FSAE Electronics

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1. **Abstract**

The University of North Dakota Formula SAE Electronics Team is responsible for mounting electronic components to the UND FSAE Internal Combustion (IC) car as well as performing mechanical design requirements for the UND FSAE Electric Vehicle (EV). This includes collaborating with other teams from the UND FSAE IC car to design mounting systems for electronic sensors, as well as converting the UND18 IC car chassis into a battery power electric Formula SAE car. While the UND FSAE EV car will not be taken to competition this year, the FSAE guidelines are to be followed in order to allow the car to be taken to competition in future years.

The criteria used for the project, which span both the IC and Electric Vehicles, are to build an electric powertrain vehicle using one motor capable of reaching 20 mph, design motor and differential mounts capable of withstanding the torque created by the electric motor, and implement mounts for steering angle, wheel speed, and suspension travel sensors on IC vehicle. The current design of the Electric Vehicle that is being manufactured uses one electric motor and is nearly ready for testing to ensure that the mounts will withstand the motor torque, and that the vehicle can reach 20 mph. The sensor mounts have been manufactured and integrated into the IC vehicle and as the Data Acquisition Unit is installed with the sensors, they will be tested and used to collect valuable data to optimize the suspension and steering setup.

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3. Introduction

3.1 Background

Over the past few years, UND has participated in the Formula SAE (FSAE) competition, a collegiate level racecar competition. Engineering students work together to design and manufacture a Formula-style racecar and compete with other student teams from around the country. Traditionally, this has only been a competition using internal combustion (IC) engine vehicles. Starting in 2013, a battery electric class was added to the portfolio with IC. [1]

While there are electronic components required on the IC car, the mounting of which is part of the FSAE Electronics team's responsibility, the majority of the effort of the Electronics team is focused on creating UND's first battery electric FSAE car. Being the first battery electric FSAE car designed and built at UND, this car will not be going to competition; the goal of this year is to design and manufacture a car that meets the FSAE regulations and can go at least 20 mph.

3.1.1 Need for project

The rise in popularity of electric consumer vehicles drives interest in also developing performance electric vehicles. While much of the design work that goes into an electric formula car won't be used in consumer vehicles, pushing the limits of EV technology helps to develop technology that can be translated into consumer vehicles to improve their performance.

While most of the IC car doesn't involve electronics, the use of sensors to gather data about the performance of the vehicle does. These sensors, such as the ride height sensor, wheel speed sensor, and steering angle sensor, provide detailed data about how the vehicle reacts and performs in different scenarios. This provides data to the other design teams for the car to help improve and fine-tune their designs, as well as providing data to help the driver improve performance.

3.1.2 Previous work/results

Steering Angle Sensor

The steering angle sensor designed on the previous year IC car used a string potentiometer mounted to the interior of the chassis near the steering rack. The string of the potentiometer was wrapped around and bolted to the steering column so that when the steering wheel was turned the string would be either pulled from or returned to the spring-loaded storage wheel inside the sensor. The sensor would calculate the distance of travel by reading the rotation of the storage wheel. This sensor provided an accurate reading, but the sensor was bulky and caused issues with ingress and egress of the driver which would get bumped or pulled off its mounted position.

Ride Height Sensor

The ride height sensor implemented on the previous year IC car used a linear stroke potentiometer that was attached to the to the chassis and the dampers of the suspension on each wheel assembly. The sensors were mounted in line on the opposite side of the bell crank from the damper. This theoretically would give a highly accurate measurement of how much the suspension has risen or fallen while the car was in motion. But due to the fact the compression of the dampers was based on the rotation of the bell crank, the displacement of the mounting points were on a rotational axis. This gave an accurate reading during minimal movement but much larger deviations with longer suspension movement.

Wheel Speed Sensor

The wheel speed sensor implemented on the previous year IC car used a stationary Hall Effect sensor, which uses a magnetic field to sense ferrous metals close to the sensor. The spokes of the brake rotor passed close to the end of the sensor which allowed for four sensor readings to be taken per wheel revolution, as the rotor had four spokes. While the Hall sensor itself performed well, having only four readings per wheel revolution made the wheel speed data only useful at higher speeds.

3.1.3 External or Existing Designs

Steering Angle Sensor

Ride Height Sensor

Wheel Speed Sensor

The Hall Effect sensor is often used, across many industries, to measure rotational speed. These designs generally use a sensor 'gear' that uses the teeth of the gear to create pulses in the magnetic field generated by the sensor. The time between these pulses, combined with the predetermined number of teeth on the gear, can be used to determine the rotational speed of the gear. This general design was used in the development of the wheel speed sensor design for the IC vehicle. [2]

3.2 Summarized results of the project

3.2.1 Problem statement/design spec

Formula SAE is an international collegiate competition that challenges engineering students worldwide. The objective of the competition is to create a completely student engineered, open wheeled, formula style racecar. Students will conceptualize, design, refine, construct, test, and finally race their design against other engineering schools from across the globe. Throughout the year, students will be expected to learn about competition vehicles of previous years and how to increase the current vehicle's performance by way of designing. These designed components will need to be tested and validated to ensure that the data achieved during the design phase was correct and assumptions were accurate.

The electronics sub-team aims to interface between the mechanical sub-teams and the Electrical Engineering (EE) team on the IC car and perform the mechanical design tasks required on the electric vehicle (EV). Being the first electric FSAE car, the chassis from the 2018 IC car will be converted to use a single electric motor which presents multiple mechanical design challenges. The development of the electric vehicle is aimed at providing a proof of concept for future years to build on and learn from to develop an optimized EV that can be taken to the FSAE competition.

The updates to the designs of the IC vehicle sensors will provide more, more accurate data that the other IC sub-teams can use to improve and optimize their designs.

3.2.2 Criteria for Success

On the IC car, the criterion for success is to have the steering angle, wheel speed, and ride height sensors mounted. This involves determining the optimal sensor, designing the mounting system, procuring the sensor, procuring or manufacturing the mounting system, and installing the sensor on the car.

The EV car's main criterion for success is to build an electric powertrain vehicle capable of reaching 20 mph. As a part of that, the design must use a single electric motor to power the car. While it is not only allowed, but also more effective, to use more than one motor it is out of the budget for this first iteration of the EV formula car. Since the EV car will be using the 2018 IC car chassis, the additional torque provided by the electric motor will have to be considered in order to ensure the differential and motor mount designs can withstand the increased forces exerted by the electric motor.

3.2.3 Status

Most of the tasks to achieve the criteria for success are on track with the required timeline. The sensor mounts have all been designed and mostly manufactured, the only remaining parts to be produced are 3D printed which can be completed quickly and easily. The motor mount, differential mount, and accumulator have been manufactured and the motor mount and motor have been installed in the vehicle. The drivetrain has been designed and is in the process of being installed. The cooling system for the water-cooled electric motor has been designed and POs for the required components have been placed.

3.2.4 Recommendations

In hindsight it seems the best way to approach the order of the tasks to be completed would be to start with the ones that were expected to take the longest or to require collaboration with other sub-teams. When it comes to collaborating with other teams, it is important that any design considerations for the Electronics team are taken into account in the related sub-teams' designs. When planning longer tasks, especially if they have an external process that has a significant lead time, it is important to get those started early in the project so that other, shorter tasks can be completed while the larger tasks are being waited on.

4. Project Charter

1.0 Project Identification & stakeholders	
Project	*FSAE – Electronics*
Faculty Advisor	*Dr. Djedje-Kossu Zahui*
Sponsor Advisor	*UND Formulae SAE Alumni Advisory Board*
Instructor	*Mr. Dominik Steinhauer*
Project Team Members	*Anton Alvestad* *Dean Rogers*
Additional Stakeholders	*Trenten Johnson – EE FSAE Team Lead* *Corbin Goodreau – UND FSAE President* *Matt Dobija – UND FSAE Vice President*

2.0 PROJECT DESCRIPTION

Formula SAE is an international collegiate competition that challenges engineering students worldwide. The objective of the competition is to create a completely student engineered, open wheeled, formula style racecar. Students will conceptualize, design, refine, construct, test, and finally race their design against other engineering schools from across the globe. Throughout the year, students will be expected to learn about competition vehicles of previous years and how to increase the current vehicle's performance by way of designing. These designed components will need to be tested and validated to ensure that the data achieved during the design phase was correct and assumptions were accurate. The admin sub-team is responsible for the proper leadership and management side of the Formula SAE club. Specifically, the admin team will manage deliverables, track sponsor relationships, monitor organization engagement, set high-level goals and monitor timeline progress. This group will work closely with Dr. Zahui to ensure adequate progress is being made on the team.

3.0 PROJECT SCOPE

In Scope:

Mechanical requirements of Formula SAE EV class car that work toward final design of vehicle.

CAD modeling

Structural (ANSYS) simulation

Mounting wheel speed, steering angle, and ride height sensors on IC and/or EV car

4.0 KEY PROJECT DELIVERABLES

Name	Description
Design Report	Class Requirement
Design Presentations	*Class Requirement*
Future Progress Report	*Document outlining summary of project and recommendations for future years.*
Electric Powertrain Vehicle	*Formula-style vehicle moving under the power of an electric powertrain.*
Mounting Points Structural Integrity Report	*Report detailing strength of powertrain mounting locations and appropriate loads applied.*

5.0 MILESTONE DATES

Item	Major Events / Milestones	Approximate Dates
1.	*Design Report*	*As Assigned*
2.	*Design Presentations*	*As Assigned*
3.	Removing unused components from UND 18 chassis	*Oct. 22*
4.	Preliminary Design Review	*Dec. 2*
5.	Electric component integration ready vehicle	*Dec. 12*
6.	Critical Design Review	*Mar. 10*
6.	Electric powertrain in car	*Mar. 11*
7.	Car completed to project requirements	*Apr. 30*

6.0 PROJECT'S CRITERIA FOR SUCCESS

- *Build an electric powertrain vehicle capable of going 20 mph.*
- *Design electric vehicle around the use of 1 electric motor.*
- *Implement mounts for steering angle sensor on IC vehicle.*
- *Design new differential mounting structure capable of withstanding electric motor torque.*

7.0 STAKEHOLDER MANAGEMENT & COMMUNICATION PLAN

<table>
<tr><th>Stakeholder</th><th>Communication Expectation</th><th>Expected Frequency</th></tr>
<tr><td rowspan="11">Instructor
Dominik Steinhauer</td><td>Progress Reports</td><td>Weekly</td></tr>
<tr><td>Email</td><td>Phone #</td></tr>
<tr><td></td><td>(701) 777-6955</td></tr>
<tr><td>Preferred Communication Method</td><td>Documentation Style</td></tr>
<tr><td>Face to Face Meeting / Phone / Email</td><td>Meeting Minutes Template</td></tr>
<tr><td colspan="2">Scope & Impact of Project on Stakeholder</td></tr>
<tr><td colspan="2">Changes in Scope affect what will be graded. Project's success will impact Mr. Steinhauer's ability to recruit more sponsors in the future.</td></tr>
<tr><td colspan="2">Desired & Current Engagement Levels with Stakeholder</td></tr>
<tr><td colspan="2">Desired by Team
• Engagement through in-class lectures
• Assistance out of class through ad hoc meetings
Current
• Committed to weekly progress meetings & ad hoc meetings as needed.</td></tr>
</table>

<table>
<tr><th>Stakeholder</th><th>Communication Expectation</th><th>Expected Frequency</th></tr>
<tr><td rowspan="9">Faculty Advisor
Dr. Djedje-Kossu Zahui</td><td>Weekly Deliverable Meetings</td><td>Weekly</td></tr>
<tr><td>Email</td><td>Phone #</td></tr>
<tr><td>dk.zahui@und.edu</td><td>(701) 330-3162</td></tr>
<tr><td>Preferred Communication Method</td><td>Documentation Style</td></tr>
<tr><td>Meetings / Phone / Email</td><td>Meeting Minutes</td></tr>
<tr><td colspan="2">Scope & Impact of Project on Stakeholder</td></tr>
<tr><td colspan="2">Dr. Zahui has been the leader of the Formula SAE team at UND for over 15 years, he is firmly committed to the success of the program and its ability to showcase the CEM.</td></tr>
<tr><td colspan="2">Desired & Current Engagement Levels with Stakeholder</td></tr>
<tr><td colspan="2">Desired by Team
• Weekly deliverable meetings
Current
• Weekly meetings and impromptu visits as needed</td></tr>
<tr><th>Stakeholder</th><th>Communication Expectation</th><th>Expected Frequency</th></tr>
<tr><td rowspan="9">Sponsor Advisor
Alumni Advisory Board</td><td>Weekly Technical Meetings</td><td>Bi-Weekly</td></tr>
<tr><td>Email</td><td>Phone #</td></tr>
<tr><td>alexswanson44@gmail.com</td><td>(218) 766-8161</td></tr>
<tr><td>Preferred Communication Method</td><td>Documentation Style</td></tr>
<tr><td>Phone Call / Email / Text</td><td>Meeting Minutes</td></tr>
<tr><td colspan="2">Scope & Impact of Project on Stakeholder</td></tr>
<tr><td colspan="2">The alumni advisory board is comprised of past FSAE team members. They have rooted interest in the success of the team.</td></tr>
<tr><td colspan="2">Desired & Current Engagement Levels with Stakeholder</td></tr>
<tr><td colspan="2">Desired by Team
• Bi-Weekly check-in’s
Current
• Ad hoc meetings as necessary</td></tr>
</table>

Stakeholder	Communication Expectation	Expected Frequency
Team Member *Anton Alvestad*	*Progress on weekly tasks submitted*	*2+ times per week*
	Email	**Phone #**
	anton.alvestad@und.edu	(701)230-1006
	Preferred Communication Method	**Documentation Style**
	Phone / Text / Email	MS Teams
	Scope & Impact of Project on Stakeholder	
	Anton is a Senior Design student within the Electronics sub-team. He is to be a key contributor to the success of the group by learning as much as he can and applying his skills towards the project. His senior design grade is dependent on the success of the sub-team. Team Success means earning a good grade in the ME 487/488 Senior Design class.	
	Desired & Current Engagement Levels with Stakeholder	
	Desired by Team • *Biweekly engagement and attends all meetings as necessary and complete tasks requested by team* *Current* • *Working with team as needed*	

Stakeholder	Communication Expectation	Expected Frequency
Team Member *Dean Rogers*	*Progress on weekly tasks discussed/submitted*	*2+ times per week*
	Email	**Phone #**
	dean.rogers@und.edu	*(585) 749-0389*
	Preferred Communication Method	**Documentation Style**
	Email / Phone / Text (limited reception during work hours)	*MS Teams*
	Scope & Impact of Project on Stakeholder	
	Dean is a Senior Design student within the Electronics sub-team. He is to be a key contributor to the success of the group by learning as much as he can and applying his skills towards the project. His senior design grade is dependent on the success of the sub-team. Team Success means earning a good grade in the ME 487/488 Senior Design class.	
	Desired & Current Engagement Levels with Stakeholder	
	Desired by Team • *Biweekly engagement and attends all meetings as necessary and complete tasks requested by team* *Current* • *Working with team as needed*	

8.0 PROJECT MANAGEMENT PLAN

The project management role will alternate between the team members. Each team member will serve as the project manager for one month.

The schedule will be as follows:

- *September: Dean Rogers*
- *October: Anton Alvestad*
- *November: Dean Rogers*
- *December: Anton Alvestad*
- *January: Dean Rogers*
- *February: Anton Alvestad*
- *March: Dean Rogers*
- *April: Anton Alvestad*
- *May: Dean Rogers*

9.0 MEETING PLAN			
Meeting	**Description & Participants**	**Frequency**	**Day / Time**
Faculty Advisor Meetings	*Meet with Faculty Advisor to discuss progress* *Attendance - Team / Faculty Advisor*	*Weekly*	*Fri 10AM*
Team Meetings	*Meet with just Team to work on & discuss project* *Attendance - Team*	*Twice - Weekly*	*Mon & Thu 6PM*
Sponsor Advisor Meetings	Meet with Sponsor Advisor to discuss progress Attendance – Team / Sponsor Advisor	*Twice – Weekly*	*Tue 7PM* *Fri 10AM*

10.0 CHANGE ORDERS	
Description	**Date Approved**
Describe what is being changed and why	?
Each change order needs to be documented separately	?

11.0 SIGNOFF	**DATE**
Sponsor Advisor:	
Faculty Advisor:	
Instructor:	
Student Project Manager: Corbin Goodreau	9/19/2021

5. Research

5.1 Wheel Speed Sensor Requirements

5.1.1 Relevant literature search

Looking into common methods of measuring wheel speed confirmed that the previous year's design using a Hall Effect sensor was on the right track but needed some small improvements to provide more useful data [6]. Researching the documentation for different wheel speed sensors showed that there are specific requirements for the design of the sensor 'gear' to obtain accurate readings with the Hall Effect sensor [3].

5.1.2 Deliverables affected

This affected the wheels speed sensor mounting deliverable, related to the criterion for success of mounting the required sensors to the IC car.

5.1.3 Findings

The findings are detailed in section 6.3

5.1.4 Project Decisions made based on results

This research led us to continue with a design using the same Hall Effect sensor as was used last year. Based on the maximum diameter of the sensor gear that would fit inside this year's 10-inch wheels, the research about the specific design requirements for the sensor gear defined the maximum number of teeth on the gear.

5.2 Cooling System Requirements

5.2.1 Relevant literature search

The specific requirements for the cooling system of the motor being used in the car determined the required flow rate to provide sufficient cooling of the motor. [5]

5.2.2 Deliverables affected

This affected the deliverable of designing a cooling system, which relates to the criteria for success of designing an electric vehicle capable of reaching 20 mph designed around the use of one electric motor.

5.2.3 Findings

The motor requires a flow rate of 6L/min of water or a water/glycol mixture. Due to a number of fittings between the motor, pump, and radiator, the pump would have to be able to be rated at a higher flow rate to overcome the additional resistance.

5.2.4 Project Decisions made based on results

This research provided a parameter to use when searching for a pump, to ensure it was sized correctly. The pump chosen is rated at 8L/min to account for additional losses in fittings.

6. Engineering Analysis

6.1 Steering Angle Sensor

6.1.1 Objective of Analysis & Description of Problem

The steering angle sensor from the previous year was an effective and accurate design to measure the angle of steering, the team would need a new design to minimize space claim on the interior of the chassis to mitigate the risk of dislodging the sensor as the driver enters or egresses the vehicle while not degrading the sensor's accuracy.

6.1.2 Deliverables Affected

This affected the steering angle sensor deliverable, related to the criterion for success of mounting the required sensors to the IC car.

6.1.3 Assumptions Made

The sizing of the driver would be assumed to fit the 90th percentile of the average American male sizes. The sizes being: 6 foot 1 inch tall and size 11 shoe size.

The sensor must be in plane with the steering column and interior of the chassis.

6.1.4 Relevant Figures, Diagrams, & Drawings

6.1.5 Description of Analysis Completed

The analysis of the positioning of the string potentiometer was conducted by calculating the total space in the interior of the chassis, the space claimed by the driver, the space claim of the sensor, and the space claim of the other components.

To start the analysis the team had an individual that meet the assumed driver sizing criteria and had them seated in the previous year's vehicle. The current chassis design is based mostly from the previous year's car, leaving a similar space claim between the two vehicles. From initial observations of the available space claim with a driver seated in the vehicle was that there was minimal space between the driver's lower body and the chassis walls. There were several spots that were determined to have a 4 inch long sensor be mounter perpendicular to the chassis walls. However, these spaces would cause an obstacle to the driver's egress which would cause a large point reduction at competition, so these options were no longer valid.

6.1.6 Results

The string potentiometer method of measuring steering angle was considered invalid and would not be pursued further. Instead, the team decided to go with a slightly more expensive rotational sensor for this project. The new sensor was small enough to be mounted directly on the underside of the steering rack and not interfere with the driver's egress or any other mechanisms within the steering assembly.

6.1.7 Relevance to the Project

This sensor will allow for increased precision in the data collection for the IC car, which in turn will allow for better optimization of the other sub-teams' designs as well as providing information to the driver to help drive improvement.

6.3 Wheel Speed Sensor

6.3.1 Objective of Analysis & Description of Problem

While the Hall Effect sensor from the previous year's design is an effective sensor, the system of using the brake rotor spokes with the sensor only provided four sensor readings per wheel revolution. The desired resolution for this sensor is at least 20 readings per revolution. In order to achieve this, a sensor 'gear' had to be designed and mounted to the hubs and the Hall Effect sensors had to be mounted to the uprights.

6.3.2 Deliverables Affected

This affected the wheel speed sensor deliverable, related to the criterion for success of mounting the required sensors to the IC car.

6.3.3 Assumptions Made

Ideal resolution of the sensor was assumed to be at least 20 pulses per revolution.

6.3.4 Relevant Figures, Diagrams, & Drawings

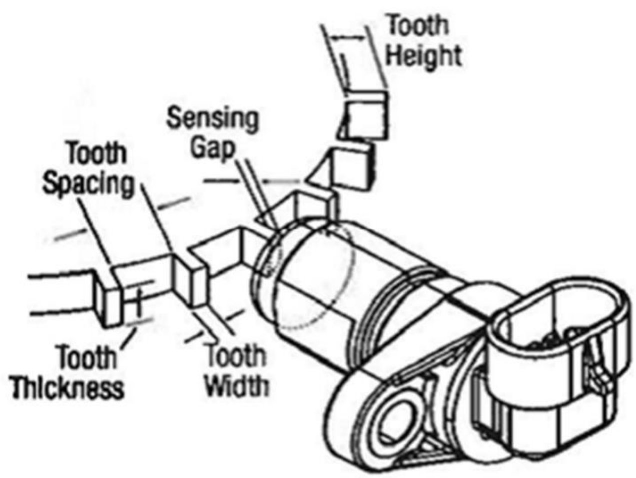

Figure 1: Wheel Speed Sensor Required Dimensions [3]

Tooth Height	Tooth Width	Distance between Teeth	Target Thickness
5.0 mm (.200")	2.5 mm (.100")	10 mm (.400")	6.35 mm (.250")

Figure 2: Wheel Speed Sensor Gear Required Dimensions Chart [3]

6.3.5 Description of Analysis Completed

In order to obtain the desired minimum of 20 sensor readings per wheel revolution, the minimum tooth spacing (t_s) and minimum tooth width (t_w) were used to determine the required circumference of the wheel speed sensor 'gear' using the equation

$$c = 20(t_s + t_w) \tag{1}$$

The radius was then calculated using

$$r = \frac{c}{2\pi} \tag{2}$$

6.3.6 Results

Using the minimum values provided in the sensor documentation, the minimum diameter of the gear was determined to be 250mm using Eq. 1. The radius is then determined to be 39.79mm using Eq. 2.

6.3.7 Relevance to the Project

This sensor will allow for increased precision in the data collection for the IC car, which in turn will allow for better optimization of the other sub-teams' designs as well as providing information to the driver to help drive improvement.

6.4 Motor Mount

6.4.1 Objective of Analysis & Description of Problem

The chassis used for the electric vehicle was previously the chassis for the IC car from 2018. The motor mounts in the chassis were designed specifically for the IC engine used that year. In order to install the electric motor a new mounting system had to be designed that could withstand the torque of the motor. According to FSAE rules, structural tubing should connect to the chassis at nodes, where multiple chassis tubes are joined. This maintains the triangulation in the chassis and helps maintain its torsional rigidity.

6.4.2 Deliverables Affected

This is an integral part of the deliverable to build a battery power electric car capable of reaching 20 mph. Converting from an IC engine to an electric motor is one of the largest changes that needs to be completed to reach this objective.

6.4.3 Assumptions Made

6.4.4 Relevant Figures, Diagrams, & Drawings

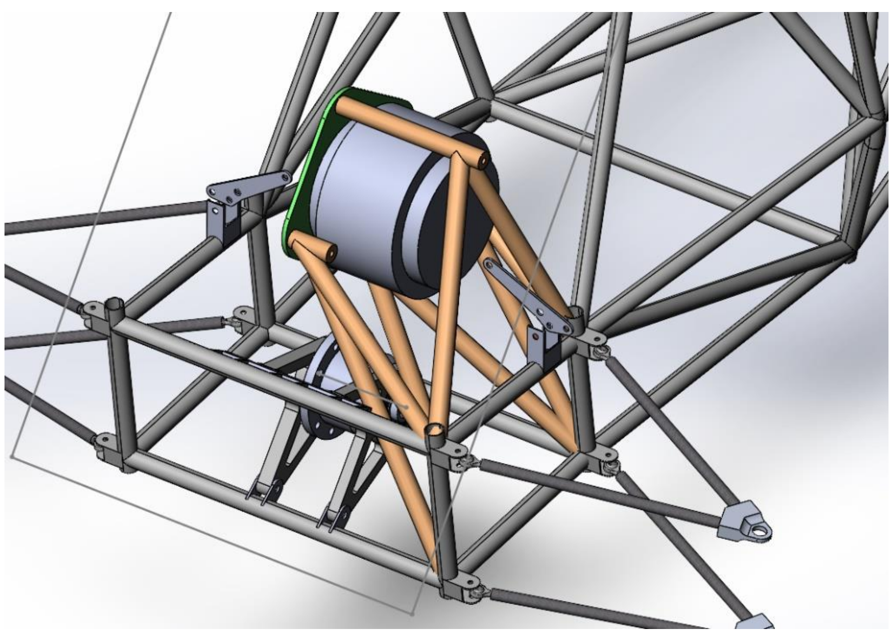

Figure 3: Initial Electric Motor Mount Design

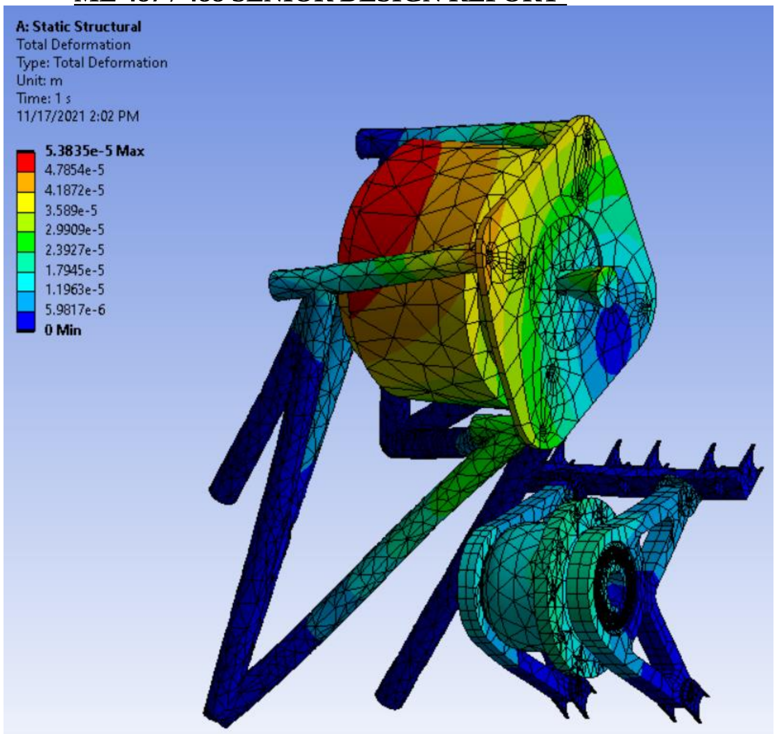

Figure 4: Motor Mount and Differential Mount ANSYS Deformation Analysis

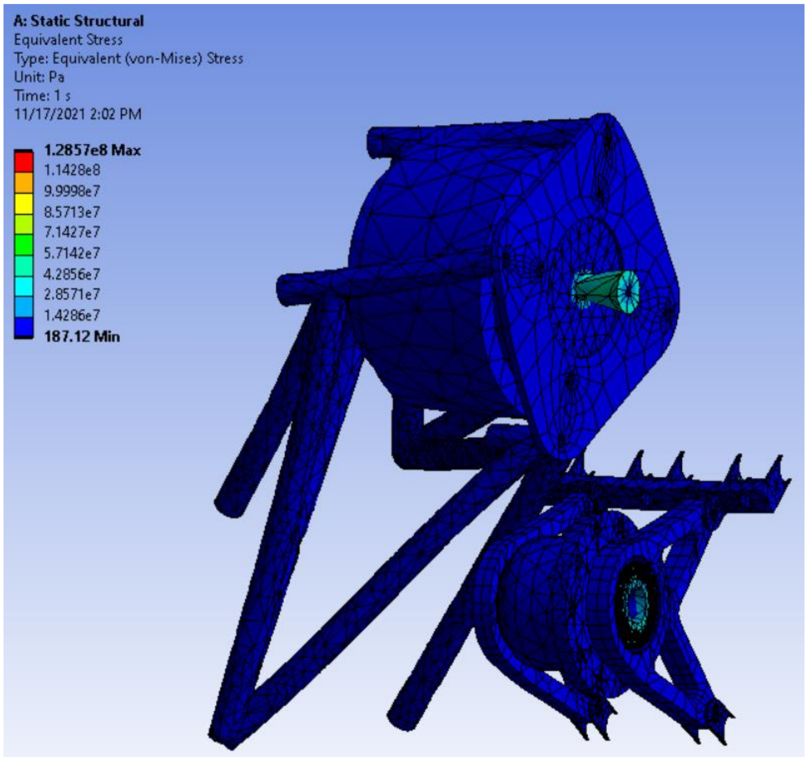

Figure 5: Motor Mount and Differential Mount ANSYS Stress Analysis

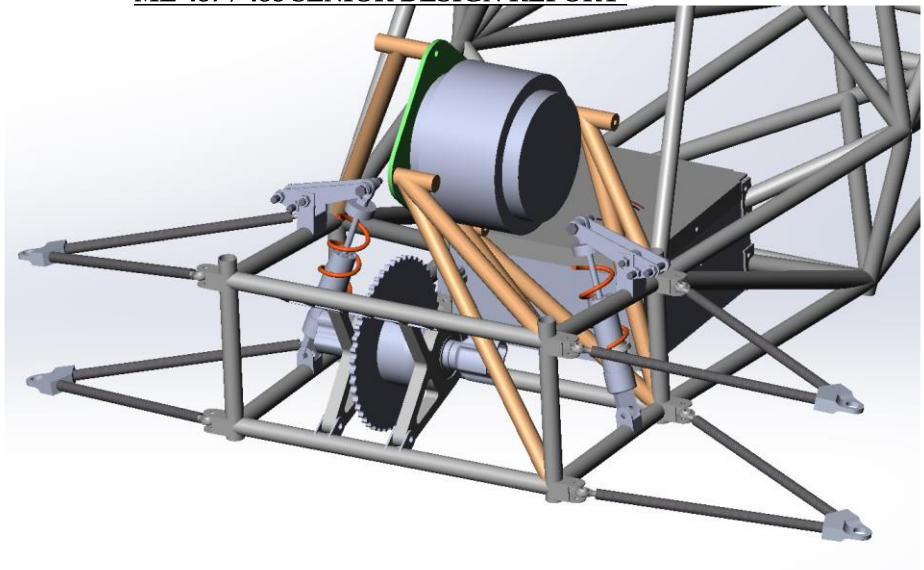

Figure 6: Updated Motor Mount Design

6.4.5 Description of Analysis Completed

While the mounting holes of the motor are on its drive side, adding the motor mounts on that side could present issues with interference between the drive chain and mounts. Instead, a steel plate was used to interface with the motor mounting holes so the motor mounts would be on the non-drive-side of the motor. With the closest frame nodes being below the motor, some of the motor mount tubing intersects the closest nodes at too small of an angle to be properly attached. This, as well as the need to keep the axle area open meant that each mount didn't necessarily connect to its closest nodes, and the top mount was only able to connect to one node.

To ensure the mounting system could withstand the torque exerted by the electric motor, the system was analyzed using ANSYS to determine the deformation and stresses in the mounting system.

It was then noticed that, in order be able to install and remove the motor after assembling the motor mounts, the top mount would have to be moved to the opposite side of the mount plate, as shown in Figure 6.

6.4.6 Results

The results of the ANSYS analysis showed a suspiciously minimal stress in both the motor mounts and the differential mounts, which were analyzed at the same time. The ANSYS analysis appeared to be correct, and the design was approved and manufactured.

6.4.7 Relevance to the Project

The motor mounting system is one of the most crucial components of reaching the criteria for success, specifically building an electric vehicle capable of reaching speeds of 20 mph. Without the motor mount, and one that can withstand the forces of the motor, this criteria for success could not be met.

6.5 Differential Mount

6.5.1 Objective of Analysis & Description of Problem

The increased torque provided by the electric motor over the IC engine requires that the strength of the redesigned differential mounts is increased. To determine the torque transferred to the differential from the motor, the gear ratio must first be determined. Additionally, the differential mount needs to allow the chain to be tensioned properly to ensure proper engagement with the sprockets and reduce wear on the drivetrain.

6.5.2 Deliverables Affected

This is an integral part of the deliverable to build a battery power electric car capable of reaching 20 mph.

6.5.3 Assumptions Made

The minimum recommended gear reduction of a chain drive is 7:1. [4]

6.5.4 Relevant Figures, Diagrams, & Drawings

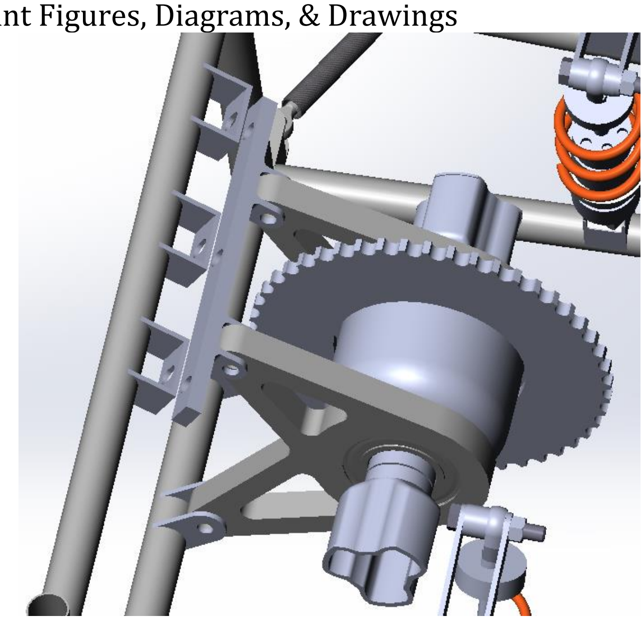

Figure 7: Differential Mount Structure

			Max Car Speed (mph)	Axle speed (rpm)	Gear Ratio (motor:axle)	Wheel Torque (ft-lbs)	Wheel Torque (N*m)
tire diameter =	16.3	in	35	721.76	9.01	675.43	915.7475473
tire radius =	8.15	in	40	824.87	7.88	591.00	801.2791039
tire circumference =	51.20796025	in	45	927.98	7.00	525.33	712.2480924
Max rpm =	6500		50	1031.09	6.30	472.80	641.0232831
Peak Torque =	75	ft-lbs	55	1134.20	5.73	429.82	582.7484392
Peak Torque =	101.685	N*m	60	1237.31	5.25	394.00	534.1860693
			65	1340.42	4.85	363.69	493.0948332
			70	1443.53	4.50	337.71	457.8737737
			75	1546.63	4.20	315.20	427.3488554
			80	1649.74	3.94	295.50	400.639552
			85	1752.85	3.71	278.12	377.0725195

Figure 8: Differential Mount Torque Calculations

6.5.5 Description of Analysis Completed

The maximum axle torque was calculated over a range of maximum car speeds, from 35 mph to 85 mph in increments of 5. Using the tire diameter, the required gear ratio for each max speed was determined, which was then used to determine the max axle torque for each max speed. Additionally, the maximum driven sprocket and minimum drive sprocket sizes were determined to calculate the maximum gear ratio.

6.5.6 Results

The analysis showed that the minimum max car speed allowable is 45 mph which results in a gear ratio of 7:1. This gear ratio put the maximum axle torque at 379.9 N*m. The track speeds from the IC car were analyzed and showed that the max speed on track was around 60 mph. Since a lower max speed increases the amount of axle torque, the max speed for the EV was decided to be 55 mph, putting the gear ratio at 5.73:1 and the max axle torque at 310.8 N*m. Due to constraints in the chassis, the maximum driven sprocket size was 41 teeth, and the minimum drive sprocket available for the 520 chain being used was 10, putting the maximum gear ratio at 4.1, resulting in an axle torque of 414 N*m.

To allow for chain tensioning, the differential mounts were designed to pivot around the lower mount and a connecting bar at the top mount allows shims to be inserted to adjust the distance between the drive and driven sprockets, while still maintaining strength as shown in Figure 7.

6.5.7 Relevance to the Project

The differential mount is critical to achieving the main criterion for success of the FSAE Electronics team; to build an electric car capable of reaching at least 20 mph. Since the previous differential was mounted directly to the IC engine, it was not able to be used in the EV.

6.6 Accumulator

6.6.1 Objective of Analysis & Description of Problem

The use of an electric motor also includes the use of a number of electronic components, as well as a battery pack. These items are all mounted inside a box called the accumulator. To reduce wiring the accumulator should be mounted close to the motor and is required to follow a number of FSAE rules in its design and mounting.

6.6.2 Deliverables Affected

This is an integral part of the deliverable to build a battery power electric car capable of reaching 20 mph.

6.6.3 Assumptions Made

Due to the large weight of the accumulator, it was assumed that the closer to the ground it could be, the better the center of gravity of the vehicle would be. For ease of maintenance, it was assumed that the accumulator would need to be able to drop out of the bottom of the chassis

6.6.4 Relevant Figures, Diagrams, & Drawings

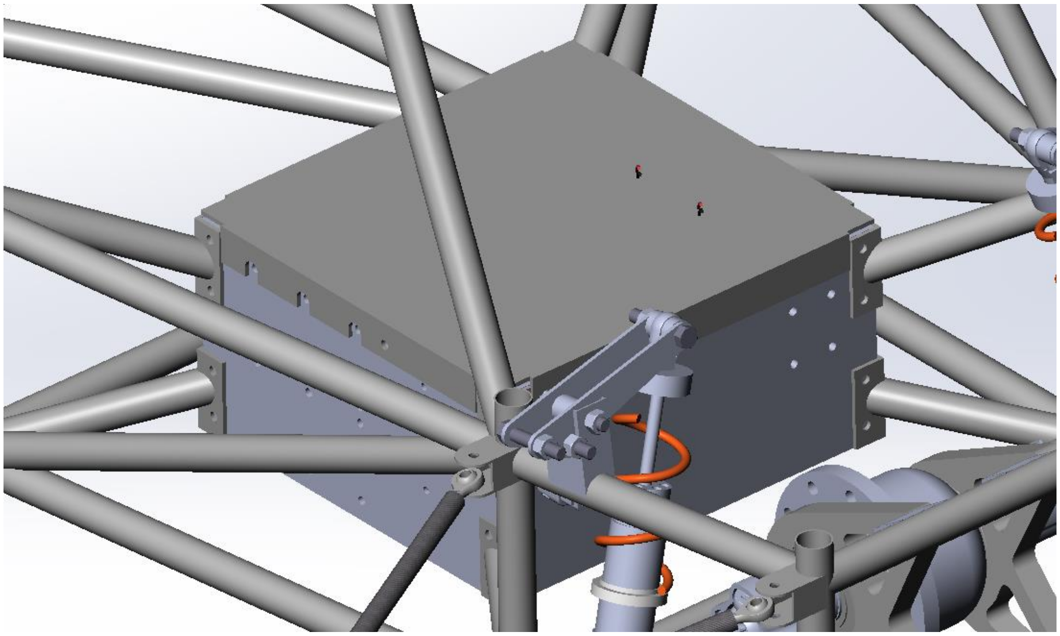

Figure 9: EV Accumulator

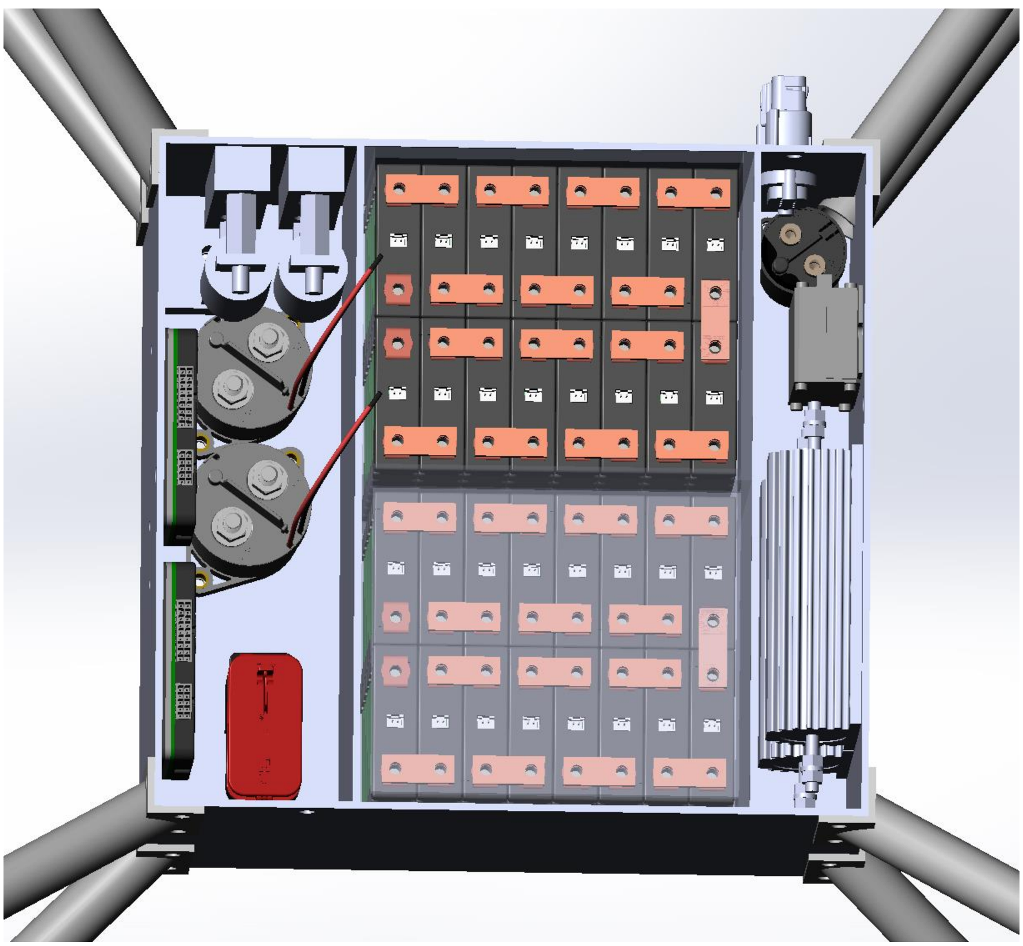

Figure 10: EV Accumulator Internals

6.6.5 Description of Analysis Completed

To ensure that the required components could fit in the accumulator, the required components were determined, models acquired, and fitted into the accumulator. Additionally, the FSAE rules have multiple requirements that specify design requirements such as the battery partitions, allowable hole sizes and locations, and mounting locations. In order to provide more mounting space for the components, the battery compartment was moved to the middle of the accumulator, freeing up one wall of the accumulator.

The accumulator mounts were designed to meet the minimum of 6 points of contact with connections at the corners and all fasteners within 5 cm of the corner. The design of the lid to have removed corners and the bolted connection to the accumulator allows the accumulator to be quickly dropped out of the chassis for maintenance.

6.6.6 Results

The design was able to fit all the required components with some adjustments to size and relocations of parts. The box was assembled into the cad model and the mounts were designed to connect each corner to the nearest chassis node to maintain triangulation of the chassis and maintain its torsional rigidity.

6.6.7 Relevance to the Project

The accumulator is critical to achieving the main criterion for success of the FSAE Electronics team; to build an electric car capable of reaching at least 20 mph. All the components that go along with the electric motor need to be safely contained inside the vehicle.

6.7 Cooling System

6.7.1 Objective of Analysis & Description of Problem

The electric motor used is liquid-cooled to reduce wear on the internal mechanical components. A system must be designed to provide cool liquid, either water or a 50/50 water/glycol mixture, and extract the heat from the heated liquid.

6.7.2 Deliverables Affected

This is an integral part of the deliverable to build a battery power electric car capable of reaching 20 mph.

6.7.3 Assumptions Made

The motor recommends a fluid flow rate of 6L/min, but due to potential losses in multiple fittings in the system, a pump with a larger capacity than 6L/min will be required. Additionally, the radiator to be used is a spare radiator from a previous IC car.

6.7.4 Relevant Figures, Diagrams, & Drawings

Figure 11: EV Cooling System Pump

6.7.5 Description of Analysis Completed

Firstly, the pump was chosen. To account for potential losses in the system, an 8L/min pump was chosen instead of the suggested 6L/min pump. With the pump chosen, the required tubing and fittings could be determined based on the inlet and outlet diameters of the pump, motor, and radiator. The radiator has a significantly larger inlet and outlet than the motor and pump, which requires a two-stage step up and step down respectively.

6.7.6 Results

The system designed was well within budget and the pump chosen is compact and can be easily fit into the chassis. The system is slightly overpowered which is being used to compensate for losses in the system due to friction and turbulence.

6.7.7 Relevance to the Project

The cooling system is critical to achieving the main criterion for success of the FSAE Electronics team; to build an electric car capable of reaching at least 20 mph. While the car can operate without the cooling system, it is crucial to ensure the longevity of the motor and to allow it to be pushed to higher speeds and accelerations.

7. Experimental Procedures and Testing

7.1 Wheel Speed Sensor Test Print

7.1.1 Purpose of Experiment or Test

The wheel speed sensor mount was designed with complex geometry that can only be created using 3D printing. Although 3D printing is a very flexible manufacturing method that is able to create very complex geometries that are impossible with other manufacturing methods, 3D printing is still susceptible to failure, especially when there are overhangs and support structures needed. In order to verify that the designed part is able to be 3D printed, a test part was printed.

7.1.2 Deliverables Affected

This affected the wheel speed sensor deliverable, related to the criterion for success of mounting the required sensors to the IC car.

7.1.3 Procedures & Experimental Set Up

The process for this experiment was to generate the gcode file for the print, set up the printer, and start the print.

In generating the gcode, a slicing software called Cura is used which allows the printing parameters to be changed such as print temperature, infill percentage, and where supports are printed. The settings were left at their default values for the material being used; PLA.

Setting up the printer simply involves preheating the printing nozzle and printing bed, cleaning the printing bed, and loading the correct filament.

Starting the print is loading the gcode file generated from the slicing software into the printer, starting the print, and monitoring for the first layer to ensure proper adhesion.

7.1.4 Results

Once the print had been completed, the part was removed from the print bed and inspected for correct layer adhesion, sagging, or deformities. The part, while not perfect as is expected with 3D printing, had no significant deformation or sagging.

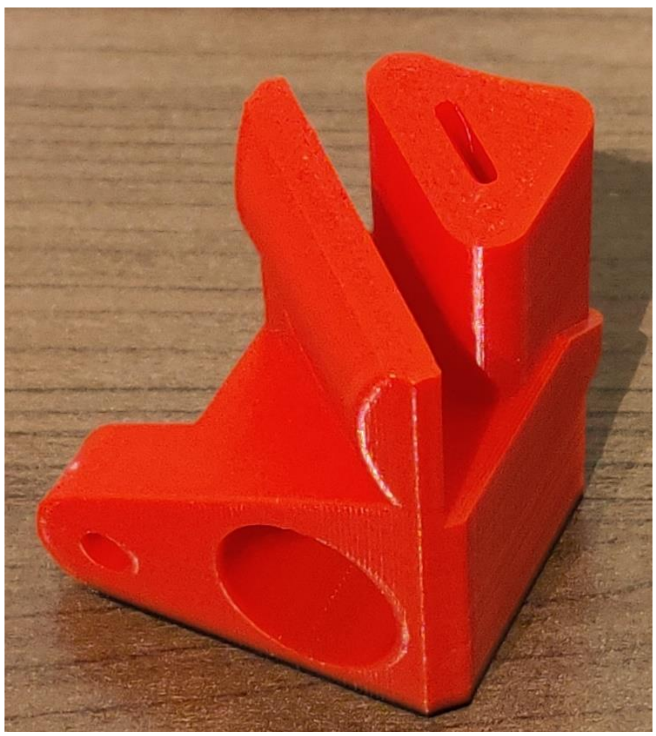

Figure 12: Wheel Speed Sensor Mount Test Print

7.1.5 Relevance to the Project

This experiment will ensure that when the designed part is manufactured it will be successful.

8. Design Process

8.1 Steering Angle Sensor

8.1.1 Component/System Description

The steering angle sensor system is to provide an accurate reading of the angle of the steering input of the IC car. The information provided by the sensor is a gradable portion of competition and also a point of regulation within the FSAE rules. The sensor will be a rotational potentiometer that is mounted directly to the steering rack.

8.1.2 Design Loadings

The forces in the system should be minimal and should have to only support its own weight.

8.1.3 Design Criteria

The sensor will have to be securely mounted to the steering rack to prevent any dead space in the measurable steering input. The forces expected in the system are minimal and will only consist of the weight of the sensor.

8.1.4 Make-or-Buy Decision

The rotational potentiometer will be purchased. Mounts of the sensor to attach to the steering rack have been designed to be easily 3D printed. This is due to the fact of minimal forces acting on the system and to minimize cost on manufacturing a very small and detailed part that will have to be manufactured externally from the team.

8.1.5 Make

8.1.5.1 Material Selection

The sensor mount will be 3D printed and will be made of a printed plastic due to minimal cost of material that meets the force requirements of the system.

8.1.5.2 Concepts

8.1.5.3 Simulations/Calculations

Stress calculations and simulations have yet to be completed.

8.1.5.4 Final Design

The mount will be a simple plug in the diameter of the internal shaft of the steering rack. The plug will be secured by friction to the shaft. The sensor will connect to the sensor by snap tabs at the opposite side of the mount from the plug. These tabs will bend to allow the placing of the sensor and bend back to its original position to hold the sensor in place and transfer the rotation of the shaft to the sensors rotating ring.

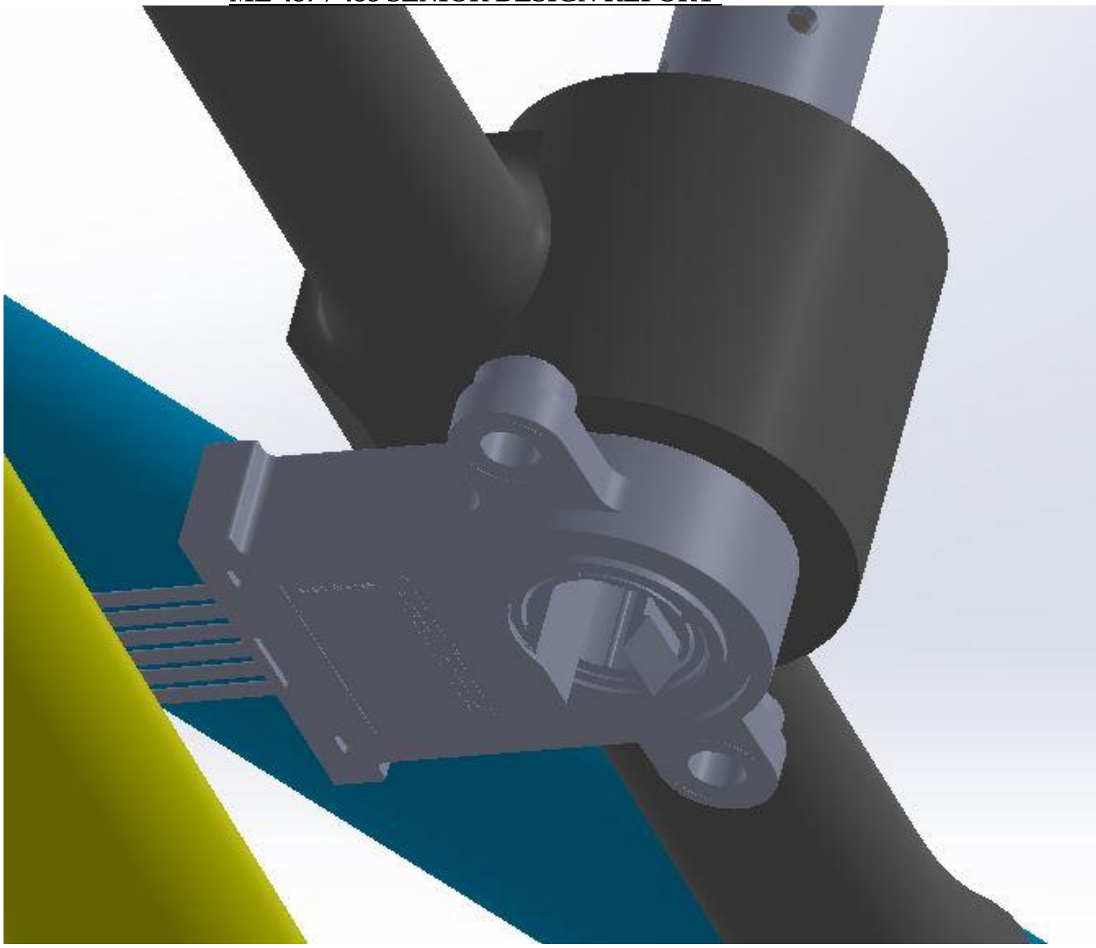

Figure 13 Steering angle sensor mounted to IC steering rack

8.2 Ride Height Sensor

8.2.1 Component/System Description

The ride height sensor is to provide an accurate reading of the vertical position of each corner of the vehicle by measuring distance traveled by the damper suspension on each wheel.

8.2.2 Design Loadings

The mounting for the sensors is to hold the weight of the sensor and keep them rigidly in place. The sensors themselves are extremely fragile and must not be put under any bending forces to prevent them from becoming inoperable.

8.2.3 Design Criteria

The sensors must provide an accurate reading of suspension location with minimal error and variable readings throughout damper compression.

8.2.4 Make-or-Buy Decision

The sensor will need to be purchased from a predetermined supplier. The mounts will be simple components that are attached to the sensors and dampers. Due to the very minimal forces expected in the sensor system and the specific sizing requirements of the mounts, it will be a prime subject for 3D printing. This will save cost and lead time on manufacturing them externally.

8.2.5 Make

8.2.5.1 Material Selection

The material for the mounts will be a 3D printed plastic polymer. This will provide simplistic manufacturing and low cost to meet the low force requirements in the system.

8.2.5.2 Concepts

The mounts will be 3D printed plastic rings that will be bolted together to clamp onto the top and bottom end of the damper. The rings will have a tab the protrudes away from the damper. These tabs will have a slot through the center to allow the sensor to slide into it. There will be a 5mm hole on either slide that will create a spot to bolt or screw the sensor to the mount.

8.2.5.3 Simulations/Calculations

Simulation and calculations are yet to be completed by the team.

8.2.5.4 Final Design

The final design is the linear potentiometer that is rigidly mounted to the end of the damper and the midsection. These mounting locations will exert minimal rotational forces to the sensor and will provide an accurate reading in the change of damper length. The mounts will be 3D printed as the forces experienced are minimal and bolted together to retain position on the damper.

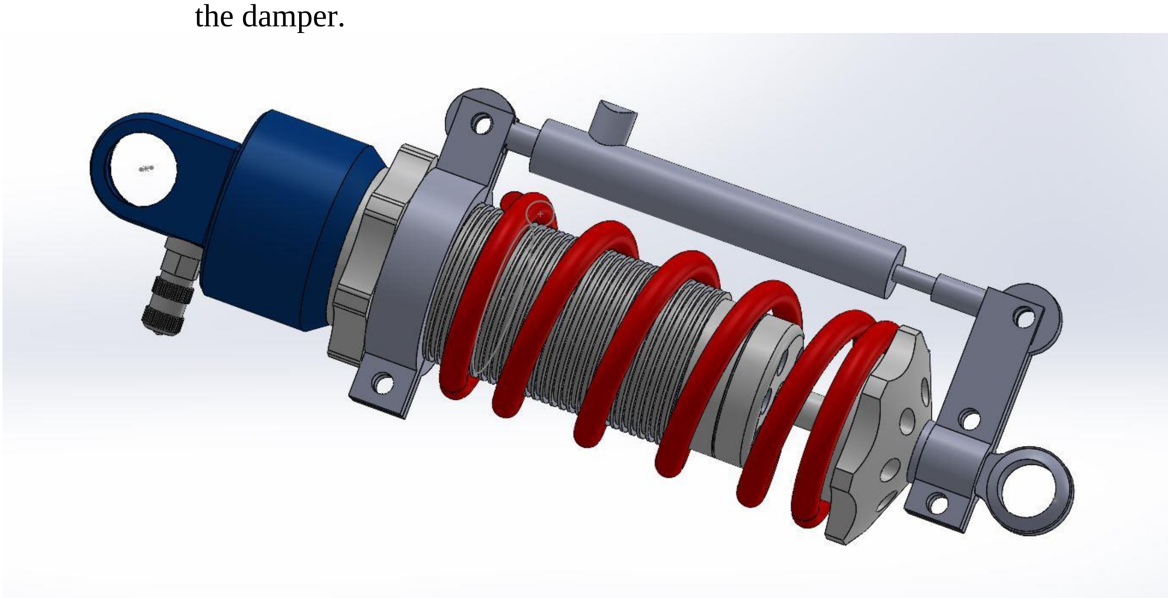

Figure 14: Ride height sensor CAD mounted to suspension dampers

8.3 Wheel Speed Sensor

8.3.1 Component/System Description

To measure the wheel speed, a Hall Effect sensor with a sensor ‘gear’ creates electrical pulses that can be read and the time between the pulses is used to calculate the wheel speed.

8.3.2 Design Loading

8.3.3 Design Criteria

The main design criterion for this system is to provide a minimum of 20 pulses per wheel revolution. This provides a higher measurement resolution than the previous year's 4 pulses per wheel revolution.

8.3.4 FMEA

8.3.5 Make-or-Buy

The Hall Effect sensor must be purchased, but the sensor 'gear' is a custom design and therefore isn't readily available. This may be purchased as a custom part from a sheet metal shop, but it would be significantly more cost effective to use up scrap 1/4" steel sheet if available in the shop.

8.3.6 Make

8.3.6.1 Material Selection

In order to be registered with the Hall Effect sensor, the sensor 'gear' material must be ferrous, so low-carbon steel was selected as it highly ferrous.

8.3.6.2 Concepts

8.3.6.3 Simulations/Calculations

8.3.6.4 Final Design

The sensor gears were mounted onto the hubs, acting as a washer between the castle nut and the bearing. This design allowed the design of the hubs to remain the same and replaced a washer, helping to reduce the amount of weight added. Since the minimum thickness of the gear is 6.35mm, which is thicker than the initially selected washers, there is still some weight gain. Due to concerns of the gear slipping during rapid acceleration or deceleration, positive engagement was designed to ensure they stayed aligned with the wheels. On the rear wheels, a friction-fit pin is used to connect the drive tripod to the sensor gear, while on the front a pin is used to connect the gear directly to the hub.

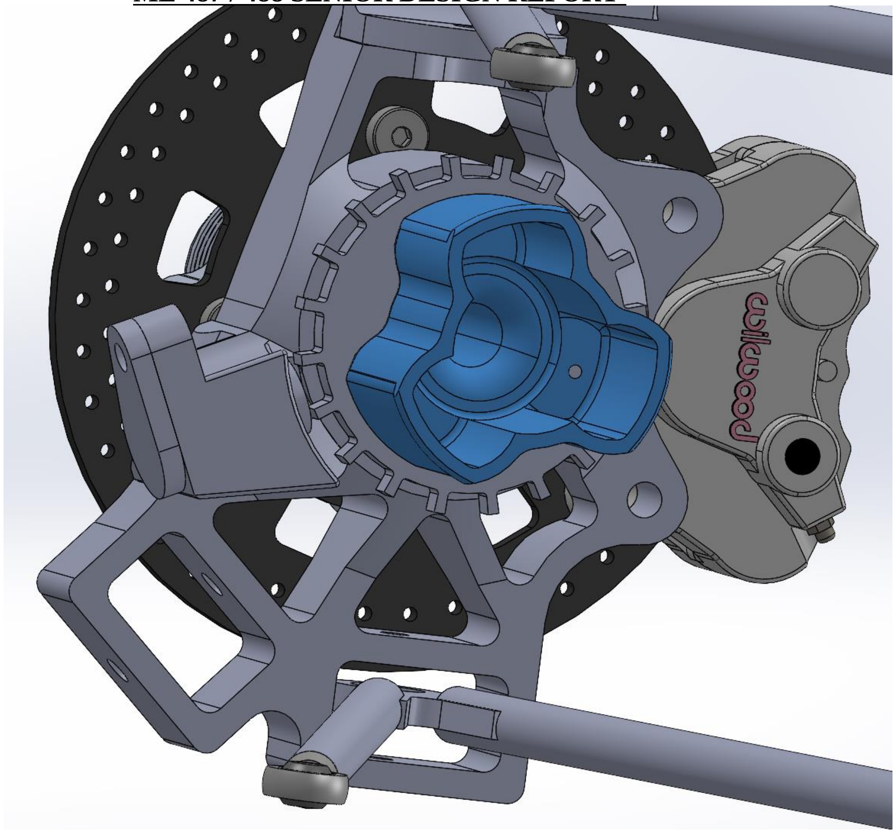

Figure 15: Rear Wheel Speed Sensor Gear Model with Positive Engagement

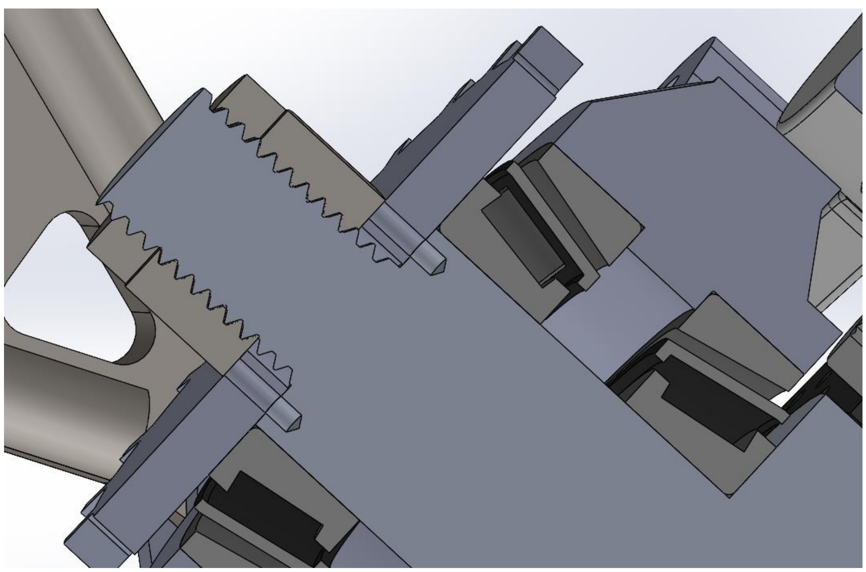

Figure 16: Front Wheel Speed Sensor Gear Model with Positive Engagement

With the sensor gears mounted, the sensors were mounted to be perpendicular to the axis of rotation of the wheel with the recommended gap between the gear teeth and the sensor of 1.5mm. The mounts were designed to fit the negative space of a section of the wheel upright. In order to achieve the desired geometry for the mounts, and to save on weight, the mounts were designed to be 3D printed. This also allowed an internal slot to be designed to pass a hose clamp through the mount to secure it to the upright.

The final design uses the Hall Effect sensor used in the previous year’s vehicle, so the design of the mount changed slightly to accommodate the slightly different mounting system.

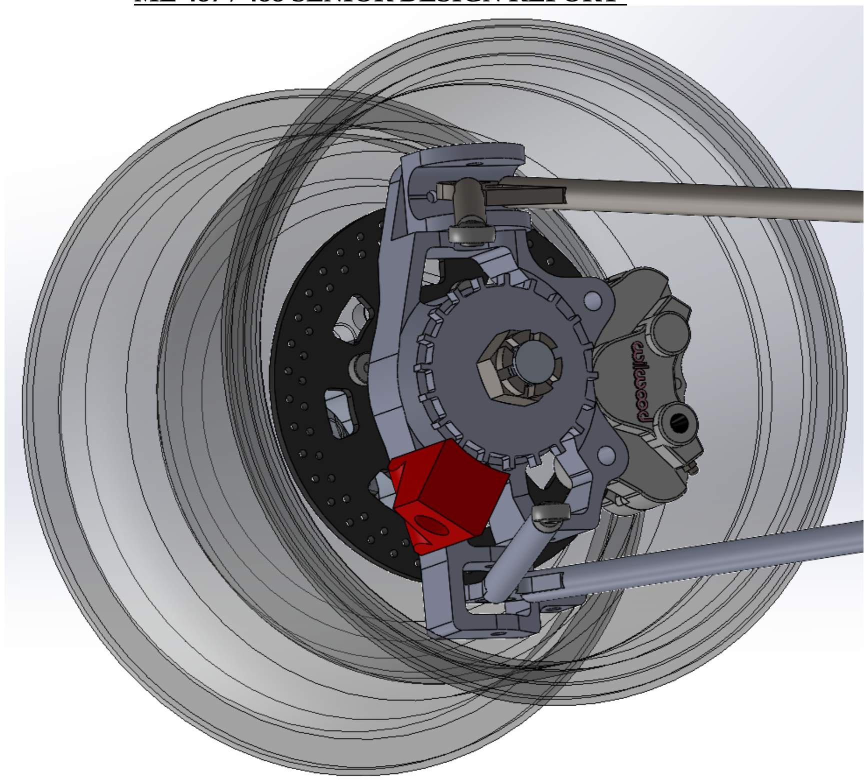

Figure 17: Wheel Speed Sensor Full Assembly with Hub Assembly

8.4 Motor Mount

8.4.1 Component/System Description

The chassis used for the electric vehicle was previously the chassis for the IC car from 2018. The motor mounts in the chassis were designed specifically for the IC engine used that year. In order to install the electric motor a new mounting system had to be designed that could withstand the torque of the motor. According to FSAE rules, structural tubing should connect to the chassis at nodes, where multiple chassis tubes are joined. This maintains the triangulation in the chassis and helps maintain its torsional rigidity.

8.4.2 Design Loadings

The motor provides a max torque of 40 ft-lbs, which converts to 54.2 N*m. This loading was applied to the drive spindle of the motor in the opposite direction of the spindle rotation.

8.4.3 Design Criteria

The design criterion for the motor mount is to be able to withstand the max torque supplied by the electric motor with a safety factor of at least 2.

8.4.4 FMEA

#	Failure Mode	Sev.	Severity Reasoning	Occ.	Occurrence Reasoning	Det.	Detection Reasoning	Risk	Failure Mitigation
1	Failure of weld	4	Weld failure could cause portion of tubing to dislodge from original fixed location, resulting in heavy injuries to the car and/or driver	1	Occurrence is very unlikely to occur if weld is performed by correctly or by a professional	3	There would be a medium detection of failure due to some components connected to chassis have several mounts welded to chassis and would be hard to notice in some occurrences	12	Team will inspect mounts after each event performed to ensure the integrity of mount is undisrupted
2	Failure of chassis or mount tube	4	Failure of chassis or mount tube may result in deformation of chassis that could cause heavy injury to driver and/or car	1	Occurrence is very unlikely to occur. Chassis would have to have excessive forces applied to it to cause any type of deformation and that is still unlikely	2	Tube failure could dislodge tube from original fixed location, this would be highly detectable since frame is not covered heavily by the body or other components	8	Team will avoid handling car in such a way that it does not operate in a way that it was not intended for

8.4.5 Make-or-Buy Decision

The motor mount will have some complex tube end profiles that are best done by a dedicated manufacturer. Once the tubes have been cut and profiled, students with welding experience can perform the tack and finish welding for a fraction of the cost of having them done by a third party.

8.4.6 Make

8.4.6.1 Material Selection

The chassis being used for the EV car is constructed of chromoly steel tubing. In order to maintain consistency and ensure full strength welds between the motor mounts and the chassis, the motor mounts are to be constructed of the same chromoly steel.

8.4.6.2 Concepts

8.4.6.3 Simulations/Calculations

8.4.6.4 Final Design

The final design of the motor mount changed from the initial design in that the top mount was moved to the drive side of the motor mount plate. This change was made to allow the motor to be installed and removed after the motor mount had been welded together.

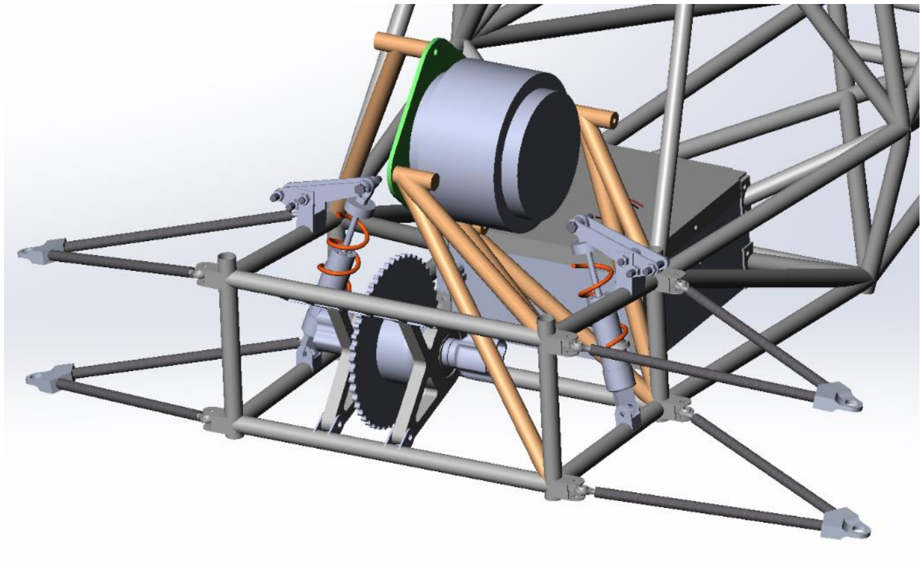

Figure 18: Motor mounted into chassis CAD model

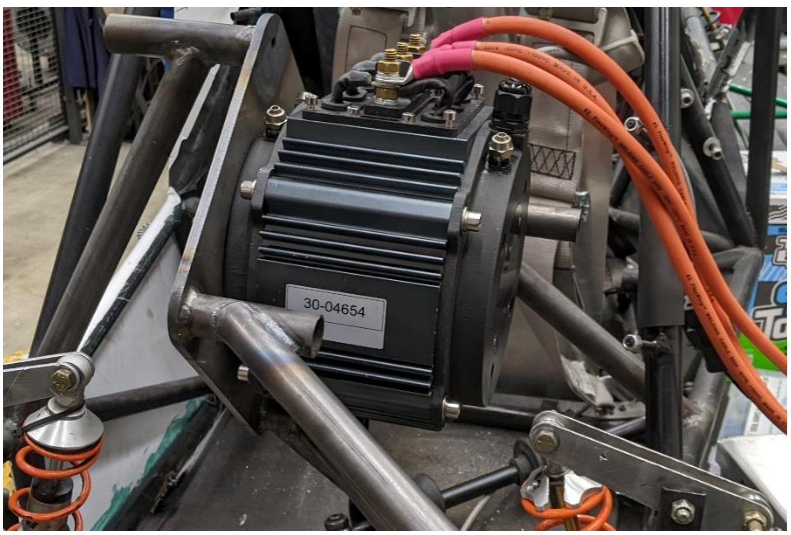

Figure 19: Motor mounted into chassis

8.4.8 Fatigue/Service Life Analysis

8.5 Differential Mount

8.5.1 Component/System Description

The chassis used for the electric vehicle was previously the chassis for the IC car from 2018. The differential mounts in the chassis were designed specifically for the IC engine used that year and were mounted directly to the engine making them unusable without the IC engine. The differential mounts had to be completely redesigned to mount to the chassis and to withstand the torque of the electric motor.

8.5.2 Design Loadings

The max rpm of the electric motor is 6500 rpm. The gear ratio was chosen to be under the maximum gear ratio such that the max rpm of the motor translated into a maximum vehicle speed of 55 mph. The maximum gear ratio able to be obtained due to space constraints in the chassis was 4.1, which transfers the max torque of 414 N*m to the axle from the motor. This torque was applied to the axis of rotation of the differential mount in the opposite direction of the axle rotation when the vehicle drives forward.

8.5.3 Design Criteria

The design criteria for the differential mount is to withstand the amplified torque of the motor due to the gear reduction with a safety factor of 2.

8.5.4 FMEA

#	Failure Mode	Sev.	Severity Reasoning	Occ.	Occurrence Reasoning	Det.	Detection Reasoning	Risk	Failure Mitigation
1	Failure of bolt	4	Bolt failure could cause the differential to dislodge from the mounting brackets, resulting in heavy injuries to the car and/or driver	1	Occurrence is very unlikely to occur if bolt grade and size are determined correctly	3	There would be a medium detection of failure due the difficulty of determining the required grade or size of bolt visually	12	Team will inspect bolts after each event performed to ensure the integrity of bolts are undisrupted
2	Failure of chassis tube	4	Failure of chassis tube may result in deformation of chassis that could cause heavy injury to driver and/or car	1	Occurrence is very unlikely to occur. Chassis would have to have excessive forces applied to it to cause any type of deformation and that is still unlikely	2	Tube failure could dislodge tube from original fixed location, this would be highly detectable since frame is not covered heavily by the body or other components	8	Team will avoid handling car in such a way that it does not operate in a way that it was not intended for

8.5.5 Make-or-Buy Decision

These components are being manufactured in the shop, using some purchased raw materials.

8.5.6 Make

8.5.6.1 Material Selection

The material selected was an aluminum alloy, the same as the differential mount from the IC car. While the stresses on this differential mount are likely to be higher than on the IC car, keeping the weight of the car down is important so a lightweight yet strong material like aluminum is required.

8.5.6.2 Concepts

8.5.6.3 Simulations/Calculations

ANSYS was used to simulate the torque of 310.8 N*m being exerted on the differential axis. This analysis showed suspiciously low stress and deformation, so the analysis is still being reviewed to ensure that it was performed correctly.

8.5.6.4 Final Design

The final design of the differential mount uses two A-arm structures that hold the differential and pivot around the lower mount to the chassis. The upper mounts are joined by a connecting bar that allows for shims to be inserted between that and the mounts on the chassis, providing adjustment for the chain tension.

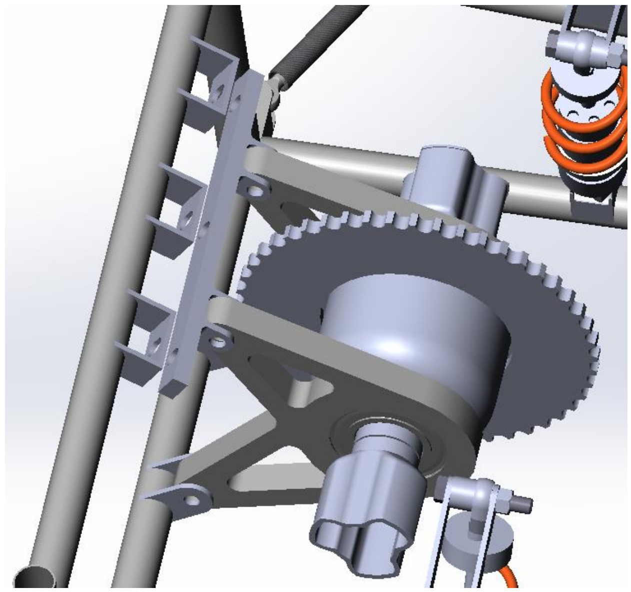

Figure 20: Differential mounting structure CAD model

Figure 21: Differential frame fabricated

8.5.7 Fatigue/Service Life Analysis

8.6 Accumulator

8.6.1 Component/System Description

The accumulator houses the battery modules and the major electrical components. This protects the components and the driver.

8.6.2 Design Loadings

The masses of all the components in the accumulator are yet to be determined.

8.6.3 Design Criteria

There are multiple rules set out by FSAE that must be met when designing the accumulator. Some of the major rules that affect the design are the container material, which must be non-flammable, at least 3.2mm thick on the bottom and 2.3mm on the sides and lid for aluminum and be able to withstand forces of deceleration in all directions: 40g in the lateral directions and 20g in the vertical directions. Welds may be continuous or interrupted, but interrupted welds must be at least 25mm long and the weld to space ratio must be greater than 1:1.

The lid must be attached with at least one fastener for each vertical exterior wall. The interior walls must be at least the full height of the accumulator segments. Each segment can contain a maximum of 12 kg. Attaching the accumulator to the chassis, all fasteners are Critical Fasteners and there must be at least 6 attachment points for an accumulator weighing between 20 and 30 kg.

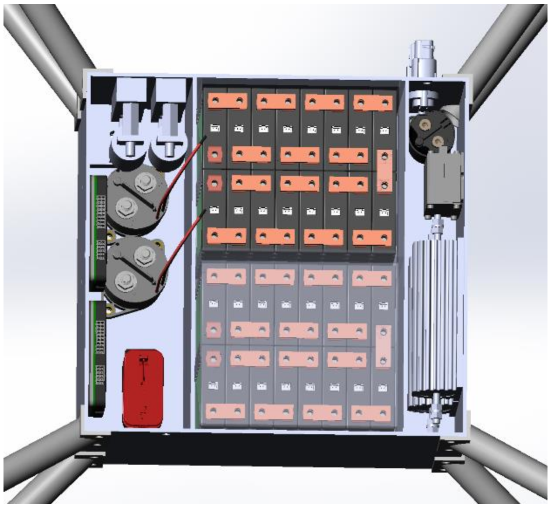

Figure 22: Accumulator CAD layout

8.6.4 FMEA

#	Failure Mode	Sev.	Severity Reasoning	Occ.	Occurrence Reasoning	Det.	Detection Reasoning	Risk	Failure Mitigation
1	Failure of weld	4	Weld failure could cause portion of tubing to dislodge from original fixed location, resulting in heavy injuries to the car and/or driver	1	Occurrence is very unlikely to occur if weld is performed by correctly or by a professional	3	There would be a medium detection of failure due to some components connected to chassis have several mounts welded to chassis and would be hard to notice in some occurrences	12	Team will inspect mounts after each event performed to ensure the integrity of mount is undisrupted
2	Failure of chassis or mount tube	4	Failure of chassis or mount tube may result in deformation of chassis that could cause heavy injury to driver and/or car	1	Occurrence is very unlikely to occur. Chassis would have to have excessive forces applied to it to cause any type of deformation and that is still unlikely	2	Tube failure could dislodge tube from original fixed location, this would be highly detectable since frame is not covered heavily by the body or other components	8	Team will avoid handling car in such a way that it does not operate in a way that it was not intended for

8.6.5 Make-or-Buy Decision

Most of the parts of the accumulator should be simple components with basic welds, making them great candidates to be manufactured in-house. The mount tubes, however, will require relatively complex profiling on the ends to mesh correctly with the other tubes at the connection nodes. These are best performed by a company that specializes in that type of manufacturing process.

8.6.6 Make

8.6.6.1 Material Selection

The chassis being used for the EV car is constructed of chromoly steel tubing. In order to maintain consistency and ensure full strength welds between the accumulator mounts and the chassis, the accumulator mounts are to be constructed of the same chromoly steel. The accumulator box, however, will be made of aluminum sheet to conserve weight

8.6.6.2 Concepts

8.6.6.3 Simulations/Calculations

8.6.6.4 Final Design

The final design of the accumulator has the battery pack offset in the center of the accumulator. This provides more mounting space on the walls of the accumulator for electronic components.

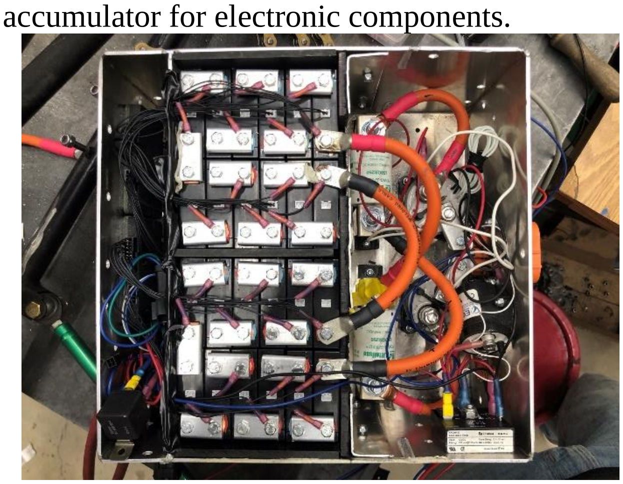

Figure 23: Accumulator assembled

8.6.8 Fatigue/Service Life Analysis

8.7 Motor Controller Mount

8.7.1 Component/System Description

The motor controller needs to be mounted to the chassis in proximity to motor to allow for simple and easy connections between the two. The chassis used for the EV car was designed for the IC car in 2017 and did not account for the mounting of this component.

8.7.2 Design Loadings

The mounts would have to support the weight of the controller and remain rigid in the event of a crash or roll to meet FSAE rules.

8.7.3 Design Criteria

The mount must meet the structural analysis of the FSAE rules. These rules state that mounted components of must be rigidly mounted and remain rigid under forces of lateral forces of 40g and 20g vertically. This in place to ensure the vehicle remains structurally intact during the event of a roll over or crash.

The electrical engineers of the team decided the connecting points between the motor and the controller should be no more than a foot long to prevent crossing wires and or causing electrical interference with the nearby components.

8.7.4 FMEA

#	Failure Mode	Sev.	Severity Reasoning	Occ.	Occurrence Reasoning	Det.	Detection Reasoning	Risk	Failure Mitigation
1	Failure of weld	4	Weld failure could cause portion of tubing to dislodge from original fixed location, resulting in heavy injuries to the car and/or driver	1	Occurrence is very unlikely to occur if weld is performed by correctly or by a professional	3	There would be a medium detection of failure due to some components connected to chassis have several mounts welded to chassis and would be hard to notice in some occurrences	12	Team will inspect mounts after each event performed to ensure the integrity of mount is undisrupted
2	Failure of chassis or mount tube	4	Failure of chassis or mount tube may result in deformation of chassis that could cause heavy injury to driver and/or car	1	Occurrence is very unlikely to occur. Chassis would have to have excessive forces applied to it to cause any type of deformation and that is still unlikely	2	Tube failure could dislodge tube from original fixed location, this would be highly detectable since frame is not covered heavily by the body or other components	8	Team will avoid handling car in such a way that it does not operate in a way that it was not intended for

8.7.5 Make-or-Buy Decision

The mounting plates should be simple components with basic welds, making them great candidates to be manufactured in-house. The mount tubes, however, will require relatively complex profiling on the ends to mesh correctly with the other tubes at the connection nodes. These are best performed by a company that specializes in that type of manufacturing process.

8.7.6 Make

8.7.6.1 Material Selection

The chassis being used for the EV car is constructed of chromoly steel tubing. In order to maintain consistency and ensure full strength welds between the accumulator mounts and the chassis, the accumulator mounts are to be constructed of the same chromoly steel.

8.7.6.2 Concepts

8.7.6.3 Simulations/Calculations

Stress simulations and force calculations are yet to be completed.

8.7.6.4 Final Design

The final design is complete. The controller will be bolted directly to the rear chassis behind the driver seat to reduce the need for a specially fabricated mounting system and to negate over-designing a very simple concept.

9. Product Operations

9.1 Operating procedures

The components required for the Electronics team require a number of different manufacturing methods, including 3D printing plastic, CNC machining, tube cutting and profiling, welding, drilling, and sheet metal cutting. The more complex operations such as CNC machining and tube profiling will be outsourced, while operations that can be performed in-house such as plastic 3D printing and welding will not be outsourced.

9.2 Safety

Each of the manufacturing processes requires a different set of safety precautions. 3D printing is entirely contained in the printer and doesn't require extra safety precautions, while welding requires a helmet for vision and face protection and gloves to prevent burns. Drilling will require safety glasses and no loose clothing or long hair to prevent anything getting caught in the machinery.

9.3 Scheduled Maintenance

Scheduled maintenance of the equipment at UND is completed by the instructors. Students are expected to report any problems with the equipment to the instructors to ensure proper use and safety. The "cage" where the FSAE car is stored and produced is cleaned weekly by the team. The sub-team that is responsible to the cleaning rotates weekly.

9.4 Disposal/recycling

All large scrap material is stored for future use by either FSAE team or other mechanical engineering students. Smaller scrap material is sent to a recycling facility.

9.5 Regulations and Standards

The UND lab is held to standard safety regulations set by OSHA. Signage requiring safety glasses is posted frequently. Safety glasses must be provided by the individual. Everything is labeled for easy storage and retrieval.

10. Budget Analysis

10.1 Fall Semester

For the fall semester the Electronics team has received a total of $6,500: $3,000 from the CEM, and $3,500 from SOFA. Some design decisions have been updated to ensure the budget is met, such as the motor choice and number of battery modules. As designs are finalized, the budget will be adjusted and confirmed.

Manufacturer	P/N	Category	Description	Cost	Qty	Total
Energus	Li1x7p25RT	Batteries	Battery Module	79.73	32	2551.36
Emus	Cu021A	BMS	BMS Master Control Unit	387	1	387
Emus	CCGM022D+Q	BMS	BMS Centralized Slave Unit	250	2	500
Emus	3WC01A	BMS	CAN Bus T-Splitter	15	1	15
Emus	?	BMS	Current Sensor	135	1	135
Emus	?	BMS	BMS Wiring Kit	25	1	25
Emus	CNT01	BMS	CAN Bus Termination	10	1	10
Emus	CNC03-100	BMS	100cm CAN Connection	12	1	12
Emus	CNC04-100	BMS	Master to Slave CAN	10	1	10
Sevcon	634A13210	Controller	Motor Controller	1050	1	1050
DLC-28	ME1302	Motor	Motor	980	1	980
Elcon	HK-J-H440-10	Charger	Charger	775	1	775
Total						**6450.36**

10.2 Spring Semester

For the spring semester, additional funding was obtained that raised our budget to $11,000. The components purchased are shown below which came in under budget at $10,770.

Supplier	Price	Items
Mouser	$150.55	HV Connectors
Grand Forks Welding	$164.23	Accumulator Aluminum
Sensor Connection	$680.20	Suspension Travel Sensors
Digikey	$72.45	Steering Angle Sensor
Summit Racing	$107.44	Electronic Throttle Body
Electric Motorsport	$59.87	Lugs, BMS Harness
Electric Motorsport	$49.52	Controller Connector
Haltech	$142.00	Ignitor
Mcmaster Carr	$116.57	Diff Bearing, Bus Bar
Amazon	$120.74	Crimping Tools
Pelican Parts	$285.47	Accelerator Pedal
Midwest Steel	$124.00	Diff Mount Aluminum
Electric Motorsport	$3,556.57	Controller, Motor, BMS
Energus	$3,209.15	Battery Modules
Evolve Electrics	$811.65	Charger, DC-DC Converter
Digikey	$428.26	HV Fuses, Timer, Resistors
RCV	$520.00	In-board Tripods
Newark	$93.42	HV Connectors
Digikey	$77.52	HV Connectors
Total	**$10,769.61**	

11. Detailed Final Design Recommendations

11.1 Major groups/systems

The Electronics team has two responsibilities of the FSAE organization: the sensors and electrical components of the IC car and the development of the EV car.

The IC car system that the team is responsible for is the implementation of the sensors for data collection. This includes sensors for ride height, steering angle, and wheel speed, and a data collection box that will be used to consolidate that information. The team has completed all preliminary designs for the sensors to be implemented in the IC and awaiting design reviews by the main team and admin.

The EV car will be fully designed by the team. The team will be using a chassis and suspension system from a previous year. The other systems in the EV car are the electronic drive train and the accumulator. The team has completed designs for the electric powertrain, which includes the motor and differential. It has also completed preparing the old chassis for modification by removing all unnecessary parts and systems.

11.2 Assembly and components

All major electrical components were assembled by the electrical engineers in the FSAE team. These items include the accumulator, motor controller circuits, and driver input control systems.

The motor was placed into the motor mount plate and positively retained to the plate by four three-eighths inch bolts that interface with the plate face towards the drive shaft and threaded into the motor mounting locations.

The differential drive sprocket was fastened to the differential using the specified 10mm left threaded bolts. The bearings were then press fit into the support frames. This support frame sub-assembly was then press fit onto both end of the differential. On either end, a drive shaft was assembled between the wheel hub assembly and the differential assembly containing a splined half-shaft that connect to a tripod which is retained into the differential by snap rings on the interior.

The brake and steering systems were cannibalized from a previous year’s design. These systems were transferred directly as a whole into this current chassis fully assembled. The steering column and steering rack were mounted into the chassis with a series of bolts on the belly pans. The brake calipers and lines were attached to the rotors present in the hub assemblies and to the master cylinders already present on the chassis pedal box.

11.3 Function/purpose

The purpose of the team project still remains unchanged. The team is to implement sensors into the IC car that will provide accurate data collection to help the rest of the FSAE team optimize their subsystems and keep the vehicle in regulation with the FSAE rules for competition. The team is also to design a proof-of-concept electric powertrain vehicle to the FSAE competition standards to create a basis of future expansion of the FSAE team as a whole.

11.4 Fabrication

The fabrication of the motor mounts have been cut to size, profiled, and welded in shop. Chromoly steel structural tubes were used to retain consistency with the rest of the chassis. This also provided a better environment for higher weld quality to maximize the design strength. The mounting was MiG welded in place and then a second higher quality weld was created by a hired professional.

The motor mounting plate was water jet by a local manufacturing company. This was made out of stainless steel plate that was than welded to the motor mount supports that were welded to the chassis.

The accumulator design was fabricated in a similar fashion to the motor mounting plate. The steel sheet metal was water jet into the initial complex shape by a local manufacturing company. The sheet was then bent on a press to fold the sheet into the 3D box shape. The lid for the accumulator box was also fabricated using this method.

The frame and mounting brackets for the differential structure was machined from a piece of aluminum using a mill. This machining was done by a manufacturing expert on campus and then delivered to the team for assembly into the rest of the vehicle.

12. Detailed Conclusion

12.1 Value provided

On the IC car, the work done by the Electronics team will allow for more detailed data collection of the vehicle performance and operation. This will provide information to the other IC car sub-teams that will allow them to improve the performance of their designs, root cause problems, and optimize the overall car performance. Additionally, the data collected can be used to help the driver improve their skills which can improve the performance of the UND team in the FSAE competition in May.

12.2 Project management goals met?

Overall, the project is a bit behind schedule. For the EV car, the project plan had specified the chassis to be electric-integration ready by December 15th. This would require the motor and differential mounts, and the accumulator to be manufactured and installed on the chassis. The motor and differential mounts are waiting on approval of the design, and the accumulator design is currently being finalized before being submitted for approval.

On the IC car, the design, manufacture, and installation of the sensor mounts is about on-track to be completed in time for the complete car assembly.

13. Post Midterm

13.1 Description of Lessons Learned

When working on a task, especially if it requires communication with another sub-team, it is crucial to at least start the communication as early as possible to ensure that any questions or discussions are completed before the due date. This leads to a more streamlined interaction between the teams and reduces the stress of being unable to contact the correct person as the deadline quickly approaches.

Revisiting some designs later in the semester showed the importance of reviewing designs with multiple people with different viewpoints earlier in the process. Design changes are more difficult later in the process and can cause delays in getting the required materials in and manufacturing completed.

13.2 Recommendations for Future Installments of the Project

It seems the best way to approach the order of the tasks to be completed would be to start with the ones that were expected to take the longest or to require collaboration with other sub-teams. When it comes to collaborating with other teams, it is important that any design considerations for the Electronics team are taken into account in the related sub-teams' designs. For example, with the wheel speed sensor, if the sensor had been taken into account when the uprights and hubs were being designed, the mount and the 'gear' could have been integrated into the main designs. When planning longer tasks, especially if they have an external process that has a significant lead time, it is important to get those started early in the project so that other, shorter tasks can be completed while the larger tasks are being waited on.

14. Team Resumes

DEAN ROGERS

1825 Penfield Rd, Apt 4 Penfield, NY 14526 (585) 749-0389 dean.rogers@und.edu

CAREER OBJECTIVE

Detail-oriented Mechanical Engineering major (3.84 GPA) currently attending the University of North Dakota, with 7+ years of work experience. Aiming to leverage a proven knowledge of data analysis, 3D design, and problem-solving skills to successfully fill the role for the FSAE - Electronics Project.

EXPERIENCE

Ranger Design, Ontario, NY

Inventory Coordinator, May 2018 – Present

- Generate and analyze forecasts and planning parameters to ensure accurate stock levels and provide purchasing suggestions.
- Verify physical counts of stock and investigate discrepancies or adjust errors.
- Prepare and maintain records and reports of inventories, adjustments, and department performance.
- Recommend disposal of excess, defective, or obsolete stock.

Procurement Specialist, Mar 2015 – May 2018

- Prepare purchase orders, manage quoting, and review requisitions for goods and services.
- Interview vendors and visit suppliers' plants to examine and learn about products, services, and prices.
- Evaluate and monitor contract performance to ensure compliance with contractual obligations and to determine need for changes.
- Confer with vendors to discuss defective or unacceptable goods or services and determine corrective action.

Production Associate, Sep 2014 – Mar 2015

- Assemble and fabricate work van products of varying complexities
- Package finished products and prepare them for shipment.
- Identify and promote improvements and efficiencies in the production processes.

EDUCATION

University of North Dakota
Grand Forks, ND

Bachelor of Science (B.S.) Mechanical Engineering Candidate (Expected Graduation Jun 2022)

- **GPA:** 3.84
- **Awards & Honors:** SCLA Honor Society Nominee

ADDITIONAL SKILLS

- Advanced Excel – Data connections, formulas, VBA
- Programming – Proficient in SQL, Arduino, and MATLAB. Intermediate in Python and C#

CERTIFICATIONS

- APICS Certified Supply Chain Professional
- Six Sigma Green Belt

ANTON ALVESTAD

Grand Forks, ND 58202 Phone: (701) 230-1006 | Email: anton.alvestad@und.edu

KEY SKILLS AND KNOWLEDGE AREAS

- Solid command of technologies, tools and best practices in designing mechanical equipment using AutoCAD and engineering drawings.
- Excellent shop and safety skills, able to design and fabricate tooling and mechanical test fixtures.
- Strong team collaboration and communication skills trained through both civilian and military courses.

EDUCATION

University of North Dakota – Grand Forks, ND
Bachelor of Science in Mechanical Engineering (BSME)

Completed Courses in Major:

- Statics, Dynamics, Mechanics of Materials, Fluid Mechanics, Measurement and Instrumentation, Thermodynamics, Machine Component Design, Mechanical Vibrations, Heat and Mass Transfer, Computational Fluid Dynamics, Composite Materials, Mechanical Engineering Seminar, Manufacturing Processes, Introduction to Robotics.

Minor in Military Leadership (Army ROTC/ National Guard)

- Learned through US Army institutional training to effectively lead small and large groups of people in situations of varying complexity and stress. Rigorous interpersonal communication training.
- Fulfilled large scale leadership and management roles that required critical thinking, communication, and technical knowledge to coordinate training of 40 to 50 soldiers.

TECHNICAL SKILLS

Programs: AutoCAD, SolidWorks, MS Office, MATLAB Machining and Welding Tools: CNCs, mills, lathes, angle grinders, oxy-acetylene torches, arc welders, band saws, grinders, shears, drill presses, chop saws, etc.

15. References

[1] "About - Formula SAE California." *SAE International*. [Online]. https://www.sae.org/attend/student-events/formula-sae-california/about. [Accessed: 05-May-2022]

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[3] "Gear tooth speed sensors - ZF switches & Sensors," *ZF Electronics*. [Online]. Available: https://switches-sensors.zf.com/us/wp-content/uploads/sites/7/2012/05/Datasheet_GS101201-GS101202_EN_29_11_17.pdf. [Accessed: 06-Dec-2021].

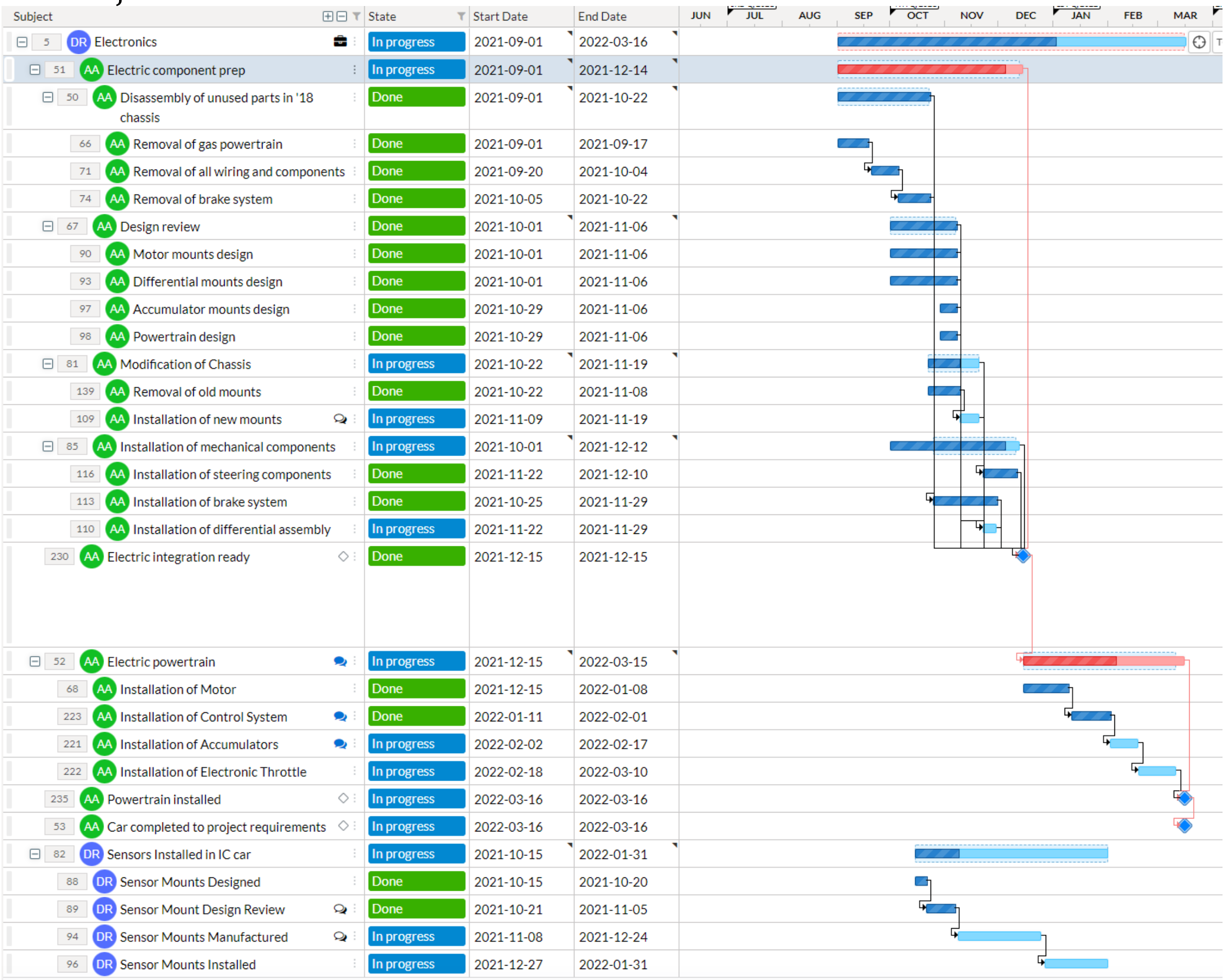
[4] "How is the drive ratio of a roller chain drive calculated and what is the maximum recommended single reduction?," *The Diamond Chain Company*, 11-Oct-2016. [Online]. Available: https://www.diamondchain.com/faq/how-is-the-drive-ratio-of-a-roller-chain-drive-calculated-and-what-is-the-maximum-recommended-single-reduction/. [Accessed: 06-Dec-2021].

[5] "ME1302 PMSM Brushless Enclosed Motor." *Kit Elec Shop*. [Online]. https://www.kit-elec-shop.com/gb/synchronous-motors/2164-me1302-pmsm-brushless-enclosed-motor.html. [Accessed: 05-May-2022]

[6] "Rotational Speed Sensors." *Rheintacho Messtechnik*. [Online]. https://www.rheintacho.de/en/products/rotational-speed-sensors/. [Accessed: 05-May-2022]

16. Appendix

16.1 Project Work Break Down Structure



#	Assignee	Subject	State	Start Date	End Date
5	DR	Electronics	In progress	2021-09-01	2022-03-16
51	AA	Electric component prep	In progress	2021-09-01	2021-12-14
50	AA	Disassembly of unused parts in '18 chassis	Done	2021-09-01	2021-10-22
66	AA	Removal of gas powertrain	Done	2021-09-01	2021-09-17
71	AA	Removal of all wiring and components	Done	2021-09-20	2021-10-04
74	AA	Removal of brake system	Done	2021-10-05	2021-10-22
67	AA	Design review	Done	2021-10-01	2021-11-06
90	AA	Motor mounts design	Done	2021-10-01	2021-11-06
93	AA	Differential mounts design	Done	2021-10-01	2021-11-06
97	AA	Accumulator mounts design	Done	2021-10-29	2021-11-06
98	AA	Powertrain design	Done	2021-10-29	2021-11-06
81	AA	Modification of Chassis	In progress	2021-10-22	2021-11-19
139	AA	Removal of old mounts	Done	2021-10-22	2021-11-08
109	AA	Installation of new mounts	In progress	2021-11-09	2021-11-19
85	AA	Installation of mechanical components	In progress	2021-10-01	2021-12-12
116	AA	Installation of steering components	Done	2021-11-22	2021-12-10
113	AA	Installation of brake system	Done	2021-10-25	2021-11-29
110	AA	Installation of differential assembly	In progress	2021-11-22	2021-11-29
230	AA	Electric integration ready	Done	2021-12-15	2021-12-15
52	AA	Electric powertrain	In progress	2021-12-15	2022-03-15
68	AA	Installation of Motor	Done	2021-12-15	2022-01-08
223	AA	Installation of Control System	Done	2022-01-11	2022-02-01
221	AA	Installation of Accumulators	In progress	2022-02-02	2022-02-17
222	AA	Installation of Electronic Throttle	In progress	2022-02-18	2022-03-10
235	AA	Powertrain installed	In progress	2022-03-16	2022-03-16
53	AA	Car completed to project requirements	In progress	2022-03-16	2022-03-16
82	DR	Sensors Installed in IC car	In progress	2021-10-15	2022-01-31
88	DR	Sensor Mounts Designed	Done	2021-10-15	2021-10-20
89	DR	Sensor Mount Design Review	Done	2021-10-21	2021-11-05
94	DR	Sensor Mounts Manufactured	In progress	2021-11-08	2021-12-24
96	DR	Sensor Mounts Installed	In progress	2021-12-27	2022-01-31

16.2 List of Change Orders

16.3 Other Applicable Information

16.3.1 Budget Breakdown

16.3.2 Manufacturer and Cost Breakdown

16.3.3 Manufacturing Breakdown

16.3.4 Design Specification Sheet