All Wheel Drive Electric Motorcycle

EML 4502: Senior Design 2

Milestone #6: Critical Design Evaluation

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Executive Summary

Electric vehicles (EV's) are rapidly increasing in consumer popularity. Currently, there are several commercial EV manufacturers of both cars and motorcycles and that number is constantly growing to match the demand of the market. To date, there are no commercially available two-wheel drive electric motorcycles, and with the exception of some concept drawings and very recent prototyping in the private sector, this concept has not been fully realized in the consumer market. There are several advantages to a motorcycle that has both wheels under power via electric motors ranging from increased battery life due to regenerative braking, environmental considerations due to minimal fossil fuel consumption, and increased acceleration due to dispersed torque over a larger contact surface.

The following report discusses the proposed methods for generating a functional prototype of a two wheel drive electric motorcycle from basic concept generation to final assembly, testing and analysis of a working prototype. The goal for the scope of this project, based on the time and financial constraints, is to generate a functional prototype for display and further testing and analysis. Ideally, the end goal is creation of a marketable "bolt-on" system targeted towards garage hobbyists who can purchase all of the parts necessary as a kit and then perform the conversion in their own garage with the use of common hobbyist tools.

Over the course of two semesters, roughly six months, significant progress has been made towards a marketable product. Bearing in mind that in industry, the development of a product of this complexity typically takes years, sometimes as much as a decade in the case of Rivan's new electric pickup truck, the progress that has been made in such a small amount of time is remarkable. The AWDEMOTO team encountered several roadblocks in development both anticipated and not. Everything from shipping and vendor communication issues to the need to re-design OEM components to malfunction of off the shelf components were encountered and overcome by the teams resourcefulness and adaptability.

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Revision History

Table 1: Revision History

Revision #	Revision Date	Revision Description	Approver
0.1	3/21/2019	Initial Formatting	C. Brennan
0.2	3/22/2019	Draft of Project Objectives & Scope and Executive Summary	C. Brennan
0.3	3/24/2019	Draft of Assessment of Relevant and Existing Technologies and Standards	C. Brennan
0.4	3/29/2019	Draft of Professional and Societal Considerations	C. Brennan
0.5	3/30/2019	List of Manuals and Other Documents	C. Brennan
0.6	4/2/2019	Draft of System Concept Development	C. Brennan
0.7	4/4/2019	List of references	C. Brennan
0.8	4/16/2019	Draft of Design Analysis Appendix A Appendix G	C. Brennan
0.9	4/23/2019	Final Formatting and Editing	C. Brennan

Glossary

- AC - Alternating Current
- AWD - All Wheel Drive
- AWDEMOTO - All Wheel Drive Electric Motorcycle
- AEM - AWDEMOTO (Designed Component)
- BMS - Battery Management System
- CAD - Computer Aided Design
- CAN - Control Area Network
- CFD - Computational Fluid Dynamics
- CNC - Computer Numerical Control
- DC - Direct Current
- EV - Electric Vehicle
- FEA - Finite Element Analysis
- FMEA - Failure Modes & Effects Analysis
- ICE - Internal Combustion Engine
- OEM - Original Equipment Manufacturer
- OTS - Off the Shelf (Component)

1. Introduction

As a result of increasing awareness of environmental issues associated with fossil fuels, the electric vehicle market is currently expanding at an astounding rate. It is projected that by 2018, the market will have grown by 15% of its 2016 value. Motorcycles are particularly well suited to an electric drivetrain, due to their minimalistic nature and light weight.. A two-wheel drive electric motorcycle has yet to hit the market. Given the rising popularity of all-wheel drive in the consumer market, a two-wheel drive motorcycle has the potential to be an innovative and popular platform. The AWDEMOTO Senior Design Project has built an AWD platform in order to test the benefits of AWD on a street motorcycle.

The benefits of all wheel drive are obvious and proven by the rise of its use in the market. These benefits include regenerative braking on both wheels, increased efficiency based on lower current supplied to multiple motors, increased power delivery and traction control. An electric AWD design can be simplified much more than it's ICE counterpart, as is evidenced in this report.

This report will clearly explain the Project Objectives and Scopes, Relevant Existing Technologies and Standards, Professional and Societal Considerations, System Requirements, Design Restraints, Concept Development,Design Analysis, Engineering Specifications and an evaluation of the final system.

2. Project Objectives & Scope

This goal of the project is to create a two-wheel drive electric motorcycle kit for a 1993-1995 Kawasaki ZXR-750 motorcycle. The customer asked for this largely because it would retain the benefits of standard electric motorcycles while adding a few advantages such as increased traction, traction control, a more efficient power distribution, and the novelty of something unique, fun and innovative for the customer. The primary user of this product is the independent, DIY-focused electric motorcycle enthusiast. Secondary users are budget-minded commuters looking for a cheaper option than buying a new or used OEM electric motorcycle. Tertiary users would be those interested in competing in electric-only motorcycle racing classes. This user would expect the design to address the following needs:

- Safe Highway Speed.
- Reasonable Commuter Range.
- Reasonable Acceleration.
- Reasonable Charge Time.
- Safe and Comfortable Handling.
- Affordability
- Serviceability
- Able to operate in appropriate conditions.

3. Assessment of Relevant Existing Technologies and Standards

3.1. Legal Requirements

By the Culmination of senior design, the team will have built a functional prototype. Testing will be done on purpose built tracks which will eliminate the necessity of registration of the motorcycle for street legality. This decision was made due to the financial and time constraints inherent to the project.

Aside from street legality, the other primary concern associated with this project is violation of any environmental regulations. As the vehicle contains no signification petroleum based lubrication or fuel due to it electric nature, the only hazmat concern the team has is derived from the batteries. This concern partly drove the team’s decision concerning specific battery type. The selected Nissan Leaf Cells are inherently some of the most resilient battery pouches available. Regardless, the teams design attempted to mitigate any potential damage to the batteries and contains them in a sealed case in the event of a leak.

3.2. Aerodynamics

Air resistance is a considerable effect on moving vehicles when designing the external structure. Motorcycles are widely affected by the drag causing a huge waste of engine power to overcome. It is a force from the difference in pressure at the front and rear of the vehicle, with a relatively high force of the viscous air at the front causing the low pressure on the back of the bike and driver. This is the parallel force of airflow. Lift contributes to the vertical effects and depends on the shape of the vehicle and how the wind catches onto the surface area. Depending on weight distribution the vehicle can move upward if there isn't enough weight in the front. Another consideration is the necessities of the internal components and temperature. To prevent overheating in the internal components there needs to be a cooling system, normally this is done using a small portion of the incoming airflow to remove some of this heat**.** Normally you will see Radiator vents on the side of a bike, as they try to release as much hot air as possible, but where the airflow comes out can be interrupted depending on if it interferes with external airflow.

3.3. Batteries

The Battery pack is one of the most critical components in an electric vehicle, and its performance is crucial. The market is full of options, but not all the battery cells can be used in automotive applications. The right battery assembly shall meet safety requirements that only a few cells can deliver. The design must be affordable, safe, and reliable. One of the most important parameters to be considered is the Chemistry of the cells because the chemistry is associated with the energy density. The energy density is the amount of energy a battery cell can provide per volume and mass, this means that the higher the Energy density, the higher the performance of the battery.

During the early development of the electric vehicle, the capacity of the batteries limited the vehicle performance. In the past decades, the advances in materials had helped to produce better and more efficient batteries. The researchers have developed cells with better storage capacity and better discharge rates[17].

The most common and most well-known battery is the lead-acid battery. Since it discovered, this type of rechargeable battery had improved significantly in amperage delivery and size. It is very common to find this type in automotive vehicles, boats, and motorcycles. The cost of this product is relatively low, but due to the nature of the components, lead is a heavy metal, its weight and size are relatively high compared to other types of batteries. The integration of a lead-acid battery into an electric vehicle could be achieved, but it will result in a large and massive battery pack. Therefore, the application of lead-acid into a purely electric car could be limited if the weight and the volume are not desirable [15].

The NiMH batteries (Nickel-metal Hydride Batteries) became very demanded and famous during the 90s with the development of mobile electronic devices. It was common to find them "on cell phones and portable computers" [15]. The chemical used to develop the NiMH made the cells very safe to operate in high demanding systems, and very safe to the environment. Commonly this cell can be found in hybrid cars. The expected life cycle of NiMH if very high, but the price of individual cells is higher than lithium-ion. This cell is desirable when a deep discharge cycle is needed, for example in a solar-power system, but is not very attractive for an electric motorcycle because the Battery pack design will have to include a ventilation system to dissipate gas formed inside the cells. [15].
The Lithium-ion rechargeable cell has a high storage capacity and a small volume per unit. These characteristics make the Lithium-ion cells to have a higher power density than NiMH. Lithium-ion Cells are also fabricated with different characteristic, but overall they have a higher energy density than the rest of the cells in the market. The Lithium-ion cells are categorized into Li-ion and Li-po; the difference is mainly in the electrolyte. In the Li-on the electrolyte is fluid, and in the case of LiPo, it is a solid polymer [15]. The most common types of cells found in an electric vehicle are $LiFePO_4$, Li-On, $LiNiMn_2O_4$, $LiNiMnCoO_2$, NCR [13]. The Lithium-ion cells can store and delivering high amounts of energy during discharge, but the durability of the materials decreases rapidly if the components are exposed to accidentally over-discharge or overcharge. The deterioration of the internal components could cause an increase in the internal resistance of the cells and produce an overheating reaction. Excessive overheating could be dangerous because it could push the cells to reach self-destruction temperatures. For this reason, other components have to be added to the battery system to monitor the battery cell's integrity and performance. "In this type of cells, it is necessary to integrate a Battery Management System, BMS," with temperature sensors [15]. The management system helps to protect the battery from overcharging and from overheating and helps to increase the life of the cells [15].

3.4. BMS and Charging

The Battery Management System (BMS) provides valuable management of the individual cells that comprise an electric vehicle's battery as a whole. The BMS is critical for safety as well as efficiently managing the distribution of power and elongating the life of the battery. Due to the large differences in potential and high levels of current draw from various components involved in an electric vehicle, it is important to keep a constant watch over the individual cells in the battery, among many things. There are many ways the BMS accomplishes this. Depending on the configuration of the battery pack, a typical BMS will run electrical leads to the terminals of individual cells or groups of cells. Most BMS modules also use thermistors to measure the temperature of individual cells or groups of cells. Through these, the BMS obtains metrics of the state of charge, state of health, and remaining useful life of each cell or group of cells monitored. When paired with a cell-switching circuit, the BMS is able to use this data to avoid having the failure of a single cell cause damage or total failure to the entire battery pack. The BMS also uses the data it collects to balance the cells that it monitors. This process slows the degradation of cells and the pack as a whole by making sure the difference in voltage among individual cells is as low as possible. There are two methods a BMS can use to balance cells. One is passive balancing, in which cells that approach full capacity during charging have the extra current redirected and exhausted, often using resistors. During discharge, once a single cell has stopped discharging, the whole pack will as well. Thus, this method does not take full advantage of the battery pack. The other balancing method is called active balancing, in which the healthier cells are used to charge the weaker cells as opposed to simply dissipating the extra energy. This method is more costly, making it the more sensible choice for larger, needier builds.

A level system is used to categorize charging methods for an electric vehicle. Level 1 is the most basic, utilizing 120 volts over a common electrical outlet found in the United States. It consists of a single charging phase and uses the vehicle's on-board charger. Level 2 requires special external equipment for a source, consists of one or three phases, and also uses the on-board charger. Level 3 charging is mostly used in a commercial setting, similar to a gas station. It requires an off-board supercharger and consists of three phases. The charge itself can be delivered unidirectionally or bidirectionally, with unidirectional charging allowing only the power sink to receive energy and bidirectional charging stabilizing energy throughout the system. The charger communicates with the BMS to determine charging phases and modes and when to switch between them in order to prevent over-voltage.

3.5. Thermal Management

With the change in powertrain from an ICE to electric motors, thermal management becomes a concern for all components involved in the safe operation of this vehicle. The primary concern for the team was the batteries, the motors, the charger, and the motor controllers. Most electrical components have a standard property of an inverse relation of temperature to performance, meaning that as the temperature increases the performance degrades rapidly. With this knowledge, each of the problem areas were evaluated on how to properly remove the heat from the components. Forced convection used in conjunction with liquid cooling are the common methods of cooling in motorcycle applications, this project will be no different. Similar to AWDEMOTOS ICE counterpart, the mid drive motor will be cooled through the use of a liquid pumped through a heat exchange mounted where airflow provided by the movement of the motorcycle will remove the heat. The charger was purchased as an OTS component with two cooling fans mounted to cooling fins on the body of the charger, these fans will run when the charger is running and begins producing heat. The two motor controllers were designed to mount to a heat sink that will have custom cooling fins and channels machined into it, this is then cooled by forced convection produced by the movement of the motorcycle and channeled through a cooling duct to direct the air at the heat sink. All of these methods will be evaluated with the use of temperature sensors or thermistors to monitor the performance, if any problems arise during testing then the team will have the ability to add cooling fans but the initial analysis does not show that they will be needed.

3.6. Motor Control

Central to the electric vehicle is the transfer and control of power to the motor or motors. This action is typically done by one or more motor controllers. The positive and negative leads of the battery, as well as the three leads of the motor, are connected to the motor controller. The actual control of the draw of power can be achieved in a number of ways depending on the way the system is configured. In one such configuration, the throttle (as well as any necessary contactor and relays) are connected to the motor controllers. The controllers can then internally decide how much power should be drawn by the motors and how quickly it should be done. In another configuration, the throttle is connected to the main controller, which is in turn connected to the motor controllers. This way, the main controller computes how much power the motor or motors will draw given inputs from both the throttle and the motor controllers themselves. This configuration can be used in electric vehicles with two or more motors in order to achieve better traction control. The motor controller is constantly recording data on the motor and its interaction with it. It records data on the power distribution currently taking place, the state and current mode of the motor, as well as the wheel speed if Hall sensors are connected to the motor controller. Some motor controllers are also equipped to handle regenerative braking, which is the process of returning energy to the battery upon the vehicle entering a decelerative state.

3.7. Power and Drive Train

The Table of Comparable and Current E-Moto and E-Moped Models, table 2, gives the project a starting point for power requirements and transmission systems.

Table 2: Specifications of Electric motorcycles currently in production

	Zero S ZF7.2 (4)	Zero FXS ZF7.2 (5)	Alta RedShift SM (6)	Energica EVA (8)	Lightning LS-218 (7)	UBCO 2X2 (9)
Peak Power (HP/kW)	34/25 @4300 rpm	46/34 @4300 rpm	42/31	109/80	200/150	3.2/2.4
Peak Torque (ft*lbs/N*m)	78/106	78/106	38/52	133/180	168/228	136/184
Transmission	Belt Drive 18/90T Belt (1:5)	Belt Drive 18/90T Belt. (1:5)	Single gear (3.5:1) to 15/50 Chain (1:3.33)	Chain Drive 16/44 Chain (2.75:1)	ChainDrive (ratio not available)	Single stage planetary gear reduction
Motor Type	IPM Z-Force 75-5 Radial Flux, permanent Magnet Brushless	IPM Z-Force 75-5 Radial Flux, permanent Magnet Brushless	PMAC 14k rpm	PMAC	IPM	DC hub Flux Drive motors
City/Highway /Combined Range	89/45/60	100/40/57	-/-/50	-/-/125	-/-/120 miles	Not available
Weight (lbs)	313	251	283	~560	496	139
Max Speed (mph)	91	85	80	125	218	30
Style	StreetFighter	Supermoto	Enduro	StreetFighter	Faired Street	Moped

The most common power transmission is by a single gear ratio from the motor's shaft to the rear wheel accomplished by belt or chain. It is notable that none of these models use a selective gearbox or a variable transmission of any kind. This suggests that for this project, a direct drive or a fixed gear transmission achieved by a chain/sprocket or pulley/belt configuration is a the appropriate solution. The front wheel can be driven directly if a hub motor is used, and the rear could be driven by either a hub motor or by a mid-drive motor.

To achieve the project's requirement for an all wheel drive application, there must be either one motor with two transmissions driving the front and rear wheel, or two motors driving one wheel each. Installing a front driving motor introduces the greatest challenge, as it either requires a traditional electric motor with a complex transmission or a direct drive motor incorporated into the wheel itself. This problem could be solved by using a Hub Motor.

Traditionally, internal combustion motorcycles have a selective gear transmission in addition to a final gear ratio between the smaller front sprocket on the transmission output shaft and the larger rear sprocket attached to the rear wheel. Internal combustion engine All Wheel Drive motorcycles utilize a mechanical transmission from the engine to the front wheel which passes through the front fork pivot and travels down one side of the forks. This adds significant design complexity, weight, and maintenance to the vehicle.

A common system to solve this problem in the E-bicycle world is a hub motor. These motors are incorporated in the hub of the wheel and drive them directly. This eliminates the need for a transmission at all. A hub motor works as a normal motor does, but it is designed to keep the axle stationary and to allow the motor casing to spin instead. One requirement of a hub motor is a lever arm or sufficient clamping force on the motor's axle to keep the axle from spinning instead of the casing.

The electric motorcycle currently in production generally use a fixed gear transmission which consists of a belt and pulley configuration or a chain and sprocket configuration. The benefits and drawbacks of each system are reviewed in Table 2, alongside a shaft-drive system common in ICE motorcycles.

Table 3: Fixed Gear Transmission Systems

	Efficiency	**Benefits**	**Drawbacks**
Chain & Sprocket (2)	~98%	High part availability Easiest to replace. Easiest for changing gear ratios.	Shortest Lifespan Requires the most maintenance. Loudest
Belt & Pulley	~89%	Requires less maintenance Longer Lifespan Quieter than Chain Easy to change gear ratios.	More complex to replace. Cannot bend as well as chain, larger pulleys are required.
Shaft Drive	~75%	Quietest of all three Minimal Maintenance	Heavy Complex Design Difficult to repair or replace.

3.8. Vehicle Dynamics

With the change of the powertrain and the component placement on the motorcycle its handling and response to rider's inputs could change drastically. The main concern for the team was dangerous handling and unpredictable responses to riders inputs.

Center of gravity is one of the main contributors to the handling characteristics of the AWDEMOTO. Battery placement and shape of the battery box was carefully considered during design stage to ensure the optimal placement for handling and packaging. Batteries were placed towards the center of the motorcycle where the ICE used to be mounted. Battery box along with the mid drive motor account for most of the weight and are positioned as low and as close to the center of the motorcycle as possible.

To fit the battery box that is bigger than the ICE that used to be mounted on the motorcycle it was needed to lengthen the wheelbase of the motorcycle by increasing the rake of the motorcycle. The trail was decreased due to rake increase. Both of those parameters are adjustable and could be changed to finetune the handling characteristics as soon as the motorcycle will shift into the testing phase.

Both front and rear tires were replaced with brand new high performance tires. Both front and rear wheels were fitted with the biggest tire that the rim allowed. Wider tires will allow for more mechanical grip and less slippage that could result in understeer/oversteer or a crash. Moreover, a taller front tire was needed to increase the ground clearance and compensate for a limited maximum RPM of the front motor.

Since the weight remained similar to the weight of the original motorcycle, damping settings and spring rates will stay the same until the motorcycle will move to the testing phase, where its damping will be analyzed over various surfaces and changed if necessary.

4. Professional and Societal Considerations

As engineers, it is largely our responsibility to look towards the future in terms of environmental issues, accessibility and market desires. By acclimating to the trend towards transferring over to EV's from ICE's, all of the above requisites are met.

According to market research, the compound annual growth rate of EV's is expected to reach approximately 30% by 2025 due to government subsidies and consumer opinion *[43]*. Expecting this type of growth in demand, it stands to reason that professional responsibility dictates pandering to the market projections.

Internal combustion engines typically operate at a thermal efficiency of around 20%. Conversely, dual cycle natural gas generators accounted for approximately 53% of all the electrical power generated in the US in 2016, by far more than any other method of generation. For simplicity, assume that 100% of power generated comes from these plants, and that these power plants can achieve a thermal efficiency of just over 60%, more accurately 62% for the most contemporary models. This means that every time a consumer switches from ICE to EV, they are reducing their fossil fuel consumption by approximately 33%. As societally and professionally responsible engineers, expanding the options and accessibility of EV's is the

5. System Requirements and Design Constraints

In the beginning, disregarding specific customer demands, the team was constrained by the problem of delivering power to both wheels and providing energy from an on board source. The solutions are fairly straight forward; as the project calls for an electric vehicle, batteries and electric motor(s) respectively. At this point everything becomes much more complex.

In order to select the correct components, the team needed to take the end user requirements and translate them into Engineering requirements and then into tangible specifications or system requirements. This process can be seen in the use of table 6 and table 7 located in Appendix A. For example, in terms of acceleration, to be competitive in the market, the motorcycle should have a 0-60 time of less than 9 seconds. Based on maximum vehicle mass (<120% of stock mass), the necessary torque, angular velocity and power values for the front wheel were determined to be approximately; 140.7Nm, 862 RPM, and 12.3kW respectively. After generating a significant amount of solid numerical data in this manner, the team was then able to determine requirements for motors and batteries which led to compatibility requirements for almost every other OTS component such as charger BMS motor controllers and like.

Initially, it seemed that having a frame and basic structure to start with would be advantageous as opposed to starting from scratch. The team quickly discovered the unforeseen pitfalls involved with that. In order to achieve the necessary ranges and speeds, the team would need to select specific motors and batteries as well as all the associated hardware described above. Initially the AWDEMOTO team believed it had more space than it needed to mount all the requisite components. It was quickly evident that this was not the case. As a result, there were several iterations of mounting hardware and re-locating different components on the vehicle and some of them were fairly creative.

6. System Concept Development

6.1. Motor Type and Placement

The basic scope of the project provided the team with a minimal amount of structure in the form of an overall shape and method of propulsion, being a motorcycle with one or more electric motors, respectively. The first order of business was to dial in how many motors were required and their orientation. Everything else stemmed from that decision.

Table 4: Motor Placement Concept Alternatives

Concept Alternatives:Motor Placement and Type									
Criteria	Importance Weight %	Option 1		Option 2		Option 3		Option 4	
		Front: Hub Motor Rear: Hub Motor		Front: Mid Drive Motor Rear: Mid Drive Motor		Front: Fork Mounted Motor Rear: Mid Drive Motor		Front: Hub Motor Rear: Mid Drive Motor	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Max Speed (rpm)	20.00%	1	0.2	3	0.6	4	0.8	4	0.8
Max Torque	20.00%	4	0.8	2	0.4	4	0.8	4	0.8
Low Cost	20.00%	3	0.6	2	0.4	3	0.6	3	0.6
Low Unsprung Weight	10.00%	4	0.4	4	0.4	1	0.1	3	0.3
Simplifies Power Transmission	15.00%	4	0.6	1	0.15	3	0.45	3	0.45
Simplifies Programming	15.00%	3	0.45	4	0.6	3	0.45	2	0.3
Totals:	100.00%		3.05		2.55		3.2		3.25

In table 4 (above) is the weighted rating process used to determine the ultimate decision as to what type of motors would be used and their locations on the motorcycle. Front wheel hub motor and frame mounted rear wheel motor, freed up a significant amount of space in the frame and simplified the system from a mechanical energy transfer standpoint. This decision dictated the required locations of the motors which helped to un-muddy the waters in terms of the next series of design decisions. For all selection charts generated by the AWDEMOTO team refer to Appendix A

6.2. Reverse Engineering of OEM Components

From this point the team disassembled the existing motorcycle and determined which components were going to be re-used for the prototype and which ones could be discarded.

Salvaged components included:

- Fork assemblies
- Primary frame
- Swing arm
- Subframe

- Brake assemblies
- Rear wheel
- Rear shock

Each assembly was cleaned and compared with manufacturer assembly drawings to verify accuracy of nomenclature, assembly, and accountability of individual components. For the design of fabricated components and verification of fitment of OTS components within the frame, it was necessary to have a working CAD assembly of the entire vehicle. As the OEM assembly was the only non-variable in the physical design, the team determined this was the logical place to start the general framework of the design. Solid models were created using the recycled bike parts as accurately as possible and put into an assembly together.

6.3. AEM Component Design

OTS components were selected based on concept alternative tables similar to table 2 (above). Refer to Appendix A for complete catalogue of selection tables. Once OTS components were selected and purchased, solid models and 3D printed mockups were made to verify dimensional accuracy using manufacturer technical drawings. From the data generated by OEM and OTS components, the team was able to design and create drawings for fabrication and or machining of all necessary AEM components.

Fabricated components include:

- Motor mounts
- Front brake rotor
- Battery containment box
- Battery box mounts
- Cooling Channel
- Motor controller mount
- Subframe mounting brackets
- Water pump mount
- Triple trees

The majority of the above components were machined from aluminum billet by E-sector Machining, an AWDEMOTO sponsor. The majority of the welding was done by AWDEMOTO's very own in house welder, John Gabler.

6.3.1. Battery Box

The selected batteries function at best when compressed to 10 ft-lbs. This allowed the team to compress all fourteen batteries into two blocks and then design a battery box around them. The box was designed completely confine the batteries, but still allow them to float within the box to mitigate any excessive vibration or impact. To accomplish this the all-thread that held the battery stacks together was captured by rubber feet on either side. For structure, the box was made out of water jet cut 3/16" aluminum plate with ⅛" angle aluminum on most corners for added structural support.

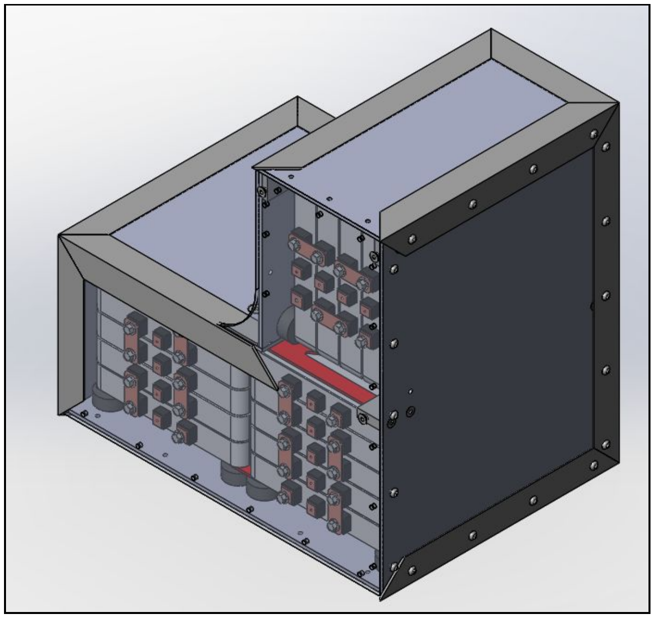

Figure 1: Battery Box Assembly

6.3.2. Cooling Channel

The cooling channel concept served multiple purposes. Naturally, it allowed ambient air to flow through the vehicle giving the team the ability to decide where it should go. Additionally, it provided a mounting surface for a multitude of components such as the charger, throttle linkage, contactor and water pump. 3” square channel was cut and welded to the specified dimensions and then bolted on to the vehicle using existing harpoints on the primary frame.

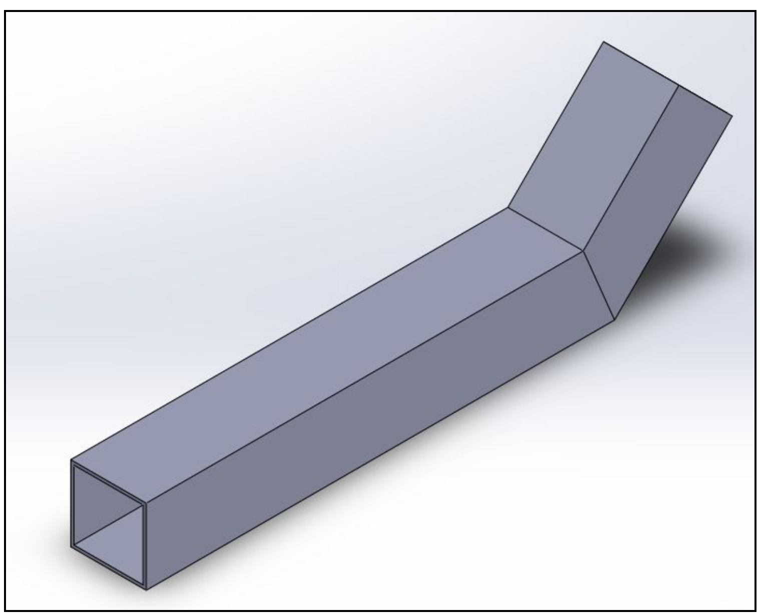

FIgure 2: Cooling Duct

6.3.3. Motor / Battery Box Mounts

On the OEM version of the motorcycle, the engine hung beneath the frame and was a primary stress member of the overall structure. This needed to be mimicked to ensure the vehicle had the necessary structural integrity for operation while providing enough space on the motorcycle for all necessary components. 1-½” aluminum rod was machined and mounted to the frame at the existing engine mounts. Battery box hangers were designed and machined from 1” aluminum plate. Motor mounts were designed and machined from ½” thick aluminum billet and welded to the battery box. This allowed two of the most crucial and by far the heaviest components to be mounted to the original frame using the six original hard mounting locations in the OEM design.

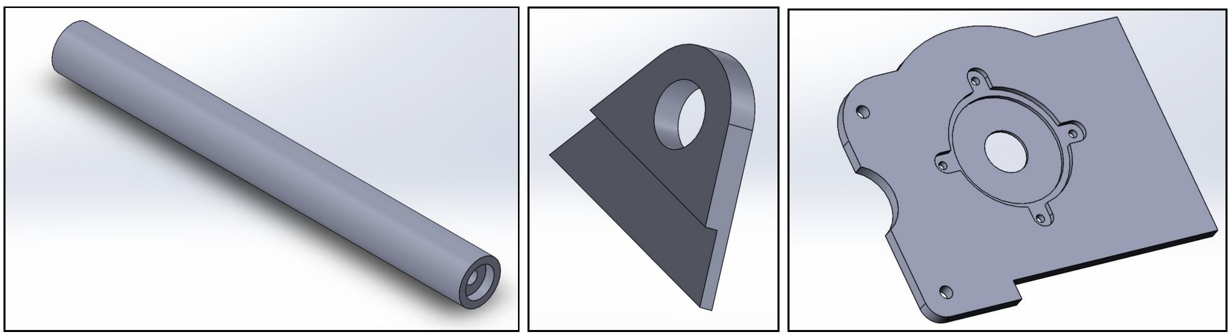

Figure 3: Motor and Battery Box Mounts

6.3.4. Triple Trees

The team suspected that after all the added components, there would be very little ground clearance and that the minimum battery box size would still interfere with the front wheel. The team solved this by re-designing and machining new triple trees out of 1-½” billet aluminum. The redesign moved the forks further away from the steering stem by approximately 2 inches. This cleared the front wheel, but did lower the entire vehicle from the front end slightly. This was fixed by sliding the forks down the triples as much as possible by making the triples as thick as possible. After some adjustments to the solid models, the team was able to achieve wheel and ground clearance.

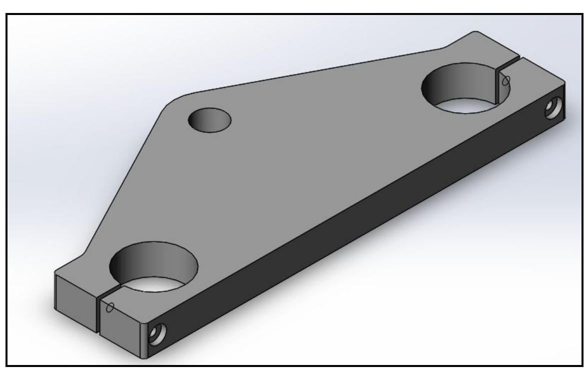

Figure 4: Triple Tree

6.3.5. Controller mounts

The team decided that the best place to mount the motor controllers was under the seat. It was out of the way and would get sufficient airflow during operation. A ⅜" aluminum plate was decided upon as a mounting surface largely due to its lightweight, machinability, and thermal conductivity. It simply was a matter of drilling and tapping mounting holes in the correct locations for mounting the controllers and mounting the plate to the subframe.

6.3.6. 3D printing

There were several parts that the team decided should be 3D printed. This would be significantly cheaper than machining some of the more dimensionally complex components that were not load bearing such as parts of the cooling channel and bushings. The team still needed something that was going to stand up to some structural stress, but more importantly, it needed to withstand some heat. PLA, a typical filament, has a tendency to warp in direct sunlight. The team did a couple of quick experiments to determine what type of filament to use. This included printing a small part out of each of three materials; PLA, Alloy 910 and carbon fiber nylon. All three parts were subjected to stress test. (They were hit with a hammer.) Then the parts were subjected to a heat test in the oven at 190 degrees F. The only part that held up was the carbon fiber nylon.

6.4. Motor Controllers

Once the team decided what motors were going to be used, the next decision to be made concerned what controllers would be purchased to go with them. Several criteria factored into this decision. First, each motor controller should be capable of handling the same (if not very close to the same) continuous current draw as the motor it is controlling, so that the motor can be used to its full potential. Each controller should also be designed to support and control the specific type of motor it is associated with. The front motor selection is a Brushless DC (BLDC) motor, while the rear motor chosen is a Synchronous Permanent Magnet AC (PMAC) motor, so the corresponding controllers needed to be compatible with those types. The controllers also needed to be able to communicate across the CAN bus protocol, so that data processing by the microcontroller and interfacing with the BMS would be possible. The team chose a Sevcon Gen4 size 6 controller for the rear motor, and a Kelly KBL96351E controller for the front motor. Since the Sevcon controller was notorious in the industry for being extremely difficult to program and configure from scratch, the team decided to purchase a programming module to aid in the setup of the controller.

6.5. Thermal Management

6.5.1. Rear Motor Thermal Management

The electric motor will be one of the main contributors to heat generation on the AWDEMOTO. With the close proximity to the batteries along with the inverse relation of temperature to motor performance, this heat generation must be minimized through the method of cooling the motor. There were 6 categories that each motor was evaluated on; rate of heat transfer, the level of performance that is achievable, the total cost of all associated components, the sound attenuation of the design, any necessary modifications that will need to be made to the motorcycle, and finally the hazardous conditions associated with the methods of cooling. After evaluating the three different options for thermal management of the the mid drive motor, it was decided that the best choice for the design of the AWDEMOTO was a liquid cooled motor.

Table 5: Mid Drive Motor Thermal Management Concept Alternatives

Mid Drive Motor Thermal Management Concept Alternatives							
Criteria	Importance Weight %	Option 1		Option 2		Option 3	
		Air Cooled		Oil Cooled		Liquid Cooled	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Heat Transfer Rate	40.00%	2	0.8	4	1.6	4	1.6
Performance	30.00%	2	0.6	3	0.9	4	1.2
Low Total Cost	10.00%	4	0.4	2	0.2	3	0.3
Sound Attenuation	5.00%	1	0.05	3	0.15	3	0.15
Modification to Motorcycle	10.00%	4	0.4	2	0.2	2	0.2
Low Hazardous Conditions	5.00%	4	0.2	1	0.05	3	0.15
Totals:	100.00%		2.45		3.1		3.6

The liquids used in cooling electric motors are great thermal conductors making them very effective at removing the heat from the motor. This allows less degradation to performance at higher RPMs due to the sheer amount of heat being removed allowing continuous torque performance throughout the range of output from the motor. This type of system requires the use of a pump, hoses, and a heat exchanger. These factors increases the cost associated with a liquid cooled electric motor but when discussing life expectancy and the lack of power and torque lost it is a very small factor for what is gained in thermal management. Another important factor is discuss is the hazardous conditions that are brought about when discussing the liquid cooled motor. There are many different types of liquids that may be used in cooling applications ranging from distilled water to highly toxic chemicals designed specifically for cooling electric motors. After researching the different properties of the possible liquids, the team has decided on using a 50/50 mixture of ethylene glycol and distilled water.

6.5.2. Battery Thermal Management

The batteries are a very large contributor to the heat produced in the AWDEMOTO project. With the large amount of heat and energy generated from the batteries coupled with their fixed proximity to the mid drive motor and charger, limiting the amount of heat soak in the area will greatly improve the quality of the operation of this project. Refer to Section 3.5 of the teams Milestone 3 Report, where the topic of Lithium-Ion battery performance degrades when temperature increases. This concept applies to most electrical components that are used within this project, therefore reducing any amount of heat inside the battery and motor compartment, the more efficiently the AWDEMOTO will operate. There were two options the team decided to compare for methods of cooling the batteries, liquid cooling and passive cooling. Liquid cooling of the battery pack provides an excellent method or removing the heat created from the batteries. If designed correctly, the use of liquid could be used both during charging and operation allowing the battery pack to be maintained at an optimal temperature during use. With the optimal temperature being maintained the lifespan of the battery is not affected as it could potentially be if it were to overheat. The main problems the team had encountered with liquid cooling was budget constraints as well as spatial limitations. The systems' footprint would drastically increase due to the addition of a heat exchanger, pumps, hoses, and a tank to hold the fluid. All of these components also come at an added expense to the owner between initial design but also maintenance and replacement parts. The power required to power the pump as well as any cooling fans utilized during charging situations would require the 12 volt system to be charged more often also decreasing the amount of energy stored for powering the AWDEMOTO in motion. This would further limit the range of the vehicle. With these problems in mind, the team decided to pursue the option of passive cooling. Passive cooling is defined as the use of forced convection to cool down the component in question. This forced convection can be provided in the form of electric fans as well as the act of the AWDEMOTO moving causing the surrounding air to flow over the components. The main cost associated with passive cooling will be the addition of cooling fans, when a battery is charging it is still producing heat, if there is no way for the heat to escape then the chances for the battery to overheat continuously increase. In the current design the team will be monitoring the battery module temperatures with the use of thermocouples. The battery pack was designed as a sealed pack without any cooling fans or cooling fins, if the test results show elevated temperatures then the team will reevaluate the design. As for operation of the AWDEMOTO, the battery pack's large frontal area allows it to be cooled by the forced convection of the actual movement of the bike.

6.5.3. Motor Controller Thermal Management

With the updated design of both the front and mid drive motor controllers mounting locations, new methods of cooling had to be investigated. Similar to the batteries, the performance of these components can degrade as temperature increases, so it is necessary to remove as much heat as possible to keep AWDEMOTO under safe and consistent operation. The new location moves them to the subframe under where the rider is located and above the wheel, this does not allow the needed forced convection like the battery pack receives. With the newly freed up space under the tank enclosure, a cooling channel was designed to deliver cooled air in a forced manner to both of the motor controllers. This cooling channel also provides the added bonus of working as a mounting location for many other components such as the charger and water pump. The two motor controllers were then designed to fasten to a large heat sink with the use of fasteners and thermal paste. This heat sink will have additional cooling channels milled into it for the forced air to flow through and remove the heat. As the controllers are only in operation when the bike is in operation, there is no use for the additional strain on the system from cooling fans.

6.6. Safety Considerations

When designing the AWDEMOTO project, safety must be held paramount. Not only does rider safety need to be considered, but environmental safety must be evaluated as well. Every single motorcycle on the market in the past and present has the possibility of death during normal use. This issue is not able to be worked around as the rider is not restrained, nor is there a protective compartment to house the rider in the case of an accident. With this being said there are design considerations that can be made to mitigate any risks associated with riding the motorcycle. To begin, the proper signals and lights need to be mounted to the motorcycle in order to signal any turns or stops that the rider is anticipating. The rider also must have a headlight equipped for riding in low light environments. In the state of Florida, as well as many other states, a headlight is actually required by law. While this project is not anticipating the acquisition of street legality, rider safety is still being placed above form and functionality. In addition to lights and signals the motorcycle must also be able to stop in an appropriate manner. This modified project will retain the use of the stock brakes that were designed for use with the stock Kawasaki frame, in addition to these brakes AWDEMOTO will utilize the braking capability of regenerative braking. With the modifications to the triple tree, a key component of the steering and suspension system, safety was made to be a critical factor in design. This component was over designed as to allow a very large factor of safety, further optimization of design can be completed with more time and resources. The current design

7. Design Analysis

7.1. Triple Tree & Forks FEA

A simulation was performed in solidworks to calculate and observe the effects of stress in critical areas, specifically on the AEM components. The analysis figures 5 & 6 (below), demonstrates the effects of applying the Maximum Torque from the hub motor of 320 Nm to the fork assembly. As a result of designing such robust triple trees, forces cause little deflection in the AEM components and the remaining deflection happens in the forks. These are inherently very strong OEM components designed for years of constant rigorous use. Even so, the torque imparted will be controlled via limiting acceleration of the vehicle.

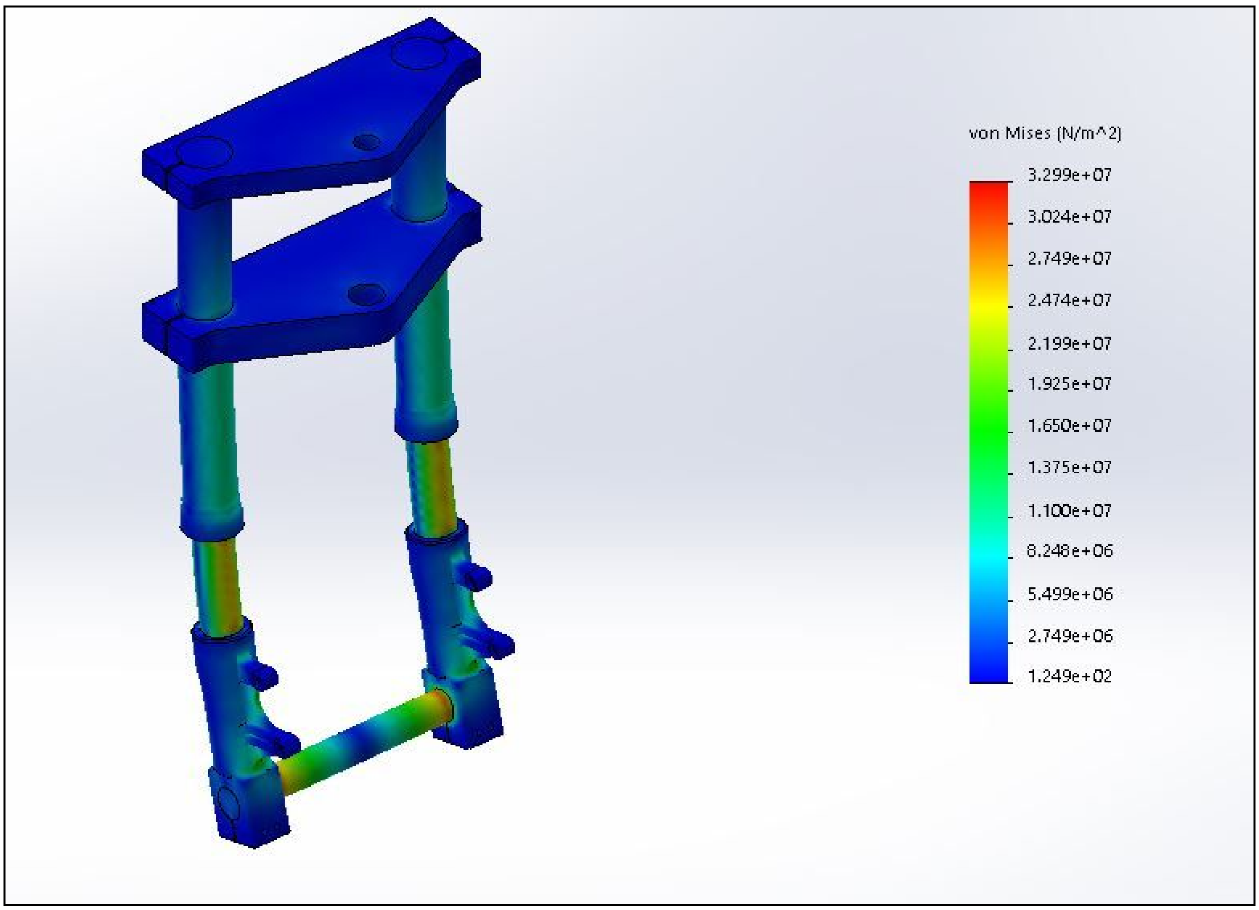

Figure 5: Von Mises Stress in Fork Assy at Peak Torque

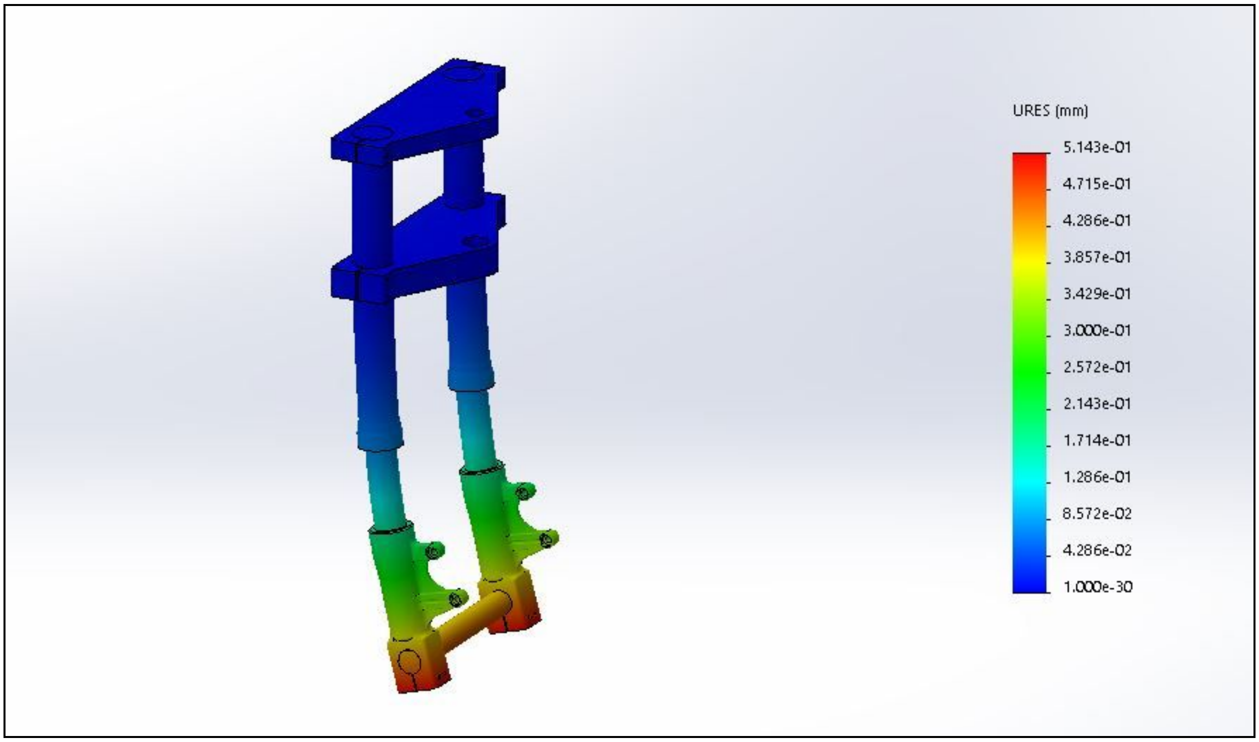

Figure 6:Deflection of Fork Assembly at Peak Torque

7.2. Battery Box & Battery Mounts CFD/ FEA

The second simulation was performed calculating the normal pressure produced if the Motorcycle is driven to is maximum speed (60 mph). In anticipation of the increased frontal surface area, the group reinforce the internal structure of the battery box assembly to minimize the deflection caused by the increase in normal pressure in the frontal plate. The CFD of the modified frontal surface area and profile of the motorcycle can be seen below in figure 7 which leads to the FEA of the battery box to determine how much the air pressure will deform the front plate of the assembly.

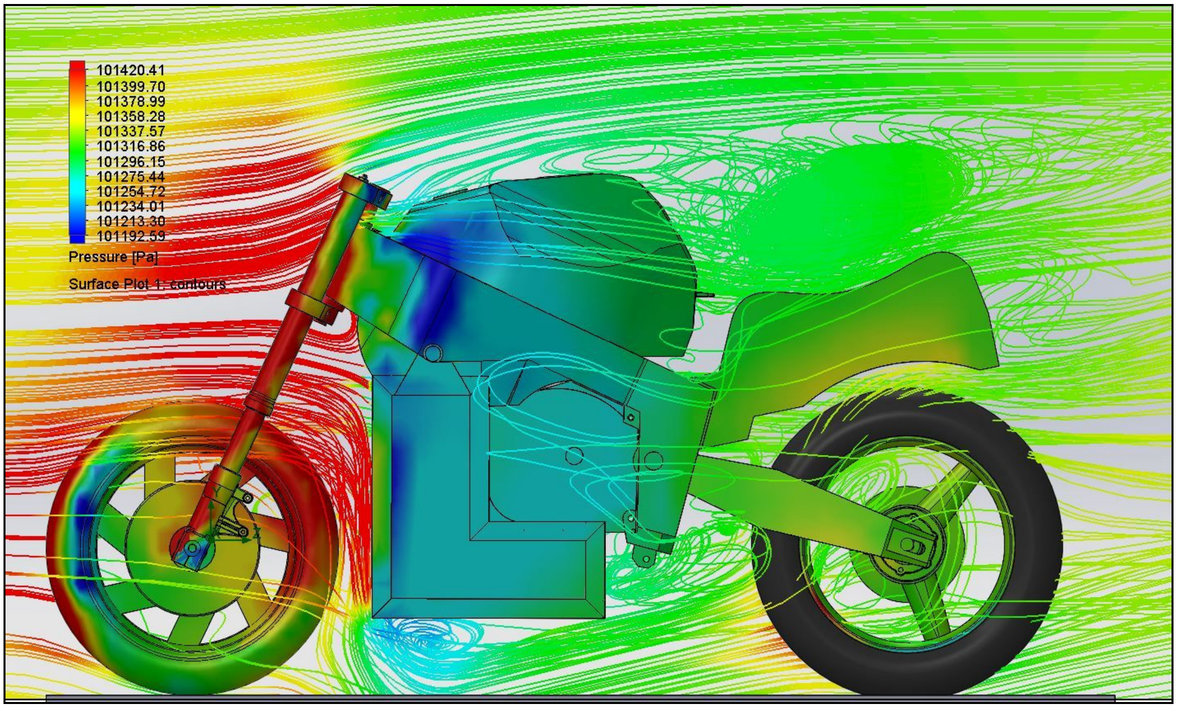

Figure 7:Normal pressure due to increase of frontal area

The pressure obtained from the aerodynamic analysis was used to perform a static analysis in the Battery assembly to observe the deformation seen below in figures 8 & 9. The reinforced structure of the battery box minimized any deformation caused by air pressure.

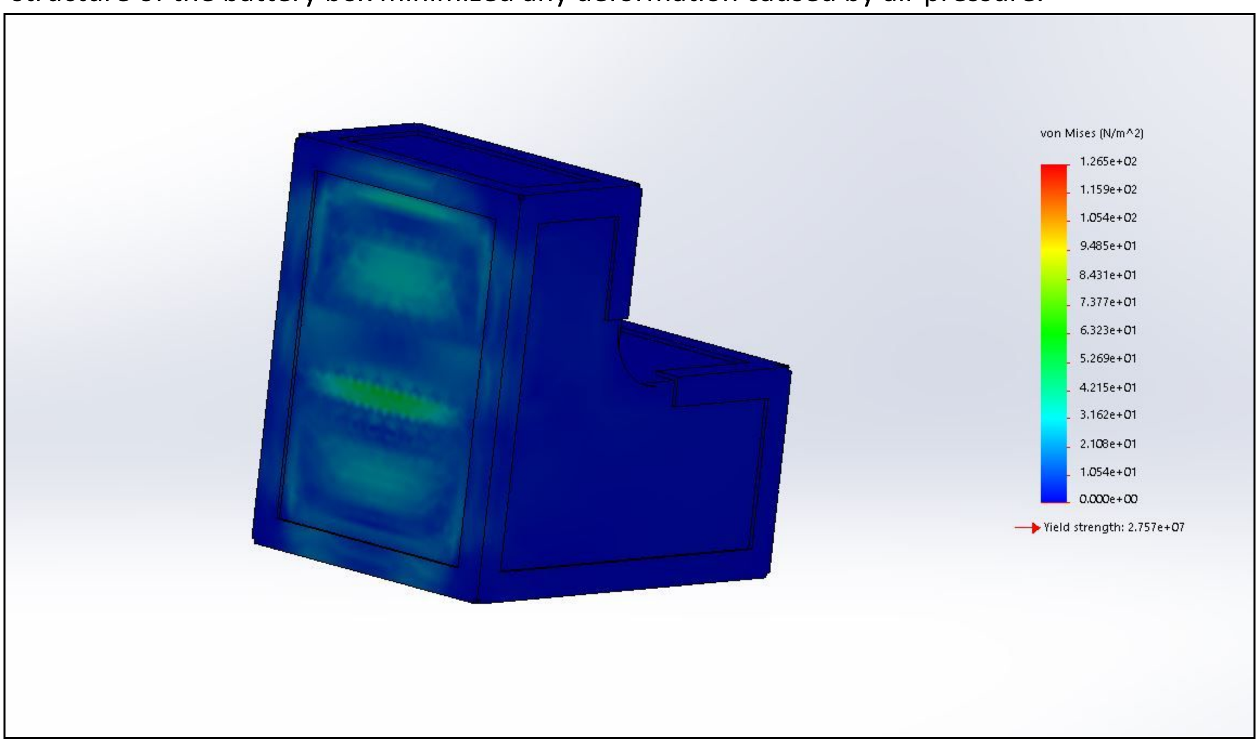

FIgure 8:Stress Resulting From Frontal Air Pressure

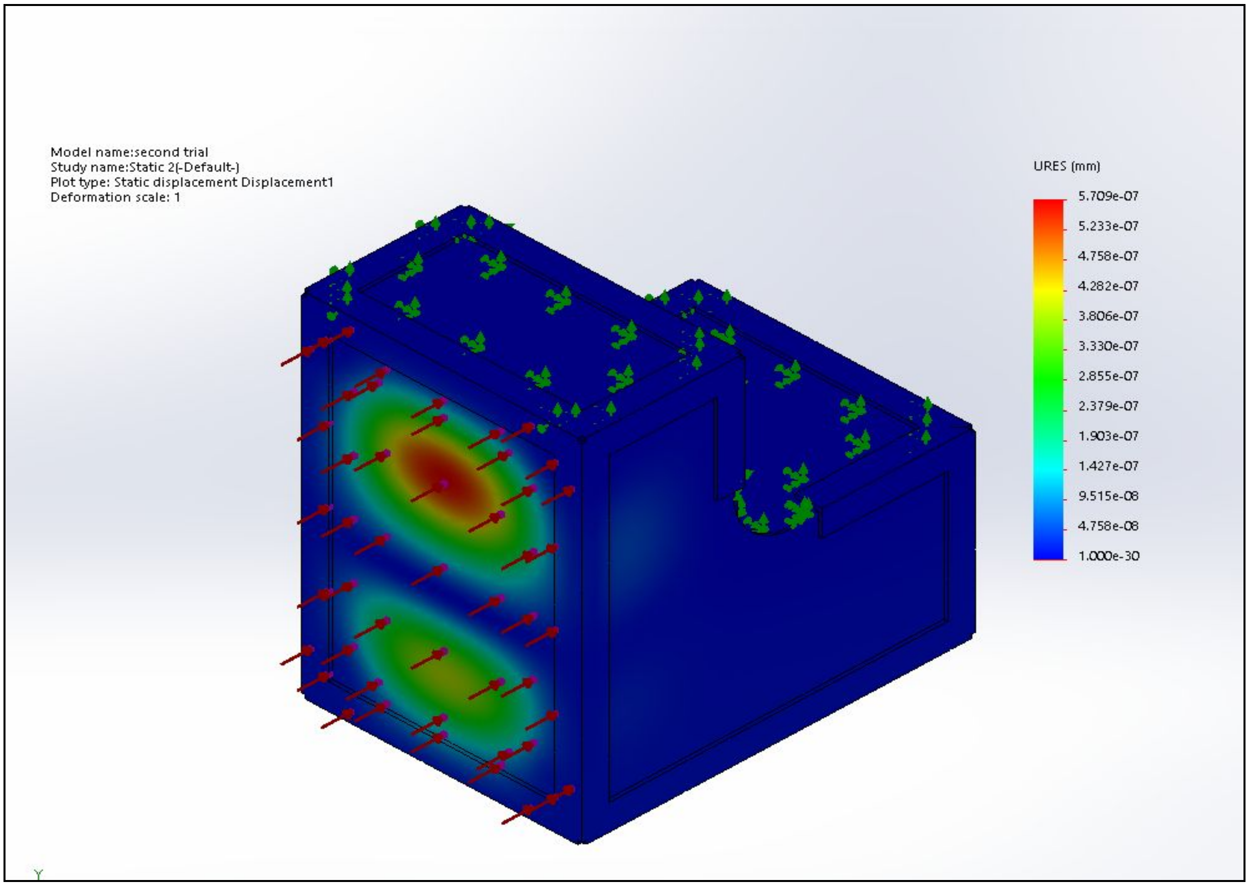

Figure 9:Deformation Resulting From Stress

7.3. Motor Controller Cooling Channel CFD

The motor controllers while in operation are anticipated to generate significant heat. The amount of heat generated is unknown until prolonged testing can be done, however as an added precaution, the team designed for the worst case scenario and added a cooling duct to direct ambient air to the motor controllers at vehicle velocity. The goal of this feature was to provide maximum convective cooling on the motor controller heat sinks and mounting assembly. CFD was done on the duct and motor controller assembly below to verify that at speed, maximum airflow was directed to the controllers. As can be seen in figure 10 (below), the team modeled the inlet air velocity at approximately 60 mph at roughly 101325 Pa (air pressure at sea level). The air is initially compressed into the duct, but then drops just slightly below ambient pressure once it reaches the motor controllers.

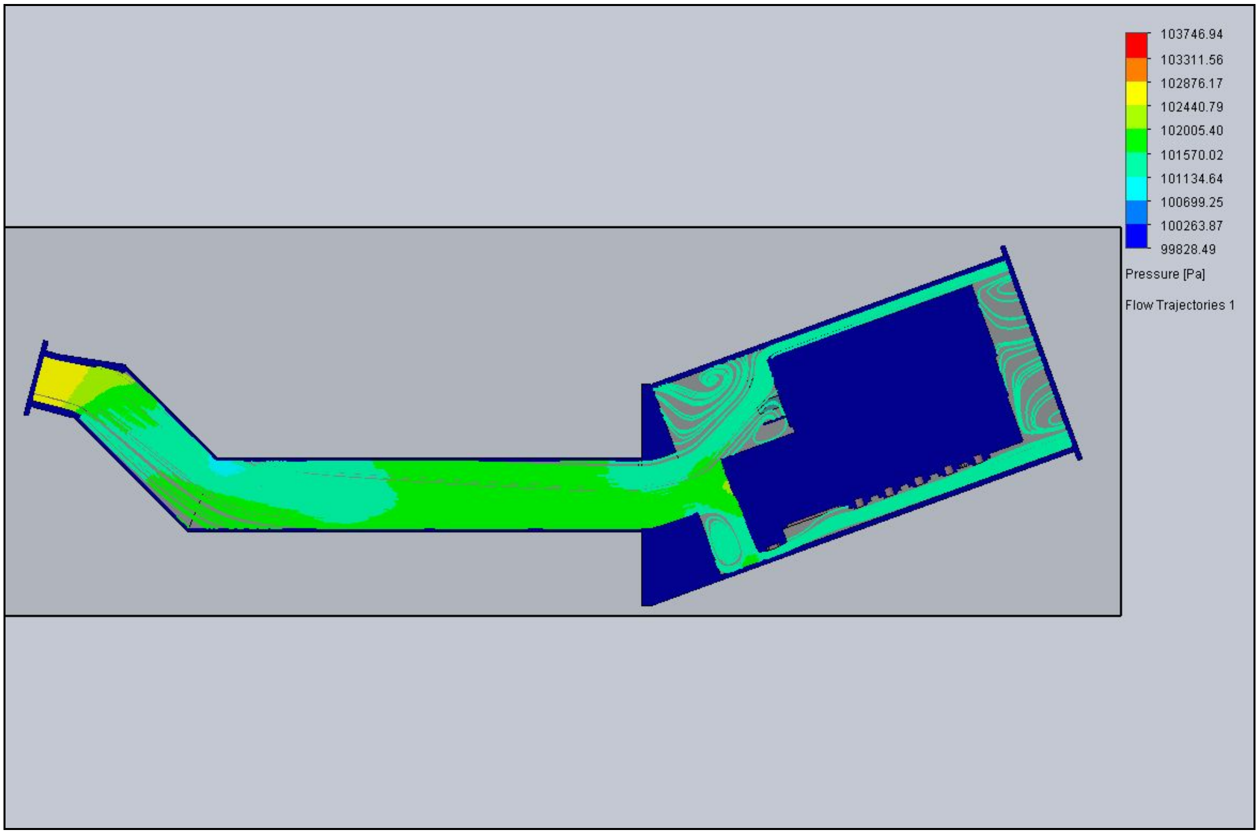

Figure 10 Cooling Duct CFD
velocity input:1056 in/s at scoop entrance

8. Final Design and Engineering Specifications

8.1. Battery Life and Available Power

The Final design of the battery system consists of 14 Nissan Leaf modules arranged in series configuration resulting in a 28 S, 2 P cell configuration. In a fully charged state with zero battery degradation, the battery assembly will provide approximately 56 kWh of available energy. At an optimal or average discharge rate of 240A continuous, and a continuous power of 24.8 kW, the vehicle will have a peak power rating of 62 kW, or roughly 83 hp.

As stated above, the pouches are rated at a draw of 240A continuous. Disclaimer: This is max draw rating and will not be the average draw from the batteries. At the max draw the battery will last from full charge to full drain approximately 20 min. Average draw on the batteries during operation will be closer to 40A (arrived at from bench testing or motors), which will yield an average battery life of 90 minutes at average draw.

8.2. Torque and Velocity

8.2.1. Front Motor Specs.

The front motor chosen and implemented in our design is a QS 273 V3 50H Motor. This motor is a direct drive, 1:1 ratio Brushless DC Hub Motor that replaces the front wheel. The motor's continuous rated power is 8 kW, and peak rated power is 20 kW. The peak torque is 290 Nm. The motor is rated for 72V-120V and a continuous current of 139 amps. The motor utilizes hall sensors and thermistors for wheel speed and temperature sensing. The motor's Maximum continuous working temperature is 70 degrees Celsius, with a maximum peak temperature of 120 degrees Celsius. The motor is waterproofed to the IP54 standard, and weighs 25 kg. The motor's efficiency is 91%.. The motor is an integral part of a cast rim measuring 17" x 3.5" wide. The motor is capable of 130 kn/h, or 1405 RPM at 96 volts. For our project, we used a 115 charged voltage which could result in a top speed of 156 km/h.

8.2.2. Rear Motor Specs.

The motor chosen for the rear drive is a Permanent magnet Synchronous AC motor produced by Motenergy. The Motenergy ME1616 is an Radial Air Gap, Permanent Magnet Synchronous Motor (PMSM) with an Internal Permanent Magnet Rotor (IPM). The ME1616 is watercooled and waterproofed to an IP67 standard. The motor is rated for 250 amps continuous, 600 amps peak. The ME1616 has a maximum RPM of 6000. The rated power is 20 kW continuous and 55kW peak. Continuous torque is 32 Nm, and peak torque is 120 Nm. The maximum operating temperature is 140 degrees celsius. The motor has a sin/cos encoder for wheel position sensing.

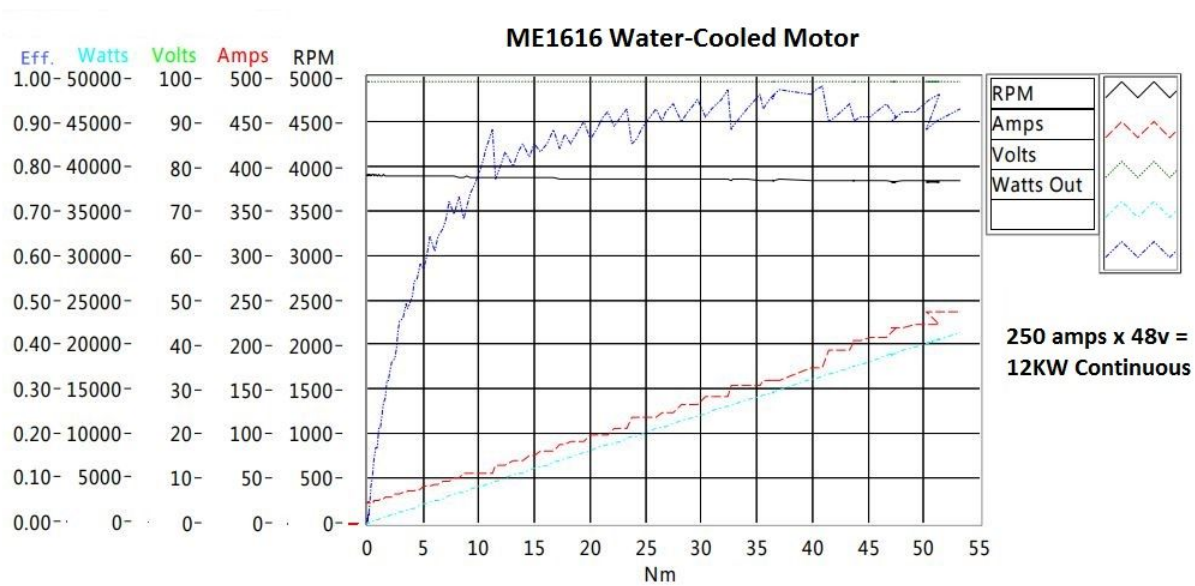

FIgure 11: Mid Drive Motor Specs

8.3. Ground clearance and maximum Lean Angle

The AWDEMOTO team has several inherent constraints that were evident from the start, the two most prevalent being time and cost. The result of this was the battery choice. The Nissan leaf cells have a unique geometry that limited the design of the battery assembly. The most optimal design of the battery box achievable in the time allotted yielded a boxy style that left little space for ground clearance and lean angle. That being said, the ground clearance and lean angle allowable, while not ideal for a high performance racing motorcycle is still well within tolerance as it is still much more capable of tight turning radius and ground clearance than many large cruisers.

8.4. Maximum Weight

After Removing The vast majority of OEM components from the vehicle and installing all AEM and OTS components, the total mass of the vehicle is projected to be and is no more than 110% of stock weight. The stock wheel bias was 48.9% /51.1% rear to front respectively. AWDEMOTO prototype wheel bias is roughly 45.2% / 54.8% which will adjust the rider ergonomics very little from stock design.

8.5. Rider Ergonomics

The AWDEMOTO team, more from necessity than any other reason decided to raise the rider position in order to accomodate the ideal location of the motor controllers. This was an acceptable change because the current customer is much taller than the average rider and will not have any issues controlling the vehicle from a taller seat. If anything, he will be more comfortable.

8.6. Safety Features

Motorcycles are inherently dangerous, so it is always recommended to wear all appropriate PPE while operating any two wheeled vehicle. In addition to that the AWDEMOTO team devised a few other safety measures.

The electrical system runs through several contactors wired in series with the the motor controllers and BMS. If any one of these three components detects a deviation from acceptable voltage limits, the contractor will disengage and the entire system will isolate itself from the batteries instead of allowing power to flow through the rest of the components causing damage or an unsafe condition for the rider. The motor controllers were programmed to allow the vehicle to accelerate at safe values in order to maintain a safe rotatum that would be less likely to break traction and cause any type of low or high siding or unintentional wheel lift.

9. System Evaluation

9.1. Performance Evaluation

On wednesday night (two days before senior design showcase), the team discovered a malfunctioning battery pouch. The circumstances of the faulty component led the team to determine that the vehicle was unsafe to continue to work on in the time frame allotted without purchasing and implementing additional safety measures. This resulted in disassembly of the battery system and wiring harness in the interest of safety. Unfortunately, this also meant that the team was unable to conduct a road test of the vehicle, or collect data for an accurate system evaluation.

10. Significant Accomplishments and Open Issues

10.1. Significant Accomplishments

In industry something of this magnitude typically takes years and significant funds to properly research and develop to the point of a functional prototype as proof of concept. The AWDEMOTO team managed to accomplish approximately 80 to 90% of this in about six months.

Furthermore:

- All necessary off the shelf components were verified and procured
- All custom components were designed and fabricated by the team
- Wiring harness designed, built and assembled by the team
- Rear motor bench testing proved successful
- To date, level of completion is under budget ($10,000)

10.2. Open Issues

- Front motor bench test: Incomplete
  Due to Electrical issues with failsafe components, it was determined that it was unsafe to further test this component until additional safety measures could be taken.
- GUI integration test: Incomplete
  The team was unable to complete the full electrical system. As a result, testing of the GUI was not possible.
- Motor controller programming: Individually tested but not synchronized
  The team was unable to complete the full electrical system. As a result, the front and rear motors could not be synchronized.
- Battery Assembly: troubleshooting In-process
  Due to potential damage of one battery module there was continuity between the battery and battery box. The team determined that it was unsafe to continue until full inspection of the batteries was complete and battery integrity was verified. Additional failsafes will need to be implemented.

11. Conclusions and Recommendations

The final result of the AWDEMOTO Senior Design Project was a complete mechanical hardware integration of all components, and a partially complete software integration of all components. The software integration was only halted because of a catastrophic internal fault in one of the battery modules in the project's power source. Due to this fault, continuing with the testing and integration process became a significant safety risk, and it was decided that integration should be halted until the power source could be made safe. As of the time of this report, the team has ordered components to replace the faulty ones, and redundant safety features to implement in the case of another module fault. However, once these components have been replaced and installed, the project will be successful as a platform on which to test the AWD drivetrain. The implementation of a microcontroller was successful as a stand-alone system receiving input and interpreting them into a usable GUI. However, due to the above issues, it was never tested an an integral part of the system as a whole.

As a whole, the project could be viewed as a success in that it provided an AWD platform on which to test the feasibility of the AWD drivetrain on a street motorcycle. The design specifications of the components show that this platform should have no problem meeting the criteria of the project, but that will not be confirmed until actual road testing.

Given the ambition of this project, and the fact that it's peers are designed/tested on an OEM level with multi-million dollar design budgets, the progress made by the AWDEMOTO team is particularly impressive in the context of a collegiate Senior Design Project. This team has certainly completed the project to a level where it can easily be completed with minimal budget and work to the sponsor's satisfaction. The sponsor is very satisfied with the work done on the project, and anticipates a very successful prototype as a result of this team's design and fabrication.

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Appendix A: Customer Requirements

Table 6: Engineering Requirements Vs. User requirements (Relationship Matrix)

	End User Requirements										
Total Impacts	Safe Highway Speed	Reasonable Commuter Range	Reasonable Acceleration	Reasonable Charge Time	Safe & Comfortable Handling	Affordability	Serviceability	Able to Operate In Appropriate Conditions	Traction Control	Selective Two Wheel Drive	Engineering Requirements
6	■	■	■	■		■	■				2.2.1.1
3				■		■	■				2.2.1.2
6	■	■	■					■	■	■	2.2.1.3
5	■	■	■		■		■				2.2.1.4
6	■	■	■	■		■	■				2.2.1.5
5		■			■	■		■	■		2.2.1.6
2					■			■			2.2.2.1
4			■		■			■	■		2.2.2.2
3			■		■			■			2.2.2.3
3					■			■	■		2.2.2.4
4					■	■		■	■		2.2.2.5
3			■		■			■			2.2.2.6
4			■		■	■			■		2.2.3.1
4			■		■	■			■		2.2.3.2
6	■	■	■		■	■	■				2.2.3.3
4			■		■	■			■		2.2.3.4
5	■	■	■		■	■					2.2.3.5
4					■	■		■	■		2.2.3.6
6		■		■		■		■	■	■	2.2.3.7
4			■		■	■		■			2.2.4.1
6	■		■		■	■		■	■		2.2.4.2
6	■		■		■	■		■	■		2.2.4.3
6	■	■	■		■			■	■		2.2.4.4
7	■	■			■	■	■		■		2.2.4.5
7	■	■	■		■	■	■			■	2.2.4.6
2						■	■				2.2.5.1
7	■	■	■	■	■	■	■				2.2.5.2
5					■	■	■		■	■	2.2.5.3
2						■	■				2.2.5.4
2					■			■			2.2.6.1
2						■	■				2.2.6.2
4					■	■	■	■			2.2.6.3
5					■	■	■	■	■		2.2.6.4
6			■		■	■		■	■	■	2.2.7.1
7			■		■	■	■	■	■	■	2.2.7.2
	12	12	20	5	27	26	15	19	18	6	Contributors

Table 7: Engineering Design Requirements and Performance

Engineering Design Requirements:		
Range Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
High Battery energy capacity to provide enough energy to meet speed and torque desired.	7.5-10 kWh @ 48-100V, depending on motor specifications. These numbers account for the limitations introduced by chained inefficiencies.	To reach the desired speed and the desired range, the battery pack must be designed with high reliability. The design should include a battery efficiency of 90% and a factor of safety of 1.1. The battery pack is expected to provide 100 volts and a Capacity of 10 Kwh
The battery should be designed with solid connections between cells to minimize wire connections	The internal connections are to be accomplished by spot welding the cells in parallel, and using a low-resistance wire or bus bars to connect in series.	The battery pack should be able to resist vibration and external temperatures. The batteries will be spot welded between cell to reduce the possibility of losing power while moving.
Software should allow the option of rapid acceleration or the ability to activate or disengage the motors to provide the best energy range	The software should have the ability to choose between performance or eco mode	User will have the ability to select the between high acceleration and energy saving mode to preserve battery capacity.
The battery pack shall be designed to minimize drastic change in vehicles CoG..	The battery pack's weight will negatively impact the CoG.	The pack will be built to be as modular as possible to allow manipulation of the CoG.
The battery cells shall be selected considering the best price, energy density, and power density suitable for this project.	The internal chemistry will determine the energy density and the power density of the battery cells.	Specifications are provided by the manufacturer and will be accounted for in component selection.
The motorcycle shall implement regenerative braking to increase battery capacity.	The regeneration system will provide the ability to recharge the battery when the motorcycle is decelerating.	The BMS will have the option to control the Voltage sensor and allow the recharge during decelerating. The regenerating braking could extend the battery range for a additional 4%.
Handling Requirements:		

Engineering Requirements	Target Values	Standards & protocols
Appropriate Rake for comfortable and responsive handling.	OEM rake is 23 degrees, can be adjusted to quicken or slow vehicle response as needed.	Acceptable responsiveness will be determined in test riding. Rake can be adjusted by changing the "deck height" of the front fork suspension and changing the length of the rear suspension linkages.
Weight Bias Suitable for AWD	Should be evenly distributed (50/50). Can be adjusted to accommodate power bias.	Adjustable by changing CG of vehicle and rider. Accounted for in CAD and rider positioning.
Center of Gravity beneficial to handling.	As close to the axle height as is feasible.	CG will be determined by CAD and checked by real world testing with multiple scale and an incline.
Suspension Damping	System should not be underdamped.	Damping will be determined by accelerometer data and is adjustable on the OEM suspension.
Suspension Spring Rate	Appropriate for final weight of the vehicle. Stiffened as needed to minimize nose dive	Suspension spring rates are adjustable on the OEM suspension by adjustable preload and replaceable springs. Spring displacement will be measured by real world testing.
Rider Position.	Adjustable to optimize CG of the vehicle.	Adjustment is made by changing handlebar position, seat height and foot peg position. CG of vehicle will be estimated in CAD. Rider CG can be determined by real world testing.
Controller Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
Quick feedback/response between sensor and inputs and the microcontroller	<= 20ms response time	Specifications Provided by manufacturer and accounted for in component selection.
Synchronous and Asynchronous control of the motor controllers	2+ modes for setting motor controller values	Specifications Provided by manufacturer and accounted for in

		component selection.
Handle peak and continuous power of each individual motor	Each motor controller handles the peak and continuous power output of the selected motor	Specifications Provided by manufacturer and accounted for in component selection.
Minimal latency between communication of the motor controllers and the microcontroller	<= 20ms response time	Specifications Provided by manufacturer and accounted for in component selection.
Efficient use of the power supplied to the motor controllers	85%+ efficiency from input power to the output power	Specifications Provided by manufacturer and accounted for in component selection.
Motor Controller handle switching the direction of the motor.	Forward and reverse "gear"	Specifications Provided by manufacturer and accounted for in component selection.
Motor controller handle bi-directional current to support regenerative braking.	Select a controller that supports regenerative braking.	Specifications Provided by manufacturer and accounted for in component selection.
Acceleration Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
0-60 MPH Acceleration Time	<=9 seconds, dependant on motor power and torque curve.	Acceleration Time can be calculated once our design has a final weight and tested drag coefficient. Can be validated with test riding on a closed track.
Torque at Front/Rear Wheel	Average value of torque from >=(140.7/152.5) N*m	Analysis of Dynamometer charts for specific motors will account for torque curves in selection. Final vehicle will be tested on a dynamometer to validate design.
Motor Power Front/Rear Wheel	>(12.3/12.2) kW for the ideal case, Power bias can be shifted to accommodate component selection.	Specifications provided by manufacturer and accounted for in component selection. Validated by real-world testing on the dynamometer.
Final Vehicle Mass	<289 kg (120% or less of stock weight)	Designed in CAD and measured by weight scale.
Wheel RPM Front /Rear	>(862/823) RPM for the loaded case.	Specifications Provided by manufacturer and accounted for in

		component selection. Validated by real-world testing on the track and dynamometer.
Transmission Efficiency	>90% Due to the stacked nature of powertrain inefficiencies of an electric drive, every link in the drivetrain should be as efficient as is feasible.	Validated by real-world testing involving measured input and output torques.
Serviceability Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
All fluid fill points must be accessible to the user for ease of serviceability.	<1 part of major importance to be removed to access fluid fill point.	In order to reach any parts that need to have fluid changed, added, or subtracted during the lifespan of the AWD Electric Motorcycle, the user must not have to remove any main mechanical or electrical components. This includes but is not limited to the batteries, the motor, any part of the structural frame or suspension components.
The main battery pack shall be designed in a manner to provide the user interchangeability between the batteries that are chosen for use in the AWD Electric Motorcycle.	>1 option for the users choice of battery selection in the event of battery/s failure.	If in the event of single/multiple battery failures, not limited to the entire battery set, the user shall be able to interchange the failed battery/s with one of comparable design and capabilities. This allows the user to not be restricted by battery manufacturer or the costs associated with batteries in different regions amongst other reasons.
The user shall have the option to view malfunction indicator lights, or MIL, in an accessible manner.	There is no value associated with this specific engineering design requirement.	In the event of any conditions that may have detrimental effects on the condition of the main components of the AWD Electric Motorcycle, there shall be a malfunction indicator light displayed. Conditions where this is necessary are, but not limited too, battery temperature, motor temperature, and motor speed.

Under the use of a hub motor, the user must have the ability to service or replace the brakes.	There is no value associated with this specific engineering design requirement.	The braking system must be accessible to the user for inspection and replacement if needed. The braking system must not be completely covered or completely enclosed.
Safety Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
Necessary PPE	Increase safety margins in the event of a collision.	Operator will at a minimum wear a helmet
Fire Hazard Mitigation	Minimize the chances of a battery fire due to overheating and blunt force impact.	Design and build an impact resistant battery box that also allows significant convection cooling of the battery assemby..
Emergency Disconnect	Easily accessible and easy to operate power disconnect isolating the power source from the system within less than .25 seconds	Emergency stop will consist of a mechanical switch either using a solid state relay with a ground interrupt or simple mechanical interrupt.
Isolated Hydraulic Caliper Brake System	Brake system capable of stopping in the motorcycle within 45 meters (150 feet) without electrical power.	Completely isolated brake system independent of the electrical system, consisting of front and rear brake calipers and rotors..
Selectable Two-Wheel-Drive Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
Power distribution system to synchronize motors	Motor Controllers able to manage desired torque for the motors, and be able to distribute power to both motors	Specifications Provided by manufacturer and accounted for in component selection.
Software distribution system to synchronize motors	One master controller to receive input from the driver and know how much torque or what state it needs to be in.	A microcontroller with a good Current & voltage rating, manageable switching frequency that is high but not enough to lose sufficient levels of power

Appendix B: System Evaluation Plan

Table 8: Rear Motor Construction

Concept Alternatives: Rear Motor Construction									
Criteria	Importance Weight %	Option 1		Option 2		Option 3		Option 4	
		PMDC		BLDC		Series DC		Synchronous PMAC	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Efficiency	20.00%	2	0.4	4	0.8	2	0.4	4	0.8
Starting Torque	20.00%	3	0.6	2	0.4	4	0.8	4	0.8
Maintenance	10.00%	2	0.2	4	0.4	2	0.2	3	0.3
Greater Control	20.00%	2	0.4	2	0.4	1	0.2	4	0.8
Controller Availability	10.00%	4	0.4	1	0.1	3	0.3	3	0.3
Cost	10.00%	3	0.3	3	0.3	3	0.3	2	0.2
Weight	10.00%	2	0.2	3	0.3	1	0.1	2	0.2
Totals:	100.00%		2.5		2.70		2.30		3.40

Table 9: Power Transmission Concept Alternatives

Concept Alternatives: Mid Drive Motor Power Transmission							
Criteria	Importance Weight %	Option 1		Option 2		Option 3	
		V-Belt		Drive Shaft		Chain	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
High efficiency	35.00%	2	0.7	1	0.35	4	1.4
Low Cost / High Availability	20.00%	2	0.4	1	0.2	4	0.8
Reliability	15.00%	3	0.45	4	0.6	3	0.45
Maintenance / Life Span	10.00%	3	0.3	2	0.2	2	0.2

Low Noise	5.00%	3	0.15	4	0.2	1	0.05
Weight	15.00%	4	0.6	1	0.15	2	0.3
Totals:	100.00%		2.6		1.7		3.2

Table 10: Front Motor Controller Alternatives

Front Motor Controller Options							
		Option 1		**Option 2**		**Option 3**	
		RoboteQ - RGBL1896		**Kelly - KBL9635E1**		**Sabvoton - SVMC96120**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Continuous Current Output	25%	4	1	4	1	3	0.75
Peak Current Output	15%	4	0.6	4	0.6	4	0.6
Cooling Solution	15%	3	0.45	3	0.45	3	0.45
Communication Interface	20%	4	0.8	4	0.8	2	0.4
Price	5%	1	0.05	3	0.15	4	0.2
Regenerative Braking	20%	4	0.8	4	0.8	4	0.8
Total	100.00%		3.70		3.80		3.20

Table 11: Rear Motor Controller Alternatives

Rear Motor Controller Options					
		Option 1		**Option 2**	
		Sevcon G9930		**Kelly KLS96601-8080IPS**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Continuous Current Output	25%	3	0.75	5	1.25

Peak Current Output	15%	5	0.75	5	0.75
Cooling Solution	15%	3	0.45	3	0.45
Communication Interface	20%	5	1	5	1
Price	5%	2	0.1	3	0.15
Regenerative Braking	20%	2	0.4	4	0.8
Totals:	100.00%		3.05		3.60

Table 12: Microcontroller Alternatives

Microcontroller Options					
		Option 1		**Option 2**	
		BeagleBone Black		**Raspberry Pi 3 B+**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Community Support	20%	4	0.8	5	1
CPU Frequency	20%	3	0.6	4	0.8
RAM Capacity	20%	3	0.6	4	0.8
CAN Bus Interface	10%	5	0.5	2	0.2
Additional Communication Interfaces	30%	5	1.5	2	0.6
Totals:	100.00%		4.00		3.40

Table 13: Battery Management System Alternatives

BMS Options							
		Option 1		**Option 2**		**Option 3**	
		Orion BMS		**Renesas ISL78600**		**Dilithium Design BMS**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating

Cell Balancing	10%	3	0.3	3	0.3	4	0.4
Communication Protocol	30%	4	1.2	2	0.6	4	1.2
Low Cost	10%	1	0.1	2	0.2	2	0.2
Cell Management	20%	3	0.6	3	0.6	2	0.4
Data Collection	30%	4	1.2	3	0.9	3	0.9
Total	100.00%		3.4		2.6		3.1

Table 14: Charger Alternatives

Charger Options							
		Option 1		**Option 2**		**Option 3**	
		TSM2500 and Charge Controller		**Elcon HK-J-H650-6**		**Elcon HK-J-H650-12**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Communication Protocol	30%	3	0.9	3	0.9	3	0.9
Charging Capacity	30%	3	0.9	3	0.9	5	1.5
Software	20%	4	0.8	2	0.4	2	0.4
Standard Port Compatibility	5%	5	0.25	2	0.1	2	0.1
Misc Accessories	5%	5	0.25	0	0	0	0
Cost	10%	1	0.1	3	0.3	3	0.3
Totals:	100.00%		3.20		2.60		3.20

Table 14: Mid Drive Motor Thermal Management Concept Alternatives

Mid Drive Motor Thermal Management Concept Alternatives							
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**	
		Air Cooled		**Oil Cooled**		**Liquid Cooled**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating

Heat Transfer Rate	40.00%	2	0.8	4	1.6	4	1.6
Performance	30.00%	2	0.6	3	0.9	4	1.2
Low Total Cost	10.00%	4	0.4	2	0.2	3	0.3
Sound Attenuation	5.00%	1	0.05	3	0.15	3	0.15
Modification to Motorcycle	10.00%	4	0.4	2	0.2	2	0.2
Low Hazardous Conditions	5.00%	4	0.2	1	0.05	3	0.15
Totals:	100.00%		2.45		3.1		3.6

Table 15: Mid Drive Motor Coolant Type Concept Alternatives

Mid Drive Motor Coolant Type Concept Alternatives							
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**	
		Distilled Water		**Water-Ethylene Glycol**		**Propylene Glycol**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Thermo-Physical Properties	40.00%	2	0.8	3	1.2	2	0.8
Low Regulatory Constraints	15.00%	4	0.6	4	0.6	4	0.6
Non-Corrosive Properties	15.00%	3	0.45	4	0.6	4	0.6
Low Hazardous Conditions	15.00%	4	0.6	3	0.45	4	0.6
Low Cost	15.00%	4	0.6	3	0.45	1	0.15
Totals:	100.00%		3.05		3.3		2.75

Table 16: Battery Thermal Management System Concept Alternatives

Battery Thermal Management System Concept Alternatives			
Criteria	Importance Weight %	**Option 1**	**Option 2**
		Passive Cooling	**Liquid Cooling**

		Rating	Weighted Rating	Rating	Weighted Rating
Low Cost	20.00%	4	0.8	1	0.2
Charging Heat Transfer Rates	25.00%	2	0.5	3	0.75
Operating Heat Transfer Rates	25.00%	3	0.75	4	1
Limits Motorcycle Modifications	15.00%	3	0.45	1	0.15
Low Power Requirements	15.00%	4	0.6	2	0.3
Totals:	100.00%		3.1		2.4

Table 17: Front Fork Concept Alternatives

Concept Alternatives: Fork Design and Type							
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**	
		Inverted Telescopic Fork		**Leading Link Fork**		**Hossack Fork**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Weight	10	2	0.2	1	0.1	3	0.3
Low Speed Handling	20	3	0.6	1	0.2	3	0.6
High Speed Handling	10	2	0.2	3	0.3	3	0.3
Wheel Base Alteration	5	1	0.05	3	0.15	3	0.15
Behaving Under Braking	5	1	0.05	3	0.15	3	0.15
Rigidity	10	2	0.2	2	0.2	3	0.3
Complexity	30	3	0.9	1	0.3	1	0.3

Totals	100		2.2		1.4		2.1

Table 18: Battery Cage Protection Options

Battery Cage Covering Options									
		Option 1		**Option 2**		**Option 3**		**Option4**	
		Fiberglass Plates		**Aluminum Plating**		**Plastic/Fiberglass Mold Over Cage**		**Hybrid Aluminum frame**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Safe	20%	2	0.4	3	0.6	1	0.2	4	0.8
Cost	10%	2	0.2	3	0.3	3	0.3	1	0.1
Mounting	18%	4	0.72	4	0.72	2	0.36	5	0.9
Aerodynamic	2%	3	0.04	2	0.04	2	0.04	3	0.08
Easy to Mold	3%	4	0.12	3	0.09	4	0.12	1	0.03
Easy to Modify	7%	4	0.28	2	0.14	1	0.07	3	0.21
Easy to Repair	20%	3	0.6	2	0.4	1	0.2	3	0.6
Weight	20%	3	0.6	1	0.2	1	0.2	1	0.6
Total	100.00%		2.96		2.49		1.49		3.32

Appendix C: User Manual

(In Development)

AWDEMOTO

The all Wheel Drive Electric Motorcycle

Please read all instructions before use.

Only licensed riders should ride a motorcycle. It is highly recommended the a motorcycle safety course is taken before use.

Always wear all appropriate PPE

- Helmet
- Gloves
- Over the ankle boots
- Reflective vest
- Eye protection
- Long pants
- Long sleeve shirt
- Body armor

Pre-Operational Checklist

1. Inspect vehicle for any damage or defects on the below components
    a. Battery box
    b. Chain and chain tensioner
    c. Front and rear tires
    d. Forks
    e. Charging port
    f. Frayed or broken wires
2. Turn on accessory system
    a. Verify all lights are functional
    b. Verify that GUI is functional
3. Engage drive system
4. All controls mimic a conventional motorcycle
    a. The only exception is there is no clutch lever or gear selector.

Caution: unlike conventional motorcycles, the max torque on electric motors is at 0 mph.

Appendix D: Cost Analysis and Manufacturability Analysis

This prototype generated by AWDEMOTO is just that. The vehicle as it currently stands is far from ready for the consumer market. It was and still is designed as a bolt on kit for at home hobbyists. When this product is developed into a marketable bolt-on kit, there will be several changes made to increase manufacturability.

3D printing is very useful for prototyping and one off production, but is not feasible for mass production. Injection molds for all plastic components will be made to decrease production time. The machined components will be cast and then machined on the necessary surfaces.

The team ended up using various electrical components from contactors to terminal boards to relays. For ease of use, space conservation and cost savings, all of the necessary components will be integrated into one or two assemblies. The team designed and built its wiring harness from scratch. Everything from power cables to cannon plugs were assembled from scratch to meet the project needs. A fully complete wiring harness would be created in large quantities.

Lastly, detailed instructions would come with the kit in the form of a video and written manual listing necessary tools and detailed steps for stripping the OEM vehicle and installing new components to create a customers very own AWDEMOTO.

Appendix E: Expense Report

Major Component Cost Breakdown	
Product Name	**Cost**
ME1616 MidDrive Motor	$850
Brushless QS Hub Motor	$756
KBL96351E Kelly Controller	$492
Sevcon Gen 4 Controller	$800
Elcon 6600W Charger	$975
Nissan Leaf Batteries	$1150
Total Cost:	$5023

Total Cost Breakdown

Expense Type	Cost
Misc. Hardware	656.87
Electrical Components	6713.33
Other Components	1165.42
OTS parts	285
misc	420.66
TOTAL:	**9241.28**

Appendix F: List of Manuals and Other Documents

- USB to CAN V2 Manual
    - https://drive.google.com/open?id=1IqqoSkpEpy_SnwpytxWQPZU2Mi1Q5tTk
- Kelly KBL User Manual
    - https://drive.google.com/open?id=1CAu3sHWYGJbc5c0Iy9VpoNeddd2cLbDO
- Sevcon Gen4 Product Manual
    - https://drive.google.com/open?id=1wQWQCzT71WX3nhzjxb1l2WwONs5rzxUL
- Throttle Manual
    - https://drive.google.com/open?id=1u5Xz1PGKm7zubcL7Ueup65z49PZnuJxM
- Nissan Leaf Owners Manual
    - https://drive.google.com/open?id=1PRks4iodsT2BkYstOiHp2kxxkYZDaDtR
- Water Pump Technical Drawing
    - https://drive.google.com/open?id=1TTwZg9xCFjfYuJJ-RuImX-8kJmbO7kKO
- Sevcon Technical Drawing
    - https://drive.google.com/open?id=1lEap0E7_wl6nyvjR_onquOORm0EPRTjy
- Front and Rear Motor Technical Drawings
    - https://drive.google.com/open?id=1WCWm0eYgAUUFXJDm4_0Hg2-9D3NxqiBn
- Kelly Controller Technical Drawings

    - https://drive.google.com/open?id=1hiIFLjwIYh1yqPCQX7HMrWsdNcxUBOhi
- Charger Technical Drawing
    - https://drive.google.com/open?id=1sNQMuxter6kS22uE2MlEE56l-R_R2iG2
- BMS Technical Drawing
    - https://drive.google.com/open?id=1oypS2ICXN-D8XnvoMeNk5Y4iuILtkcVU

Appendix G: Design Competencies

Table 19: Design Competence Evaluations

Mechanical Engineering Design Competence Evaluation						
Rate this design project in illustrating effective integration of mechanical engineering topics						
Project Title: AWDEMOTO (All Wheel Drive Electric Motorcycle)						
ME Design Areas	Critical/ Main Contributor	Strong Contributor	Necessary but not a Primary Contributor	Necessary but Only a Minor Contributor	Only a Passing Reference	Not Included In This Design Project
Thermal-Fluid Energy Systems			X			
Machines and Mechanical Systems		X				
Controls and Mechatronics	X					
Materials Selection			X			
Modeling and Measurement Systems	X					
Manufacturing	X					

EML 4105C	Spring 2019 Semester		
Project: AWDEMOTO			
Topic	Criticality to Project	Section, Page(s)	Comments
Thermal-Fluid Energy Systems	3/6		
Machines and Mechanical Systems	5/6		
Controls and Mechatronics	6/6		
Materials Selection	4/6		
Modeling and Measurement Systems	6/6		
Manufacturing	6/6		