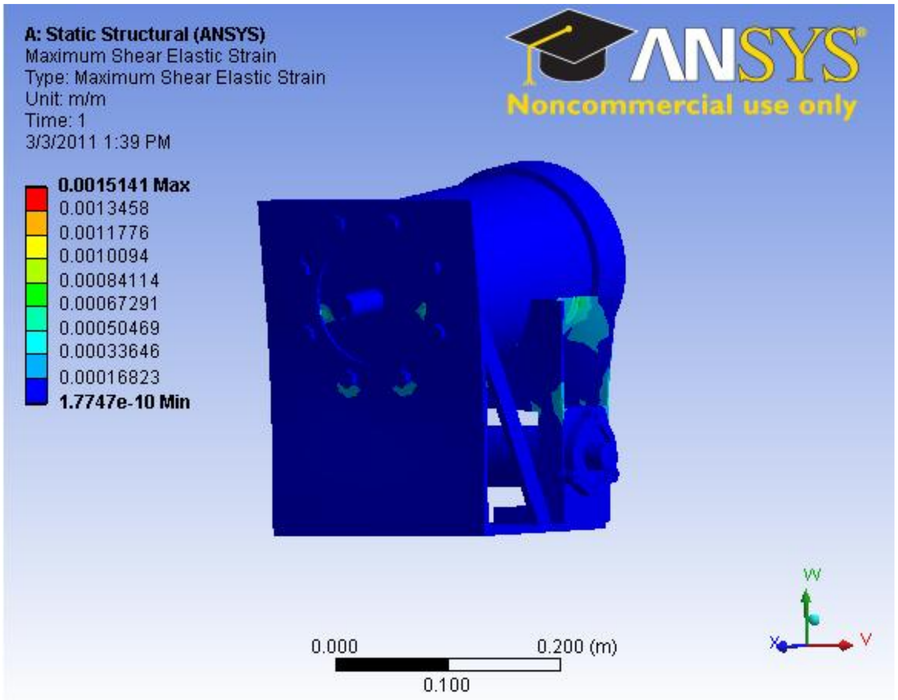


Figure 20: Maximum shear elastic strain

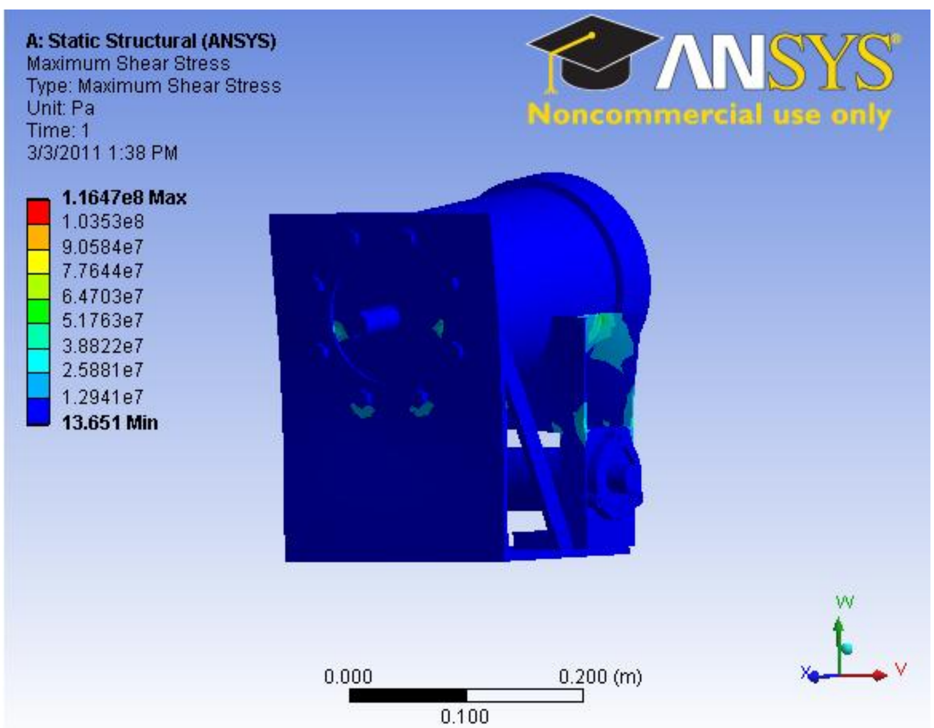


Figure 21: Maximum shear stress

TABLE 18
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Maximum Shear Stress*	*Maximum Shear Elastic Strain*	*Total Deformation*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Maximum Shear Stress	Maximum Shear Elastic Strain	Total Deformation
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Integration Point Results			
Display Option	Averaged		
Results			
Minimum	13.651 Pa	1.7747e-010 m/m	0. m
Maximum	1.1647e+008 Pa	1.5141e-003 m/m	3.2735e-004 m
Minimum Occurs On	Solid		
Maximum Occurs On	Solid		

Material

All custom components will be made of an annealed aluminum alloy (6061-O). The maximum tensile strength is 125 MPa and maximum yield strength of 55 MPa. All parts will then be anodized to increase their resistance to corrosion in order to be protected from the external environment. This material can easily be machined and bent to form the desired components, and it is readily available. This aluminum alloy is commonly used in aerospace and aircraft structures as well as boats, and other marine and salt water-sensitive applications.

Electric Vehicle Safety Requirements

Motivation for a safe electric vehicle

The vehicle is expected to be designed and fabricated in accordance with proper engineering practices. All members of the ATV team are committed to the ultimate safety of any users or other individuals that may come into contact with the vehicle. Members are aware that carelessness can result in serious injury or death and safety is paramount for everything. The vehicle operation will be safe for the user with zero assumed knowledge of electric vehicles and systems.

In case of an accident

- Presence of circuit breakers and fusible links in the electric vehicle that will break open an electrical circuit and cause an open circuit. (Refer to 'Fuses' section)
- Batteries must be adequately secured inside steel racks, firmly mounted on the chassis. If this is accomplished, the battery pack will act as an energy absorption device during an accident.
- Center of gravity and the track of the vehicle must combine to provide adequate rollover stability. The vehicle should not roll when tilted 60º.
- Commercially available on-board fire systems or portable extinguisher.

Failure mode of system / presence of contactors

- Should be one switch that performs the following actions:
    1. Shuts down all drive systems.
    2. Repeated actuation of the ignition switch will not restore power.
    3. Designed so that the driver cannot reset it.
- Master switch must disable all electrical circuits; thus all battery current must flow through the switch. The switch is direct acting, as oppose to acting through a relay.
- Kill switch that is extremely visible (big red button), easily accessible to the driver.
- Suggestion of a minimum of 3 shutdown buttons or master switches. It is possible that electronic systems within the vehicle may need to be fitted with isolation diodes. Once pushed, these master switches must stay pushed until they are manually pulled outward, effectively resetting the system.
- Proposed system of 3 contactors, one between the motor and controller, and two at the rear of the vehicle on either side of the battery packs. In case of emergency, any of

these two contactors are located directly at the source of power, easy access for the user to cut vehicle power and operation.

Distribution of weight of components

- Weight of battery pack and other components should be well-balanced, both front-to-rear and side-to-side (Uneven distribution of components could potentially affect the handling and braking of the system).
- Attempt to keep the weight of the batteries as low and centered as possible.

Danger in the release of hydrogen gas by batteries

- Only of concern when the battery pack is very low in charge and being worked very hard. Attempt to cease use once the charged capacity is relatively low.
- Since hydrogen is lighter than air, it will rise and dissipate if given the opportunity. Thus, if the batteries are enclosed in a box, ventilation should be provided to the outside air.

Brake system

- Brake system should act on all 4 wheels, operated by a single control. Should be composed of 2 independent circuits, so that if one fails, the other 2 wheels can brake.
- Regenerative braking should only be dedicated to up to the first 50% of brake pedal travel.
- Brake light should be present for nearby pedestrians, given that the vehicle will come into close proximity of many individuals.

Body Work of Vehicle

- Avoid any sharp edges that could impact people.
- All bolts, nuts, and other fasteners are secured from unintentional loosening by the use of positive locking mechanisms (Cotter pins, nylon lock nuts, prevailing torque lock nuts).
- A minimum of 2 full threads must project from any lock nut.
- All threaded fasteners that are used in the drivers' area, steering or braking must meet SAE Grade 5 or Metric Grade 8.8.
- Prohibited to use button head cap, pan head, flat head or round head screws or bolts in critical locations. Instead, use hexagonal recessed drive screws or bolts.

- All fasteners securing scatter shields must meet SAE grade 5 (1/4 inch) or Metric Grade M8 (6mm)

Jacking Point

There must be a jacking point at the rear of the car that is capable of supporting the vehicle's weight, without causing damage to any electrical components. The jacking point should be:

- Painted orange
- Visible from 1 meter behind the vehicle.
- Made from round aluminum or steel tubing.
- Minimum 300 mm long.

Drive Train Shield and Finger Guards

Exposed drive train equipment operating at high speeds such as gears, sprockets, clutches, belt drives and CVT's should be fitted with scatter shields due to the possibility of failure. These shields serve to contain the parts of the drive train that could separate from the vehicle. Do not use perforated materials for scatter shields.

- Chain drive: Scatter shields for chain drives must be three times the width of the chain. They must be made out of 0.105 inch steel.
- Belt drive: Scatter shields should be made out of 0.120 inch steel.

Finger guards function to protect any parts of the drive train which rotate when the motor is running even though the vehicle is stationary. As the name implies, they are simply meant to resist finger forces using perforated material or mesh.

Fusing

Available current is often much greater than what the electric vehicle can handle. Thus, fuses function to interrupt the current in a circuit once it exceeds a designated 'safe limit'. All electrical systems, both high and low voltage, should be fused. Fuses help control hazards such as:

- Fires: Wiring and circuit components can overheat and start a fire.
- Shock hazards: Note that as much as 50mA of current can be lethal, and a fuse will not limit such a low value of current. However, a short circuit may often result in too much current, thus posing a shock hazard.

- Damage to circuitry and wiring: Without a fuse, the entire electrical system can be damaged. On the contrary, replacing the fuse would be the only repair required.

Note that the fuse serves primarily to prevent the overheating of the wire. Thus, the minimum value for the wire current rating must equal or exceed the current rating of the fuse. If a wire is too small in comparison to the fuse being used, overheating will occur before the fuse fails, thus eliminating the functioning of the fuse. We will use the guideline that any fuse must have a rating that is approximately 25% larger than what is expected in terms of maximum continuous current.

For a series-string connection of batteries, a series fuse is used. For a parallel-string connection, each string of batteries must be fused individually. For a parallel-cell configuration of batteries, each cell is fused individually.

In addition to current ratings, fuses have voltage ratings as well as interrupting capacity ratings.

- Voltage rating must be at least the maximum voltage of the system. Even if they are in series, each fuse must be rated for the entire voltage. Fuse rated for AC voltage are often double the DC rating.
- Interrupting capacity ratings must be greater than the potential short circuit current. Note that short circuit currents increase when the batteries are connected in parallel as oppose to series.

Fuses do not blow immediately, since the blow time is proportional to the amount that the circuit is operating over the current limit. A fuse which blows slowly is particularly useful in an electric ATV given that currents only peak for short amounts of time, for example during acceleration.

Batteries:

- Any wet cell battery must be enclosed in a non-conductive marine type container.
- Any batteries as well as other on-board power supplies must be properly attached and secured to the vehicle frame.

High Voltage On-board Systems

High voltage systems are defined by a system producing more than 30V.

- There must be a high voltage shutoff to disable high voltage current flow while allowing work to be done on other systems.

- No connection should exist between a part of the high voltage circuit and the frame that the user could come into contact with. In addition, no high voltage connection should be exposed to the user, making use of non-conductive covers to protect from accidental human contact. Body panels cannot act as a means of enclosure to a high voltage connection, nor is electrical tape.
    - As a test, an insulated test tube 10 cm in length and 0.6cm in diameter should not be able to touch an high voltage connections.
- High voltage connections should not be located in the driver's area nor behind the instrument panel. All bolted connection must be locked my means of devices such as a lock washer.
- High voltage wiring outside of electrical enclosures must be enclosed by non-conductive conduit of type LFNC-A or LFNC-B.
- Regenerative controls associated with high voltage must be actuated through linkages that are grounded.
- High and low voltage systems must be physically separated. If they are close to one another, there must be moisture resistant insulating barriers between them.
    - For voltage less than 100V, maintain 1 cm between wires of each system.
    - For voltage between 100V and 200V, maintain a 2 cm separation.
    - For voltage over 200V, maintain a minimum of 3 cm separation.
- Ground fault detectors should be mounted on the vehicle, with the output of the device wired to the shutdown buttons in series. They function to instantaneously shut down the entire system if a ground fault occurs.
- The vehicle must be rain and water certified. To achieve this, it must be able to withstand a minute of spraying water, while all electrical systems are running, without causing the ground fault detector to shut down the vehicle.

Charging Equipment

Any high voltage power supplies or chargers should be labeled as "high-votlage". When the vehicle is being charged by an external source:

- ATV should be as de-energized as possible.
- No other activities or maintenance should occur.

Conclusion

At this point, the required electrical components have been chosen and designed for its implementation in the electric ATV. An HPEV AC-15 72V motor will be used, capable of outputting sufficient power levels at reduced currents in order to minimize losses. The motor will be secured with a motor mount as well as a motor/sheet metal support for its base. Ideally, the 1238 Curtis Controller will be implemented due to its elevated performance ratings, however budget permitting, the Curtis 1236 will be used with some additional modifications. The 800 mm timing belt will be used to link the motor and the transmission, in addition to a belt cover to ensure that the belt remains protected from the outside elements. The original bearings will be used in the electric ATV, with new bearing housings to be press-fit. A charger/DC-DC converter from ‘DeltaQ’ will be installed either in the front of the vehicle beneath the front panels, or in the rear, just behind the transmission. Note that its placement depends entirely on whether the 1236 or the 1238 Curtis Controller is purchased. As far as the battery pack, a functioning prototype will be manufactured with Zellerion Ni-Zn batteries. Once the final design changes have been made, the 72V battery pack will be purchased, given that this is by far the most expensive electrical component.

The next step is to construct detailed wiring diagrams of the 12V accessory system as well as that main electrical system linking the batteries to the other electrical components of the vehicle. Once this is accomplished, the necessary components will be purchased, supporting structures will be machined and the designed vehicle will be ready to be constructed.

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Appendices

Appendix A: Experiment to Determine the Coefficient of Rolling Resistance

Introduction

The primary objective of the experiment is to obtain an experimental coefficient for the rolling resistance of the ATV on the various trails of the Gault Nature Reserve (GNR). Although the exact ATV had not yet been acquired at the time of the testing, a substitute 2-seater gas powered ATV will serve as a testing prototype. The first portion of the experiment consists of the ATV rolling down a slope at a constant speed. By accurately measuring the grade of the slope whereby the ATV achieves a constant speed, the coefficient of rolling resistance can be determined. The second portion of the experiment consists of calculating the time required to decelerate the ATV to a standstill over a series of designated entry speeds. A secondary objective of the experiment is to compare and contrast the results obtained with those published in literature, representing the theoretical values of rolling resistance on similar surfaces.

Theory

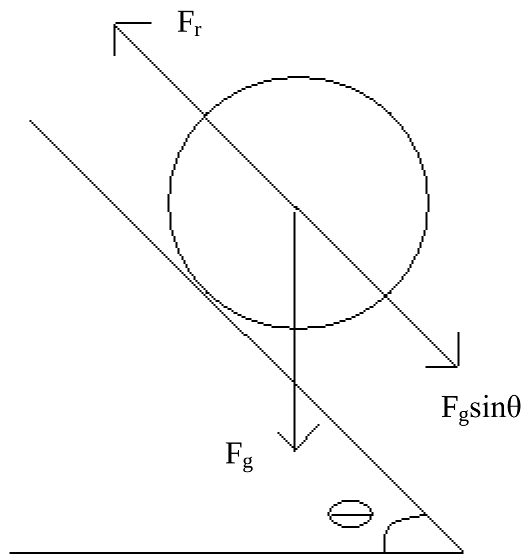
Rolling resistance in the context of this experiment is defined as the resistance occurring from a tire rolling on a flat surface. It is also commonly referred to as the rolling friction. Although it is influenced by a series of factors, the primary contributors include the type of ground and the material of the wheel. The following table illustrates various theoretical values for rolling friction based on an ordinary car tire:

Rolling Friction	Material of Surface
0.01-0.015	Concrete
0.03	Asphalt
0.04-0.08	Solid sand
0.2-0.4	Loose sand

Table 1: Theoretical Rolling Resistance Coefficients for Various Surface Materials

One of the main causes for rolling resistance relates to the study of deformable solids. The rubber material in a tire will undergo repeated deformation followed by a recovery stage, whereby energy is dissipated and lost as heat in each and every cycle. Thus, materials such as rubber which deform more and take a longer time to recover from the deformation will demonstrate larger coefficients of rolling resistance in comparison to materials that are not as flexible and recover more quickly. In addition, the deformation of the tire is dependent on the tire pressure of the ATV. A relatively low tire pressure will cause an elevated grade of deformation, resulting in a higher value for rolling friction.

The first portion of the experiment involves rolling downhill at a constant speed. Given that there is no change in speed, the kinetic energy, involving both rotational and translational kinetic energy is constant. As a result, the emphasis is to discover the specific slope whereby a constant speed is maintained, for this will deliver the most accurate result for rolling resistance. Below is a force diagram corresponding to a wheel of the vehicle at any given moment:



In the figure above figure, F_r represents the force due to the rolling friction, while F_g represents the force due to gravity, broken up into components. This gravitational force is equal to the mass of the object multiplied by gravity. Upon performing a force balance of the above configuration:

$$F_r = mg\sin\theta \qquad (1)$$

In addition, given that,

$$F_r = \mu N = \mu mg\cos\theta \qquad (2)$$

Whereby μ represents the coefficient of rolling resistance, we can solve for μ by equating (1) and (2) above,

$$\mu = \tan\theta \qquad (3)$$

An alternate method to obtain the rolling resistance is by incorporating the energy lost due to rolling friction, denoted E_r. This can be found by the simple laws of conservation of energy. Denoting point 1 as the starting point (uphill) and point 2 as the finishing point (downhill), the energy balance reduces to:

$$PE_1 + KE_1 = PE_2 + KE_2 \qquad (4)$$

Whereby, PE_1: Potential Energy at point 1
PE_2: Potential Energy at point 2
KE_1: Kinetic Energy at point 1
KE_2: Kinetic Energy at point 2

Given that the vehicle maintains a constant speed through, the kinetic energy, $0.5mv^2$, is the same at both points. Referring to the second point (downhill) as the reference or the point of zero elevation, the value for potential energy at point 2 is simply zero. Thus from equation (4), we are left with only the potential energy uphill of the slope. Furthermore,

$$E_r = PE_1 = mgh \qquad (5)$$

Note also that,

$$E_r = F_r \times d \qquad (6)$$

In the above equation (6), 'd' represents the distance travelled downhill at constant speed.
Similar to equation (2), Substituting for F_r, the coefficient for rolling resistance is obtained as,

$$\mu_r = \frac{E_r}{mg\cos\theta \times d} \qquad (7)$$

The second portion of the experiment involves a measurement the time and distance necessary to decelerate to a standstill. Let point 1 represent the instant the ATV is shifted into neutral and point 2 represent the location where the vehicle comes to a complete stop. Similar to calculations above,

$$E_r = F_r \times d = \mu N \times d = \mu mg \times d \qquad (8)$$

In the above equation, 'm' represents the total mass of the ATV as well as human weight and weight of various pieces of equipment such as a trailer.

Upon applying the laws of conservation of energy, it can be noted that for the case of this part of the experiment, given that there is negligible change in elevation, the potential energy will remain a constant. Since the velocity and thus kinetic energy at point 2 is zero, we are left with the following:

$$E_r = KE_1 + E_{rotational} \qquad (9)$$

Since the velocity of the vehicle does not remain constant, there is additional kinetic energy to dissipate which is given in equation (9) as the rotational energy. By definition,

$$E_{rotational} = \frac{1}{2} I w^2 \qquad (10)$$

Where, 'I' is the rotational inertia and 'w' is the angular velocity. Combining equations (8) and (9), we have,

$$\mu_r = \frac{KE_1 + E_{rot}}{mgd} = \frac{0.5mv^2 + E_{rot}}{mgd} \qquad (11)$$

Given the nature of the experiment and the limited measurable quantities, it is not possible to calculate the rotational inertia. Thus, a constant 'K' is introduced which is meant to represent this rotational kinetic energy. As a result, equation (11) becomes,

$$\mu_r = \frac{0.5Kmv^2}{mgd} = \frac{Kv^2}{gd} \qquad (12)$$

Thus, the only purpose of the 'K' value is to indicate that this value of rolling resistance acknowledges the presence of a rotational kinetic energy factor. The effective rolling resistance would be expected to be less due to the additional kinetic energy to dissipate. In other words, the ATV would take longer than expected to stop.

Recall that in the first portion of the experiment, a coefficient of rolling resistance was calculated which did not depend on any other factors. This first rolling resistance, μ_{r1}, can be thought of as a 'whole' quantity, while the rolling resistance from the second experiment, μ_{r2}, can be thought of as partial, due to the presence of a rotational kinetic energy factor. Thus, this 'K' value can be calculated by means of comparing rolling resistance values from each experiment. Furthermore,

$$K = \frac{\mu_{r\,decelerating}}{\mu_{r\,constant\,speed}} \qquad (13)$$

Apparatus

Apparatus and instrumentation for the two parts of this experiment include:

- Tire pressure gauge

- Laser level (measure elevation change)
- Level
- 2 large wooden sticks, one end sharp to allow access into the ground.
- Tape measure (minimum 50 feet)
- Stopwatch
- Camera

Procedure

1. Upon arriving at the reserve, place safety helmets on as well as research vests.
2. Drive the ATV through the parking lot in order to gain familiarity with it. Practice switching into neutral at various speeds, as well as braking sharply.

Part 1 – Coasting at a Constant Speed

3. Drive the ATV onto the trails and search for a slope that will allow it to roll at constant speed when geared in neutral. One such slope used for this part of the experiment is found 1km from the pavilion house on the Burned Hill trail.
4. Shown in 'Image 1', the wooden stick marks the beginning of the slope whereby constant speed is achieved. A second stick would be installed at the end of the coasting path, as shown in 'Image 2'. Both serve as markers for starting and stopping of times as well as to measure elevation.
5. Measure the distance between the two wooden markers. This will serve as the hypotenuse. Note that the ATV would begin from rest at least a dozen feet prior to the first marker in order to allow the time to accelerate to a constant speed.

Image 1

Image 2

6. In order to measure the specific change in elevation over the testing area, install the laser device on a level in order to ensure a horizontal trajectory, as shown in 'Image 3'. Note that even the slightest angle could distort the measured elevation by several inches.

Image 3

7. Align the laser level so that a clear mark is made on the wooden marker at the bottom of the slope. This is not an easy task; it is helpful to use an experimenters' back as a target board for the laser mark, as a means of a coarse adjustments. Then, perform finer adjustments by shifting the laser apparatus to align directly onto the marker, as shown in 'Image 4'.

Image 4

8. Measure the distance between the laser mark and the ground. This value represents the elevation change of the chosen. Note that the laser device also delivers a horizontal distance to where it hits the obstacle. Although this value is not entirely accurate, it can be used to compare to the calculated value according to Pythagoras.

9. Ensuring that the ATV is geared into neutral, coast down the constant slope. Perform approximately 5 trials by noting the time taken across the testing zone for each one. Place two people on the ATV during testing in order to simulate the expected weight during usage.

Part 2 – Decelerating to a Standstill at Designated Entry Speeds

10. This experiment is to be performed on flat ground with the same surface type that is observed on the trails. The specific area is in front of the storage barn, across from where the trailers are kept.
11. Shown in 'Image 5', extend a tape measure along the length of the distance whereby the ATV will be shifted into neutral and decelerate. Be sure to set up a marker to indicate the beginning of the measuring zone.

12. Enter the measuring zone at 5 km/h and shift to neutral at the marker indicating the beginning of the measuring zone. Be sure that there are always two people riding the ATV, for reasons explained earlier.
13. Begin the timer once the ATV has entered this zone, only stopping once the ATV comes to a complete stop. Record this time.
14. Measure the distance that the ATV has travelled while decelerating to rest, as shown in 'Image 6'.
15. Repeat this experiment 5 times.
16. Repeat steps 12 through 15 at entry speeds of 10 km/h and 15 km/h. Note that at elevated speeds, it may be necessary to use more than one tape measure.

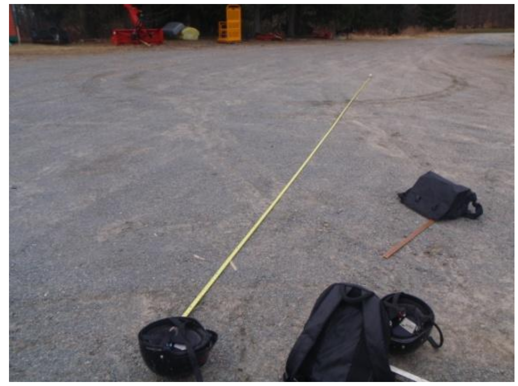


Image 5


Image 6

Results (Experimental Data)

The following table outlines some of the general properties of the ATV. Details of unit conversions will be elaborated upon in the 'Sample Calculations' section.

Gravity	9.81 m/s^2
ATV Mass	745 *lbs*
Driver Mass	360 *lbs*
Trailer Mass	NA
Total Mass	501.22 *kg*
Tire Pressure	4 *psi*

Table 2: General ATV Properties

The following table outlines the results from the first portion of the experiment.

Speed	2.5 *mph* = 4.0 *km/h*
Elevation Change	1.07 *m*

Distance Downhill	14.78 *m*
Grade of Slope	0.07 *rad* = 4.14 *degrees*
E_r	5245.2 *J*
μ_r	0.0724

Table 3: Results of Experiment 1 - Coasting at a Constant Speed

The following table outlines the results from the second portion of the experiment.

Run	Entry Speed		Time	Distance		μ_r	K
	(km/h)	(m/s)	(s)	(ft)	(m)		
1	5	1.39	3.20	8.00	2.44	0.04	0.56
2		1.39	2.70	6.00	1.83	0.05	0.74
3		1.39	2.70	6.00	1.83	0.05	0.74
4		1.39	2.90	8.00	2.44	0.04	0.56
5		1.39	2.90	7.50	2.29	0.04	0.59
1	10	2.78	3.60	19.00	5.79	0.07	0.94
2		2.78	3.90	18.00	5.49	0.07	0.99
3		2.78	4.10	19.00	5.79	0.07	0.94
4		2.78	4.20	19.50	5.94	0.07	0.91
5		2.78	4.40	21.00	6.40	0.06	0.85
1	15	4.17	5.30	33.00	10.06	0.09	1.22
2		4.17	4.90	31.50	9.60	0.09	1.27
3		4.17	5.70	37.00	11.28	0.08	1.08
4		4.17	5.90	41.50	12.65	0.07	0.97
5		4.17	5.90	42.00	12.80	0.07	0.96

Table 4: Results of Experiment 2 - Decelerating to a Standstill at Designated Entry Speeds

Sample Calculations

- Total Mass = (ATV Mass + Driver Mass) *lbs* x (0.45359 *kg/lbs*)
  = (745+360) *lbs* x (0.45359 *kg/lbs*) = 501.22 *kg*

<u>Part 1 – Coasting at a Constant Speed</u>

Traveling Speed

- $2.5 mph \times 1.609344 kph / mph = 4.0 km / h$

Horizontal Distance between Markers

- Pythagoras Theorem: $a^2 + b^2 = c^2$

  b = 1.07 *m* , c = 14.78 *m*

  a = $\sqrt{(14.78^2 - 1.07^2)}$ = 14.74 *m*

Grade of Slope

- θ of constant slope: $\tan^{-1}(1.07/14.78) = 4.14°$

Rolling Resistance Coefficient

- $4.14^\circ \times \left(\frac{2\pi}{360}\right) = 0.0724 rad = \mu$

Energy Lost due to Rolling Friction

- $E_r = mgh = 501.22kg \times 9.81m/s^2 \times 1.07m = 5245.42J$

Alternate Rolling Resistance Coefficient

- $\mu_r = \frac{E_r}{mg\cos\theta \times d} = \frac{5245.42J}{501.22kg \times 9.81m/s^2 \times 14.78m} = 0.0724$

Part 2 – Decelerating to a Standstill at Designated Entry Speeds

The following set of sample calculations pertains to run 1. All other runs are performed in a similar manner:

Braking Distance

- $\frac{8\,ft}{3.28\,ft/m} = 2.44m$

Coefficient of Rolling Resistance

- $\mu_r(K) = \frac{KV^2}{2gd} = \frac{(1.39m/s)^2}{2 \times 9.81m/s^2 \times 2.44m} = 0.04K$

K Factor

- $K = \frac{\mu_{r\,decelerating}}{\mu_{r\,constant speed}} = \frac{0.04}{0.0724} = 0.56$

Discussion

The need to experimentally determine the coefficient of rolling resistance stems from the inability to determine a concrete value that would accurately satisfy our specific ATV conditions. For instance, according to a textbook titled “Road Vehicle Dynamics”, the coefficient of rolling resistance ranges between 0.015 and 0.05. In another text titled “Build your own Electric Vehicle”, a value of 0.08 is assigned to the rolling resistance pertaining to a medium-hard surface. Finally, the McGill BAJA team chose a value of 0.0425 based on an unreliable internet source. These values listed apply to electric vehicles in general and not necessarily to off-road vehicles. Furthermore, rolling resistance depends greatly on the weight of the vehicle as well the specific type of surface on which the vehicle will be operating. As a result, it is evident that an experimental determination of the coefficient of rolling resistance is most appropriate.

By definition, the coefficient of rolling resistance is the value that relates the resisting force of motion to the weight of the vehicle. This coefficient is important for calculating the force that the ATV experiences, and thus it is a significant element in calculating the power requirements. In fact, a slight modification in the rolling resistance resulted in a vast range of the power required. Many of the values from the sources listed above are dependent on certain constants that simply do not relate to the ATV demands on the trails of the GNR. This further affirms that the most efficient and logical course of action was to perform the experiment to obtain a most accurate value of rolling resistance with little ambiguity.

Sources of error in this experiment are plentiful. In both portions of the experiment, recorded times were obtained by means of manually stopping and starting a stopwatch. This is naturally accompanied with a considerable amount of error, whether it be delays or premature stops and starts. As a result, multiple trials were performed for each experiment, whereby outliers were disregarded and averages were taken to obtain a most accurate final result. The first portion of the experiment required coasting at a constant speed. Given the difficulty in finding a slope that delivered an exact constant speed, a trail was chosen that delivered a near-constant speed. The method for measuring the elevation of the trail used, as shown in the procedure, is naturally accompanied with a great deal of error. The slightest modification in the orientation of the laser level would skew the measured elevation by several inches. In the second portion of the experiment, involving decelerating to a standstill at designated entry speeds, the vehicle needed to be switched to neutral at the exact entry point. This introduces a considerable amount of error, given the improbability of performing the shift at the appropriate time for each trial. Even more error is introduced when performing the experiment at elevated speeds. Once again, several trials were performed in order to obtain an average that would lead to a more accurate result.

Recall from the first portion of the experiment that μ_r did not depend on any other factors. Thus, as mentioned in the theory section, this value is a 'whole quantity', while the μ_r from the second experiment is a 'partial quantity', due to the presence of a rotational kinetic energy factor. Thus, the 'K' value as it is calculated is deemed correct, in that the effective rolling resistance would be expected to be less due to the additional kinetic energy to dissipate. In other words, equation (13) should deliver 'K' values that are less than 1, which is in fact observed for the most part in 'Table 3'. The exception is at elevated speeds, where error is assumed to be higher.

It should be noted that there exists a change in rolling resistance with respect to speed, as seen in the increasing μ_r with respect to speed in the coast-down tests. This would indicate that a higher than expected average speed will need to be chosen. This will be done in order to be somewhat conservative in the power consumption model.

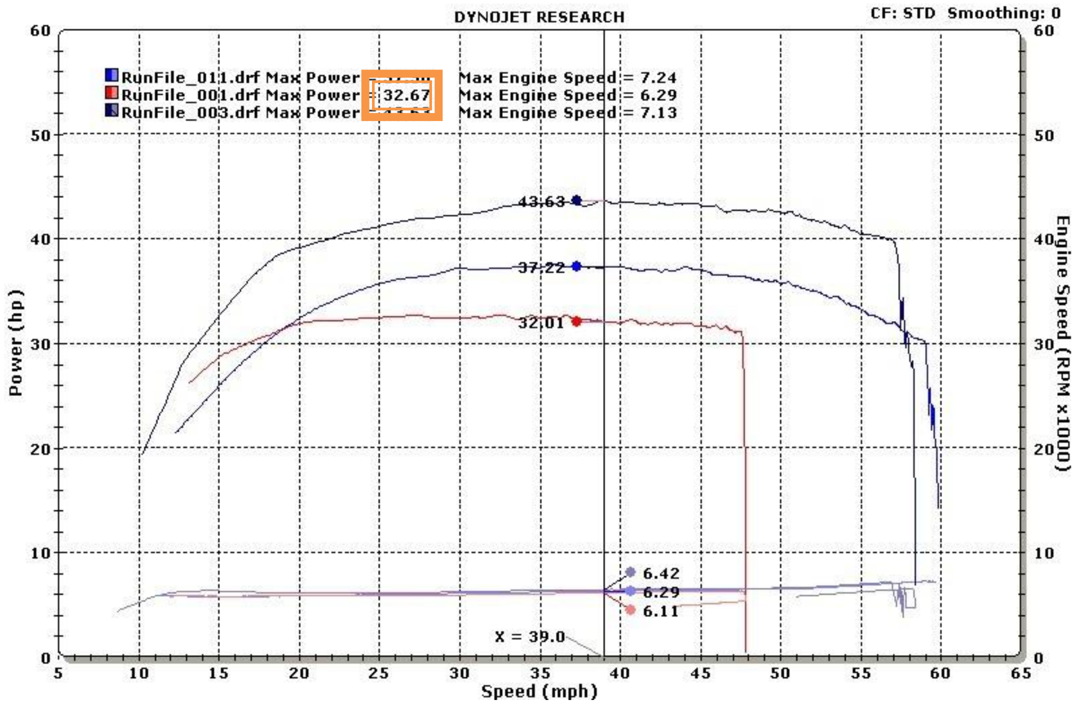
Conclusion

In conclusion, it was determined that the literature road vehicle rolling resistance coefficient values cannot be applied directly to ATVs. Due to the many factors contributing to the coefficient, determining this value experimentally for each specific vehicle is most appropriate.

The calculated value for the coefficient of rolling resistance is 0.0724, which falls in the range of the values listed in literature. As a result, it is attributed with an adequate level of credibility. As mentioned, a 'K' value was introduced in the second experiment due to the presence of a rotational kinetic energy factor. Due to this additional kinetic energy to dissipate, effective rolling resistance would be expected to be less.

Appendix B: Drive Efficiency, $\eta_{drivetrain}$

Dynamometer Results for 2007 Yamaha Grizzly 700 (Stock vs 2 different levels of modifications) [3]



This dynamometer graph was taken from the owner of a 2007 Yamaha Grizzly 700 ATV who wanted to see the power increases he would be able to achieve through modifications. This is relevant to our calculations because it gives a real life number to the hp available at the wheels of a rugged 4 x 4 Utility ATV. The red line represents the power to the wheels of the stock ATV, **32.67** hp after losses have been incurred in the drive train (axles, transmission, etc…).

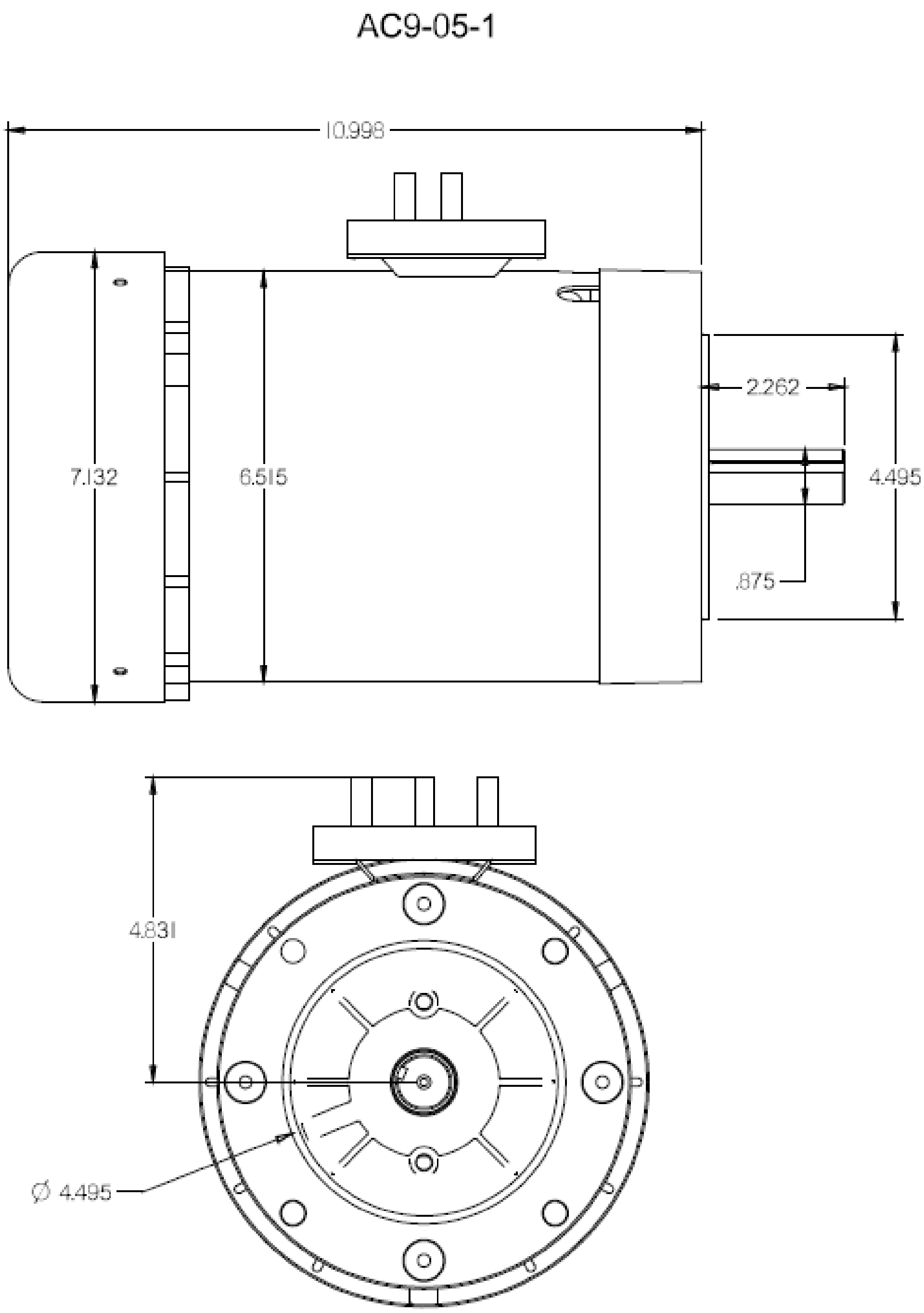
Although official numbers for the rated HP at the crank of this particular model of ATV could not be found on the Yamaha site (Outdated model), a thread post was found by an owner of the same ATV saying, "My title showed **46.9**hp."[4] This drive train efficiency number is used when and if our motor is connected through the AWD differentials

$$\eta_{drivetrain} = \frac{HP_{to\ wheels}}{HP_{rated}} \times 100\% = \frac{32.67}{46.9} \times 100\% = 69.66\% \approx 70\%$$

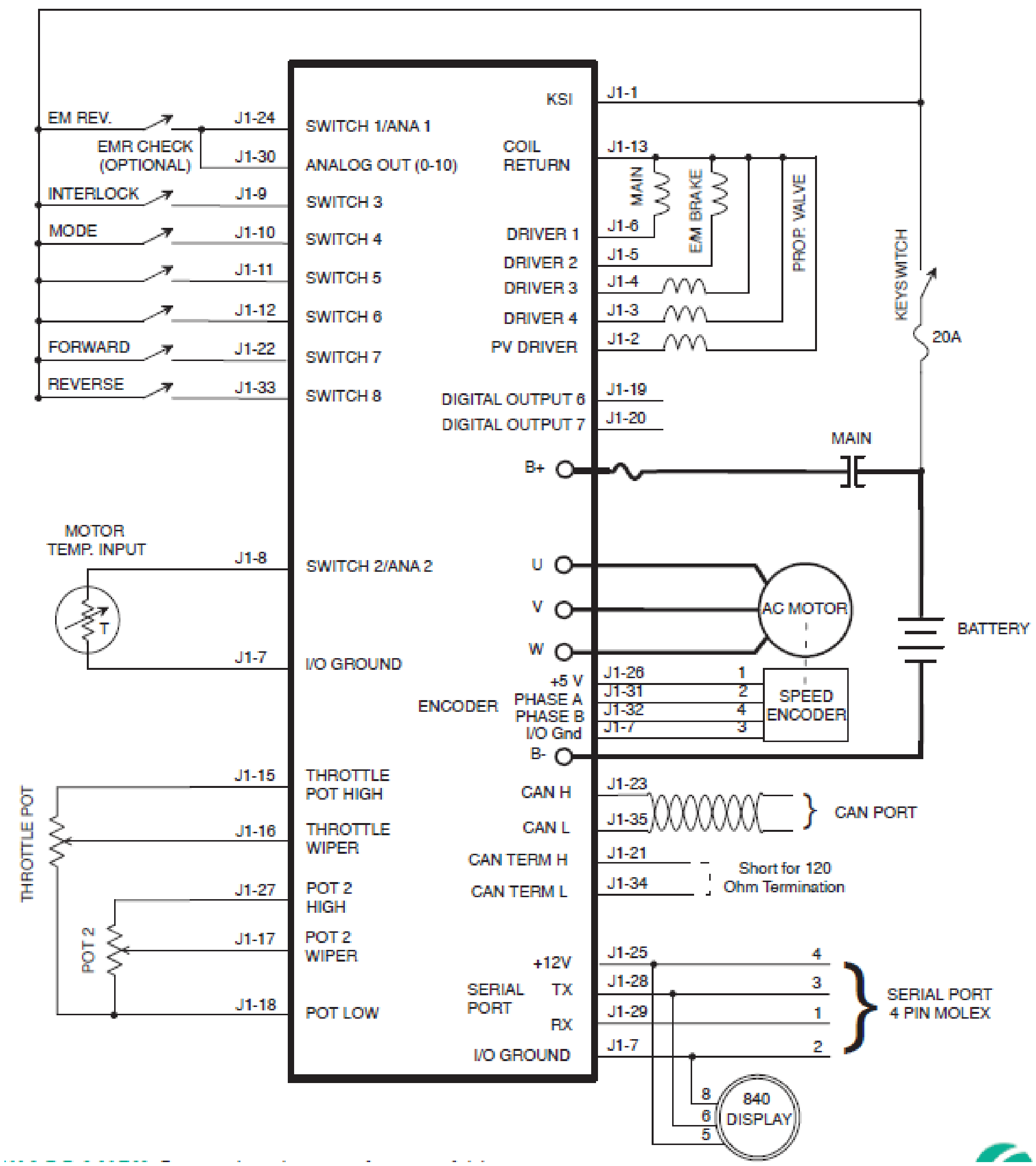
[3] http://www.grizzlycentral.com/forum/grizzly-dyno-tuning/3721-dyno-results-stock-vs-fully-modified.html

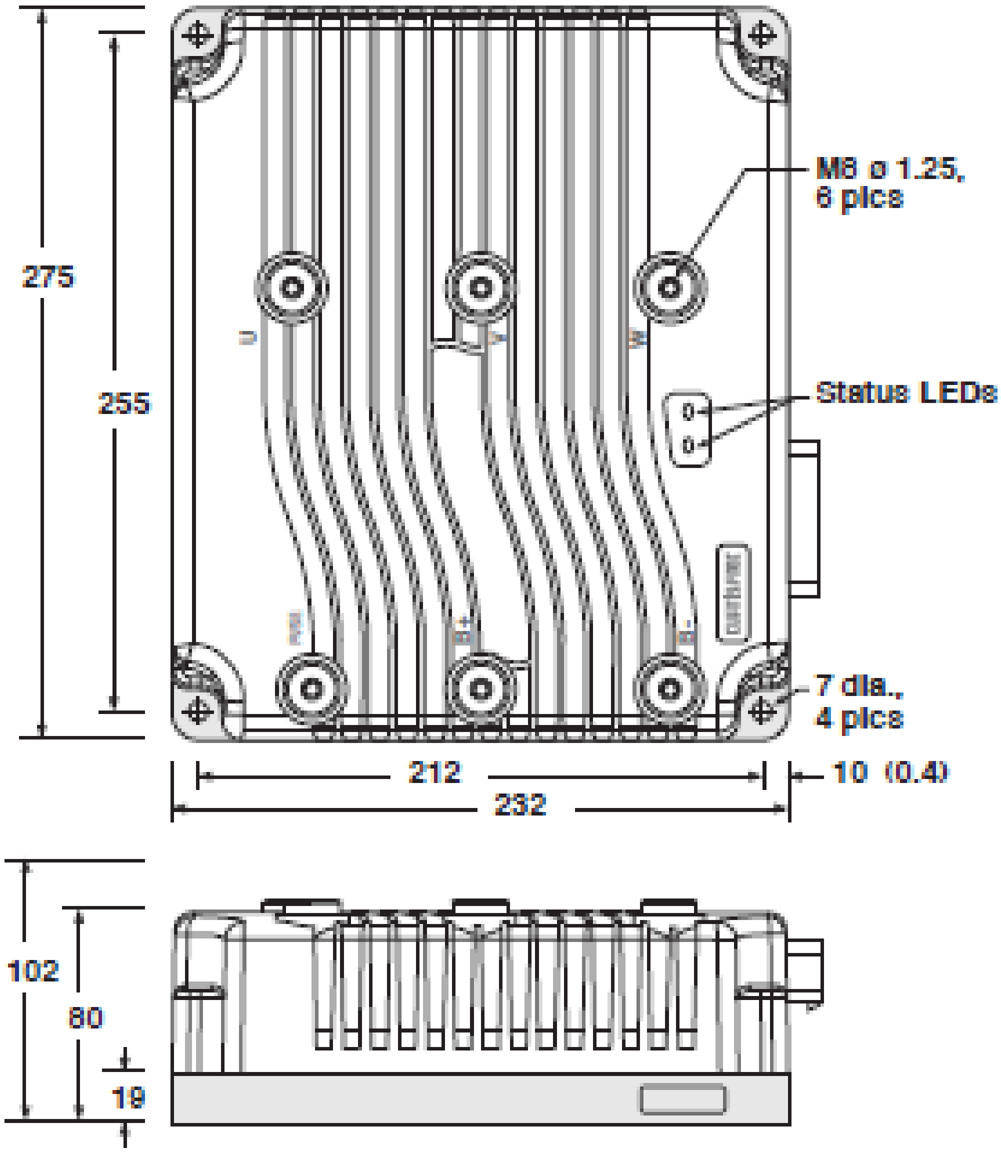
[4] http://www.grizzlycentral.com/forum/grizzly-engine-transmission/2546-horsepower.html

Appendix C: HPEV AC-15 AC Electric Motor



Appendix D: Curtis 1238 AC Motor Controller Wiring Diagram and Dimensions

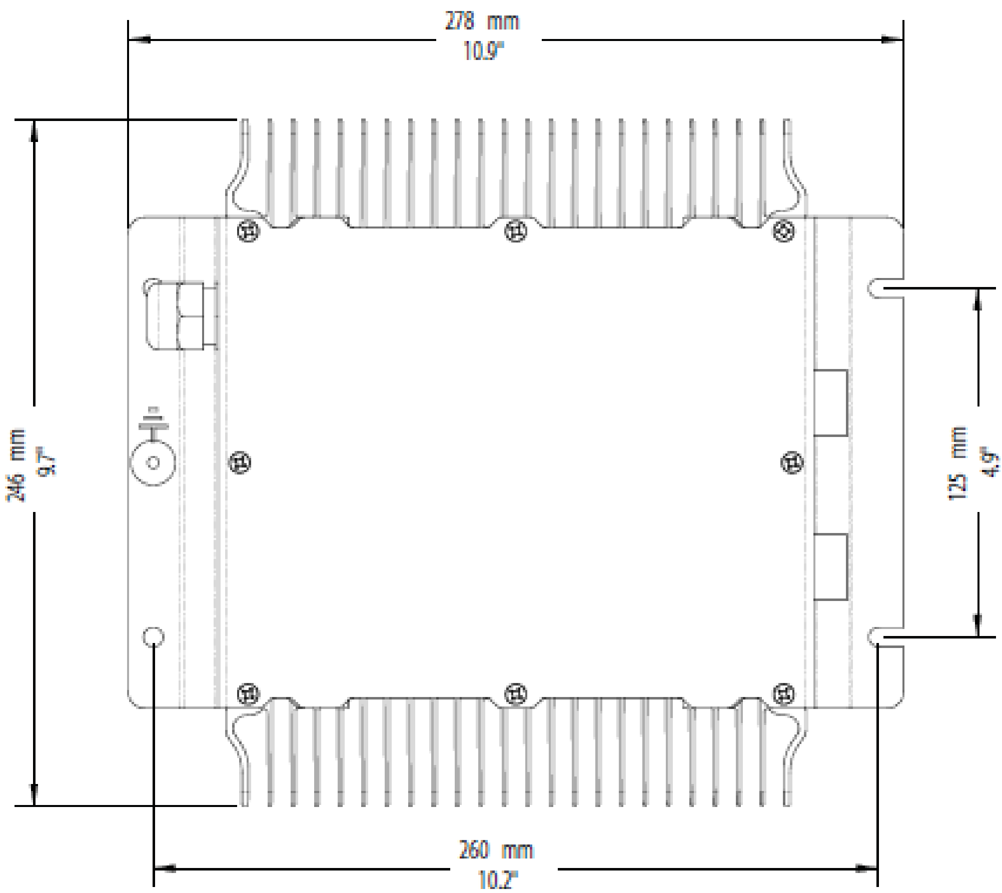




M8 ø 1.25,
6 plcs
275
255
Status LEDs
7 dia.,
4 plcs
212
232
10 (0.4)
102
80
19

1238

Appendix E: Dimensions of QuiQ-dci



Appendix F: Test Batteries

Xellerion

Technical Specifications — Xellerion Xell-20

Product Name Xell-20 NiZn Battery Module
Product Code AN00820PP01A
Product Model Xell-08-E20C
Target Applications E-bike, Light EV, Off-road EV, AGV, Medical Applications, UPS, Energy Storage

Nominal Capacity	20 Ah	@0.5C
Nominal Voltage	13.0 V	@0.5C
Nominal Energy	260 Wh	@0.5C
Peak Current	100 A	5C
Internal Resistance	< 30 mΩ	@OCV
Dimension (L×W×H)	185*75*170	Unit: mm
Module Weight	4.7kg	
Recommended Charging Time	4 hr	CC/CV
High Limit Voltage for Charging	15.4V	@0.25C
Low Limit Voltage for Discharging	10V	@0.5C
Operating Temperature Range for Charging	-10～45℃	
Operating Temperature Range for Discharging	-20～60℃	
Recommended Storage Conditions	-20～25℃	

eVionyx™ *Innovative Energy Solutions for Humanity*

6 Skyline Drive, Hawthorne, NY 10532, USA
Phone: +1-914-345-0321 Fax: +1-914-345-0450
www.eVionyx.com
www.Xellerion.com

Appendix G: 48V GBS 100 Ah Specifications

SPECIFICATION OF GBS-LFMP100AH

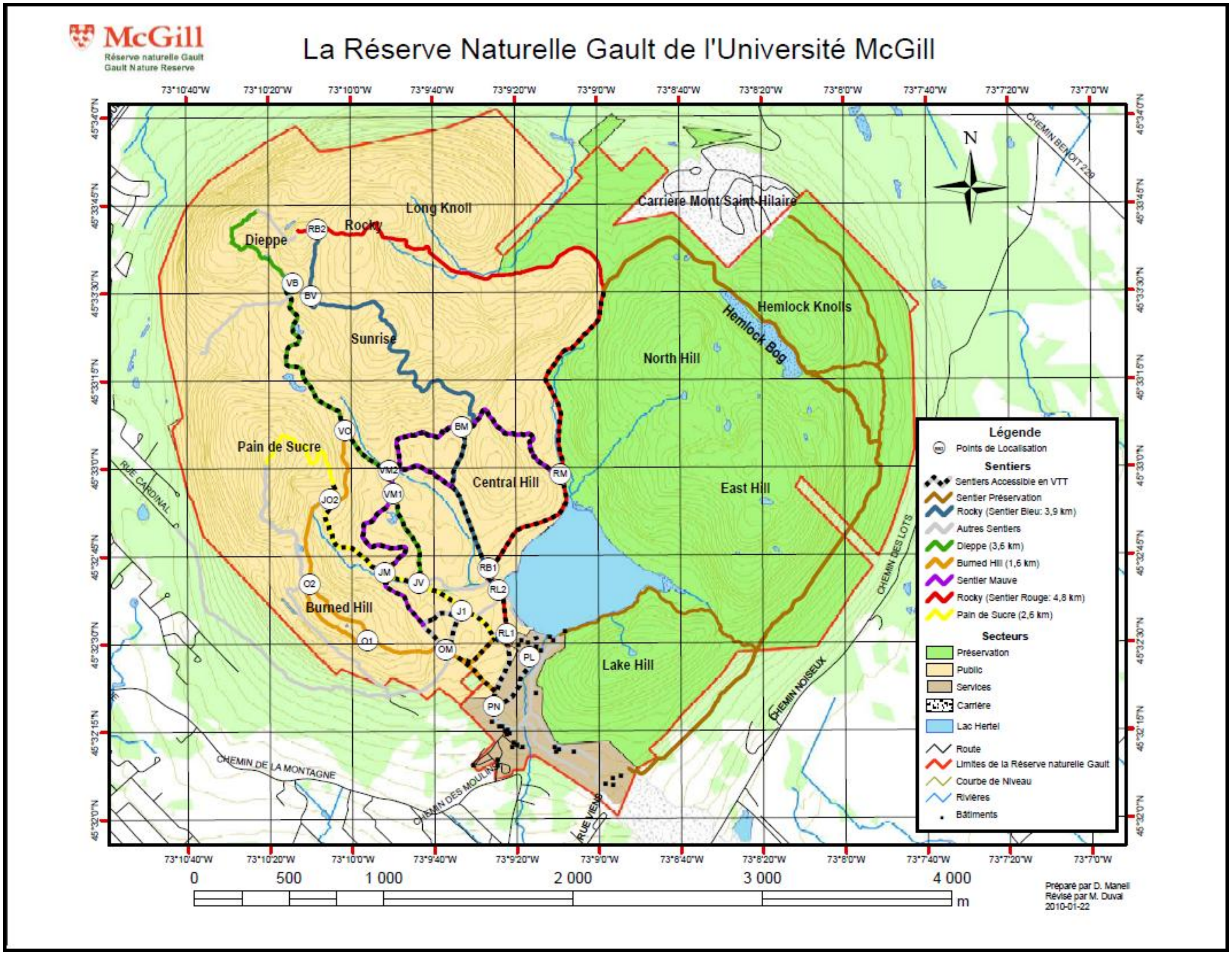
Chemistry: Lithium Iron Manganese Phosphate

Nominal Capacity	100Ah	Working Voltage	Single cell charging：3.8V
			Battery pack charging：3.65V
			Single cell charging：2.5V
			Battery pack discharging：2.8V
Max. Charging Current	≤3C	Max. Discharging Current	Consistent Current：≤3C
			Impulse Current：≤10C
Standard Charging Current	0.3~0.8C	Best Charging Current	0.5C
Internal Resistance	≤1.8mΩ	Cycle Life	Single cell ≥2000 times （80%DOD）
			Battery pack≥1500 times （80%DOD）
Temp. resistance of Shell	≤135℃	Working Temperature	Charging：＞0℃
			Discharging：-20℃-65℃

Self Discharge rate (month)	≤3%	Cell Weight	3kg±100g
Energy Density	90~110Wh/kg	Power Density	> 800w/kg
Dimension	126mm*65mm*234mm		

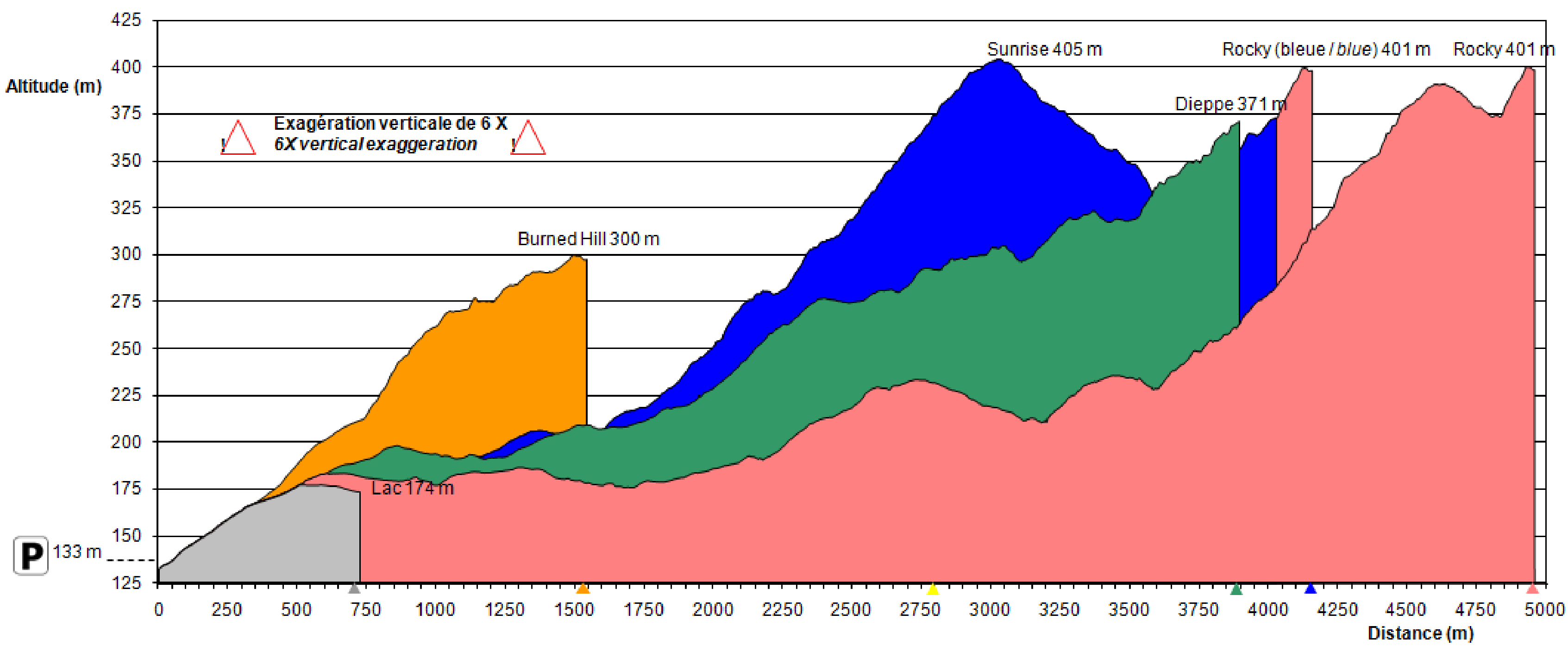
GBS-LFMP100AH

Map of Trails



Trail Profiles

Profils des sentiers / *Trail profiles*



Destination	Distance	Altitude	Dénivellation / *Altitude difference*	Temps / *Time* *
Lac Hertel	0.75 km	174 m	41 m	10 min
Burned Hill	1.6 km	300 m	177 m	35 min
Dieppe	3.9 km	371 m	238 m	1h 15
Rocky (bleu)	4.2 km	401 m	272 m	1h 30
Rocky (rouge)	5.0 km	401 m	267 m	1h 40

*Aller seulement / *One way only*