Zips Electric Racing Drivetrain Design

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Abstract

The purpose of this project is to design and manufacture drivetrain components for The University of Akron Zips Electric Racing (ZER) team. This report will serve as a guideline for future ZER team members. The ZER19 drivetrain design include motor mounts, differential mounts, axles, and chain tensioning method. The main purpose for this project is to mount the pre existing components such as the motor and differential to the frame of the car. Moreover, the drivetrain will be optimized for durability and ease of use. We will be incorporating a chain tensioning method that is easy to use while increasing the performance. All components must meet the SAE rules and requirements in order to be eligible for competition.

This report includes detailed description of all components and functions to allow for knowledge transfer to future teams.

Acknowledgment

We would like to acknowledge Dr. Daniel Deckler for his guidance on this project. It was an honor to be a part of the Zips Electric Racing team.

We would also like to acknowledge the Zips Racing team for all of their help with design insights as well as manufacturing. The Zips Racing team is full of experience that is incredibly helpful for new members such as ourselves.

A special thanks to Bill and Ian in the university machine shop for all of their help with manufacturing.

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Chapter 1: Introduction

Zips Electric Racing is a design team for The University of Akron. The team will compete in two competitions involving dynamic and static events. Dynamic events involve skidpad, acceleration, autocross, and endurance. While static events include cost, and design analysis. The ZER19 will be the first electric formula car to be entered into competition for The University of Akron. It is the teams goal to make it through technical inspection and compete.

This race car includes new mounting designs, and optimized chain tensioning method. The chain tensioning design allows for ease of use without disturbing differential alignment. Shims of varying size are manufactured to tension the chain to precision.

The completion of this project resulted in a functional FSAE electric race car. The drivetrain designed allowed for increased overall performance and sets a baseline for years to come.

1.1 Background

The drivetrain is designed around pre-existing components. These components include the motor, differential, sprocket, and driven gear. We will be using the course book for vehicle dynamics, The University of Akron Zipsearch, and FSAE rule book. Race Car Vehicle Dynamics by Milliken and the lecture notes of Dr. Richard Gross.

1.2 Principles of Operation

The drivetrain delivers power from the motor to the wheels. The Emrax 228 motor supplies a max peak torque of 230 Nm. This torque is multiplied through a chain driven transmission with a gear ratio of 3.51. Therefore, the maximum torque to the differential is 820 Nm. The differential is a MK2 Quaife limited slip differential (LSD). This differential is purely mechanical using helical gears that allow for the transfer of torque immediately to the wheels without the use of clutches or fluids. This immediate transfer of torque allows for high responsiveness to the road.

1.3 Product Definition

The drivetrain is the part of the vehicle that connects the transmission to the axles. Power from the motor is transferred through a single gear chain drive to the differential. The design for the motor and differential mounts need to be lightweight as well as durable.

Chapter 2: Conceptual Design

The ZER19 is designed around pre existing components and subsystems. The frame and suspension were designed prior to the start of the Fall 2018 semester. The initial constraints to consider included how much space in the frame was needed to fit the motor and differential. A SolidWorks full car model was used to determine the proper location. The differential needed to be placed such that the driven gear does not fall below the frame of the car. This is a requirement for FSAE. Moreover, the axle location from the inboard hub to the outboard hub needs to avoid contact with the frame when the suspension moves. Below is a function diagram of how the subsystem operates. See Figure 1. Due to preexisting components a morphological chart was not necessary for this project. Next years design may have more choices when it comes to transmission, number of motors, and differential.

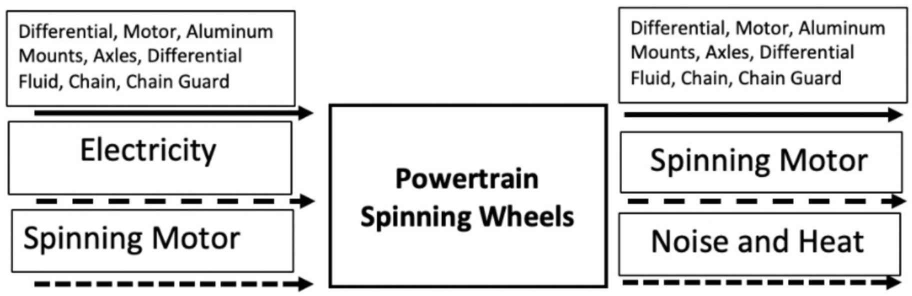


Figure 1: Function structure diagram of drivetrain.

The weighted decision matrix was used in order to develop a new chain tensioning method. The new method needed to meet criteria including durability, ease of use, weight,etc.. The options considered were turnbuckles, shims. and arm rollers. See Table 1. The final result was to shim the differential in order to tension the chain. This method is easy to use, lightweight, as well as rigid. Turnbuckles were used on the previous years car therefore making this design new for the upcoming year. A concept sketch was drawn to demonstrate how shims will function. See Figure 2.

Table 1: Weighted decision matrix for chain tensioning method.

Chain Tensioning Method							
Criteria	**Weighting**	**Shims**		**Turnbuckles**		**Arm Roller**	
		Rating	**Total**	**Rating**	**Total**	**Rating**	**Total**
Cost	**4**	2	8	3	12	2	8
Weight	**5**	3	15	3	15	1	5
Durability	**6**	6	36	1	6	6	36
Manufacturing	**3**	5	15	4	12	5	15
Ease of use	**2**	5	10	2	4	3	6
Total			**84**		**49**		**70**

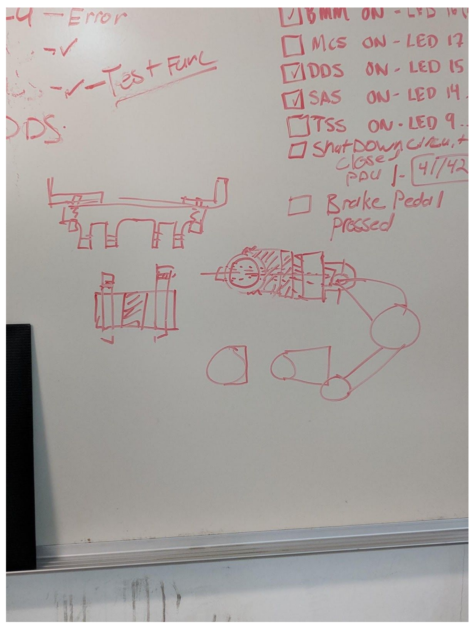


Figure 2: Initial concept sketch of chain tensioning method.

Furthermore, the team created a concept sketch for mounting of the motor and differential. See Figure 3. The sketch is a top view. The motor and differential mounts drawn in red. This sketch includes the full assembly.

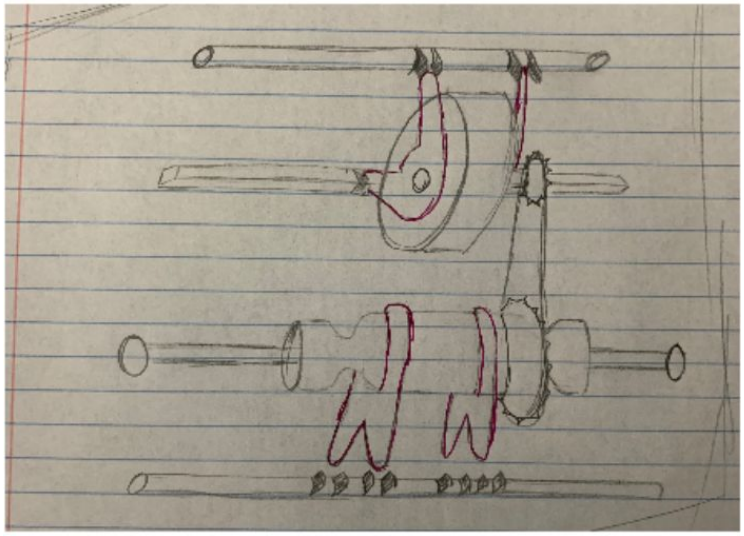


Figure 3: Concept sketch for full powertrain assembly including new mount design.

Chapter 3: Embodiment Design

A product architecture diagram is shown below to highlight the flow of energy in the system. See Figure 4.

Development of the drivetrain components utilized design principles. Evidence of force transmission is displayed through the force from the motor output shaft to the differential through a chain drive. The principle of stability and self-help is incorporated in the shim tensioning method by allowing a rigid connection so the differential remains aligned with outboard tulips. Moreover, division of tasks is incorporated by allowing for easy functionality and repairs if needed.

Embodiment rules are followed in the development of the mounts. Clarity of functions can be shown in the development of the motor mounts. The motor mounts are easily distinguished for left and right side of the motor and serve the sole purpose of holding the motor in place. This is also the case for the differential mounts.

Simplicity is shown by using purchased components. Axles, snubbers, plungers, springs, constant velocity joints are all purchased from Taylor Racing. The new designs only include the mounting systems. The overall design is simple using only one motor and purchased components. This allows for simplicity with motor setup for electrical purposes.

Thick motor and differential mounts allow for increased durability of the drivetrain representing safety of the design. FEA calculations with solidworks were used to determine maximum stress the mounts can withstand and designed to a factor of safety of 1.5.

The Electric car itself reduces environmental impact. One Emrax 228 motor is used in this years car. Motor performance charts can be found in the Appendix A.

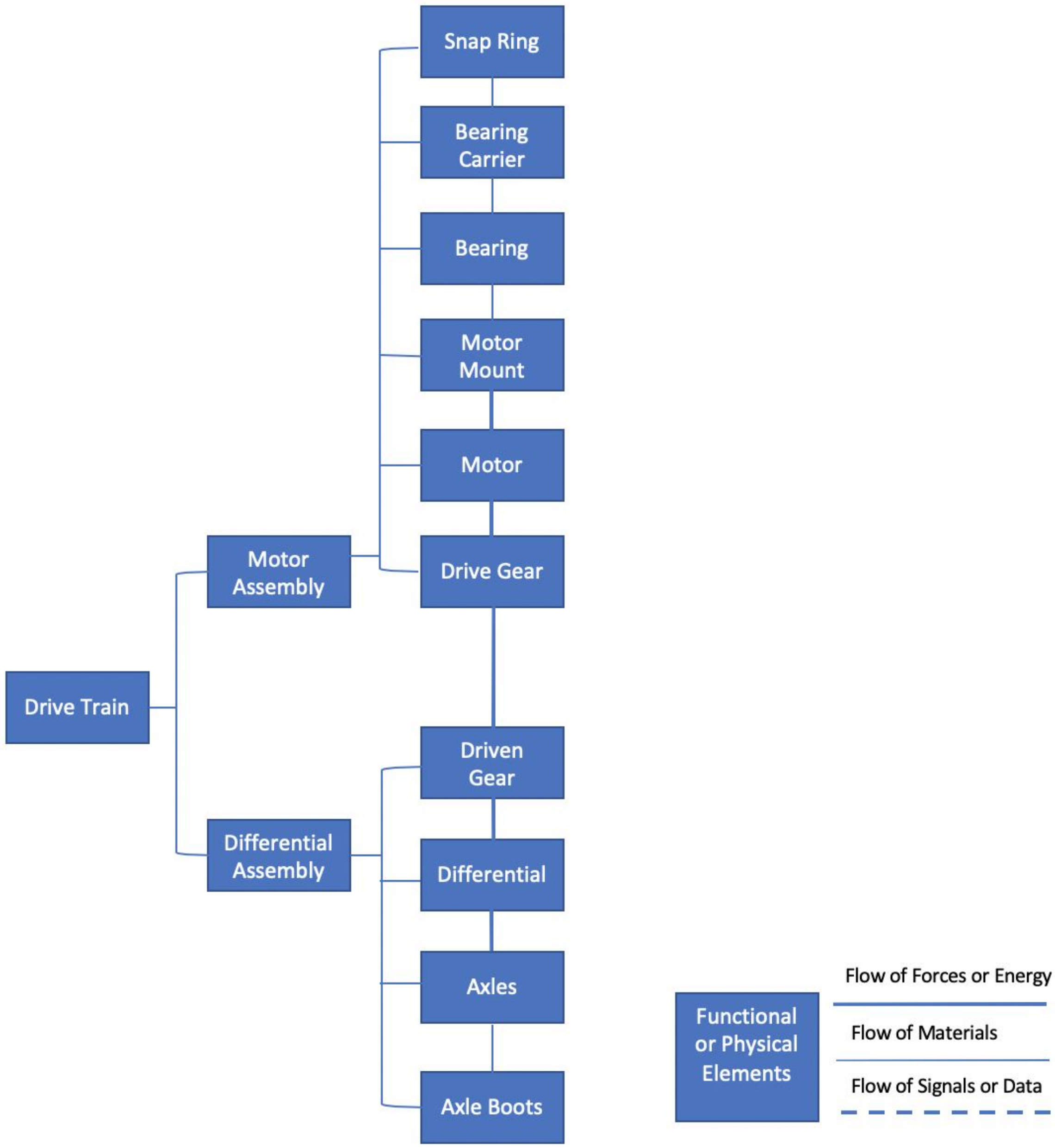


Figure 4: Product architecture diagram for product development.

Failure analysis is an important role for this project. Since there will be someone in the driver's seat it is important to review components that can potentially fail. The FMEA can be found in the Appendix B. Failure modes included mount failure, axle failure, motor failure, and differential lock up. With durability being of main concern this year the team is confident these components will be durable for all dynamic events. The FMEA follows FSAE rules and is defined in Table 2. The failure for this subsystem that poses the highest risk is motor failure caused by overheating. This failure can not be detected while driving and can cause motor damage. The motor also has the potential to catch fire along with the accumulator. These systems on the car pose the most threatening.

Table 2: FSAE guidelines for FMEA.

Rating	Severity (Sev)	Occurrence (Occ)	Detection (Det)
1	No injuries may be caused, but general safety is affected by this failure	Failure occurrence is very unlikely	Certain detection of the failure
2	Light injuries may be caused by this failure	Relatively few failure occurrence	High chance of detecting this failure
3	Medium injuries may be caused by this failure	Occasional failure occurrence	Medium chance of detecting this failure
4	Heavy injuries may be caused by this failure	Frequent failure occurrence	Low chance of detecting this failure
5	Fatal injuries may be caused by this failure	Persistent failure occurrence	Failure cannot be detected

Selection of material was only necessary for the motor mounts, differential mounts, and shim tensioning method. See Table 3 for list of components, selected materials, and machining processes. Aluminum 6061 T6 is chosen due to its limited weight. The material is also tempered allowing for higher yield strength of 240 MPa. Most components are CNC machined in The University of Akron machine shop. The differential mounts are identical to one another and allow for simplicity in machining. Therefore, only one g code needs written for both mounts. Materials were purchased at desired thickness of component to avoid extra machining time. Furthermore, few components were outsourced. Tabs, shims, and motor case were laser cut with help from Zips Racing sponsors. Purchased components from Taylor Racing allowed for parts to be delivered ready to assemble. The shim mounting system is comprised of two pieces. One piece is welded to the frame therefore is made of the same material as the frame for easy weldability. The shim mount that acts as the differential tabs is made of 6061 T6 aluminum for reduced weight. Delrin rod is machined on a lathe to create a sleeve for tighter fit into axles.

Table 3: Material summary.

Component	**Material**	**Machining**
Motor mounts	6061 T6	CNC
Differential mounts	6061 T6	CNC
Motor case	6061 T6	Laser cut
Differential shim tabs	6061 T6	CNC
Shim mount	4140 HR	CNC
Tabs	4140 HR	Laser cut
Shims	6061 T6	Laser cut
Chain guard	Low carbon steel	Cut and bent
Axles	Steel	Purchased
Snubbers	Delrin	Cut

Plungers	Delrin	Lathe

The following subsections 3.1 to 3.5 describe individual designs and assembly.

3.1 Chain Tensioning and Chain Guard

The team developed a new method for chain tensioning. Previous years used a turnbuckle method that bolted to the bottom of the frame. For this method two turnbuckles were adjusted in order to get the proper chain tensioning. The issues with this method included the frame moving, and not having both turnbuckles at the same displacement therefore offsetting the differential. This year's chain tensioning method is a shim design. The shims will be mounted on the rear top of the frame. Initially the chain will be "pre-shimmed" up to 8 mm. Once the chain becomes worn and needs tension shims will be removed thus pulling the differential towards the back of the frame making the chain tensioned again. This method allows for an even displacement of the differential. The shims will be made of aluminum for weight reduction. They range from 1 mm thickness to 5 mm thickness allowing for a precise tension.

There are two chain tensioning mounts. One mount is welded to the top of the frame while the other is bolted to the differential mounts. See Figure 5. In this figure it can be seen how the shim design will be assembled. One shim mount has tabs with clearance for ¼-28 bolts that will support the differential mount. The other shim mount is welded to the frame. Between the shim mounts the aluminum shims are placed. The assembly will be bolted to the frame in the final design using three 5/16-24 bolts. Bolts range in length depending on the amount of shims. When bolting through the frame “spacers” need to be machined. These spacers are inserted into the frame and allow for the head of the bolt to rest on a flat surface.

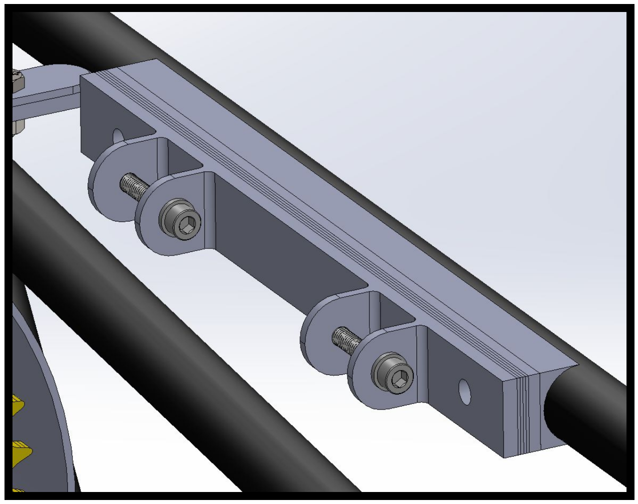


Figure 5: Shim mounting assembly.

A tab FEA was run with ANSYS to determine max stress on differential tabs. A fixed support is applied to the back of the differential tabs. Forces are applied acting downwards to simulate the weight of the differential. The max stress resulted in 20.2 MPa. See Appendix C for FEA analysis setup and results.

The chain guard is designed according to the FSAE rule book. FSAE rule book section T.7.2.2 and T.7.2.5 state the chain guard requirements. The chain guard must be three times the chain width, and 0.105 inches thick. It must start and end parallel to the lowest point of the chain. See Figure 6. The chain guard is mounted to the frame via two connections. One connection is with a tab to the back of the frame. Another connection is made to the side of the frame with another tab. Both tabs are welded directly to the frame. The chain guard is bolted using FSAE critical fasteners, ¼-28 1 inch long grade 8 bolts. See Figure 7. In this figure the chain guard assembly is shown.

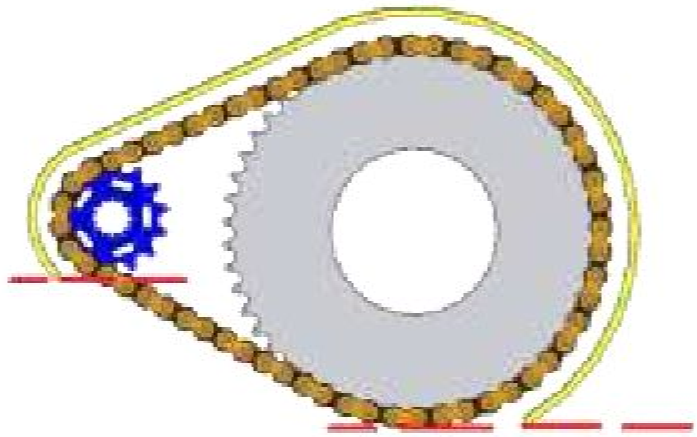


Figure 6: Chain guard requirement.

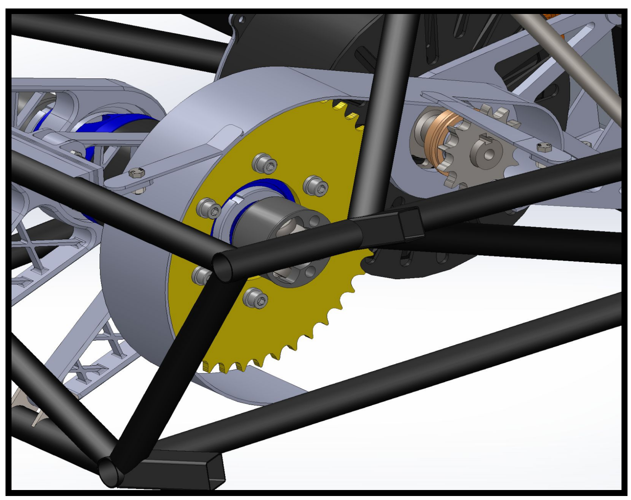


Figure 7: Chain guard and mounting.

3.2 Differential Mounts

Differential mounts are a critical part of the drivetrain. They function to mount the differential to the frame. The two differential mounts are made of 6061 T6 aluminum for weight reduction. These mounts need to withstand the torque for the motor as mentioned previously. They were designed with a factor of safety of 1.5. The initial design of the mounts began in SolidWorks. Both mounts are identical for ease of manufacturing. They are 1 inch thick and weight approximately 1.4lbs each. The mounts are fastened with ¼-28 bolts grade 8, and 2 inches in length. Four bolts total are used to fasten the mounts to the frame. See Figures 8 and 9. All fasteners are required to have nylon lock nuts, or top lock nuts.

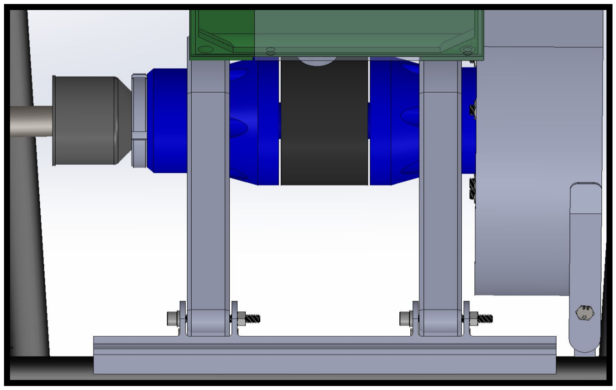


Figure 8: Top view of differential assembly fasteners.

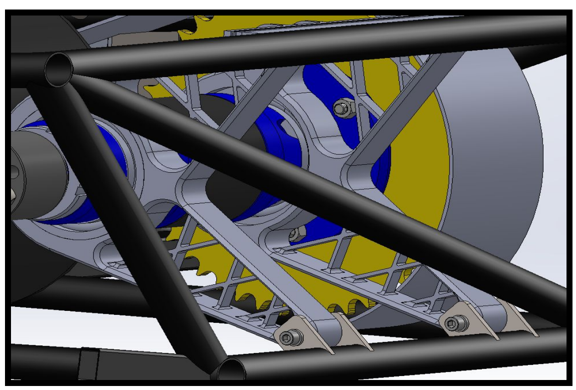


Figure 9: Differential mounts fastened to bottom tabs that are welded to the frame.

An FEA analysis was run in Solidworks Simulation. A torque of 1275 Nm was applied where the differential is held. This torque is the max torque multiplied by the factor of safety. The part was then fixed where the bolts would be. The FEA results concluded the max stress is

110 Mpa which is below the yield stress of 270 Mpa. The mounts are durable. Optimization was made in the cutouts by rounding edges to 0.125 in. See Figure 10 for original optimized design.

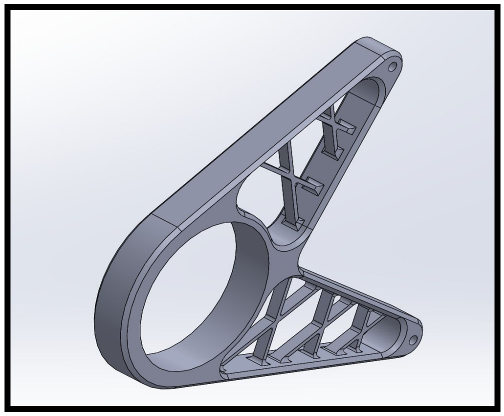


Figure 10: Original differential design.

3.3 Motor Mounts

The motor mounts mount the motor to the frame. Considering the the load coming from the weight of the motor as well as the torque. The motor mounts are designed to be manufactured out of 6061 T6 aluminum for weight reduction, and durability. Measurements were taken from the full solidworks model in order to ensure perfect fit of the mount compared to the whole assembly so that no major changes have to be made to the mounts after manufacturing. The mount were designed to be a third of an inch thick because that is all the space that is available between the motor and other car components. After designing the main shape of the motor, FEA analysis was done in order to ensure the optimum mount design and also to reduce any unnecessary weight that the entire model holds. See Figures 11 and 12 for optimized motor mounts, note that the geometry of the two mounts are different for each side. See Appendix C for FEA analysis.

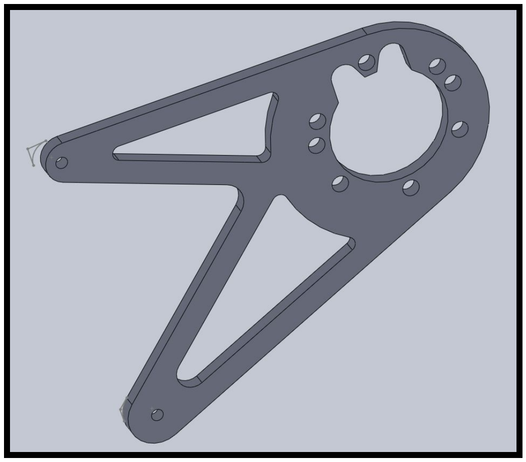


Figure 11: Left motor mount.

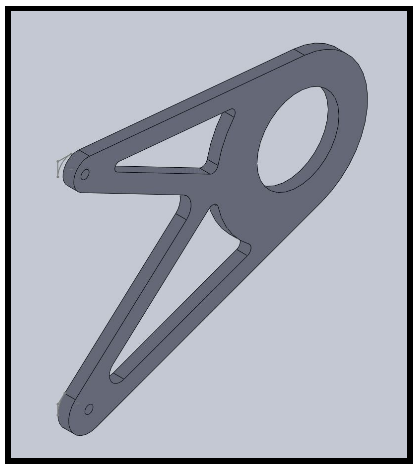


Figure 12: Right motor mount

3.4 Half Shaft Assembly

The axles transmit torque to the wheel. To ensure failure does not occur the axles cannot be rigid. Rigid axles can result in serious damage to the differential, and axles. To allow for axle play a spring is installed in the outboard housing in the wheel hub with optimized preload. This allows the axles to “give” and reduce stress in the outboard housing.

The axles, constant velocity joints, boots, springs, external snap rings, and plungers are all purchased components from Taylor Racing. Additional delrin rod of 0.465 inch OD is ordered from McMaster Carr and cut to size to manufacture snubbers. The axles are hollow with an OD of 1.125 inches and an ID of 0.5 inches. Technical resources from Taylor Racing allow determination of axle length, snubber length, and spring preload. The ZER19 has one axle length of 15 inches and another axle length of 15.375 inches. See Figure 13 for Taylor Racing reference sheet.

Due to limited clearance of axle to frame Taylor Racing boots were used on both the inboard and outboard hubs. In order to fit a boot on the outboard housing a hub nut was designed. This nut allowed for an easy fit of a smaller boot. The Hub nut is made 7075 aluminum and CNC machined due to custom thread size.

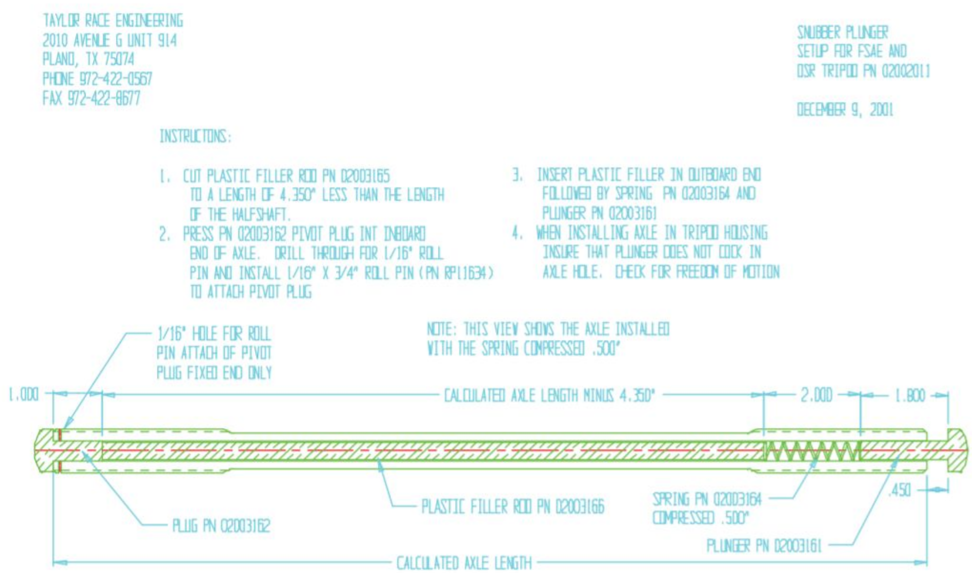


Figure 13: Half shaft assembly. (Taylor Racing)

Chapter 4: Detail Design

4.1 Chain Calculations

To calculate the force experienced within the chain the equation below will be used:

<u>Force (F):</u> Where H_a = Horsepower Allowable, V = Driveshaft Velocity

$$F = \frac{33000 * H_a}{V}$$

For this equation Ha and V will be needed. These can be found using the equations:

Driveshaft Velocity (V): Where N_1 = number of sprockets on Diff gear, P = pitch of chain, n = rpm

$$V = \frac{N_2 * P * n}{12}$$

Horsepower Allowable (H_a): Where H'_{Tab} is the tabulated horsepower (Found from tables)

$$H_a = K_1 * K_2 * H_{tab}{}'$$

For H_a to be found the correction factors K_1 and K_2 will be used. They are:

Correction factor for tooth number other than 17 (K_1): Where N_1 = number of sprockets on driven gear, N_2 = number of sprockets on motor gear

$$K_1 = \left(\frac{N_1}{N_2}\right)^{1.5}$$

Strand correction factor (K_2):

$$K_2 = 1$$

With all of these equations the maximum force the chain would experience could be calculated for whichever runtime parameters were chosen. For the car values were chosen at the peak performance since that would be the maximum force the chain would experience. These values can be seen in the Table 4 Below:

Table 4: Measured data.

Number of teeth (Driven Gear)	Number of teeth (Sprocket)	Center to Center Distance	Horsepower (Impulse)
46 teeth	13 teeth	8.314 In	134.102 Hp

Horsepower (Constant)	Peak rpm	Runtime	H'_{Tab}
56.32 Hp	5500 rpm	200 hrs	39.0376 Hp

With these values the force and Velocity were calculated and are included in Table 5 below:

Table 5: Calculated results.

Velocity	Force
4763.55 ft/min	1203.72 lbf

Looking at the spec sheet for a DID 530VX Chain it can be seen that the maximum tensile strength it can experience is 9220 lbf. This means that the force value the chain experienced during operation is well under the allotted force value. Therefore the chain will not break under maximum loading and run time conditions.

4.2 Drivetrain Performance Calculation

Drivetrain performance is evaluated through the use of the vehicle dynamics textbook. Assumptions were made in order to simplify analysis. These assumptions include drag coefficient (Cd) is equal to 0.5, weight of car is 500 lbs, motor is outputting max RPM of 5500, standard atmospheric conditions, slip is 3%, and front car area is calculated from the nose cone area. The wheel diameter is 14 inches, with a mass of approximately 23.39 lbs. The inertia of the wheel is calculated from SolidWorks to be 0.0002375298 lb/in^2.

Vehicle speed (V): Where n_e = engine speed, r = tire radius, δ_0 = gear ratio, and i = slip

$$V = \frac{n_e r}{\xi_0}(1 - i)$$

Mass factor (γ_m): Where I_w = wheel inertia, I = rotating inertia, m = vehicle mass

$$\gamma_m = 1 + \frac{\Sigma I_w}{mr^2} + \frac{\Sigma I_1 \xi_1^2}{mr^2} + ... + \frac{\Sigma I_n \xi_n^2}{mr^2}$$

Vehicle thrust (F): Where M_e = engine torque

$$F = \frac{M_e \xi_0 n_t}{r}$$

Total resistance (R): Where R_a = aerodynamics resistance, R_r = rolling resistance

$$\Sigma R = R_a + R_r$$

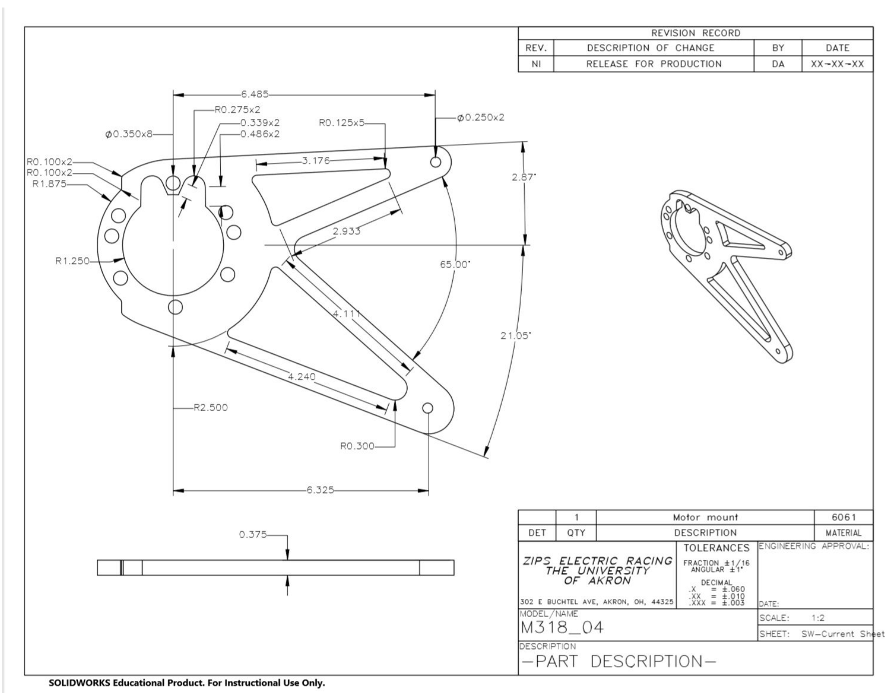
Acceleration (a):

$$a = \frac{F - \Sigma R}{\gamma_m m}$$

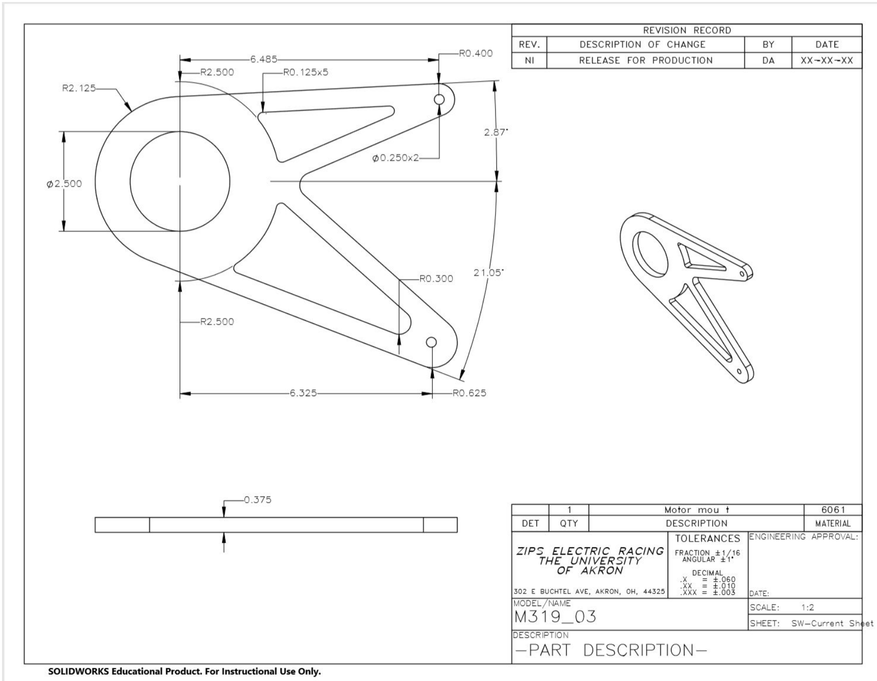
The velocity of the car at max engine speeds is calculated to be up to 61 mph. Solving for vehicle thrust and air resistance results in an acceleration of 49.44 ft/s. This results in a 0 to 60 in about 6 seconds. These solutions make sense.

4.3 Part Drawings

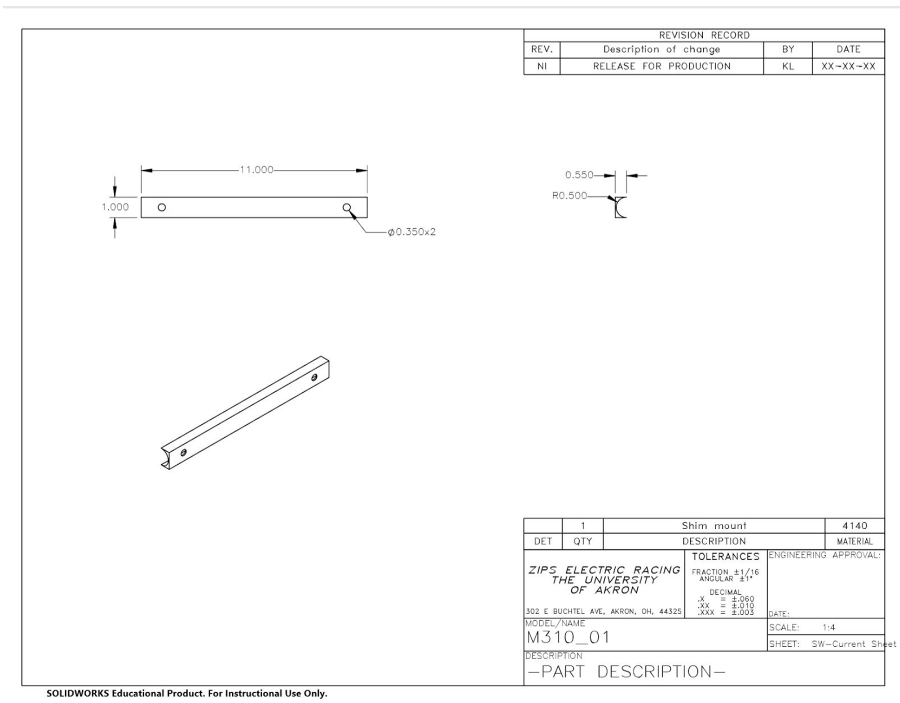
Left motor mount.



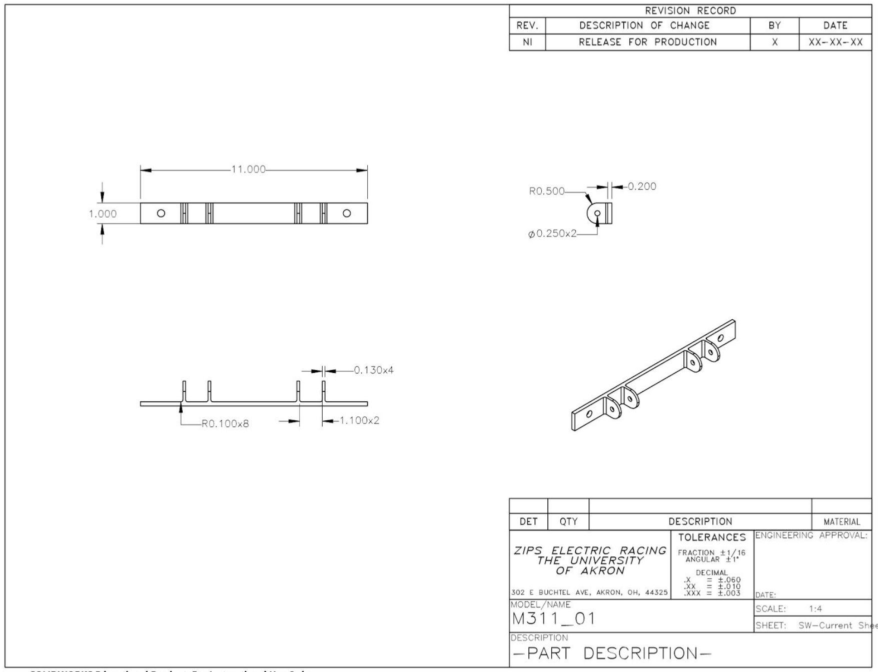
Right motor mount.



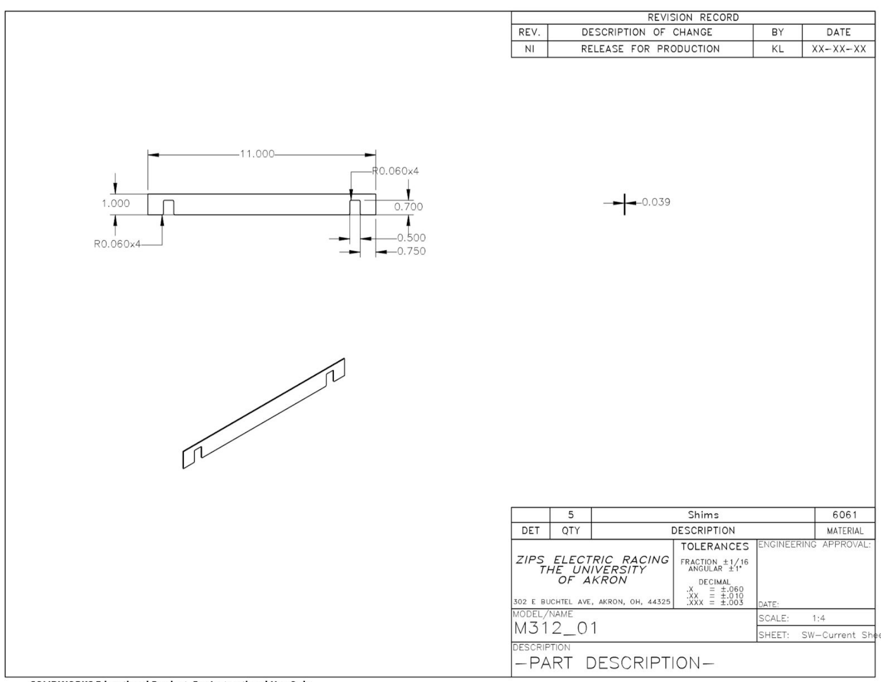
Shim mount welded to the frame.



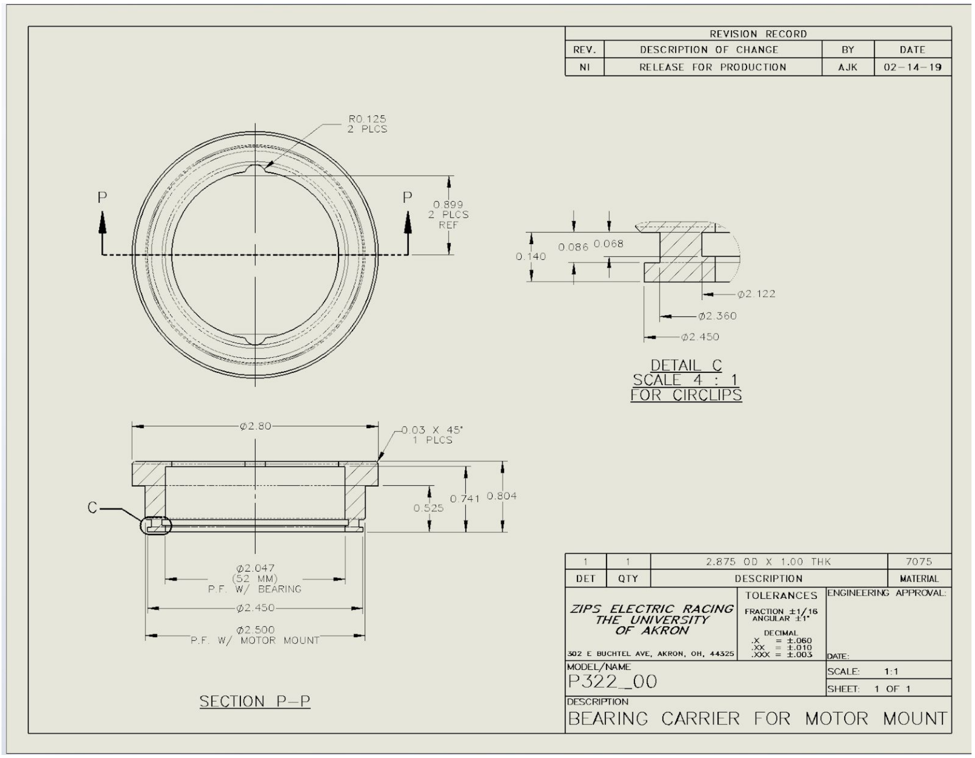
Differential tabs.



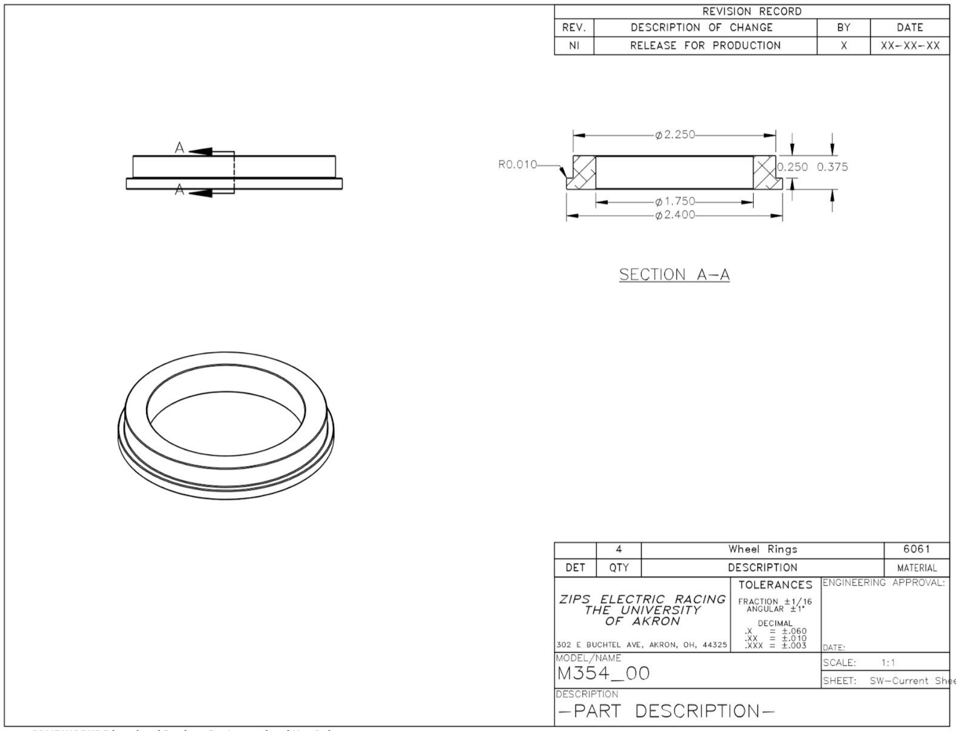
Shims.



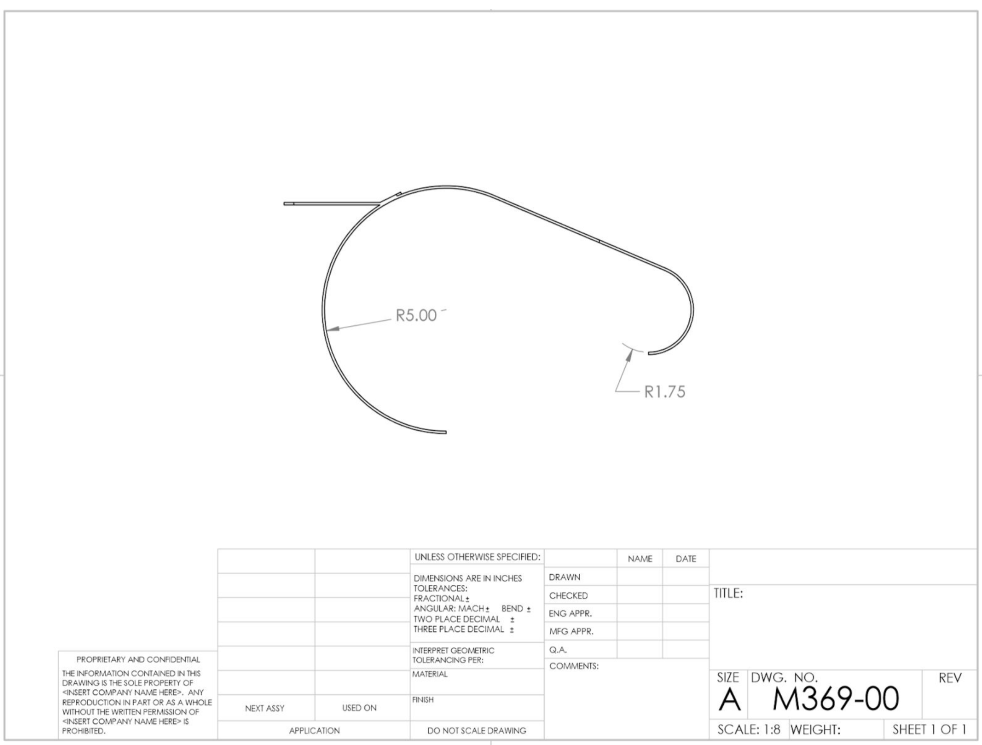
Motor bearing carrier for motor shaft.



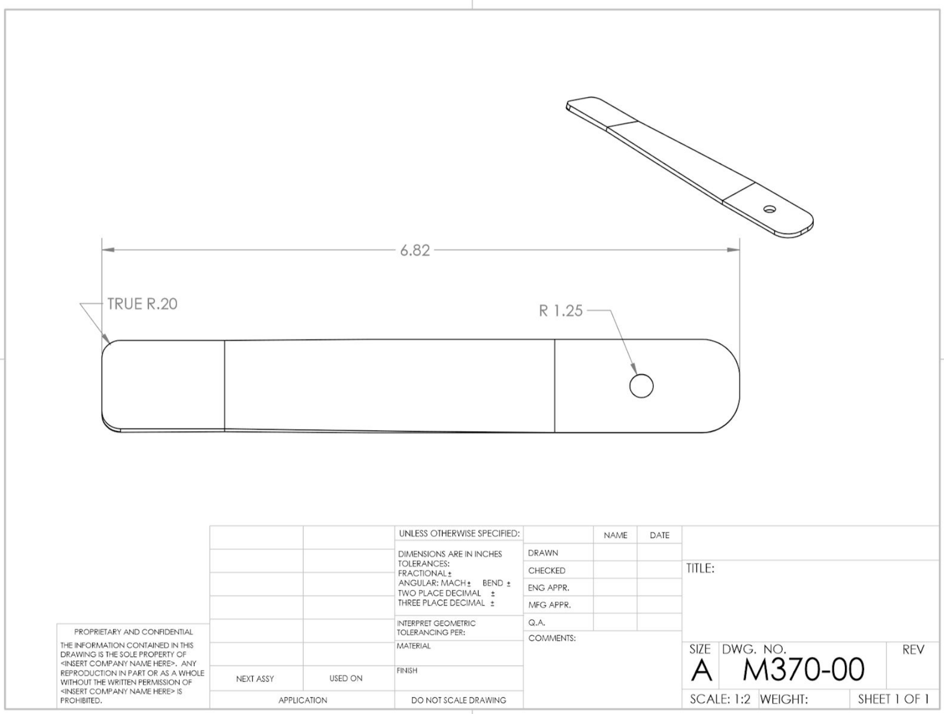
Wheel rings for wheel hub.



Chain guard.

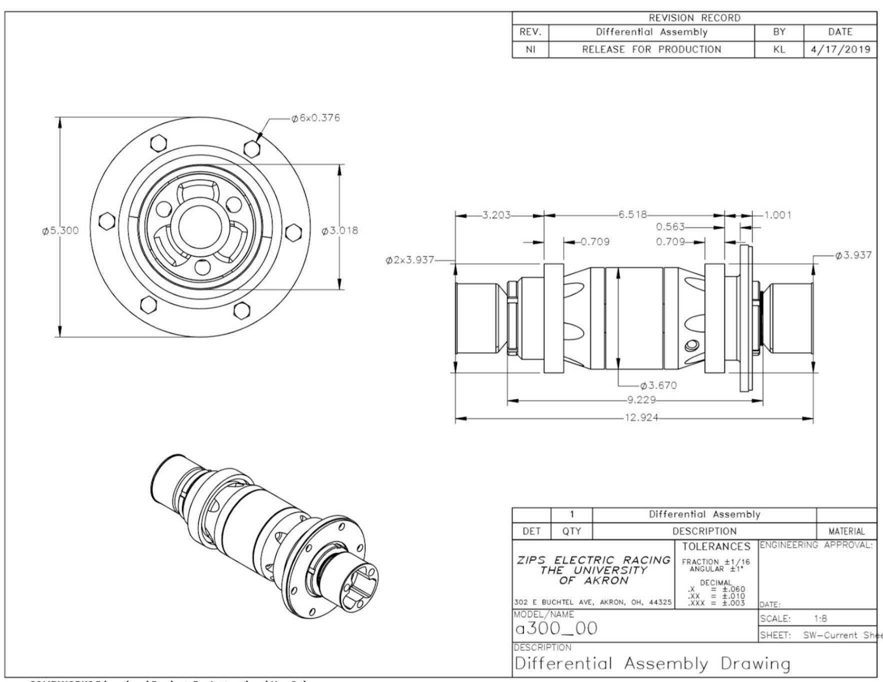


Chain guard tabs.

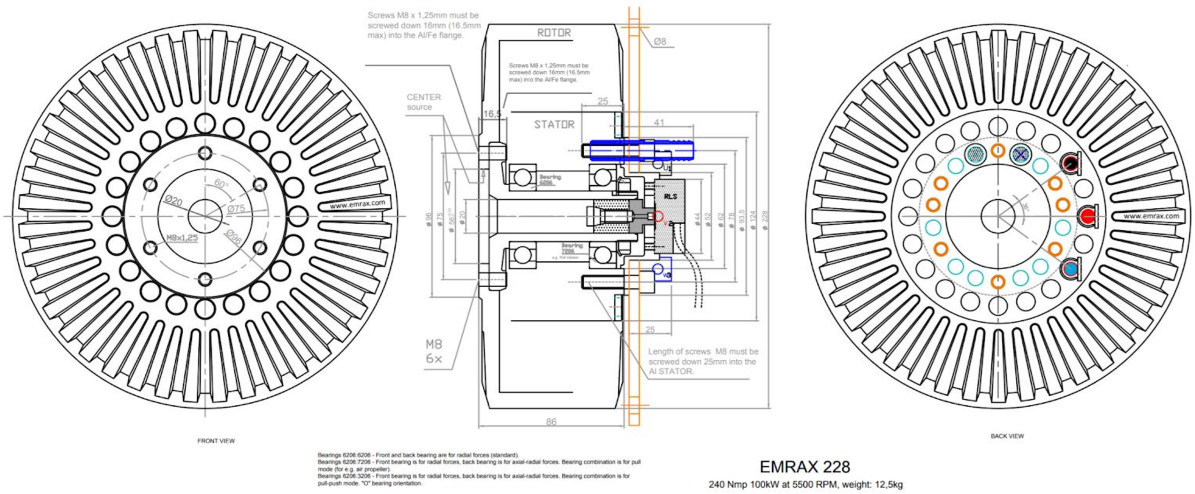


4.4 Assembly Drawings

MK2 Differential assembly.

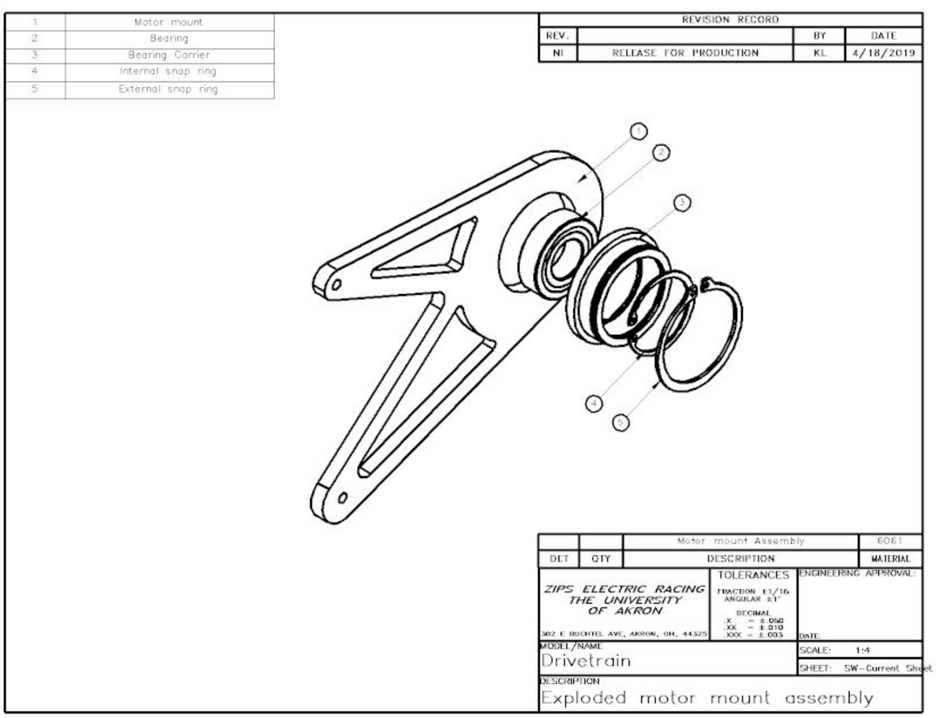


Emrax 228 motor assembly.

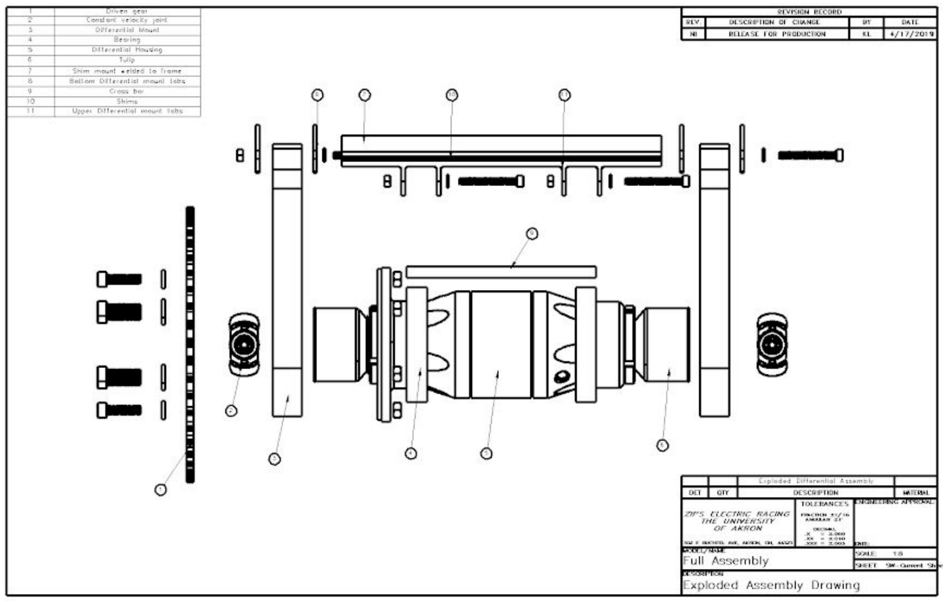


4.5 Exploded-view Drawings

Motor mount and bearing carrier assembly.



Differential and shim mounting assembly.



4.6 Cost Report/BOM

Cost analysis based on FSAE guidelines. Below is the following cost report for Engine and Drivetrain. See Table 6. Costs include manufacturing of components and work hours. Furthermore, hardware is ordered from Fastenal. Final assembly hardware is shown in Table 7.

Table 6: Cost analysis and bill of materials for engine and drivetrain.

Cost Summary

System	Materials	Processes	Fasteners	Tooling	Totals
Brake System	1269.6400	1252.3000	28.5000	0.0000	2550.4400
Engine & Drivetrain	10549.5200	782.2600	29.0000	0.0000	11360.7800
Frame & Body	1002.4900	945.1900	57.6500	1.1700	2006.5000
Instruments, Wiring & Accessories	2487.9300	124.1600	1.0200	100.0200	2713.1300
Miscellaneous, Safety, Finish and Assembly	86.1600	37.8000	0.0000	0.0000	123.9600
Steering System	106.3200	136.3100	10.2500	0.0000	252.8800
Suspension & Shocks	1897.1800	565.3600	47.7600	5.3200	2515.6200
Wheels, Wheel Bearings & Tires	1244.8900	4.4800	0.0000	0.0000	1249.3700
	18644.1300	3847.8600	174.1800	106.5100	22772.6800

Cost Summary – Area Totals

- Brake System
- Engine & Drivetrain
- Frame & Body
- Instruments, Wiring & Accessories
- Miscellaneous, Safety, Finish and Assembly
- Steering System
- Suspension & Shocks
- Wheels, Wheel Bearings & Tires

System	Asm/Part #	Rev. Lvl.	Assembly	Component	Description	Unit Cost	Quantity	Material Cost	Process Cost	Fastener Cost	Tooling Cost	Total Cost
Engine & Drivetrain			Driveline and Differential Assembly				1					
Engine & Drivetrain			Chain Guard, Chain, and Chain Tensioning		0.12 in thick, 3 in wide, 6 ft long chain guard steel		1					
Engine & Drivetrain			Motor		Emrax 228. Used from previous year	4500.00	1	4500.00				4500.00
Engine & Drivetrain			Cooling System Assembly			1.00	1		0.31	0.69		1.00
Engine & Drivetrain				Chain Guard		39.64	1	7.51	31.78	0.35		39.64
Engine & Drivetrain				Motor mounts		45.07	2	23.44	19.27	2.36		90.14
Engine & Drivetrain				Differential	Includes bolts, washers, springs, grease, and o-rings.	132.54	1	110.00	20.76	1.78		132.54
Engine & Drivetrain				Radiator		53.66	1	10.11	36.79	6.76		53.66
Engine & Drivetrain				Drive Sprocket		0.73	1	0.54	0.19			0.73
Engine & Drivetrain				Chain		171.55	1	171.29	0.26			171.55
Engine & Drivetrain				Motor Housing		21.07	1	11.43	9.64			21.07
Engine & Drivetrain				Fan		31.39	1	30.28	1.11			31.39
Engine & Drivetrain				Ductwork		28.30	1	3.30	25.00			28.30
Engine & Drivetrain				Driven Sprocket		6.84	1	0.48	4.88	1.48		6.84
Engine & Drivetrain				Shims	Laser cut shims ranging in thickness	0.89	20	0.51	0.38			17.80
Engine & Drivetrain				Differential mount		106.79	2	22.40	84.00	0.39		213.58
Engine & Drivetrain				Shim mount		29.41	1	3.48	24.57	1.36		29.41
Engine & Drivetrain				Water Pump		22.91	1	22.91				22.91

System	Asm/Part #	Rev. Lvl.	Assembly	Component	Description	Unit Cost	Quantity	Material Cost	Process Cost	Fastener Cost	Tooling Cost	Total Cost
Engine & Drivetrain				Tubing		9.06	1	3.32	5.74			9.06
Engine & Drivetrain				Differential tabs		17.77	1	3.36	14.41			17.77
Engine & Drivetrain				Bearing		85.38	2	85.00	0.38			170.76
Engine & Drivetrain				Halfshaft	Purchased Taylor Racing	262.30	2	257.95	4.30	0.05		524.60
Engine & Drivetrain				Tube Elbow Reducer		1.06	1	1.06				1.06
Engine & Drivetrain				Tube Straight Reducer		1.06	2	1.06				2.12
Engine & Drivetrain				Stubshaft		8.23	2	2.50	5.69	0.04		16.46
Engine & Drivetrain				Hub Nuts	Attach at inboard hub of wheel	29.56	2	1.80	27.76			59.12
Engine & Drivetrain				Catch Can		22.62	1	12.00	10.08	0.54		22.62
Engine & Drivetrain				Wheel ring	Inserted inside of wheel	39.74	4	8.44	31.30			158.96
Engine & Drivetrain				Motor Hose Barb Fitting		2.97	2	0.58	2.39			5.94
Engine & Drivetrain				Inverter Hose Barb Fitting		3.71	2	0.67	3.04			7.42
Engine & Drivetrain				Air Bleed Valve		6.50	1	6.50				6.50
Engine & Drivetrain				Quick Disconnect		5.96	2	5.96				11.92
Engine & Drivetrain	4		Accumulator			26.62	1	2.21	14.05	10.36		26.62
Engine & Drivetrain				HV BMS		1440.00	1	1440.00				1440.00
Engine & Drivetrain				Batteries		2400.00	1	2400.00				2400.00
Engine & Drivetrain				AIRS		240.00	1	240.00				240.00
Engine & Drivetrain				Fans		50.00	1	50.00				50.00
Engine & Drivetrain				IMD		300.00	1	300.00				300.00

System	Asm/Part #	Rev. Lvl.	Assembly	Component	Description	Unit Cost	Quantity	Material Cost	Process Cost	Fastener Cost	Tooling Cost	Total Cost
Engine & Drivetrain				Fuse		136.00	1	136.00				136.00
Engine & Drivetrain				Current sensor		4.00	1	4.00				4.00
Engine & Drivetrain				Connectors		100.00	1	100.00				100.00
Engine & Drivetrain				Wires		144.94	1	7.50	137.44			144.94
Engine & Drivetrain				LED		0.50	1	0.50				0.50
Engine & Drivetrain				Maintenance plug		15.82	1	11.66	4.16			15.82
Engine & Drivetrain				Insulation		128.03	1	113.40	14.63			128.03
Engine & Drivetrain				**[Area Total:]**				**10549.52**	**782.26**	**29.00**		**11360.78**

Table 7: Fastenal order for final assembly.

Fastenal						
Hardware	**Class/grade**	**Quantity**	**Cost**	**Total**	**SKU**	**Description**
5/16-24 top lock nuts	8	11	0.798	8.778	11541127	Shim bolts
5/16-24 bolts 1.75in long	8	11	0.8128	8.9408	152426	Shim bolts
1/4-28 bolts 1in long	8	8	0.3652	2.9216	152401	CG
1/4-28 top lock nuts	9	40	0.7172	28.688	38080	CG
1/4-28 1.5 inch long bolts	8	15	0.51	7.65	152403	motor tabs
1/4-28 2in long bolts	8	15	0.6546	9.819	152405	Diff tabs
3/8-24 1.25in long	8	18	0.7737	13.9266	152443	Sprocket bolts

bolts						

Chapter 5: Discussion

After the manufacturing of the mounts, carrier, chain guard, and shims, our group ran into some problems while building our system. This section will explain the problems and suggest solutions for the teams coming in the next years.

The differential mounts are manufactured to be identical to one another. The team was informed by Zips Racing that bearings can “walk” during driving. This means that the press fitted bearing may push out or into the differential mount. To combat this effect a cross bar was manufactured to keep the mounts pulling toward one another to prevent bearings from “walking outward. The cross bar is manufactured from a hollow aluminum rod and a long ¼-20 bolt. For next year it is recommended to include an internal snap ring, along with a ledge that the bearing can be pressed to. A reference design can be found in Appendix D.

Furthermore, the motor tabs interfered with the accumulator tabs during assembly. Therefore to solve the problem, the bottom part of the left motor mount will be single shear. Later on in the manufacturing we also figured out that the motor mount will have interference with the same tab, so what we did to solve it was grind off thin layers off of the accumulator tabs as well as the motor mount in order for the entire assembly to fit together well.

We also ran into some problems while assembling the axles. The axle assembly contained two axles, two plastic snubbers, four plastic plungers, and two springs. The snubbers from Taylor Racing fit loosely inside of the axle. New delrin material was ordered from McMaster to insure a tighter fit. This allowed for the red lock tight to create a better seal for full assembly. We then tried adding sleeves to the plungers while increasing the diameter of the rod in order for it to have less clearance with the inner diameter of the axles.

Chapter 6: Conclusions

All in all this senior design project did an excellent job balancing design and manufacturing style work, offering the group an enriching learning experience. With the diversity of the team's subsections it taught us how to micromanage our system while simultaneously learn about others ranging from cooling, brakes, steering, and even electrical. With the opportunity to work in such a large group it offered a different perspective on learning then what would be experienced through a single 3-5 person group, and helped develop strong communication and problem solving skills from the interactions that occurred. Overall, joining the design team was an excellent and accelerated learning process, and gave meaningful work with concrete results at the end. The group is proud of the work that was accomplished over the span of a year and thankful for the opportunity to work on a project such as this. This team provided numerous lessons and memories that will carry on throughout the rest of our engineering career and ultimately make each of us better engineers as a whole.

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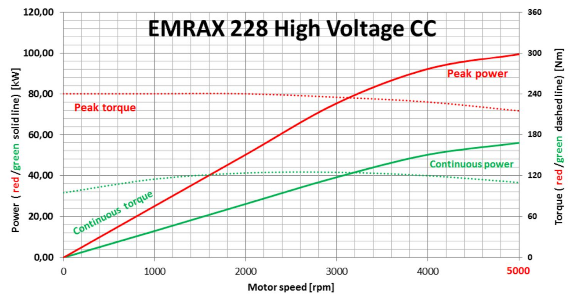
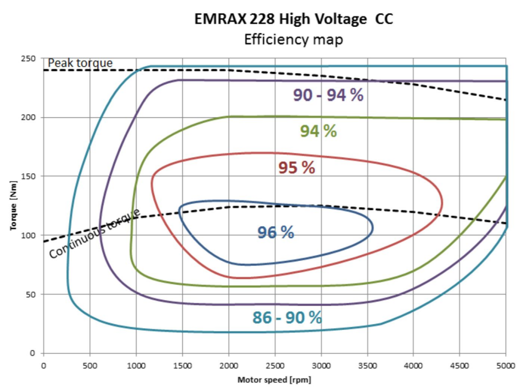
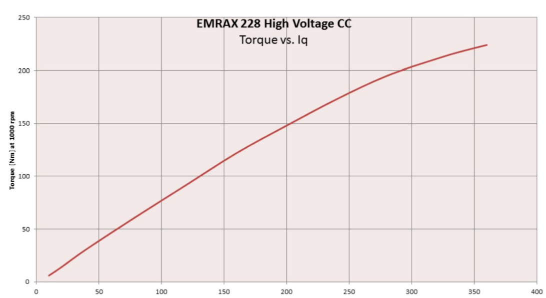
Appendices

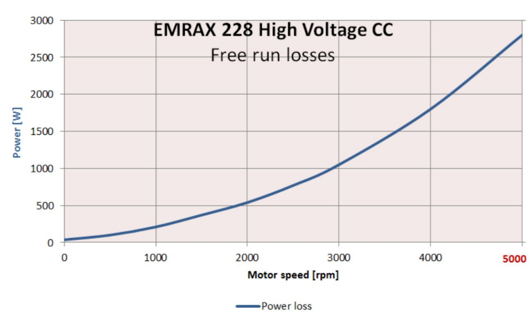
Appendix A: Motor performance curves

Graphs valid for EMRAX 228 High Voltage Combined Cooled (CC):









Appendix B: FMEA

2019 FORMULA SAE - FMEA

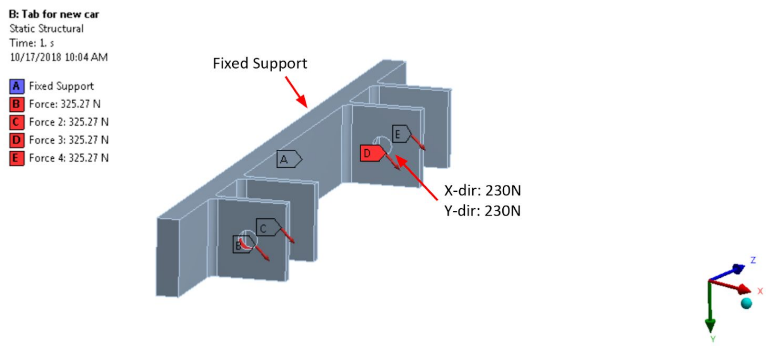
Car No.: E224 University: The University of Akron Contact: Kaitlyn Lester kml112

FMEA No.:	Component/Item	Function	Failure Mode	Failure Cause	Failure Effect		Sev	Severity Reasoning	Occ	ccurrence Reasonin	Failure Detection	Det	Detection Reasoninc	Risk	Failure Handling - Vehicle	Failure Handling - Team	Comments
					Local	Global											
1	Motor	Supplies torque to wheels	Overheat	Damage/breakdown of motor components. Motor stops working	Exposes person to high temperatures.	Vehicle should power down. Leaves people exposed to high temperatures	3	Contact with motor could cause burns	2	Heating of motor would result in cooling system failure.	Monitoring system	2	Can check motor temperature after each use of car by plugging into system to read parameters of motor. Would be able to determine failure easily.	12	Upon detection team can analyze cooling sytem and cool motor.		
2	Motor	Energy transfer	System connection not made. Motor doesnt spin	Bad connections	Car will not move	Motor will not have power	1	No injury will result	1	Motor connections are positive locking	Car doesnt move	1	Spin wheels before running the car	1	System will not have power	Motor connections will be secured	
3	Differential	Energy transfer	Lock up	Differential could be shimmed too much causing helical gears not to spin	Wheels will not react to turns	Driver may not be able to control vehicle as well	2	Loss of control could cause accident	1	Differential reassembled to ensure its not locked	Loss of ease of turning. Wheel dragging effect	1	Driver will be able to feel the locked effect	2	Helical gears can be damaged	Disassemble differential to determine cause of loc up	
4	Axles	Turns wheels. Moves the car	Axle does not have any dynamic movement	Spring not preloaded properly	Axle will undertake a large load during trung cause high stresses that can damage the differential and axles	Vehicle could loose the proper function of the differential	3	Driver could lose control of the vehicle causeing injury to driver or others	1	Axles are properly preloaded with plungers that allow for proper contact of spring to snubber and plunger. This allows for spring to not bend while inside of axles.	Loss of ability to drive car	3	If axles become static the driver would not be able to tell. The axles could cause significant damag when not detected	9	Differential and axles damaged	Asses why failure occured. Replace and modify snubber/plungers to ensure prope spring preload	
5	Motor mounts	Carry the motor. Mount the motor to the frame	One mount is in singe shear. Bolts can fail	Bolts can shear due to load of motor	Motor can break off of the car	Vechicle can loose function. Inoperapble without a motor	5	Driver could lose control of vehicle, causing injury of driver or bystanders. Can cause serious injury to driver or others	1	Motor mounts are designed to withstand motor loads. FEA analysis completed.	Loss of power	1	Driver will be able to notice immedietly	5	Loss of power	Approach vehicle and ensure driver safety	
6	Differential mounts	Carry the differential. Mounts the differential to the frame	Bolts shear	High stress in bolts	Differential can separate from frame.	Vehicle can loose function	5	loss of control and severe damage to drivetrain	1	Differential mounts are designed to handle large loads from the motor. FEA analysis completed.	Loss of function	1	Driver will notice	5	Loss of performance	Approach vehicle and ensure driver safety	
7	Chian	Transfers torque from driver gear to driven gear	Can break under load	High stresses from motor	Disengage motor from differential. No torque supplied to move car	Drivetrain no longer functions	3	loss of control of acceleration	1	Chain is durable and can withstand very large forces	Loss of function	1	Driver will notice	3	Car will no longer move	Replace chain	

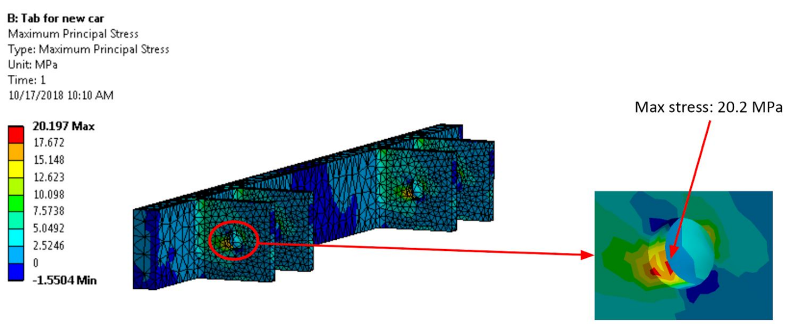
Appendix C: FEA Setup and Results

Shim mount FEA ANSYS

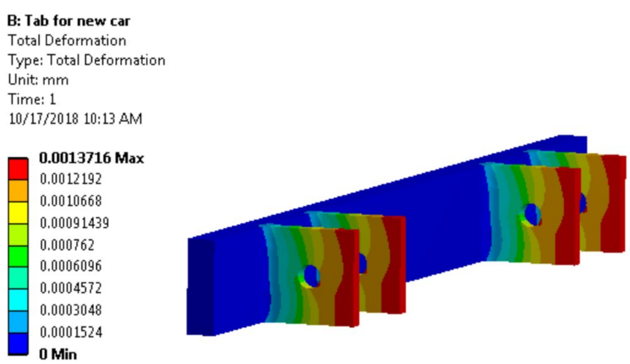
FEA Setup



Results Max Stress

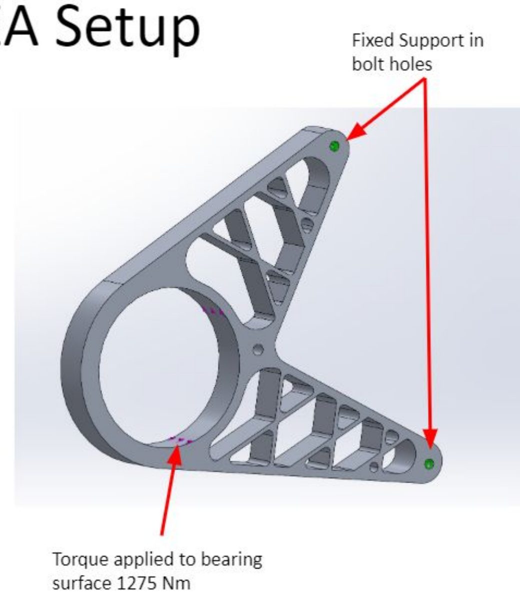


Deflection

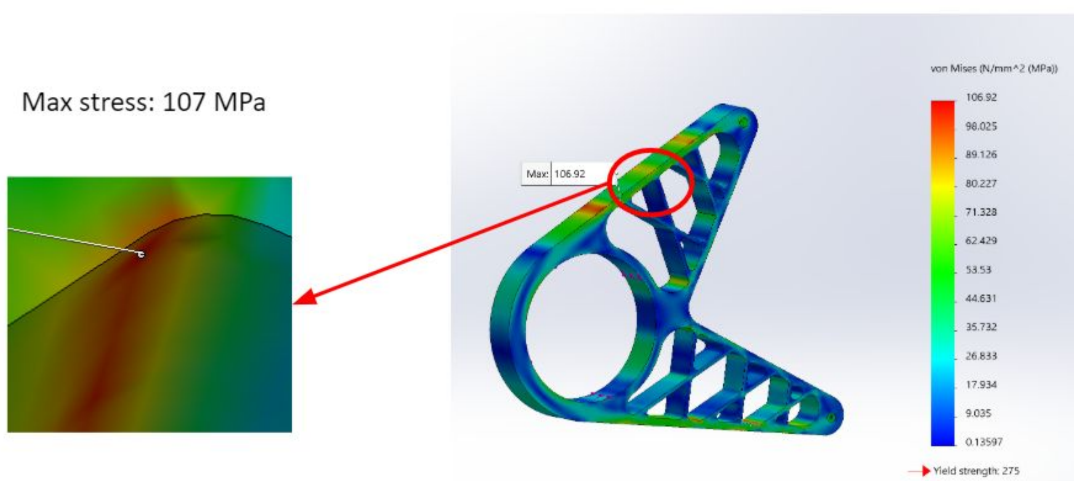


Differential mount FEA SolidWorks

FEA Setup



Results Max Stress



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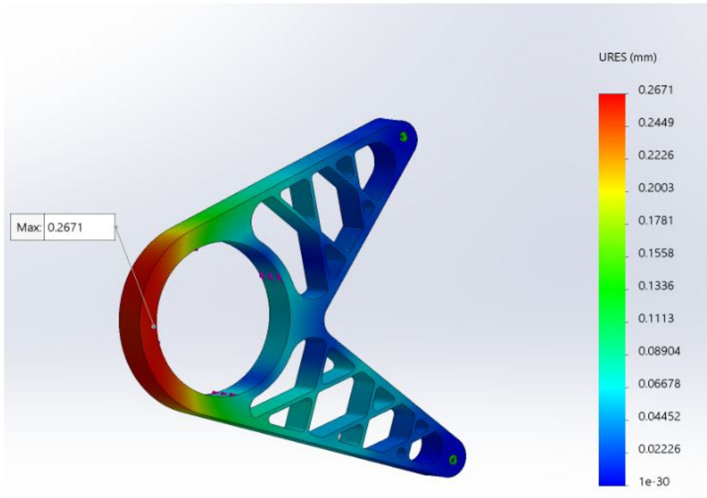
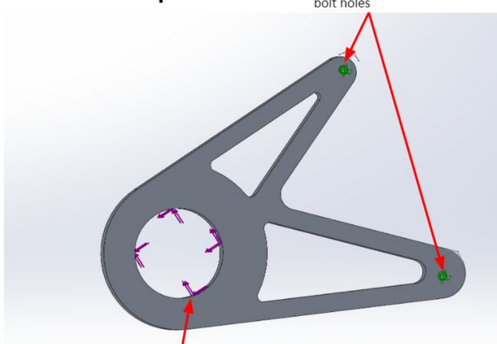


<u>Motor mount FEAs SolidWorks</u>

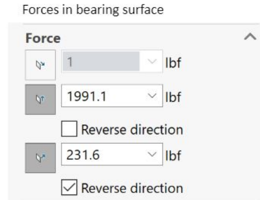
FEA Setup

Fixed Support in bolt holes



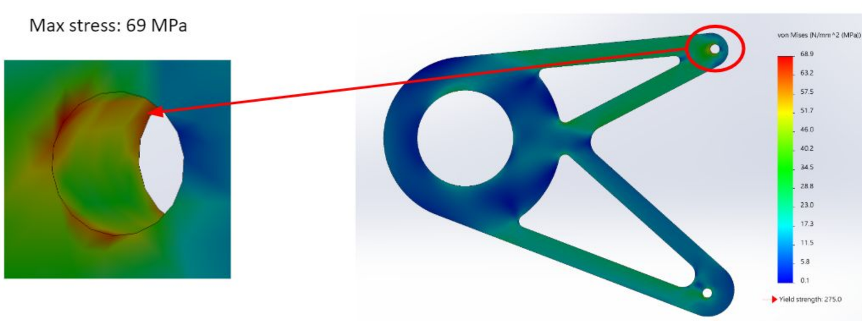
Torque applied to bearing surface

Forces in bearing surface

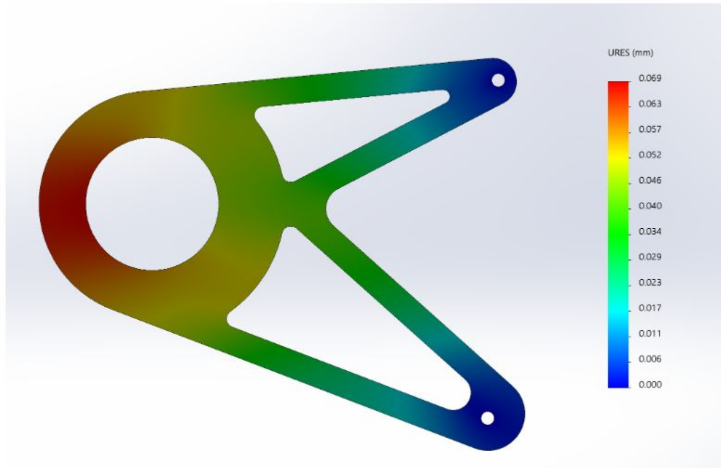


Results Max Stress

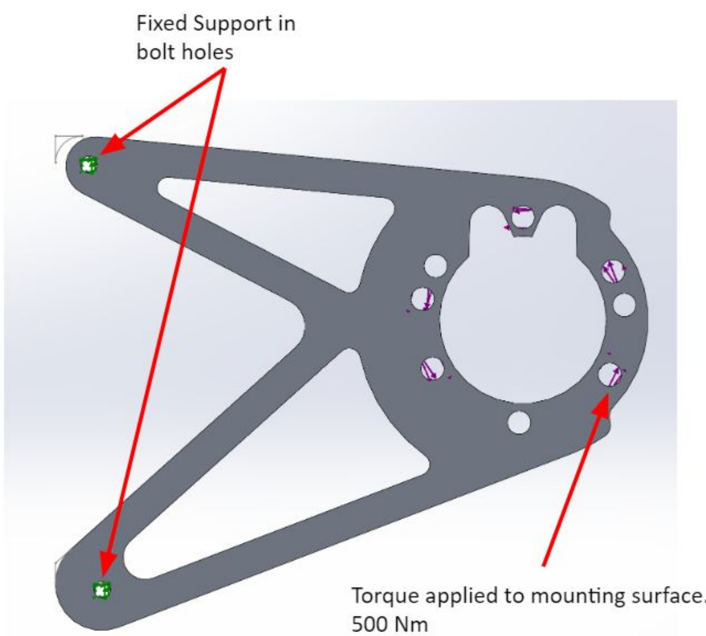
Max stress: 69 MPa



Deflection

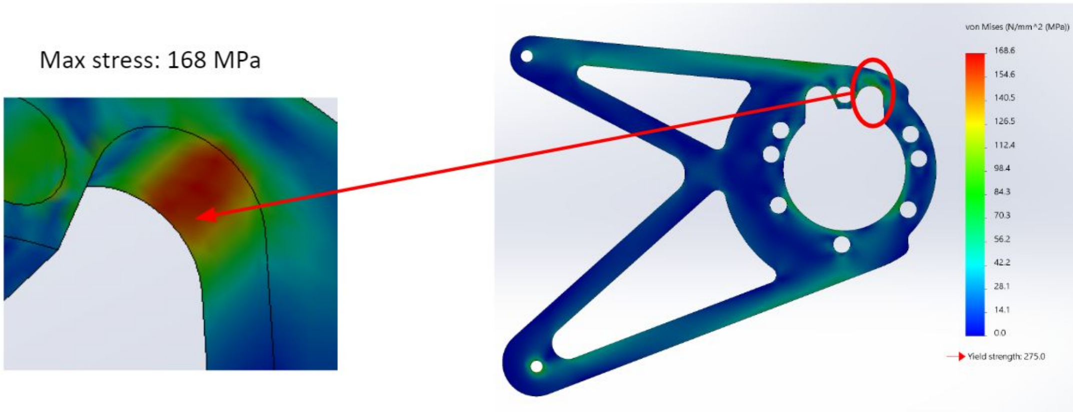


FEA Setup

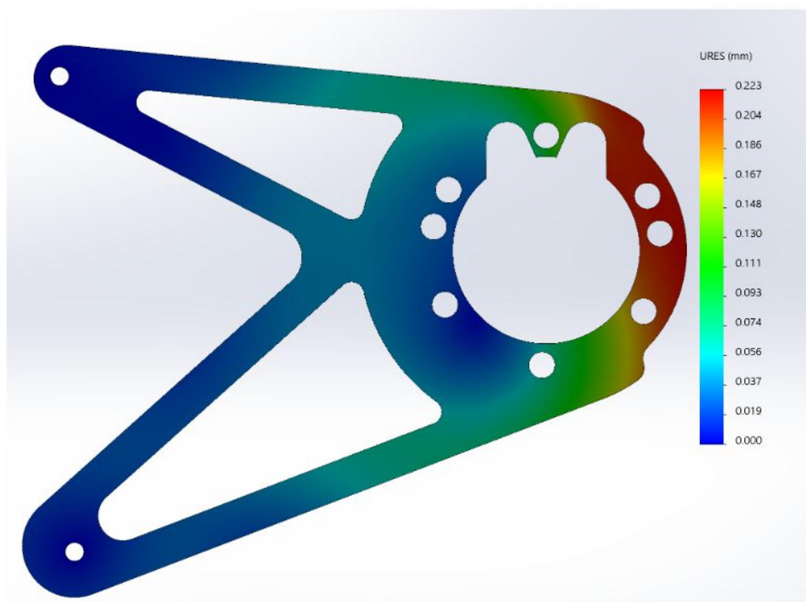


Results Max Stress

Max stress: 168 MPa



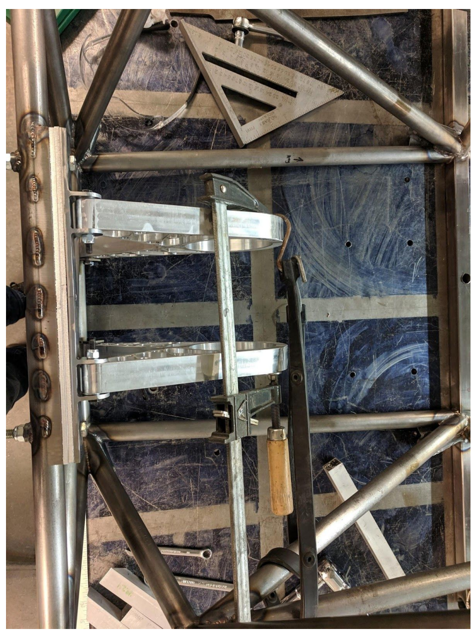
Deflection



Appendix D: Reference

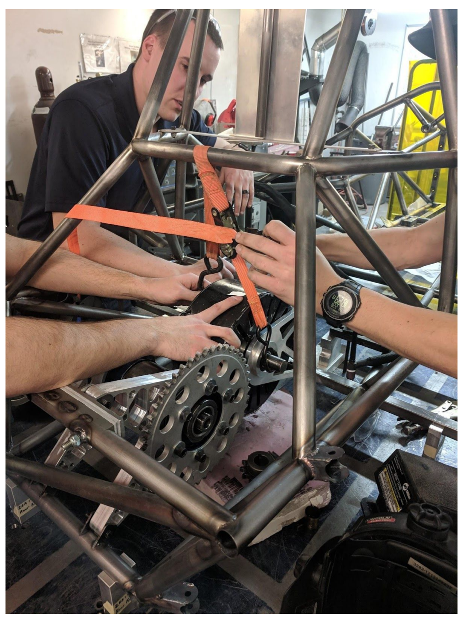
Disassembled differential with all components.

Setup for welding bottom differential tabs (top view).

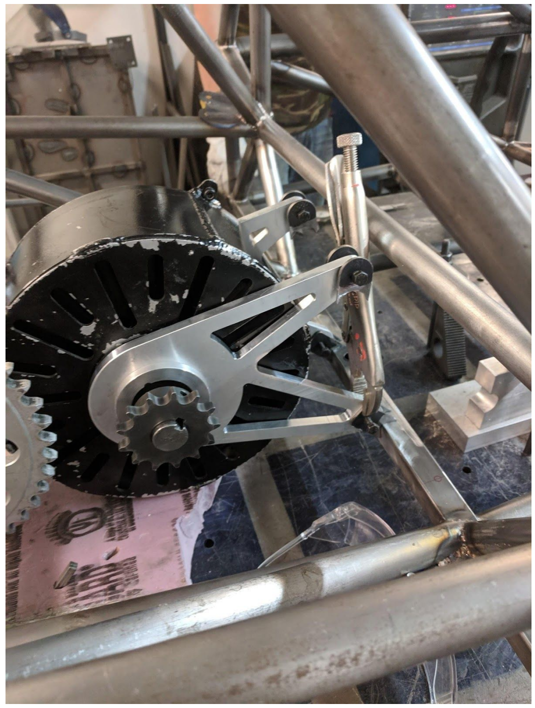


(side view)

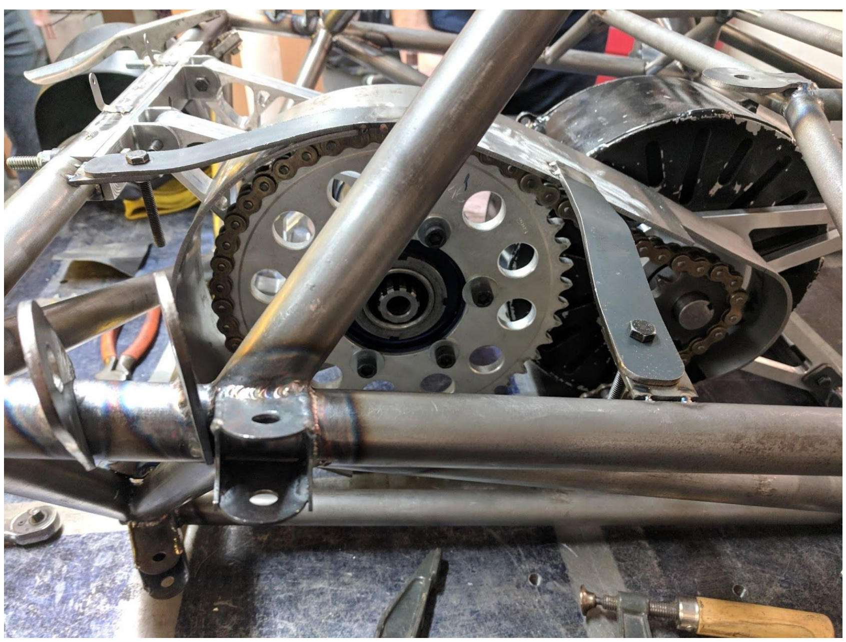
Setup for welding motor tabs.



Setup for welding motor tabs.



Chain guard and chain installation.



Loctite used for differential bolts.

Full drivetrain assembly.