MAE94 Project: Solar Powered Minicar Final Design Report

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Mechanical and Aerospace Engineering Department
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Abstract

This report presents the design of a solar-powered mini car, featuring front-wheel drive, a bevel gear drivetrain, and topology optimizations. The process begins with three different hand-sketched design concepts, each with a unique driving design element in mind (rear-wheel drive, front-wheel drive, front-wheel drive with a motor placed at the center). Concept 2 was the selected design concept. A rudimentary model was first created to further conceptualize the design. Later, proper mating of parts and subassemblies were formed to create a "working" car assembly. FEA analysis was performed to assess and optimize the structural integrity of the car. Weight reductions were made using topology optimization. Lastly, assembly and fabrication instructions, design specifications, and a detailed working drawing package were formulated for proper documentation of the design.

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List of Symbols (if you use equations add a List of Symbols)

Symbol	Description	Unit
N/A	**N/A**	**N/A**

I. Introduction

I.1 Problem Statement

The MAE94 Summer 2022 class was tasked with designing a solar powered minicar. A solar panel and DC motor is provided. Students were tasked with designing their own drivetrain and frame.

I.2 Design Requirements

The Design Requirements (DRs) consists of the following:

1. Device dimensions are not to exceed 0.20 x 0.20 x 0.30 m^3
2. The device must utilize the given 2"×2" solar panel and the DC motor – no other power source can be used.
3. Use of the bevel gears is optional - you may design your own gears or gear box using as many gears as you need.
4. Design of metal fasteners, such as rods or pins made of metal are encouraged, but are limited to a diameter of 1-mm.
5. Power transmission components (motor, gears, axles,...) should be designed to allow replacement using screws (use as many M2x6 screws as needed) – i.e., should be interchangeable.
6. All Structural components should be designed to be either laser-cut from a single 24"x 24" Acrylic Sheet*–1/8" thick (3.175 mm) or 3D-printed (ABS).
7. If a prototype was to be build, all structural components may be assembled using adhesives, such as Gorilla Glue.

II. Design Description

II.1 Design Concept Development

<u>Concept 1</u>: This rear-wheel drive design uses a three wheel design that sacrifices stability for improved speed. The three wheel design is pair with the sleek/thin frame of the car to further optimize speed. The car uses a pinion gear system to transfer energy from the motor to the rear wheels. A low gear ratio will be used to maximize top speeds even further.

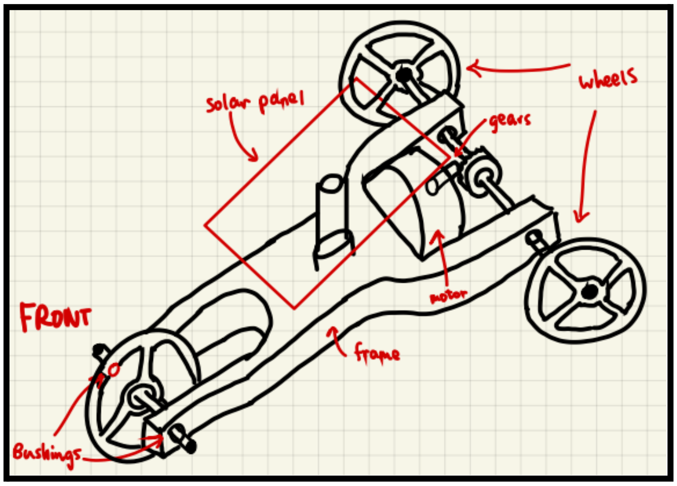


Figure 1: Mini-car concept using real-wheel drive

<u>Concept 2</u>: This front-wheel drive design will theoretically have improved traction climbing uphill roads and slippery roads. The solar panel is placed toward the back of the car to counteract the weight of the motor and subsequently optimize load transfer. The cutout is for topology optimization.

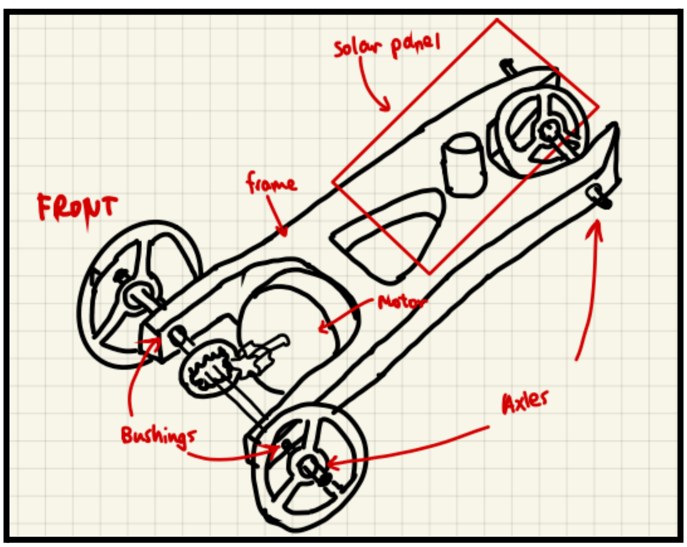


Figure 2: Mini-car concept using front-wheel drive

Concept 3: Even weight distribution was the goal of this design concept. The motor and solar panel are placed in the center of the car. There are also 4 wheels instead of 3 like the previous 2 designs to keep the design as symmetric as possible. Even weight distribution will theoretically produce a more efficient vehicle. The gearing a slightly more complicated to accommodate the motor placement.

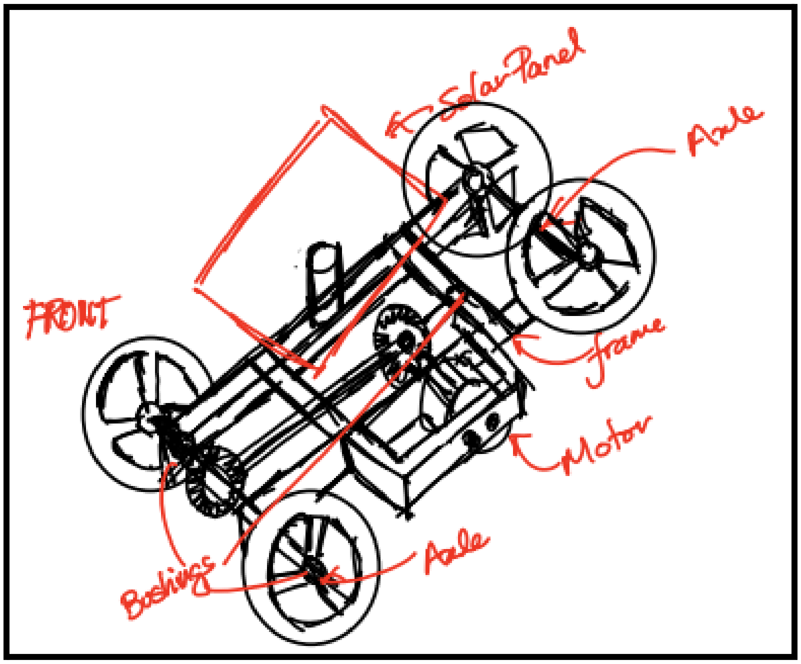


Figure 3: Mini-car concept with a motor and solar panel placed in the center

Out of the three design concepts, I pursued the second concept to completion. This is because this design is interesting while being relatively simplistic in form. This means the design can be refined to a greater extent than a complicated design while still retaining unique design elements (the front-wheel drive being the driving unique design component).

II.2 Design Overview

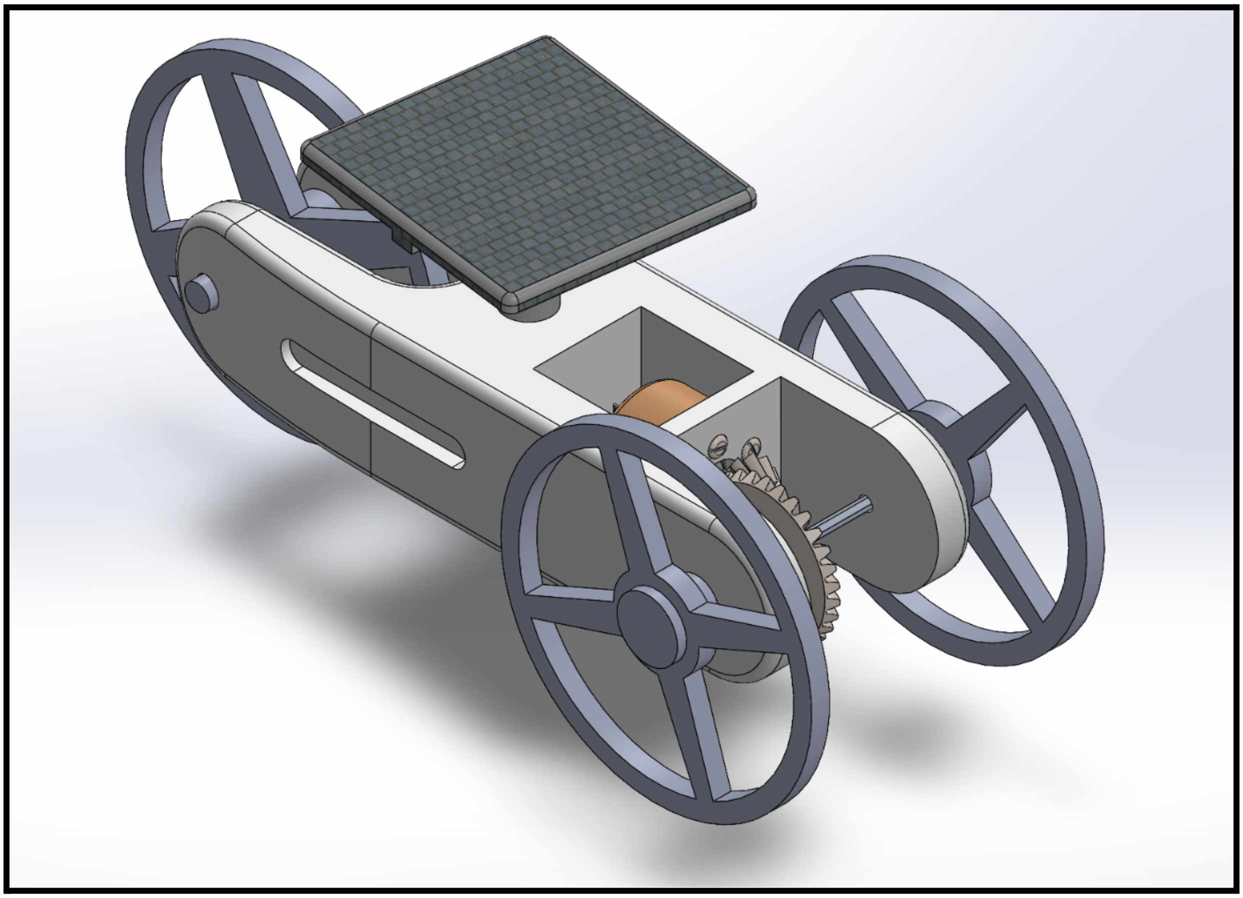


Figure 4: Isometric shaded view of the final CAD model

The solar car operates via a 2"×2" solar panel power source placed on top of the car that's connected to a DC motor. The motor is attached to the center of the chassis using 6 phillips screws. Rotational motion of the DC motor is then converted into translational motion using a bevel gear drive train located at the front of the car.

The bevel gear drive train transmits the power of a singular rotating mechanical drive shaft through 90° angle to supply power to the two wheels at the front of the solar car. The wheels are driven at a 2:1 gear ratio, providing a mechanical advantage of 2. The singular back wheel is free spinning. This front-wheel drive design allows for improved traction as the vehicle is front-loaded.

Unwanted translational motion of the front axle is mitigated with the use of a set screw that holds the straight bevel gear to the axle, and tight tolerances between the wheels and the chassis. Translational motion of the rear axle is mitigated using axle fit on both sides of the axle.

The contours of the frame make for a structurally rigid design while still being relatively light.

II.3 Systems Specifications

Table 1: Device Specifications and Dimensions

Parameter	Value
Height*	76.19 mm
Width	69 mm
Length	182.86 mm
Mass	147.12 g
Number of Wheels	3
Number of Gears	2
Primary Material	ABS (Acrylonitrile butadiene styrene)

*height dimension taken with solar panel parallel to the top plane

Table 2: Motor Specifications

Specification	Description
Angular Velocity	254 RPM @ 0.5V 2540 RPM @ 5V
Torque	0 N·mm @ 26 mA (No load, no resistance) 1.23 N·mm @ 120 mA (max efficiency) 6.86 N·mm @ 540 mA (stall torque, max load)

Table 3: Additional Specifications

Specification	Description
Power Source	Solar Panel
Fabrication Method	3D Printing
Cost	~$20

II.4 Mechanical Systems

Drivetrain: The bevel gear drive train transmits the power of a singular rotating mechanical drive shaft through 90° angle to supply power to the two wheels at the front of the solar car [1]. The singular back wheel is free spinning.

III. FEA Analysis

III.1 Description of FEA Analysis

I first performed linear static FEA analysis on the chassis of the solar car. I chose the chassis to perform FEA analysis as it is the primary structural component of the car. FEA analysis of the chassis is crucial to the design process as structural failure in the chassis could expose glaring issues with the overall design. The chassis is also the most optimizable component of the assembly when compared to other components that could easily lose or alter functionionality when modified.

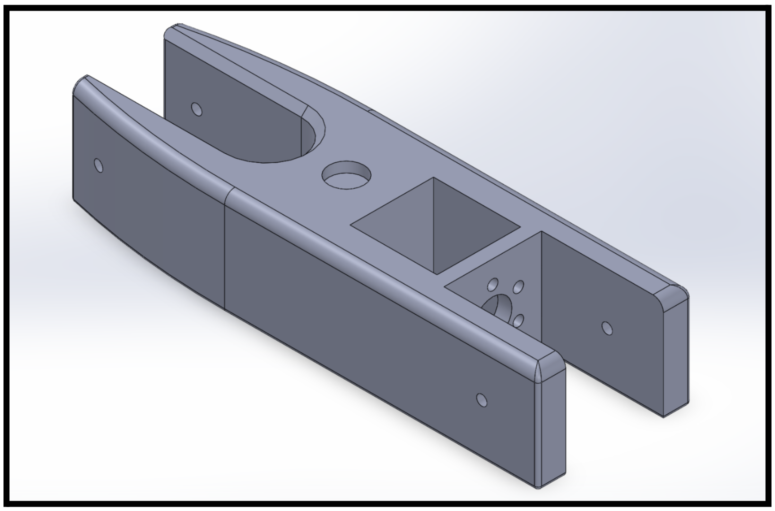


Figure 5: Initial model of the chassis

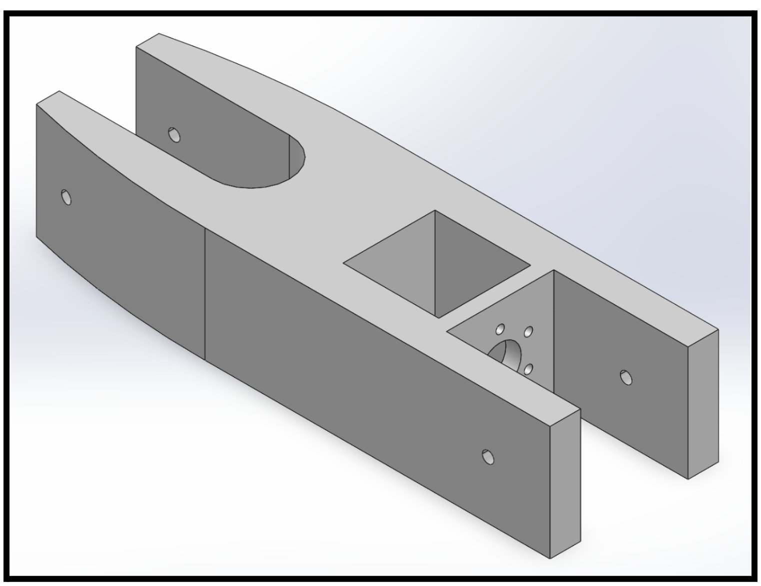


Figure 6: Simplified model of the chassis.

I created a simplified configuration of the chassis for FEA analysis. All fillets/chamfers, the indent at the top of the model for mounting the solar panel, and the indents for motor screws were removed.

III.2 Boundary Conditions

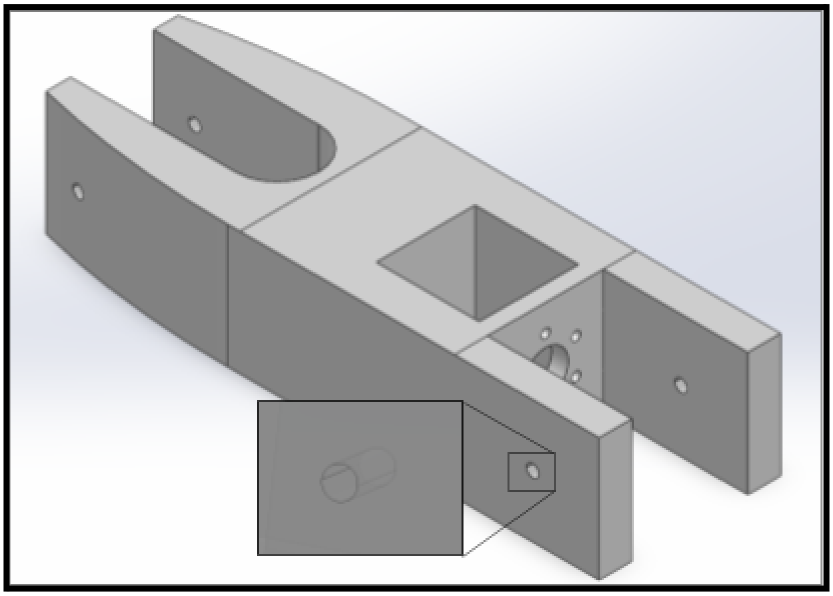


Figure 7: Simplified model with split lines

Split lines at the top of the model isolate the simulated downard force to the central portion of the chassis. Split lines through the axle holes allow a more accurate simulation of the reactionary force applied to the chassis by the axles when a downward force is applied to the model.

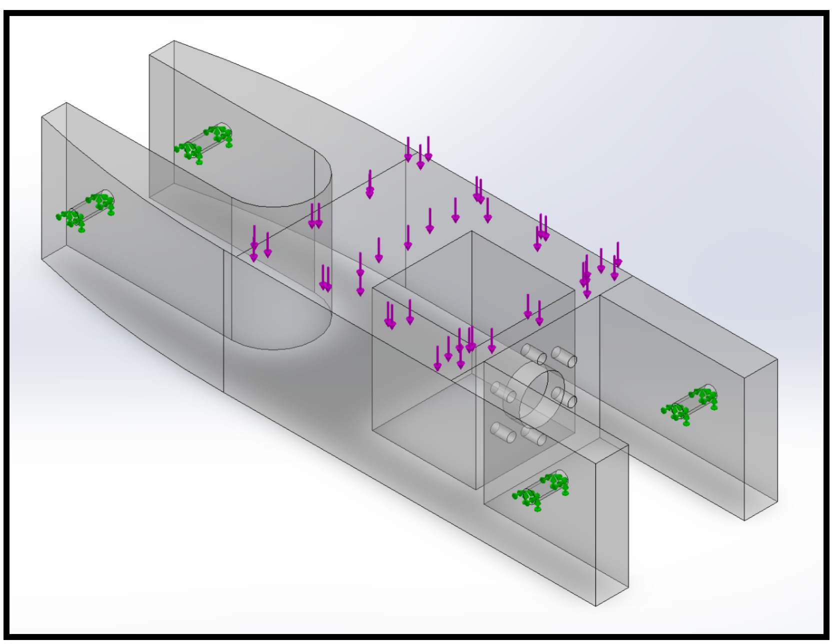


Figure 8: FEA model showing the applied BCs (Fixtures and Force).

Fixtures were placed in all four axle holes, excluding the holes for mounting of the motor. I only fixed the top side of the axle holes to resist the upward forced applied by the axles when a downward force is applied to the top of the car as shown.

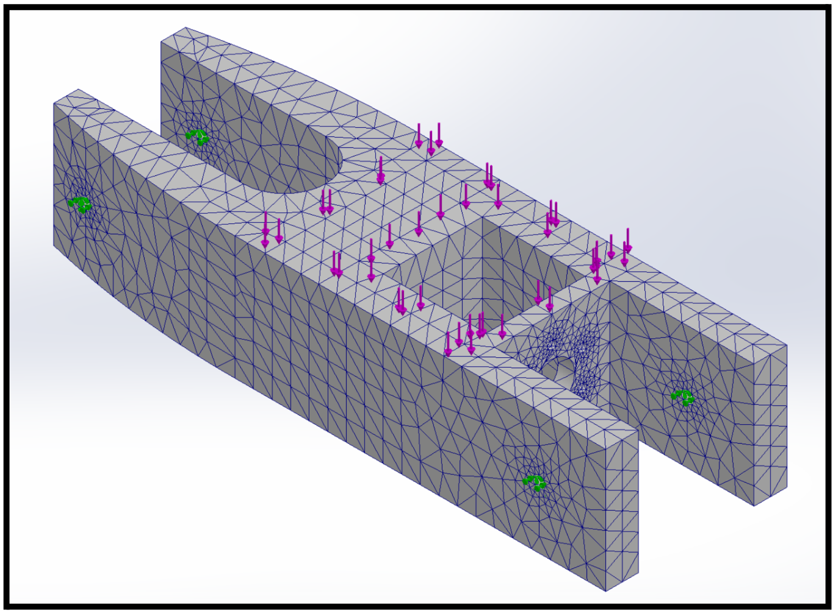


Figure 9: FEA model showing the applied BCs and mesh

III.3 Analysis Results

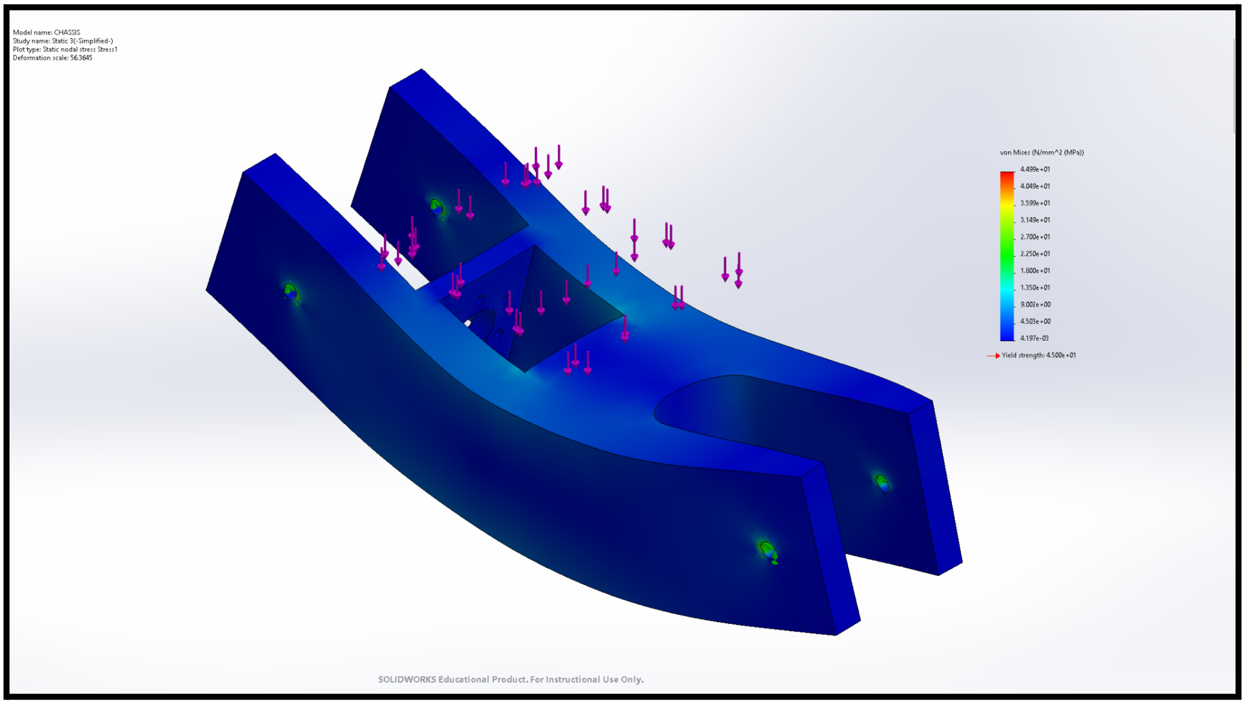


Figure 10: Stress results. The maximum stress: 44.99 MPa

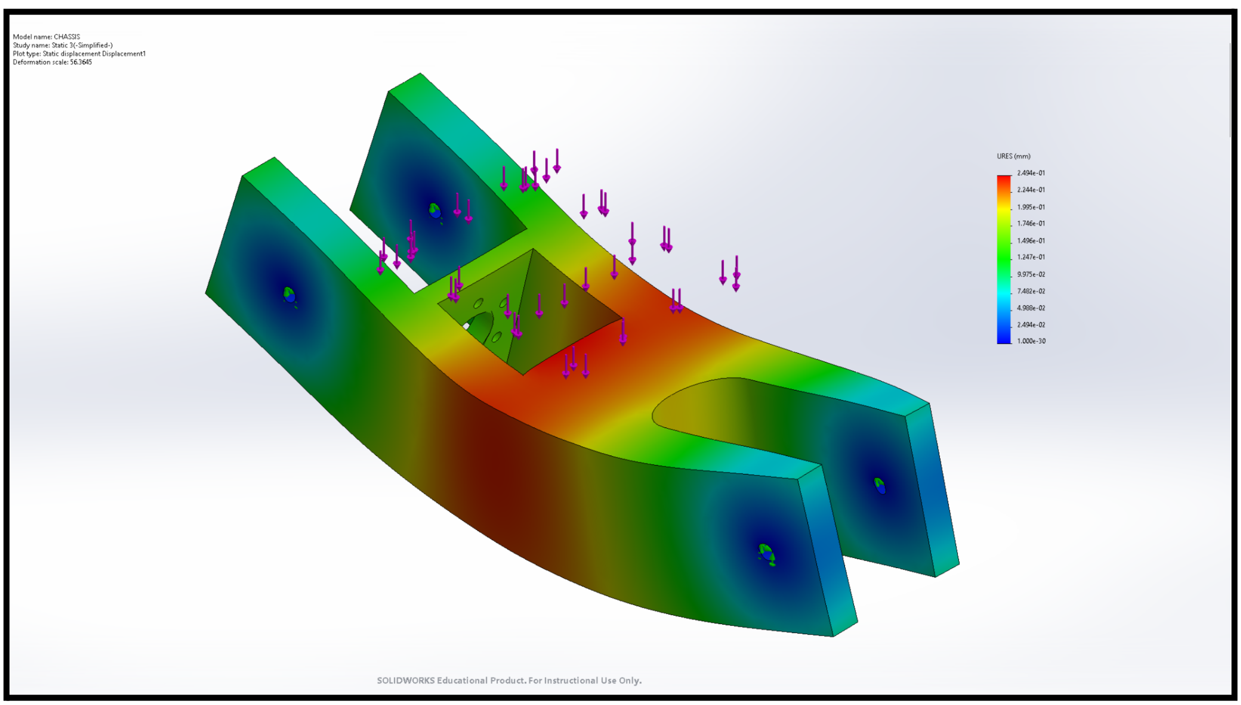


Figure 11: Displacement contours

Material yield strength [Acrylic (Medium-High Impact)]: 45 MPa
The maximum load the chassis could handle was approximately 1250N of force.

Topology Optimization

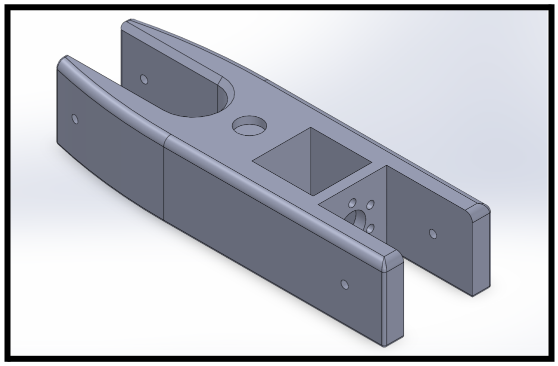


Figure 12: Initial model of the chassis before topology optimization

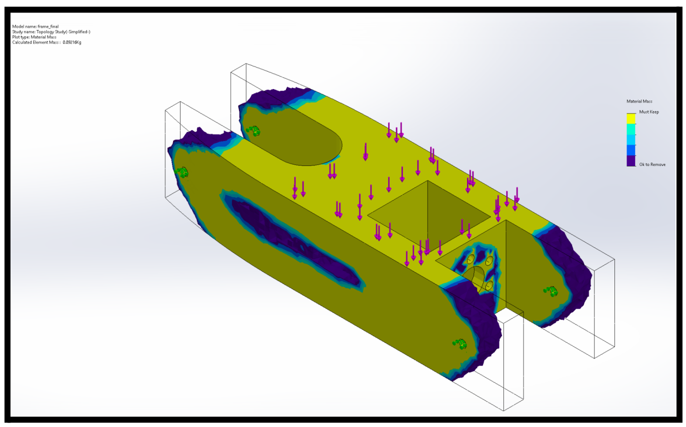


Figure 13: Material mass plot obtained from topology optimization

The same parameters used for linear static FEA analysis were used for topology analysis. The goal was to achieve the best stiffness to weight ratio with a mass reduction of 30%.

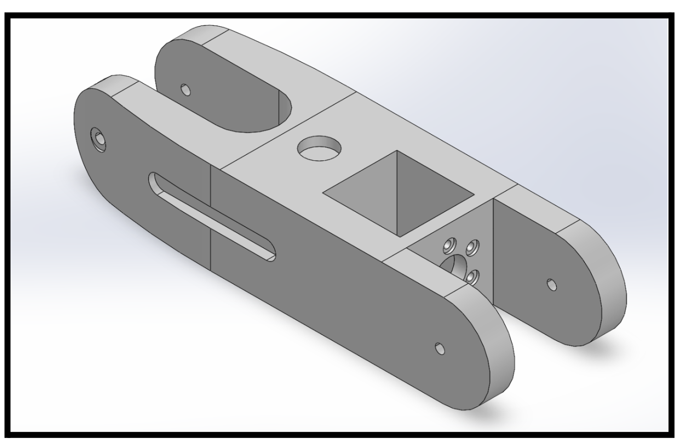


Figure 14: Chassis after modifications using topology optimization (fillets on final chassis not shown)

Following the mass reduction contours from the mass material plot, I used extruded cuts to conservatively remove portions of the chassis.

VI. Product Fabrication

VI.1 Fabrication

The chassis, wheels, gears, solar panel mount, ball caster, and axle caps will be 3D printed. The screws, axles, and motor are pre-fabricated.

VI.2 Assembly

The motor is screwed into the frame using 6 screws in the designated motor cutout. The straight bevel pinion gear is friction fitted onto the motor axle. The front axle is fitted through the axle holes at the front of the chassis and the straight bevel gear simultaneously. Once the axle is centered, the straight bevel gear is shifted along the axle until engaged with the pinion gear attached to the motor axle. A set screw holds the bevel gear in its finalized position. Once the gears are set, attach the two front wheels to the front axle. To attach the rear wheel, the rear axle is fit through the rear axle holes and the rear wheel simultaneously. Lastly, the solar panel subassembly is super-glued to the top of the chassis at the designated solar panel mount cutout.

V. Summary and Conclusions

The design process began with rudimentary design sketches that brought an overarching vision to the project. Out of the three major design ideas, the front-wheel drive design was chosen. The first iterations of the car established a general shape of the car and the basic gearing, motor positioning, and solar panel placement for an operational vehicle. Once a general 3D concept was formed, I created a CAD design with proper mating of various components so that a moveable CAD design could be conceptualized. Additionally, I had to solve two design problems. I developed a secure motor bracket, and translational axle motion was mitigated with proper tolerances and a gear hub. The car was then refined to be lighter and faster using FEA analysis, eventually reaching the final design.

Many lessons were learned during the design process. I initially overlooked the importance of a concept sketch, but it actually became an extremely helpful guide for realizing the overall design vision. Another key lesson was compartmentalizing the design process especially through the creation of subassemblies. This was crucial to simplifying, organizing, and streamlining my workflow. I also learned to complete and perfect subassemblies before rushing to fully assemble the complete product. I would make changes to various subassemblies many times during the design process that would completely ruin the final assembly, forcing me to remake the final assembly a frustratingly large amount of times. It is important to avoid being overzealous and complete the smaller building blocks before rushing to complete the final product. Another important way to mitigate redundancies during the design process is to think about design intent. Although I was able to implement design intent into the creation of individual parts with relative ease, I found it a bit difficult to use the concept of design intent in the assembly process.

IV. References

1. "How a Bevel Gearbox Works." Power Jacks - Precision Linear Actuation. Web. 15 Aug. 2022.

IIV. Appendix

A. CAD Models:

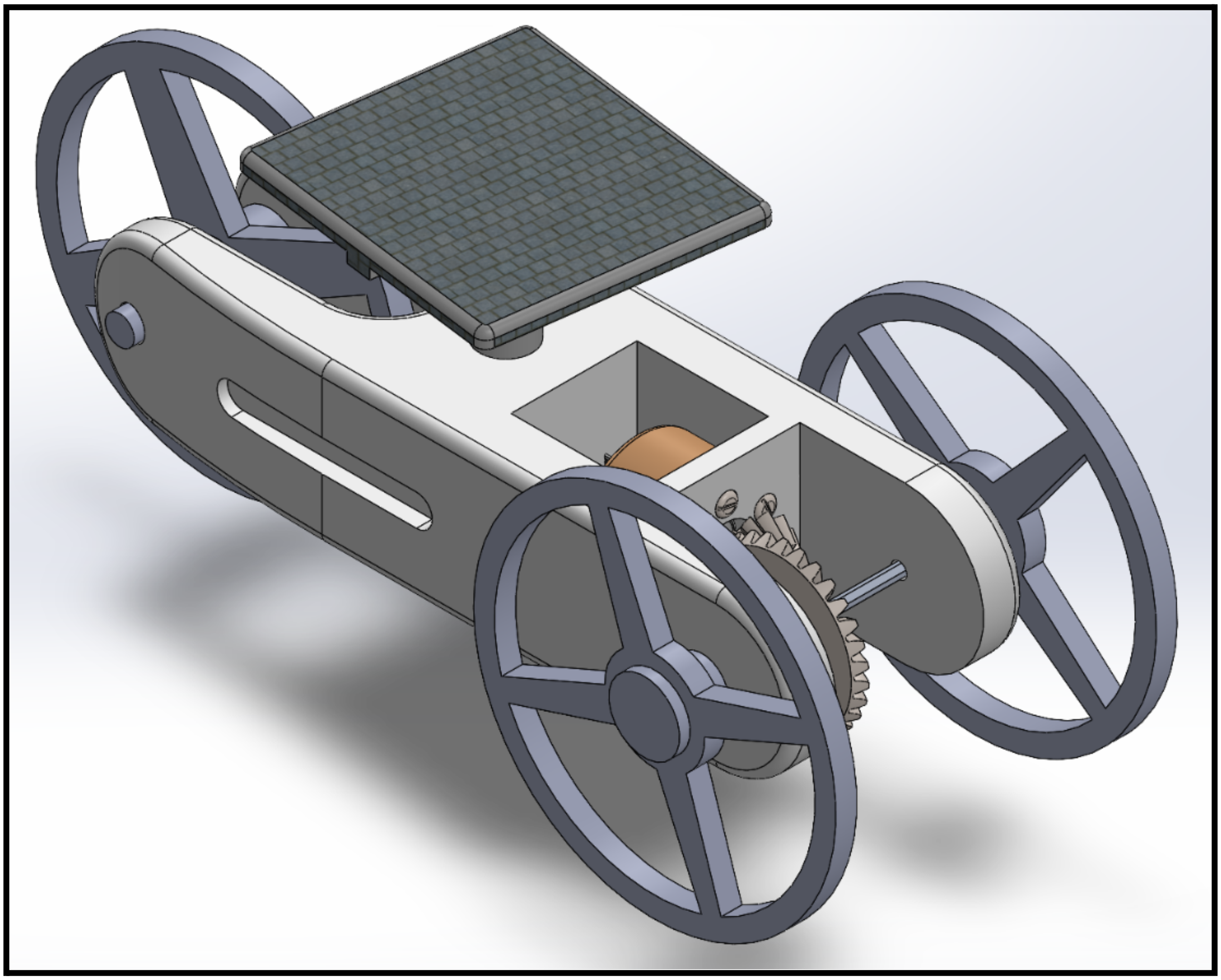


Figure 15: Isometric view of the Solar Car

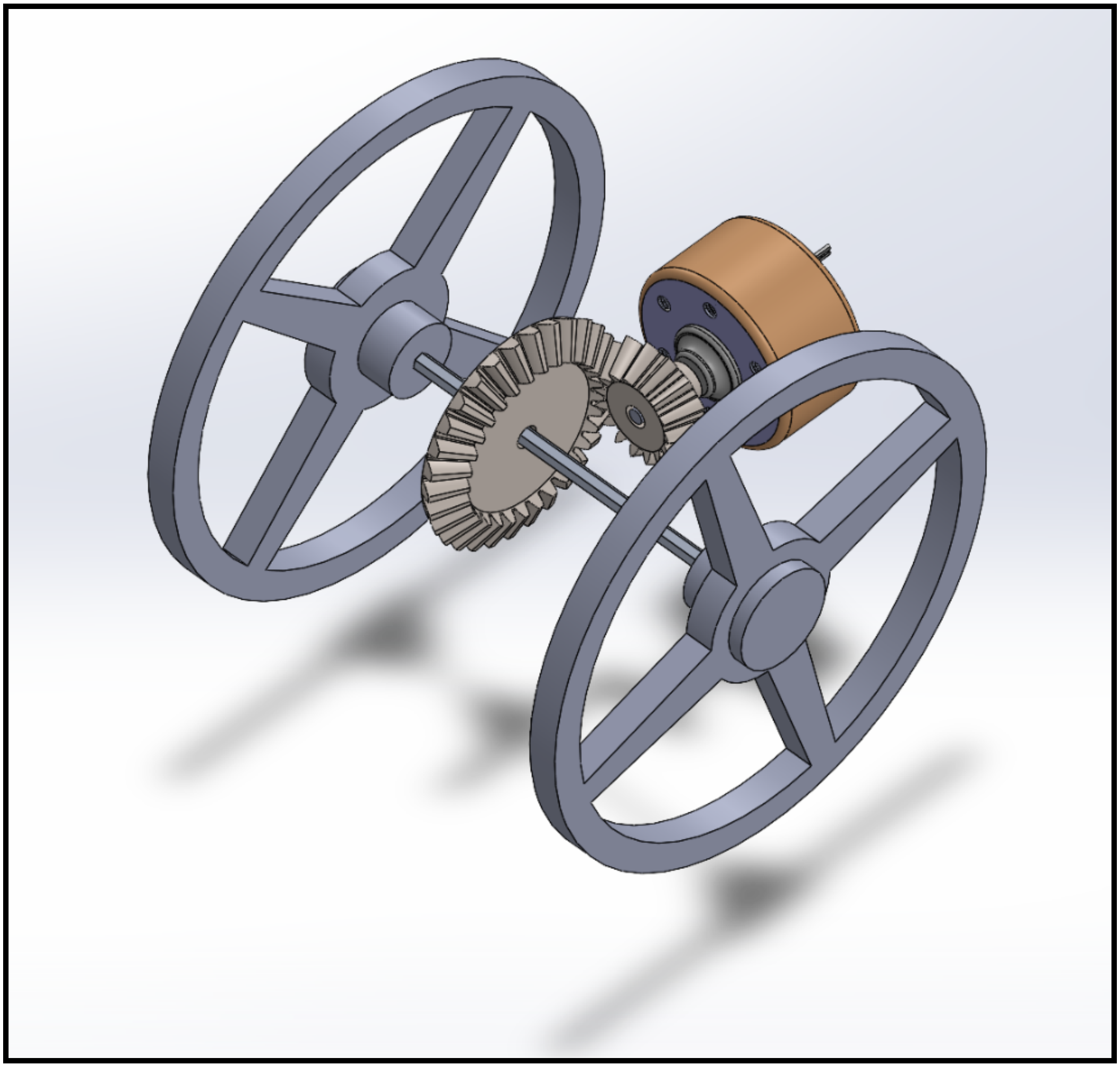


Figure 16: Isometric View of the Drivetrain/Gear subassembly

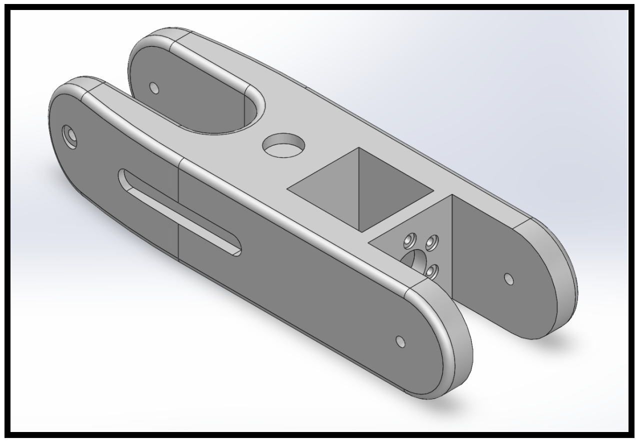


Figure 17: Isometric View of the Chassis

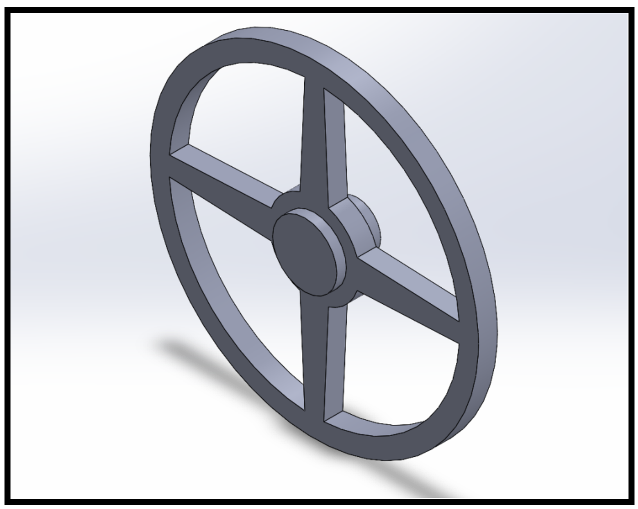


Figure 18: Isometric View of the Front wheel

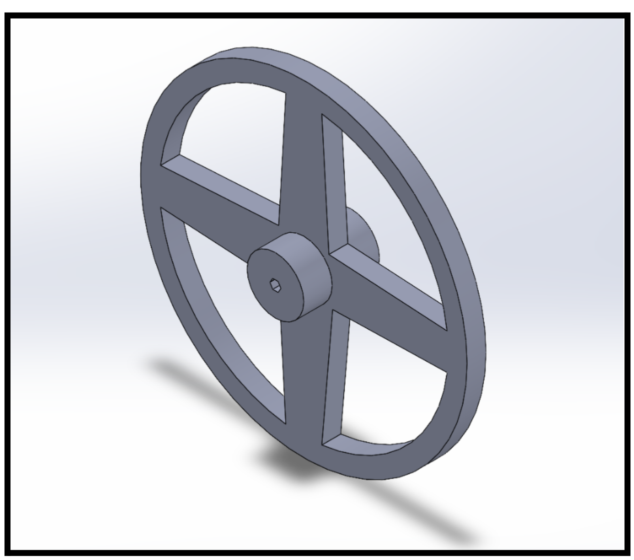


Figure 19: Isometric View of the Rear wheel

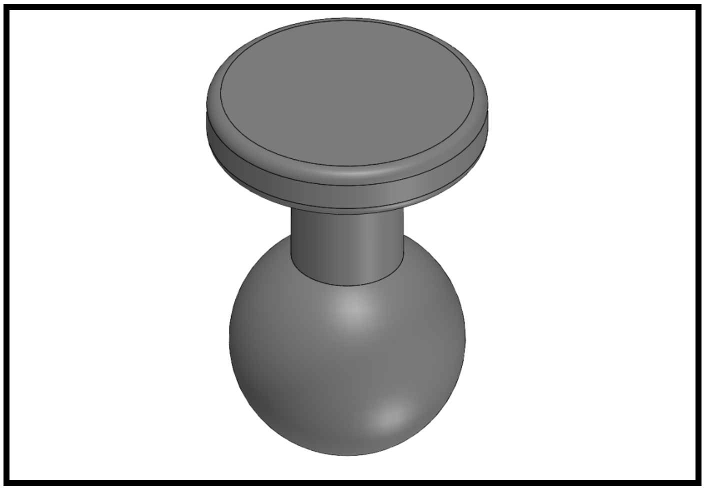


Figure 20: Isometric View of the Ball Caster

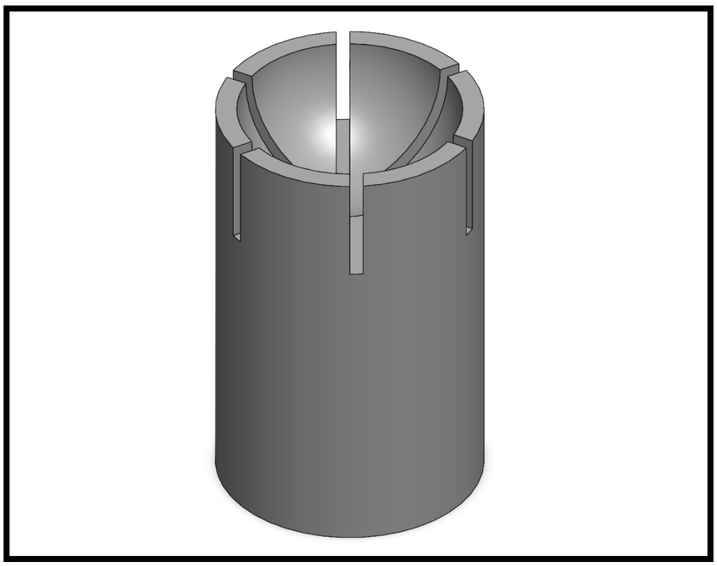


Figure 21: Isometric View of the Solar Panel Mount

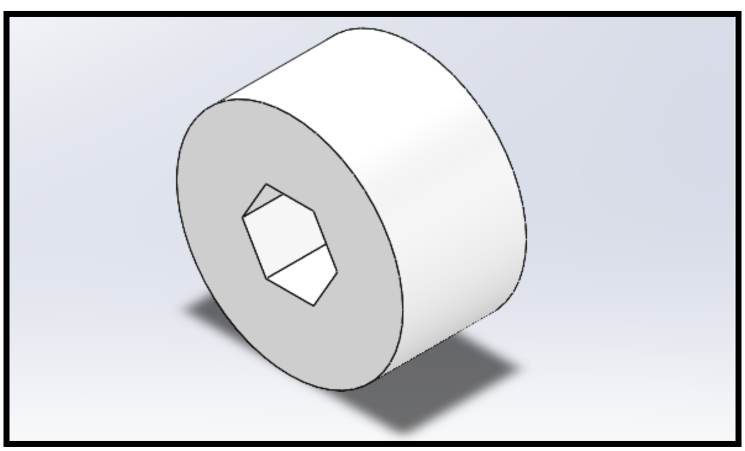
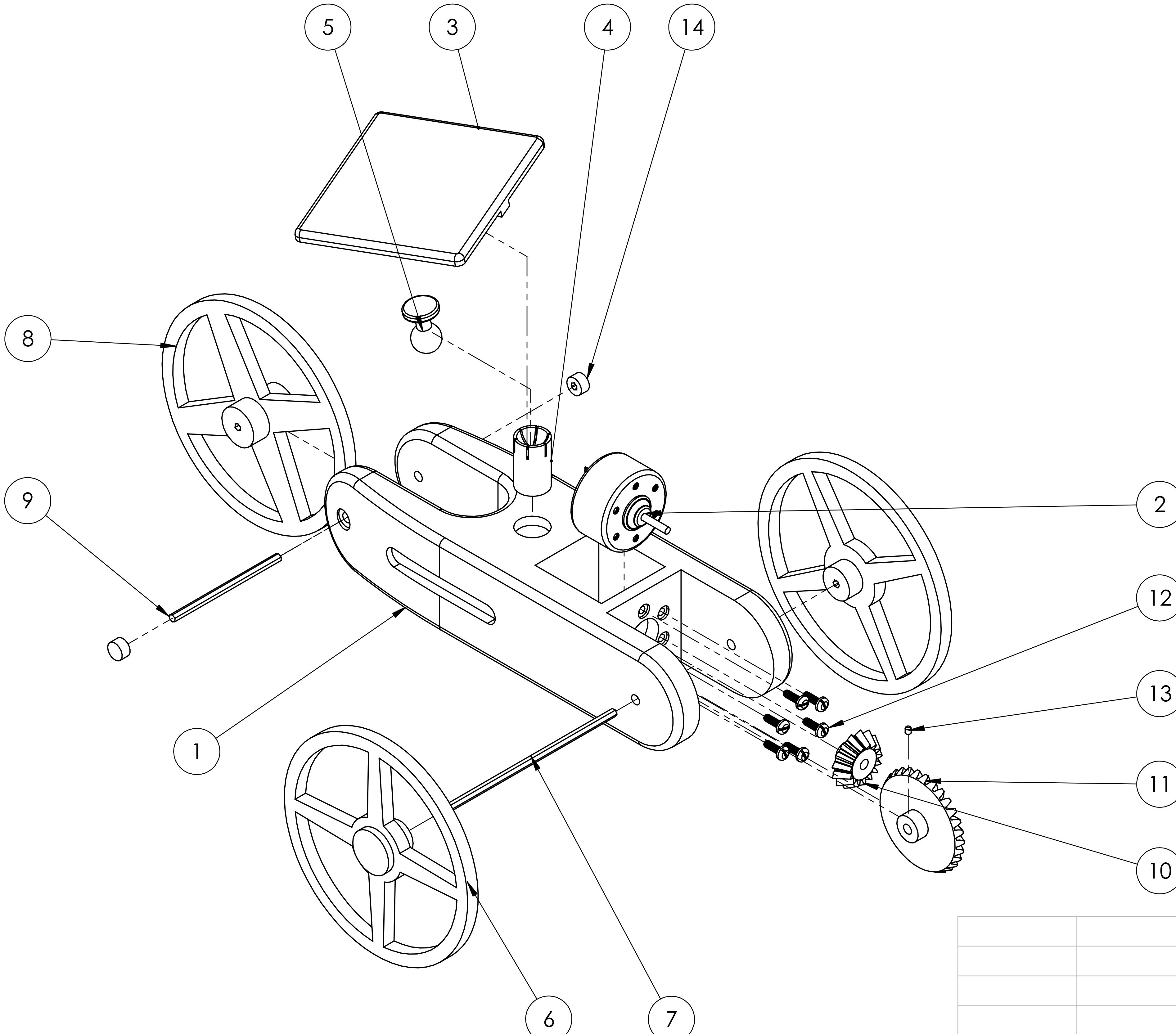


Figure 22: Isometric View of the Axle Cap

B. Engineering Drawings



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2	DC_MOTOR		1
3	SOLAR_PANEL		1
4	SOLAR_PANEL_MOUNT	ABS	1
5	BALL_CASTER	ABS	1
6	FRONT_WHEEL	ABS	2
7	FRONT_AXLE	AISI 304	1
8	REAR_WHEEL	ABS	1
9	REAR_AXLE	AISI 304	1
10	Metric - Straight bevel pinion 1M15PT 30GT 20PA 5FW --- 15O5H19MD3N	ABS	1
11	Metric - Straight bevel gear 1M 30GT 15PT 20PA 5FW --- 30O8H13MD3N	ABS	1
12	PHT 2x6x5.2-slot-D-S	AISI 304	6
13	B18.3.6M - M1.6 x 0.35 x 2 Hex Socket Flat Pt. SS --C		1
14	AXLE_CAP	ABS Plastic	2

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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
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THREE PLACE DECIMAL ±
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ENG APPR.		
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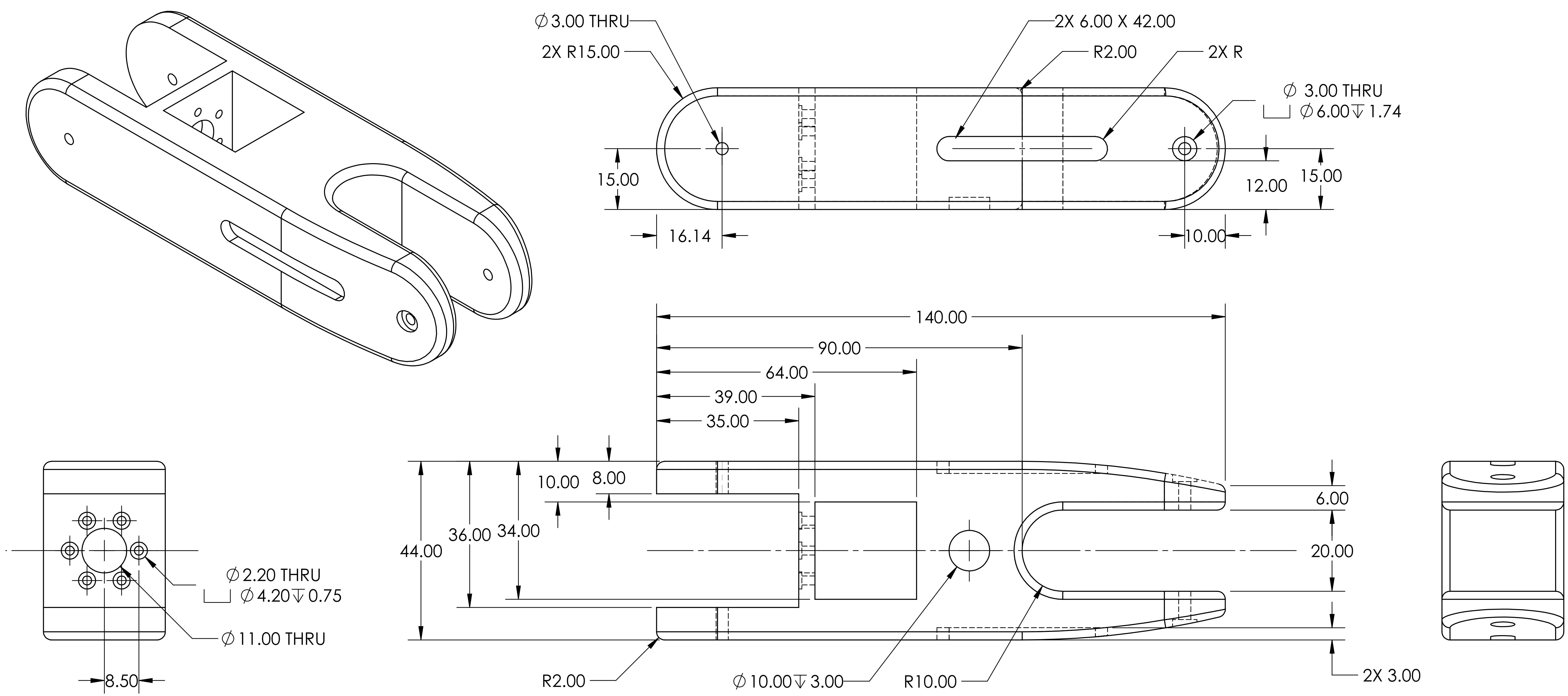

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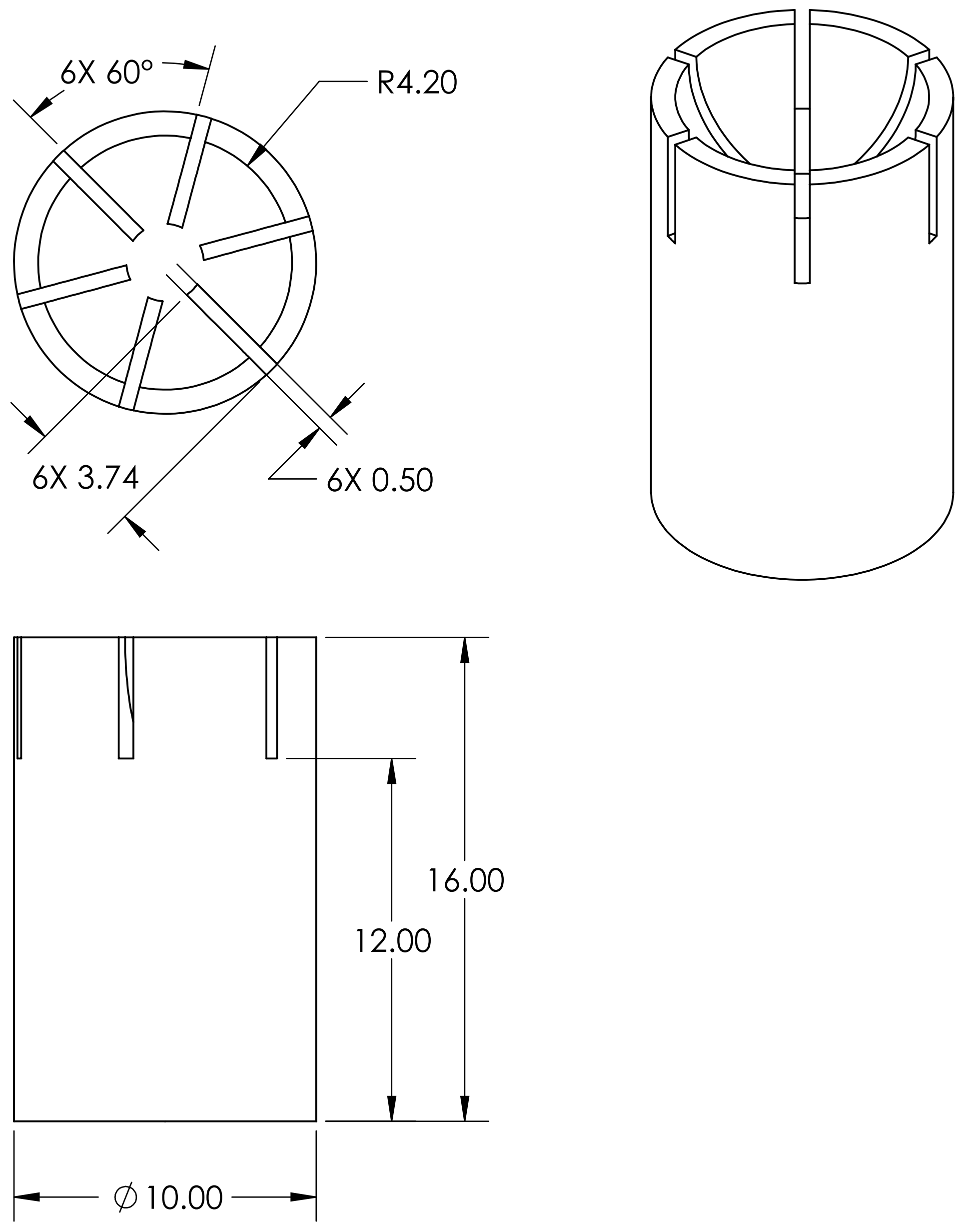

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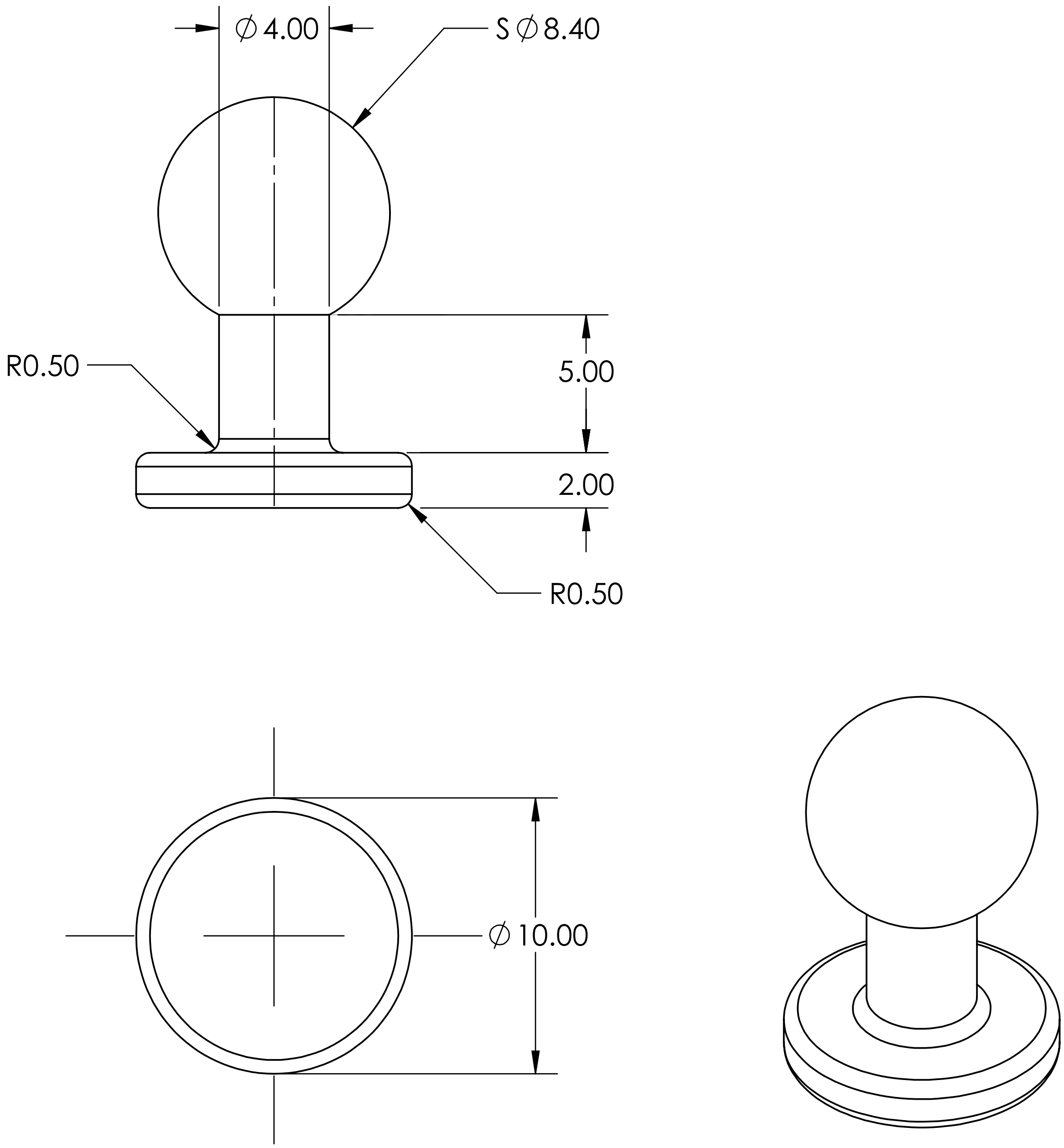

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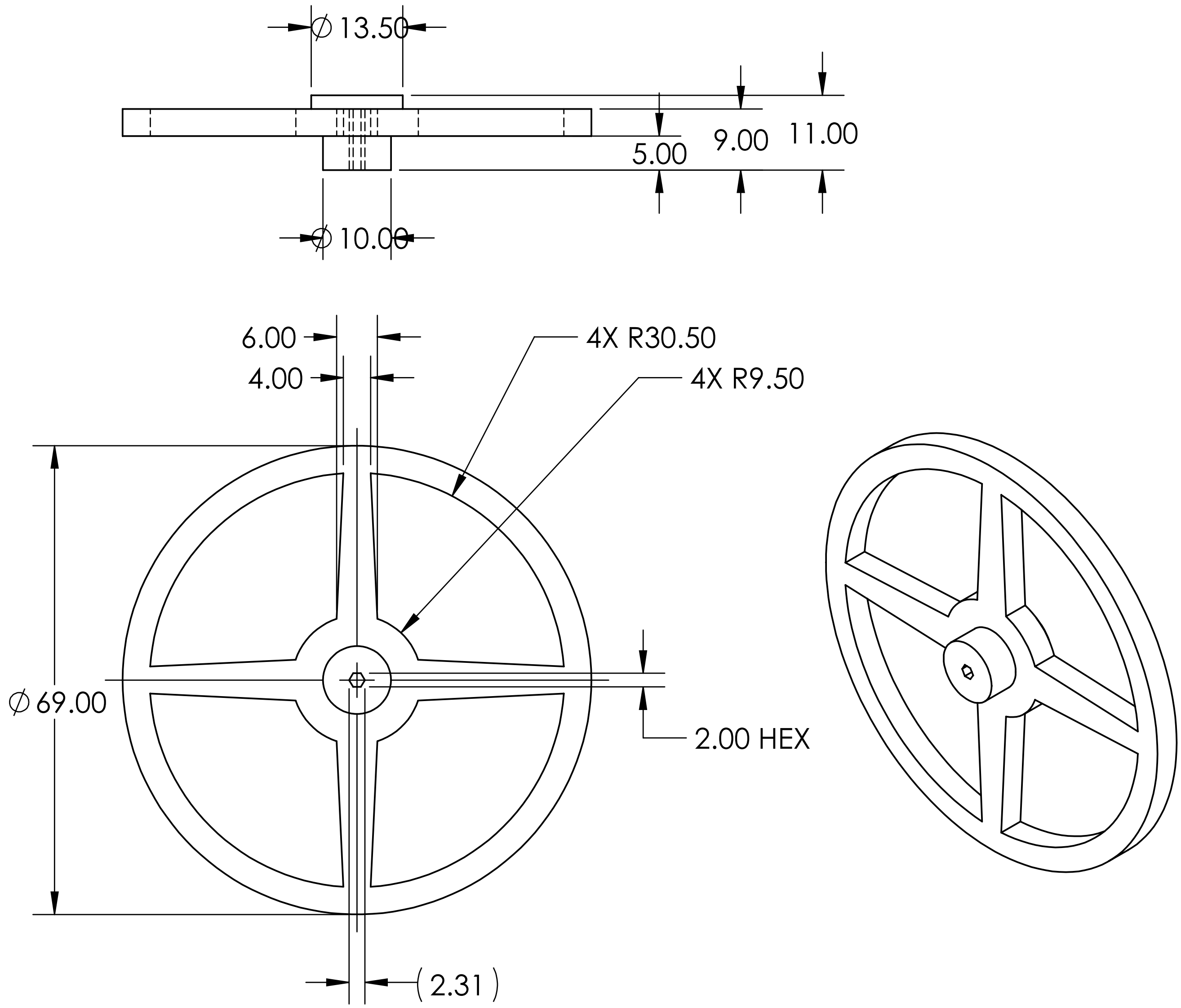

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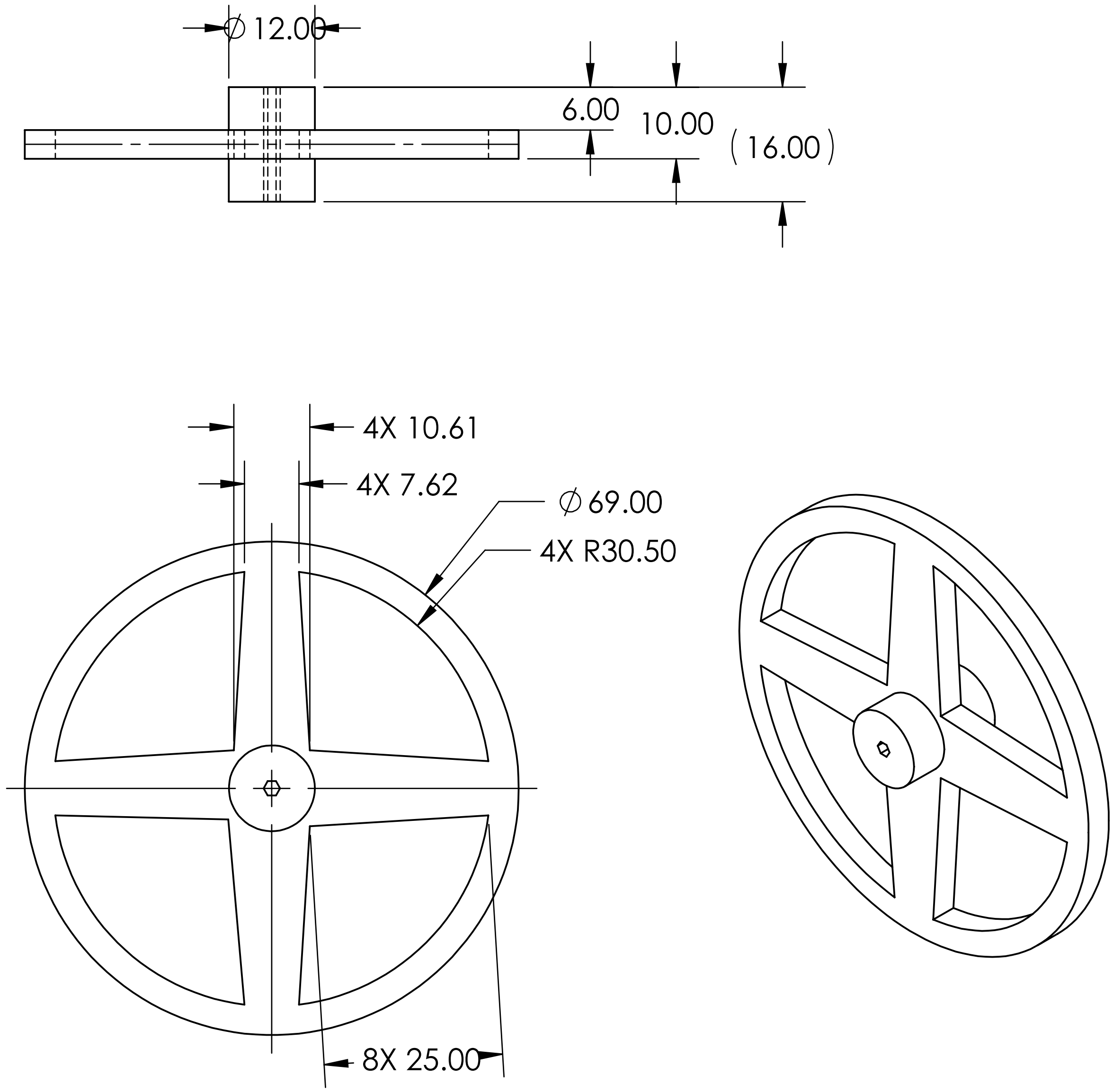

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REAR_WHEEL

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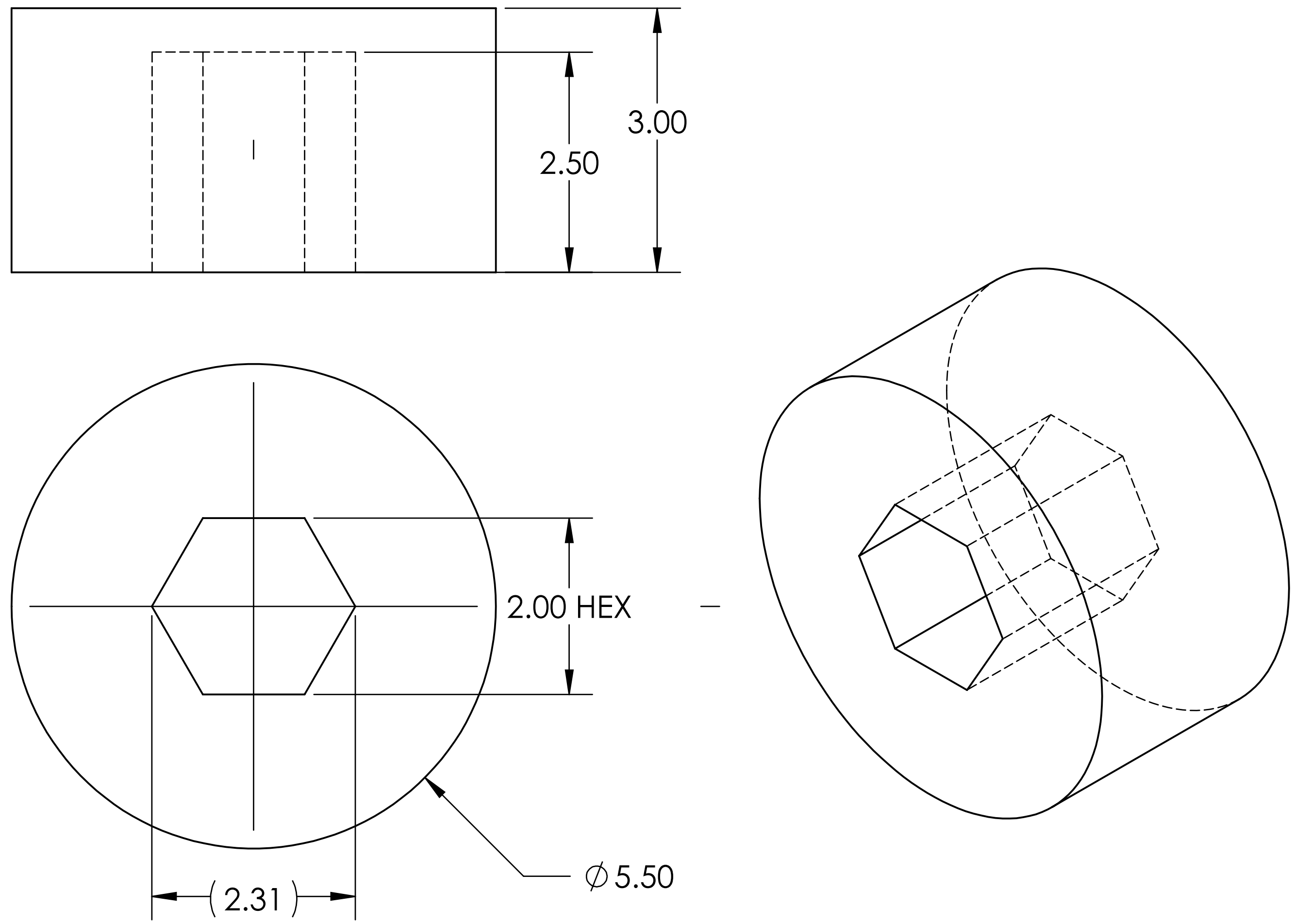

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MAE94 - UCLA

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2540 RPM @ 5V
REQD = 1

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~50 X 55
MAX OUTPUT ~ 5V
REQD = 1

7 AXLE
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LENGTH = 65
AISI 304
REQD = 1

9 AXLE
HEXAGONAL CROSS SECTION (∅2)
LENGTH = 40
AISI 304
REQD = 1

10 STRAIGHT BEVEL PINION AI
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PRESSURE ANGLE = 20
FACE WIDTH = 5
HUB ∅ = 5
MOUNTING DISTANCE = 5
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HUB ∅ = 8
MOUNTING DISTANCE = 13
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REQD = 1

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REQD = 6

13 B18.3.6M SOCKET SET SCREW FLAT POINT
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MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	NG	8/15/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

MAE94 - UCLA

TITLE: STANDARD PARTS

SIZE	DWG. NO.	REV
B	STANDARDS	A

SCALE: 1:1 WEIGHT: SHEET 1 OF 1