Mechanically Advantageous Wheelchair

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MEMS 411 Design Report

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 PROJECT PROBLEM STATEMENT

This project will use a gear system to create a multi-speed wheelchair. Multiple speeds will allow users to adjust the speed for appropriate scenarios. Our approach will use a different gear mechanism than products currently in the marketplace.

1.2 LIST OF TEAM MEMBERS

Carlo Balleria

Noah Dromgoole

Katy Hagerty

Andrew Orona

2 BACKGROUND INFORMATION STUDY – CONCEPT OF OPERATIONS

2.1 A SHORT DESIGN BRIEF DESCRIPTION THAT DESCRIBES THE PROBLEM

This project will utilize a gear system to create a multispeed wheelchair. Multiple gears will allow users to adjust the speed of the wheelchair for appropriate scenarios. Our device will be modular and use a different gear mechanism than products currently in the marketplace. The device will have three different gear ratios—100%, 75%, and 62.5%.

2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION

The two major competitors for the product are MAGICWHEELS and Wijit.

MAGICWHEELS are wheelchair attachments, which use hypocylindrical drives to provide manual wheelchairs with 2 speed options. The first speed is the standard speed where 1 revolution of the hand rims results in 1 revolution of the chair's wheels. The second speed shifts the chair into low gear where every 2 revolutions of the hand rim results in 1 revolution of the wheel. This 2:1 ratio makes it easier to traverse hills, inclines, and rough terrain. Pushing the shift handle (as seen in Fig. 1) allows users to shift to different gears. Users are discouraged from shifting when the wheels are under load.

Similar to MAGICWHEELS, the proposed design will use a gear system to provide a multi-speed wheel chair. Unlike MAGICWHEELS, the proposed design will allow users to shift between gears during motion and offer more than 2 speeds.

Wijit is a manual wheelchair attachment that allows consumers to go faster and break easier using a nearly 1:2 lever-drive system. The Wijit's levers allows users to propel a wheelchair forwards and backwards as well as to break without ever having to touch the wheel. Turning the shifter at the top of the handle enables users to shift to forwards, backwards, or break mode.

Similar to the Wijit, the proposed design has a completely mechanical approach to making wheelchairs faster. Unlike the Wijit, the proposed design has multiple speeds and will use a gear-drive rather than a lever-drive.

The project centers on the gear system. The gear system allows for wheelchair's multiple speeds. Any complications that cause the gear system to either not shift between gears or break would be the most significant risk to the design process.

Failure Modes in Gears

This site indicates any failure in the gear system results in the failure of the system. It describes different types of failure to be cognoscente of during the design process.

Reference: http://www.brighthubengineering.com/cad-autocad-reviews-tips/8443-failure-modes-in-gear-part-one/

Gear Failures

This site also focuses on recognizing, causes of, and avoiding gear failures.

Reference: http://www.xtek.com/pdf/wp-gear-failures.pdf

3 Concept Design and Specification – Design requirements

3.1 Operational requirements allocated and decomposed to design requirements

3.1.1 List of identified operational and design requirements

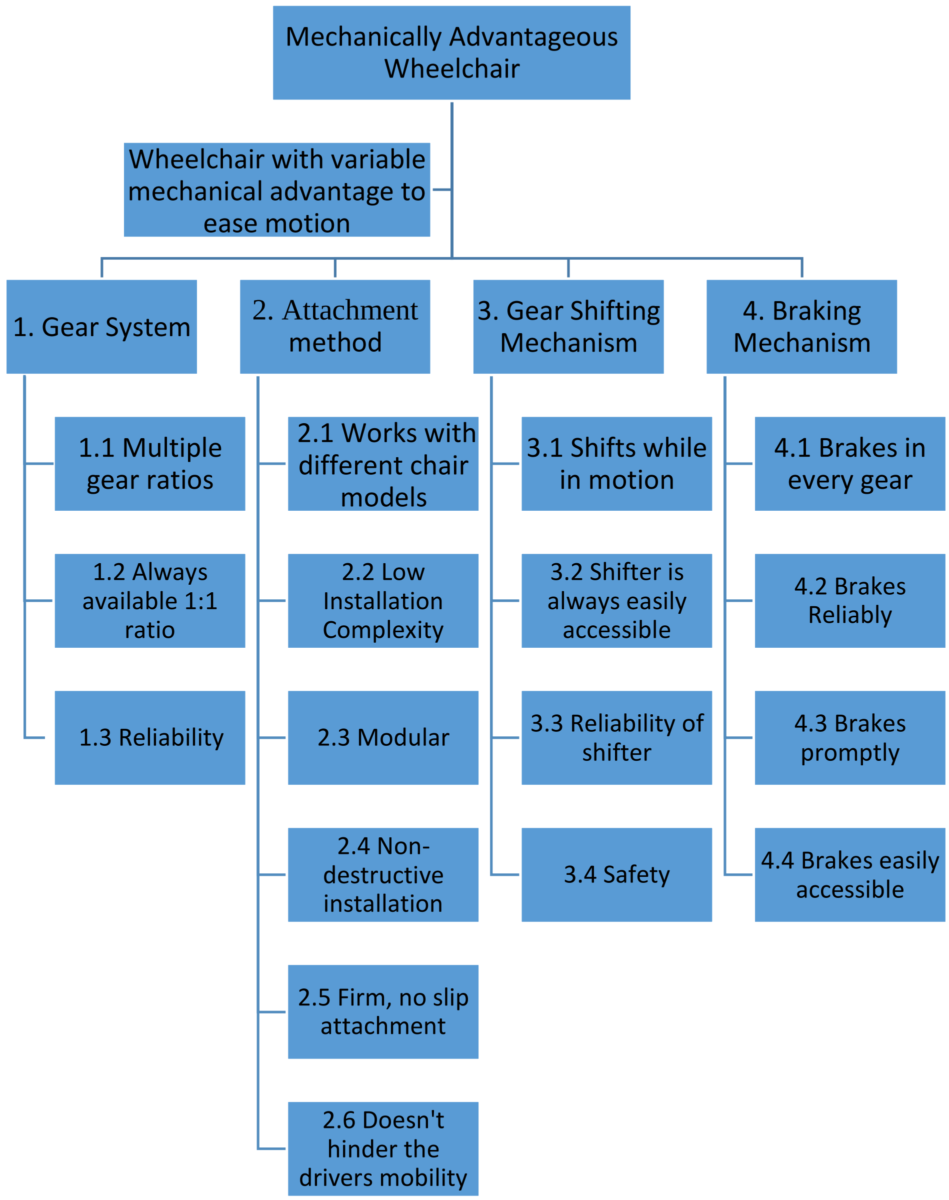


Figure 1 Operational Requirements

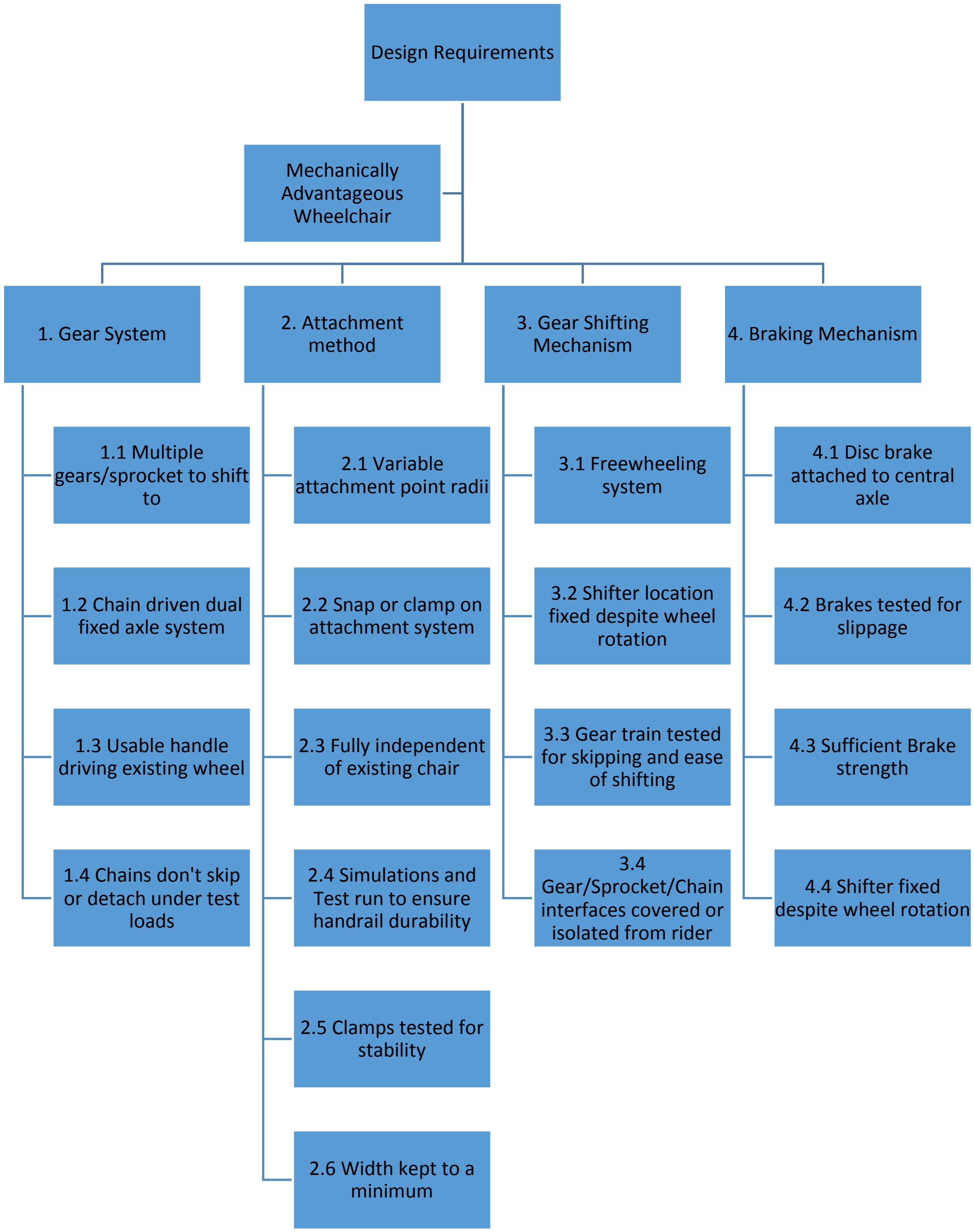


Figure 2 Design Requirements

3.1.2 Four concept drawings

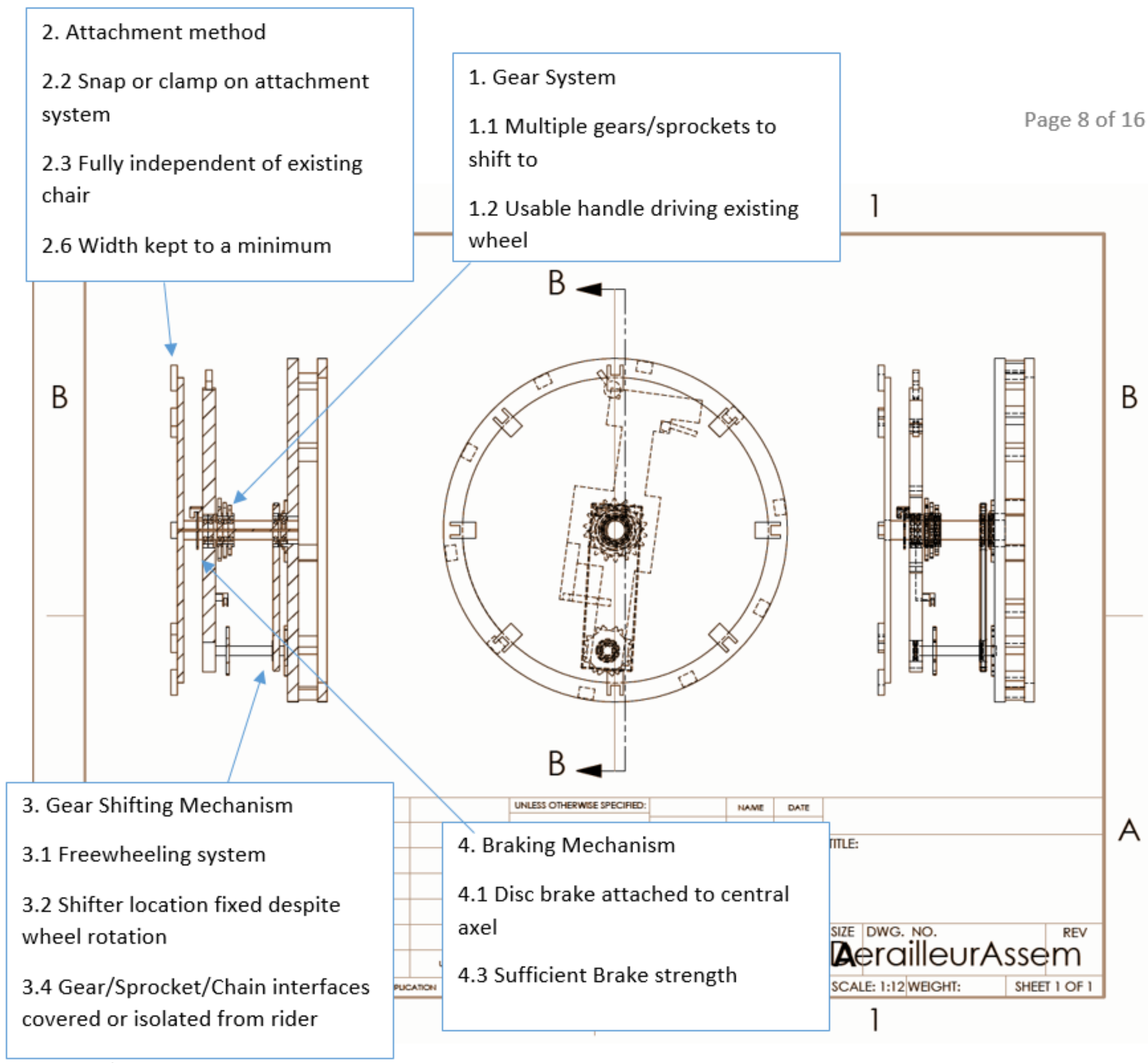


Figure 3 Concept drawing with functional allocations for Derailleur concept

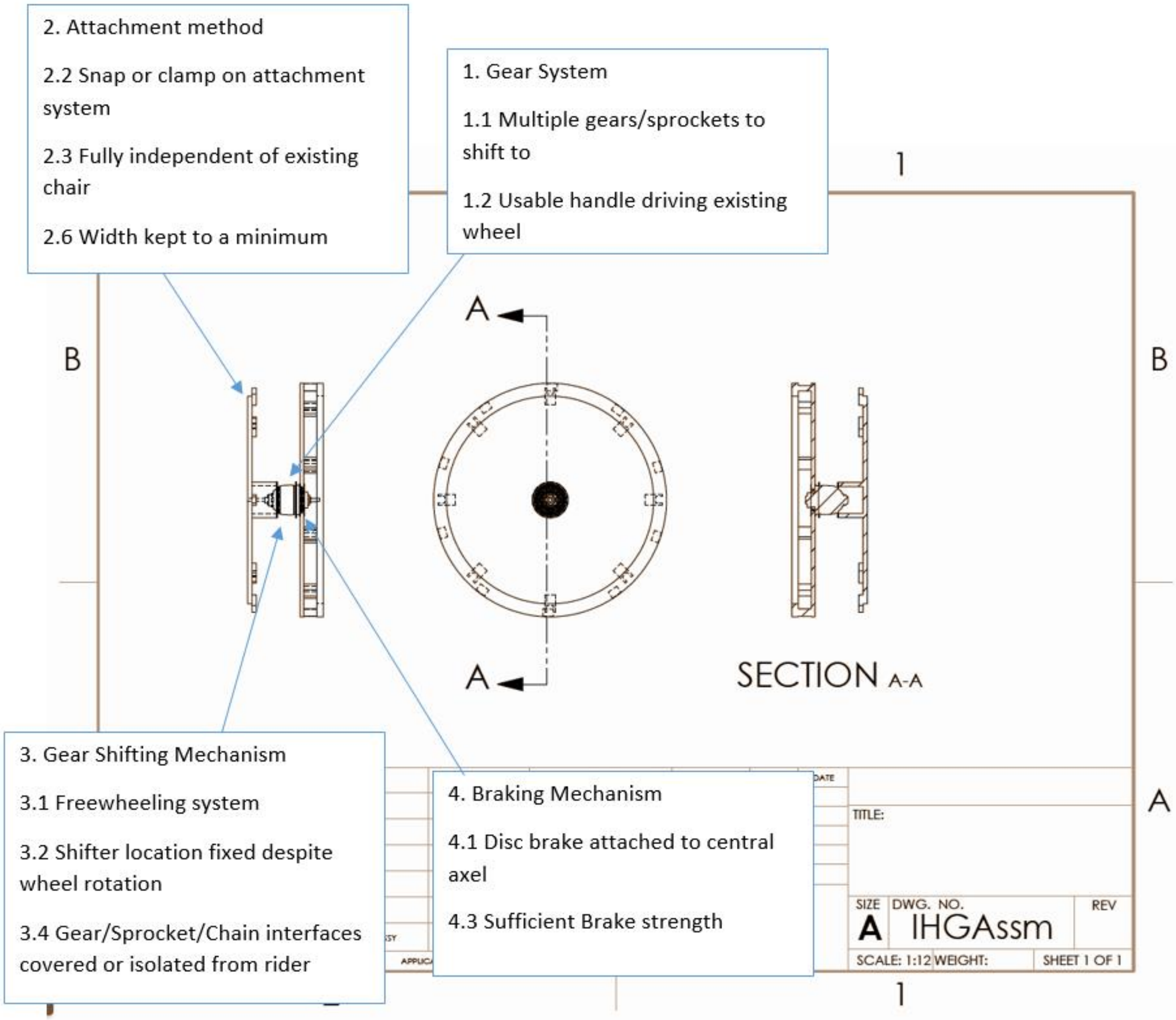


Figure 4 Concept drawing with functional allocations for Sturmey Archer Hub concept

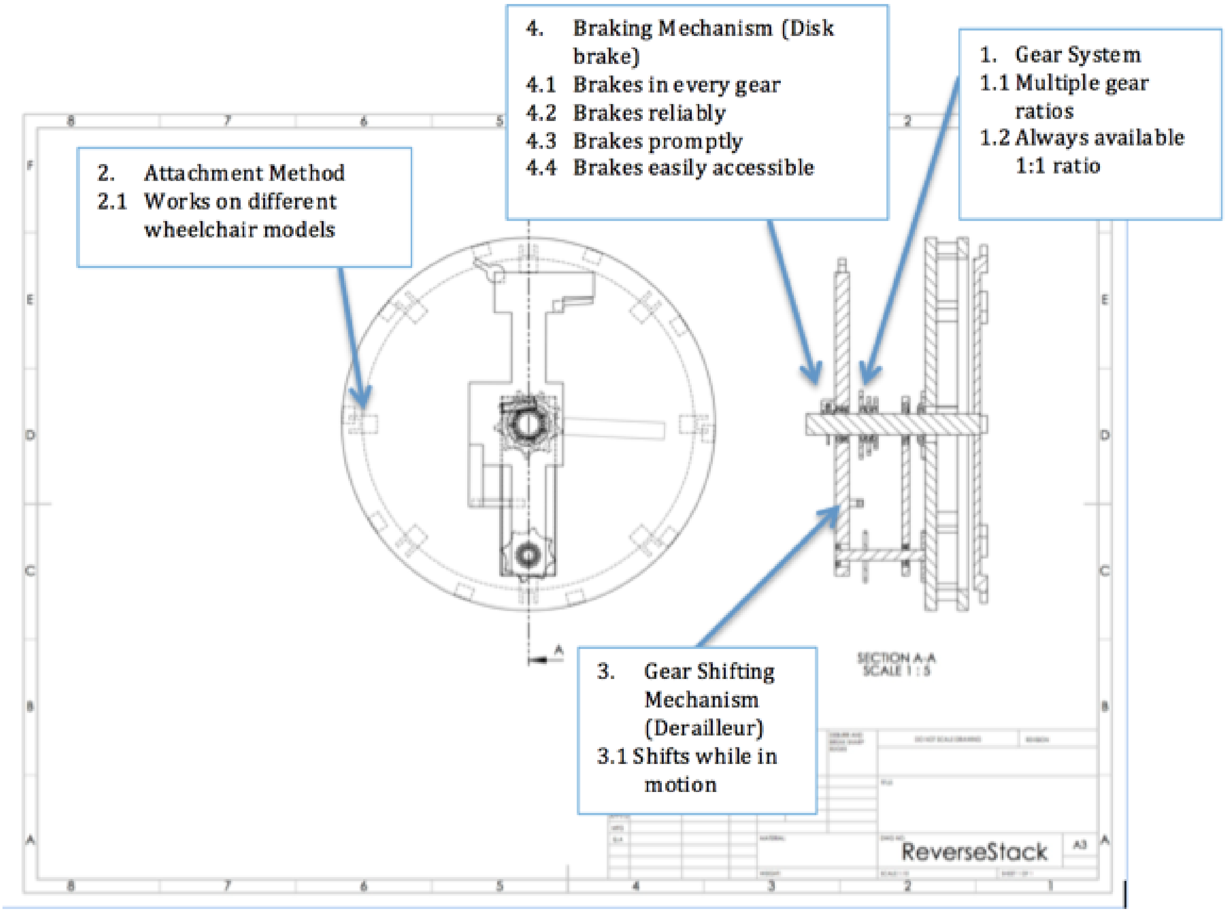


Figure 5 Concept drawing with functional allocations for Reverse Stack concept

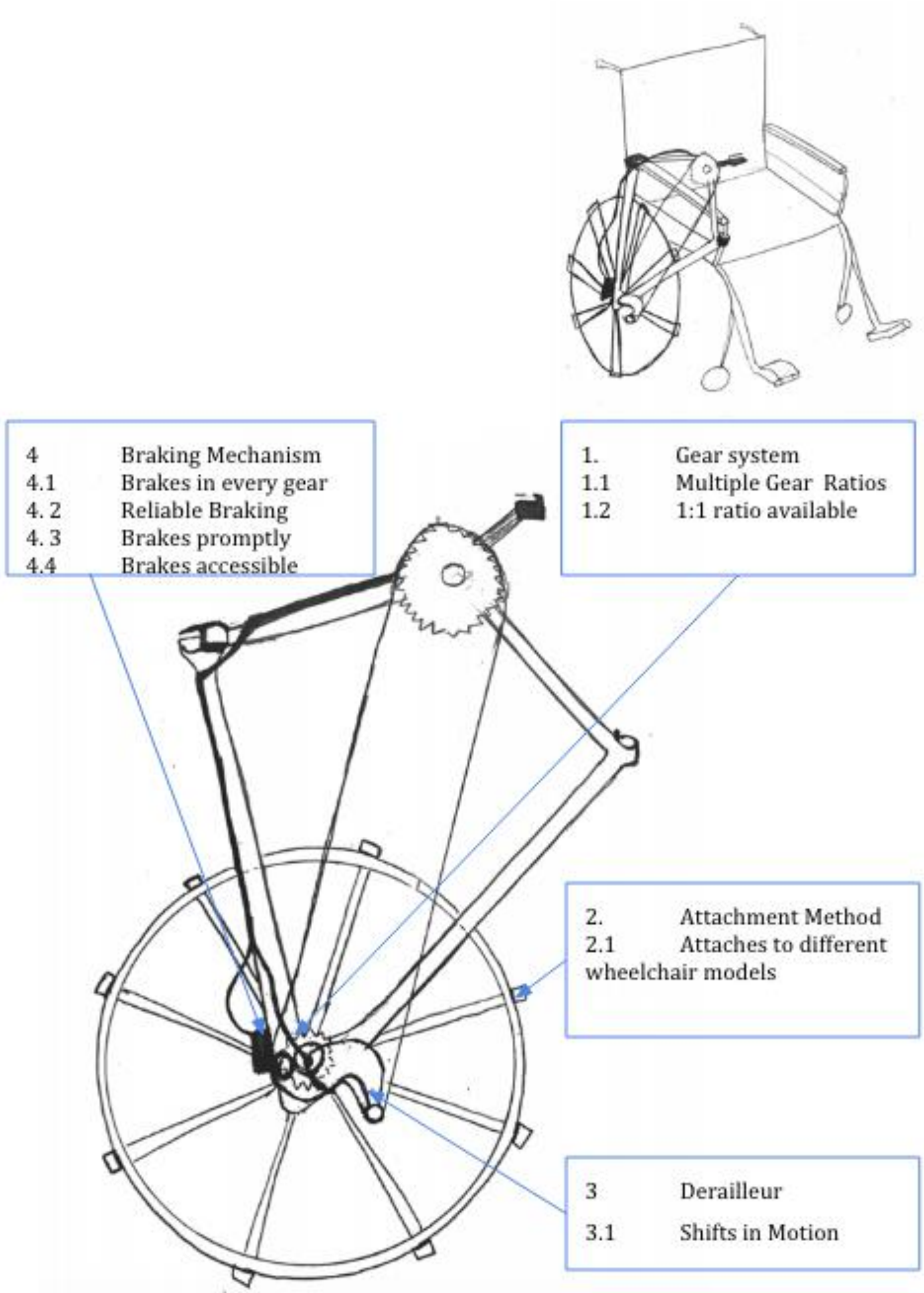


Figure 6 Concept drawing with functional allocations for chaircycle concept

3.2 CONCEPT SELECTION PROCESS

3.2.1 Preliminary analysis of each concept's physical feasibility based on design requirements, function allocation, and functional decomposition

Derailleur Concept

This concept has a high feasibility. When this design was presented to the class, the majority (54%) of the class rated it as 4 for feasibility. Most of the risks associated with this is concept center around the gear system and the shifting mechanism. Without a reliable system that allows users to shift easily from one gear to another, the final product will not have any added benefits over a standard manual wheelchair. This concept is possible because it draws heavily from a multi-speed bike, a system that reliably shifts between gears even after many uses. Since multi-speed bikes must withstand harsh, outdoor weather, the gear and shifting mechanism will be ideal for customers who use their chair in a variety of weather. Also, the bike gear systems allow users to shift in motion, a critical operational requirement of our design. This concept would use bike parts such as gears and chains. In addition, this concept relies on two derailleurs. Since derailleurs can be expensive, it can be considered a special design requirement. Also, this design requires two disk brakes. This could be classified as a special design requirement since the disk brakes will need to be able to stop a large force. Some design restraints include keeping the width to a minimum. As mentioned in the customer interview, wheelchairs are already difficult to maneuver in tight spaces and any additional width would create an extra hindrance for the user. Another design constraint is keeping the shifter fixed while the wheels are moving.

Hub Concept

This concept is feasible because it integrates a Sturmey Archer 3-speed hub, a reliable, commonly used bike part, into a wheelchair. Since the gear system is already assembled within the hub, it's less complex than the other concepts which involve more parts. Less parts means less additional width. As seen in the customer interview, keeping the width at a minimum is of high importance to users since added width makes steering a wheelchair in tight spaces difficult. Another benefit of this concept is that the gear system resides inside the hub. This aligns with the design requirement for having a protective covering over the gearing (Design Requirement 3.4). One risk this concept has is converting the hub to work on the left wheel since these hubs are designed to mount to the right side of a bike. Using a right hub on the left wheel would result in the left wheeling moving backwards. Thus, this concept needs a flip-flop hub, a special design requirement. Some special design requirements include two Sturmey Archer 3-speed hubs. The concept depends on these hubs to provide a reliable gear system that shifts while in motion. The minimal width design constraint applies to this concept. Another design constraint associated with this concept is ensuring that the brakes and shifter are easily accessible. Since this design involves an internal bike hub, the concept is constrained to gear ratios in the hub. Thus, this concept offers less customization than concepts with an external gear system. That lack of customization might restrict the options of where to place the shifter and the brake.

Reverse Stack Concept

The Reverse Stack Concept is a feasible design because it uses reliable bikes parts such as a gearing system, chain, and derailleur (shifting mechanism). This concept draws heavily from the Derailleur concept. The difference between this concept and the Derailleur concept is the placement of the input wheel. The Reverse Stack Concept has the input wheel closer to the wheelchair with the gear system and shifter on the other side of the input wheel. Since the class scored the Derailleur concept high in feasibility, it is reasonable to conclude the class would also find this concept highly feasible. Risks associated with this concept include gear system failures such as inability to shift or a dislodged chain. Also, since the gear system and the shifter are on the outer ends of the wheelchair and not protected by the input wheel, there is a risk of the gear system getting bumped and damaged. Special design requirements for this concept include two derailleurs because each wheel needs a mechanism to shift between gears. Another special design requirement for this concept is two disk brakes. Since this brakes must stop the weight of a person and a chair moving faster than usual, these disk brakes will have to stop a large force. Also, these brakes need to be able to withstand wear. Some design constraints for this concept are minimal width and keeping the shifter fixed while the wheels rotate.

Chaircycle Concept

The chaircycle concept draws directly from a multi-speed bicycle, allowing feasible constructability and reliability. This design attaches to the existing wheelchair push rim and armrest, allowing for a user sitting in the upright position to intuitively use of the drive crank, gear shifting, and brakes. The repurposing of materials from a bicycle will reduce the cost of manufacturing custom components, provide flexibility in gearing systems and ratios, and ensure the quality needed to operate and withstand varying weather conditions. An assortment of braking systems may be used, similar to the variety provided in the bicycle market such as disk, rim, or drum systems. Because we are seeking to use a gearing and braking system on a freewheel mechanism, there is a risk of cable winding in the other designs. However, this design runs the braking and derailleur cable along the frame of the attachment while never interfering with the moving components. Two of the chaircycle attachments will be required and a flip-flop hub will aid in the correct rotational direction of the bicycle cassette. The risk of this design is the added weight involved with the larger attachments and the increased attachment time. The added weight and time in this design, increases the exertion of the user, and therefore the target consumer audience may need to be altered to an audience seeking a fitness commodity.

3.2.2 Concept scoring

Table 1 Design metrics list

Need Number	Need	Importance
1	Multiple Gear Ratios	5
2	1:1 ratio always available	4
3	Gearing is Reliable	5
4	Works across chair models	2
5	Low installation complexity	3
6	Modular	4
7	Doesn't Hinder Chair Mobility	4
8	Shifts in Motion	4
9	Easy to Use	3
10	Brake are Reliable	5
11	System is Safe	5

Concept Scoring

Table 2 Derailleur concept scoring

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	7	Width added to chair	in	6	0	6	0
2	1	Number of Gears	Integer	2	6	3	0.25
3	3	Gearing Failure Risk	%	1	0	0.2	0.8
4	4	Attachment Radius Range	in	0	5	4	0.8
5	5	Removal/Install Time	sec	0	100	60	0.6
6	3	Max Handle Pull Force	lb	10	50	30	0.5
7	9, 3	Shift Time	sec	1	0	0.5	0.5
8	11	Number of Exposed Gears	Integer	3	0	1	0.667
9	10	Brake Time	sec	3	0	1	0.667
10	2	1:1 Driver Always Available	Binary	0	1	1	1
11	8	Shifts in Motion	Binary	0	1	1	1
12	6	Modular	Binary	0	1	1	1
						TOTAL	7.784

Table 3 Hub concept scoring (selected concept)

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	7	Width added to chair	in	6	0	4	0.333
2	1	Number of Gears	Integer	2	6	3	0.25
3	3	Gearing Failure Risk	%	1	0	0.05	0.95
4	4	Attachment Radius Range	in	0	5	4	0.8
5	5	Removal/Install Time	sec	0	100	60	0.6
6	3	Max Handle Pull Force	lb	10	50	30	0.5
7	9, 3	Shift Time	sec	1	0	0.2	0.8
8	11	Number of Exposed Gears	Integer	3	0	0	1
9	10	Brake Time	sec	3	0	1	0.667
10	2	1:1 Driver Always Available	Binary	0	1	1	1
11	8	Shifts in Motion	Binary	0	1	1	1
21	6	Modular	Binary	0	1	1	1
						TOTAL	8.9

Table 4 Reverse stack concept scoring

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	7	Width added to chair	in	6	0	5	0.167
2	1	Number of Gears	Integer	2	6	3	0.25
3	3	Gearing Failure Risk	%	1	0	0.3	0.7
4	4	Attachment Radius Range	in	0	5	4	0.8
5	5	Removal/Install Time	sec	0	100	60	0.6
6	3	Max Handle Pull Force	lb	10	50	30	0.5
7	9, 3	Shift Time	sec	1	0	0.3	0.7
8	11	Number of Exposed Gears	Integer	3	0	2	0.333
9	10	Brake Time	sec	3	0	1	0.667
10	2	1:1 Driver Always Available	Binary	0	1	1	1
11	8	Shifts in Motion	Binary	0	1	1	1
12	6	Modular	Binary	0	1	1	1
						TOTAL	7.717

Table 5 Chaircycle concept scoring

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	7	Width added to chair	in	6	0	6	0
2	1	Number of Gears	Integer	2	6	3	0.25
3	3	Gearing Failure Risk	%	1	0	0.2	0.8
4	4	Attachment Radius Range	in	0	5	4	0.8
5	5	Removal/Install Time	sec	0	100	60	0.6
6	3	Max Handle Pull Force	lb	10	50	40	0.75
7	9, 3	Shift Time	sec	1	0	0.1	0.9
8	11	Number of Exposed Gears	Integer	3	0	2	0.333
9	10	Brake Time	sec	3	0	1	0.667
10	2	1:1 Driver Always Available	Binary	0	1	1	1
11	8	Shifts in Motion	Binary	0	1	1	1
12	6	Modular	Binary	0	1	1	1
						TOTAL	8.1

3.2.3 Final summary

Ultimately, we decided to choose the hub shifter design as our winning concept. This was based on a number of factors. First, the hub shift scored better than the other concepts in the preliminary design evaluation.

While that is not a concrete indication of success, it suggests that this design would have the best performance. Second, the hub design is the only design that has no exposed gearing components, meaning that it is the only design that comes with no potential safety risks, which is a significant point in its favor. Finally, it has a lower design complexity than the other concepts, meaning that it will be easier to construct and more likely to be successful, particularly given the very limited time we have to construct a functioning prototype. The fact that it relies upon a purchased part might drive up the cost some. However, since we are certain that the part will function, that will reduce the risk associated with the purchase, meaning that it might end up being a better investment if the other gearing systems don't work out. This additional reliability also helps to limit the time we might spend on rebuilds, which will also help us stay within the narrow time budget.

3.3 Proposed Performance Measures for the Design

- Will have at least two gear ratios, one of them at 1:1, that can be switched between by the rider
- Will have an adjustable attachment radius of at least 3 in
- Will have an installation time of less than 90 sec
- Will have a removal time of less than 90 sec
- Will require only 2 tools to be installed
- Will do no damage to the existing chair upon installation
- Will not slip under a load of 40 lb
- Will add no more than 4 in. of width to the existing chair body
- Gearing will fail no more than 0.2% of the time
- Gear shifting will take no more than 1 sec
- Gear system will have no exposed gears
- Brake time will be no more than 3 seconds under high operating speeds
- The entire device will weigh no more than 10 lb
- Handrail will not break under a 100 lb
- Shifter will function while the unit is in motion
- Brakes will stop the chair at maximum operating speed
- Brakes and shifter control will remain accessible at all times
- Gearing system will be covered or at least 8 in. away from operator at all times
- Operator will be able to comfortably use the chair for 12 hours at a time
- Will cost no more than $250 to produce

3.4 Design constraints

3.4.1 Functional

We require the device to withstand 100 lb-ft of user applied input torque. The original motion of the wheelchair should not be compromised. The motion of the input plate and the wheelchair wheel should be simultaneous. The gear system must be able to shift in motion and remain in the correct gear. The materials should remain rigid while reducing the total weight as much as possible.

3.4.2 Safety

The device should not compromise static or dynamic stability. Sharp edges and exposed moving parts should be avoided. User must be able to provide or resist motion to the wheelchair at all times.

3.4.3 Quality

The static stability should not be reduced as a result of the added device. User should be able to shift reliably between all three gears while both stationary and in motion. The U-bolts used to attach the device should not fail more than 0.005%.

3.4.4 Manufacturing

All fasteners should be tool tightened. Tolerances for the hybrid attachment plates must be ±0.005 in.

3.4.5 Timing

All stages of the project must be completed by the end of a semester. Design must be finalized before the engineering analysis is completed. The engineering analysis must be completed before the prototype is manufactured.

3.4.6 Economic

The final cost of the prototype must be below budget. External manufacturing is unavailable.

3.4.7 Ergonomic

The prototype must retain original motion of the wheelchair and intuitive use. The shifter location should be easily accessible and operated. The distance between the user and the input plate should not exceed the average arm length of users.

3.4.8 Ecological

Materials used should be non-toxic and not cause significant pollution in their manufacture.

3.4.9 Aesthetic

The rim of the input wheel should provide a gripped feel, remain relatively smooth. The color scheme and graphic patterns of the device should appear gender neutral.

3.4.10 Life cycle

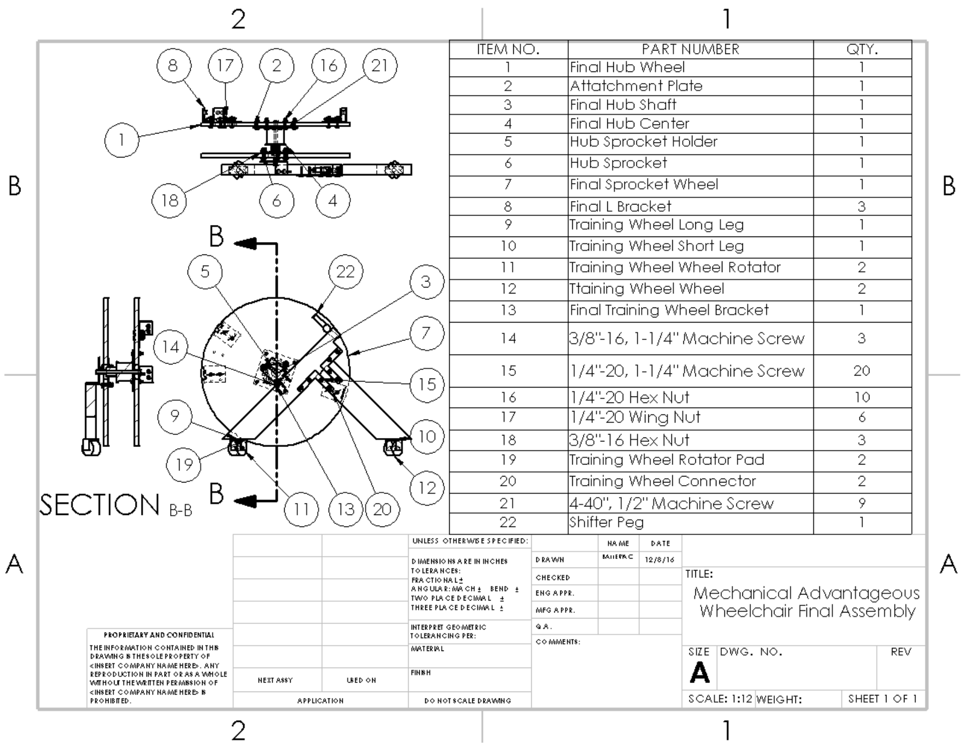
The device should be able to be disassembled and reassembled for transportation. The life of the device should be no less than 20 years. Device should not require maintenance or servicing more than once a year.

3.4.11 Legal

The design should significantly differ from competitors and comply with ADA.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT DRAWING



ITEM NO.	PART NUMBER	QTY.
1	Final Hub Wheel	1
2	Attatchment Plate	1
3	Final Hub Shaft	1
4	Final Hub Center	1
5	Hub Sprocket Holder	1
6	Hub Sprocket	1
7	Final Sprocket Wheel	1
8	Final L Bracket	3
9	Training Wheel Long Leg	1
10	Training Wheel Short Leg	1
11	Training Wheel Wheel Rotator	2
12	Ttaining Wheel Wheel	2
13	Final Training Wheel Bracket	1
14	3/8"-16, 1-1/4" Machine Screw	3
15	1/4"-20, 1-1/4" Machine Screw	20
16	1/4"-20 Hex Nut	10
17	1/4"-20 Wing Nut	6
18	3/8"-16 Hex Nut	3
19	Training Wheel Rotator Pad	2
20	Training Wheel Connector	2
21	4-40", 1/2" Machine Screw	9
22	Shifter Peg	1

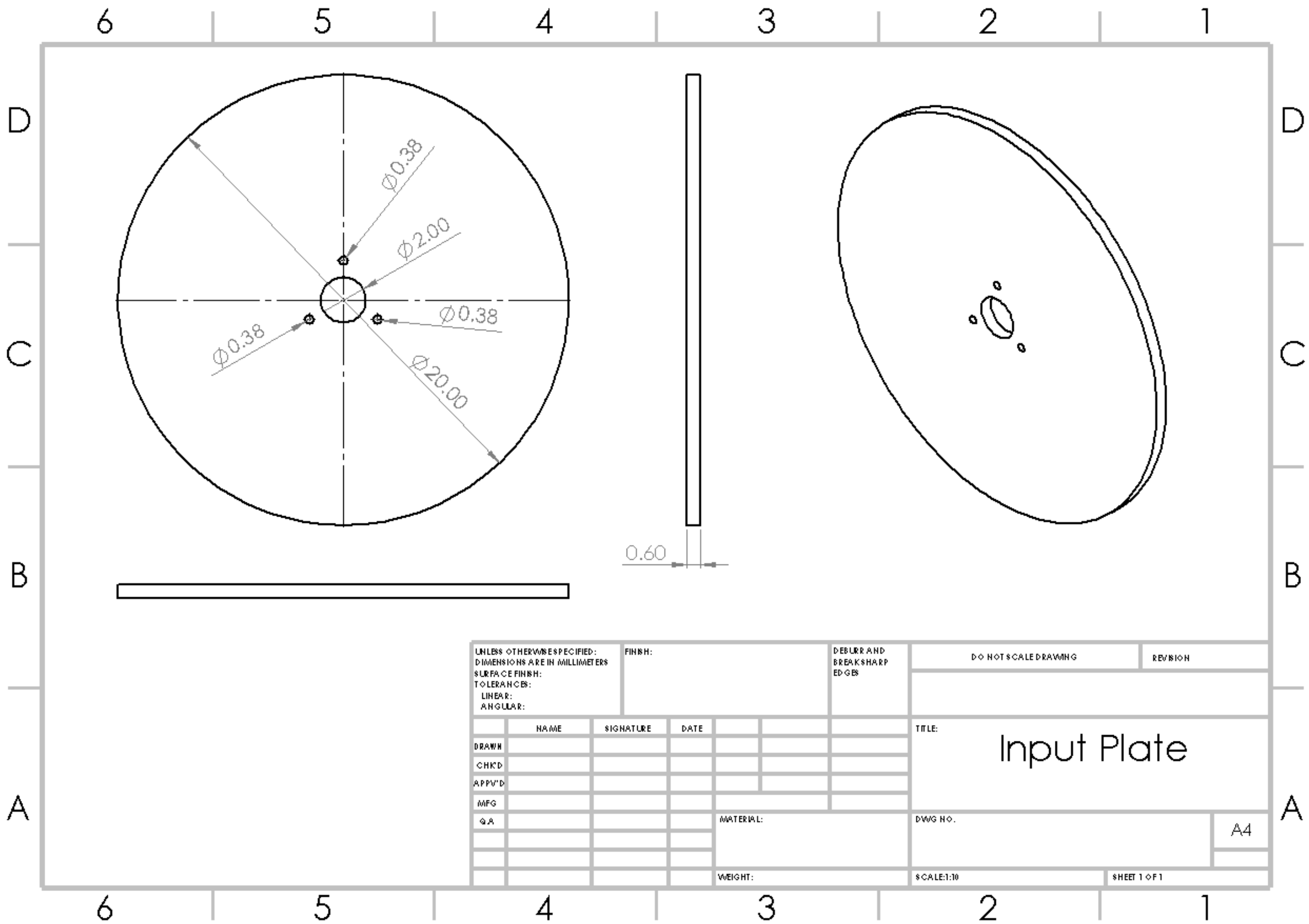
4.2 PARTS LIST

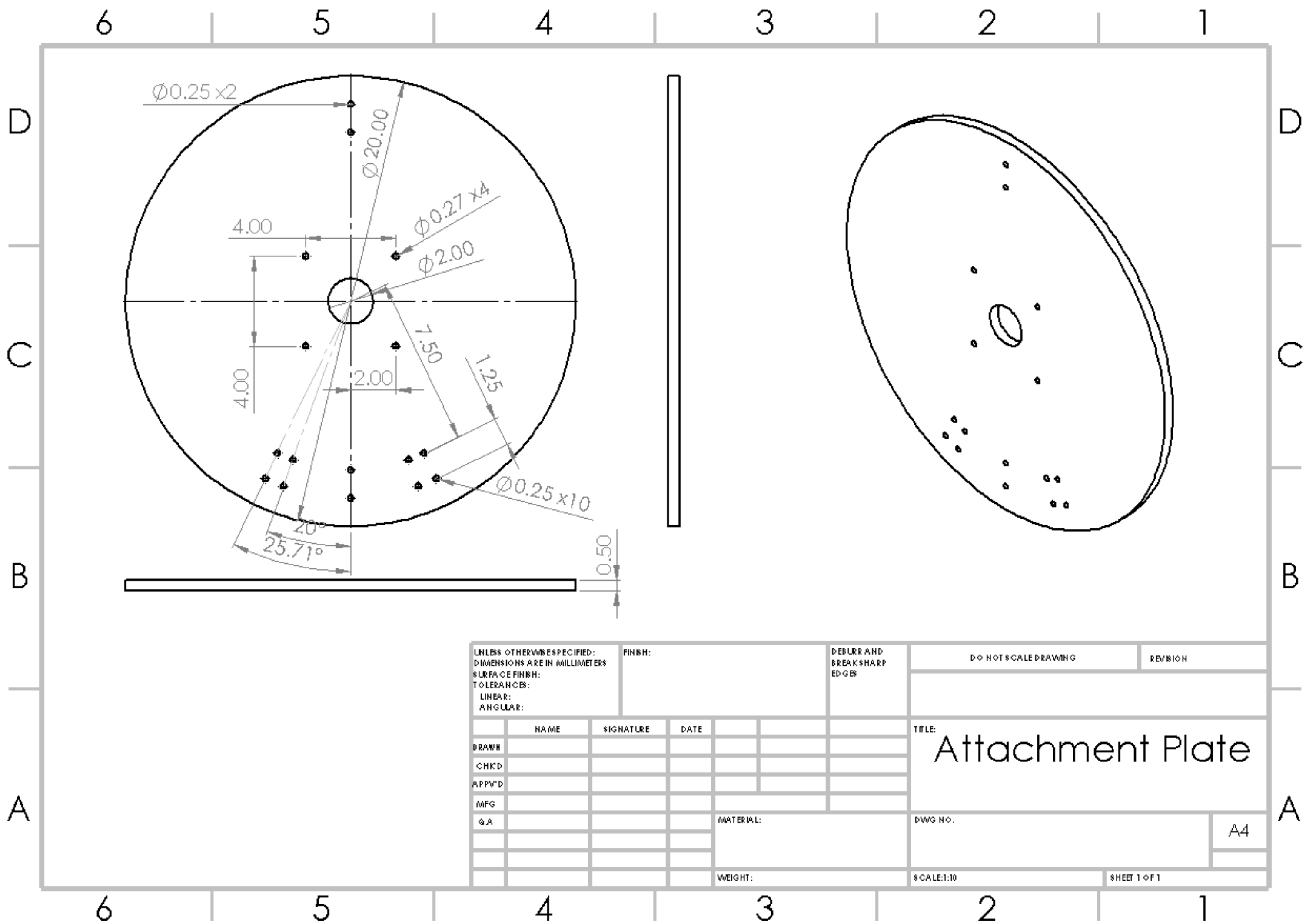
Please see next page.

	Part	*Source Link*	*Supplier Part Number*[CB1]	*Color, TPI, other part IDs*	*Unit price*	*Tax ($0.00 if tax exemption applied)*	*Shipping*	*Quantity*	*Total price*
1	Aluminum sheet metal 1/4”	Machine Shop	Supplied	NA	0	$0.00	$0.00	4	$0.00
2	Wood	MEMS basement							$0.00
3	Tubing	MEMS basement							$0.00
4	Sturmey Archer hub	Jenson USA		NA	$142.49	$0.00	$6.99	2	$291.97
5	4-40 steel screws	McMaster Carr	91772A110	NA	$13.81	$0.00	$2.76	1	$16.57
6	4-40 steel hex nut	McMaster Carr	90480A005	NA	$0.87	$0.00	$1.62	1	$9.72
7	1/4”-20 hex nuts	McMaster Carr	95462A029	NA	$4.40	$0.00	$0.88	1	$5.28
8	1/4”-20 hex head screws, 3/4” long	McMaster Carr	90401A540	NA	$12.06	$0.00	$2.41	1	$14.47
9	1/4"-20 steel wing nuts	McMaster Carr	90866A029	NA	$10.29	$0.00	$2.06	1	$12.35
10	1/4"-20 U-bolts	McMaster Carr	3043T639	NA	$0.65	$0.00	$0.13	6	$4.03
11	1/4”-20 hex screw with washer	McMaster Carr	90401A542	NA	$9.13	$0.00	$1.83	1	$10.96
12	Sprocket	Big Shark Bicycle Shop	NA	NA	$30.00		NA	1	$30.00
13	Tension Cables and Connector	Big Shark Bicycle Shop	NA	NA	$8.00		NA	2	$16.00
14	Sprocket	Mikes Bikes	NA	NA	$8.00		NA	2	$21.94
Total:									$433.29

*Note: McMaster Carr does not provide shipping costs. Numbers above are estimates.

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PARTS





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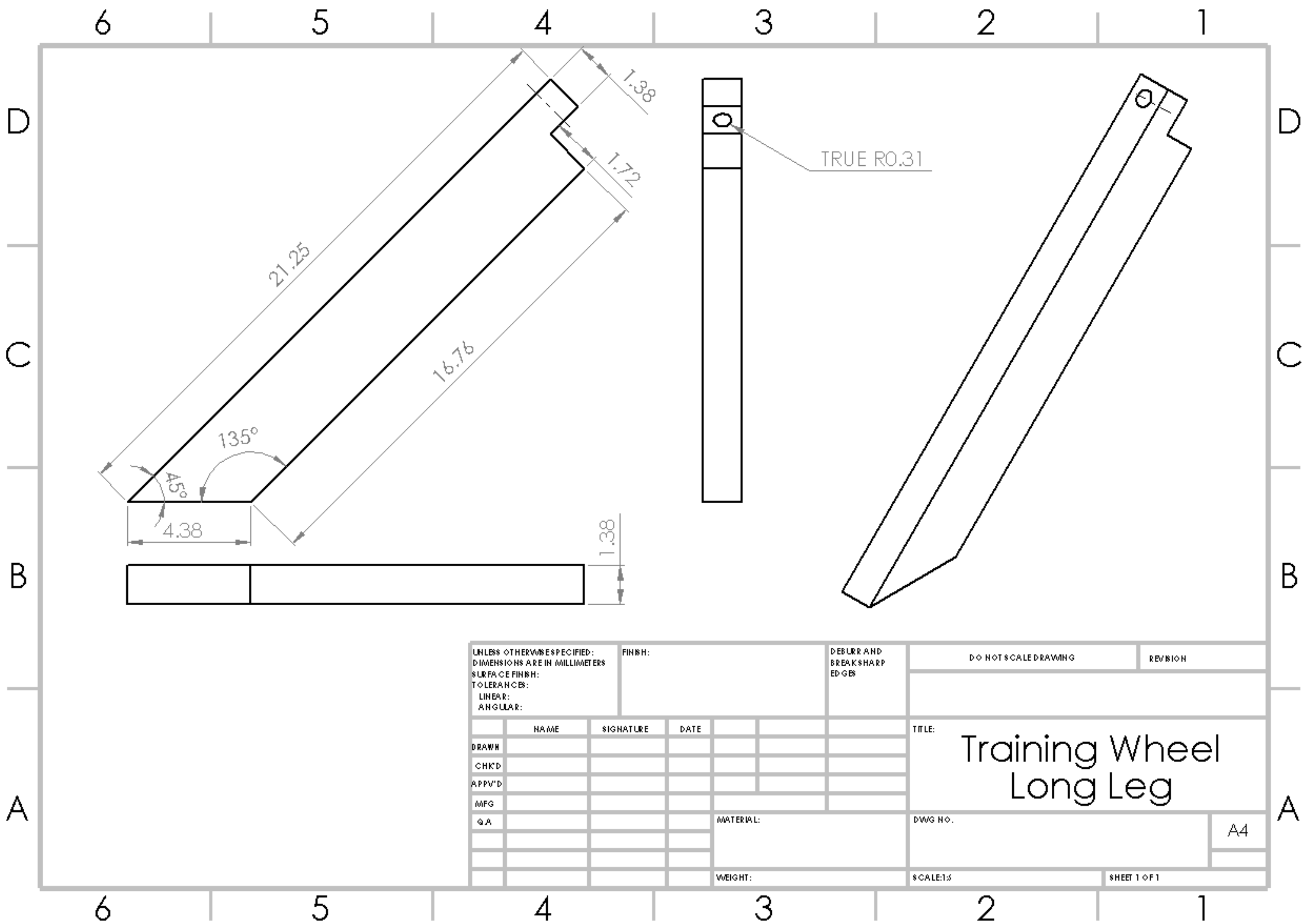
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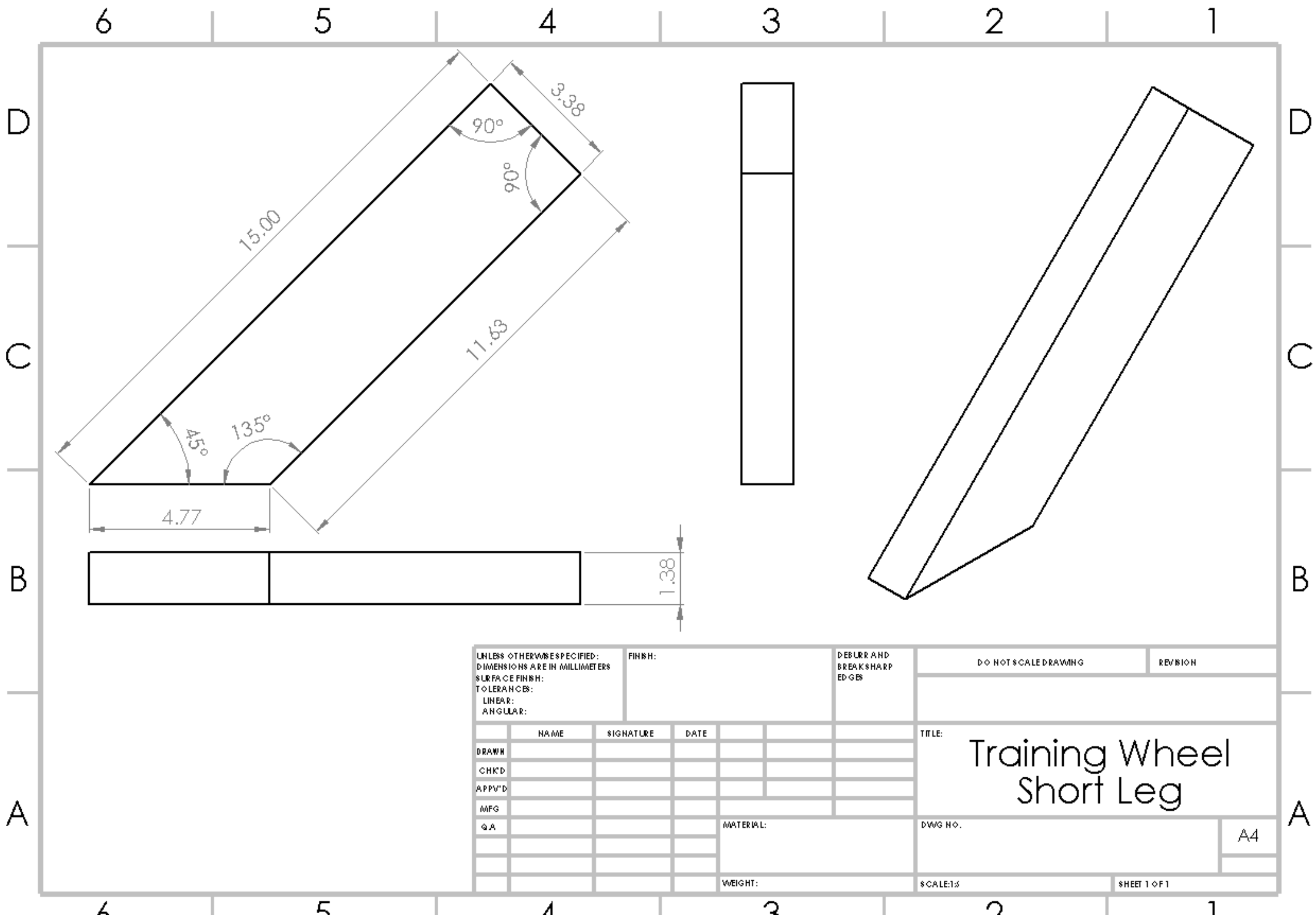
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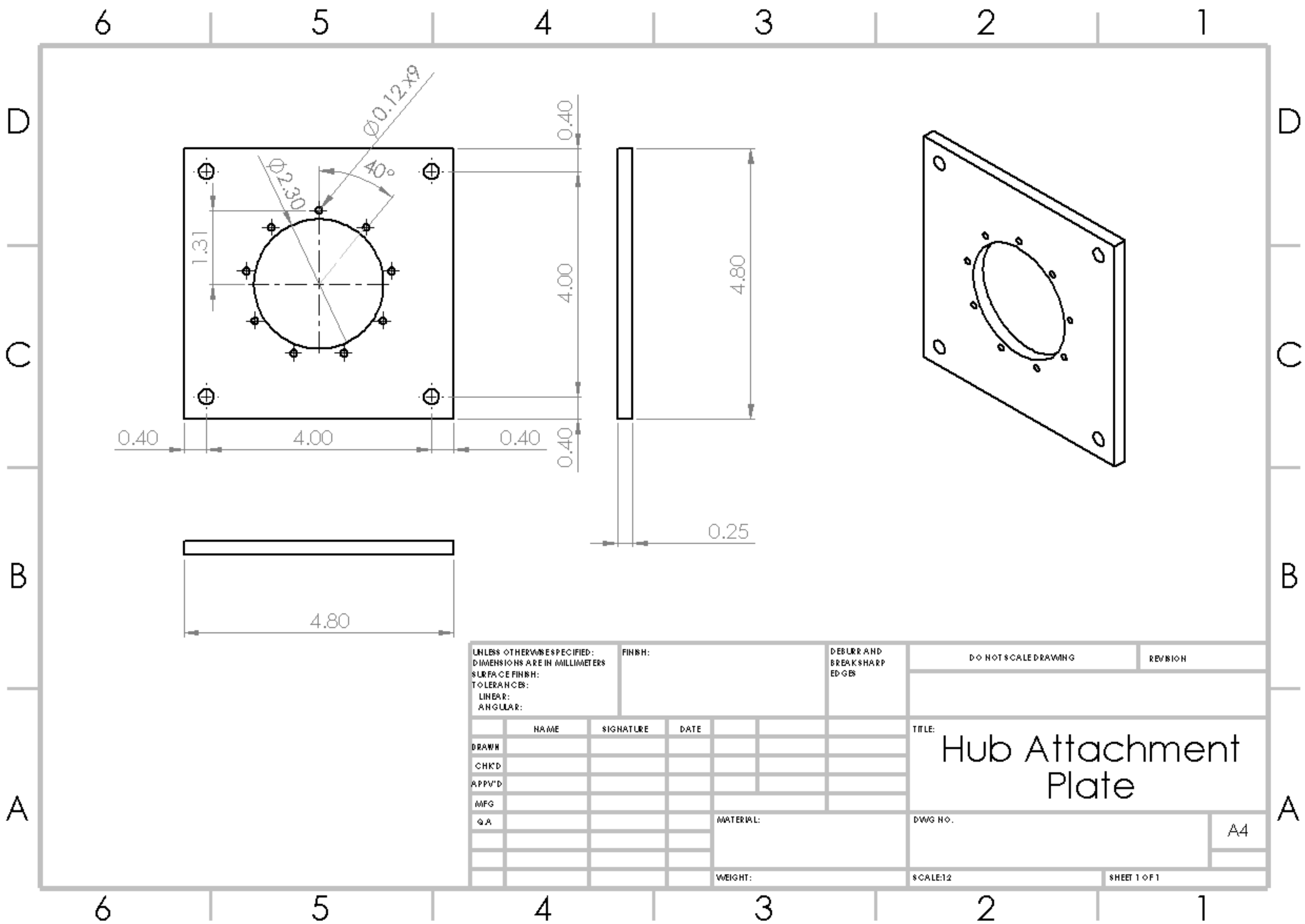
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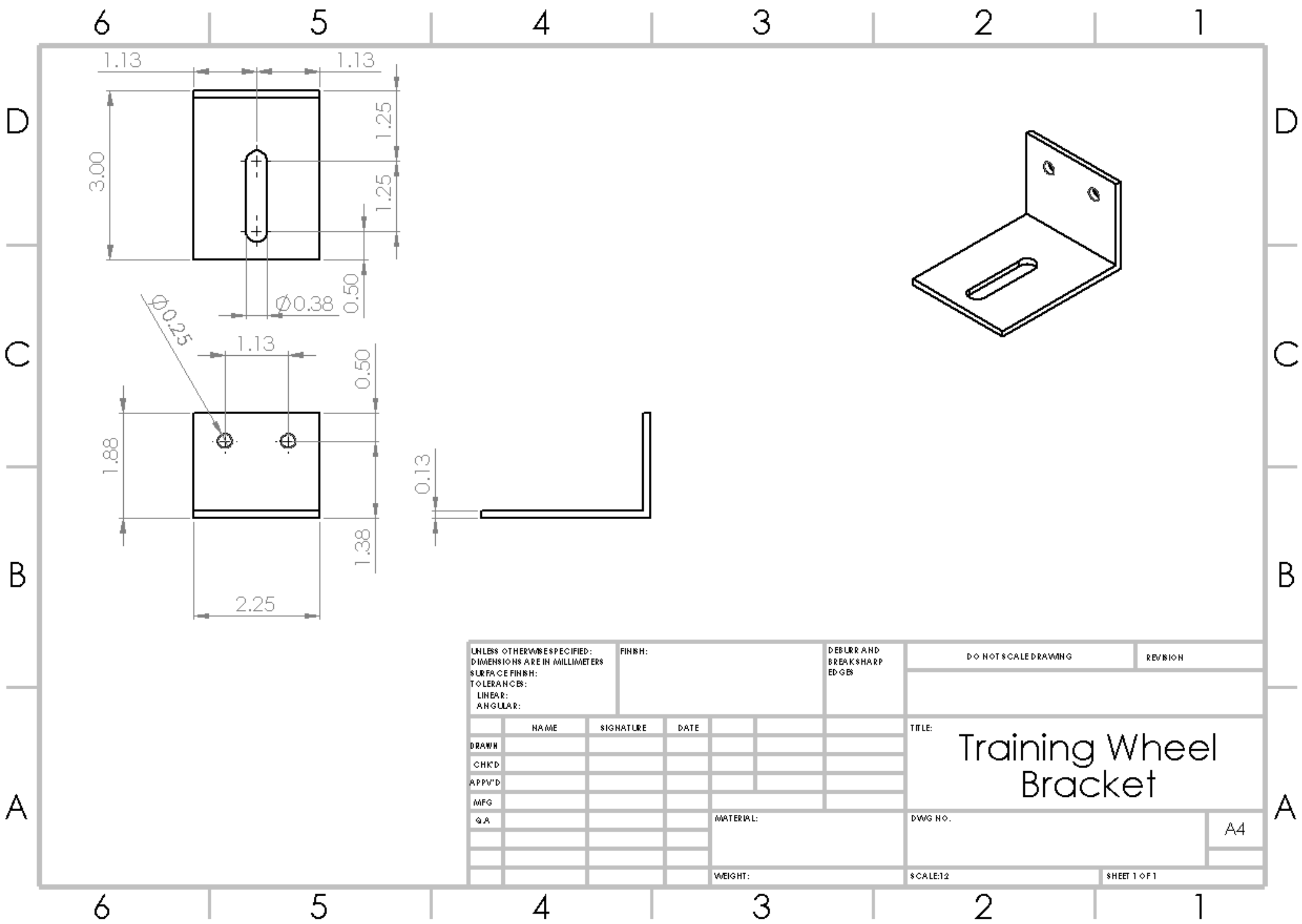
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WEIGHT:
SCALE:1:2
SHEET 1 OF 1

4.4 Description of the Design Rationale for the Choice/Size/Shape of Each Part

Assembly Drawing 1	Assembly Drawing 2	Name	Design Rational
#2, #6	**#7, #11**	U-Bolts and Wing Nuts	The 1/4"-20 steel U-bolts were chosen because it makes the product attachable. Their bends fit nicely around the pegs connecting the original push rim to the wheelchair. The wing nuts were chosen because they will secure the Angles (which are bolted to the Attachment Plate) to the U-bolts. Also, the wings will it make it easier for the user to tighten or remove the product.
#8, #14	**#12, #4**	Bolts and Nuts	The 1/4"-20 hex head steel bolts and nuts were selected because they will securely attach the Angles to the Attachment Plate. The bolts are 3/4" long so they will be able to fit through two 1/8" plates and still have enough room for the nut.
#13	**#17**	PVC pipe push rim	PVC pipe was selected as the material for the push rim because it is cost effective, lightweight, strong, and malleable when heated. To create the circular push rim, the material needed to be easy to mold, but also durable. The PVC pipe is bolted to the Input Plate and the nut is placed inside the pipe for aesthetic purposes. The 1" diameter pipe was chosen because there needs to be enough room to screw on the nut.
#5	**#10**	Internal Hub	The S-RF3 3 Speed Sturmey Archer hub was selected based on its cost, size, and

			performance. The hub is relatively small which is desirable because it minimizes the width of the wheelchair. Since it was critical that the hub work reliably, a Sturmey-Archer hub was chosen based off the manufacture's reputation for quality hubs. The gear ratios are 75%, 100%, and 133%. A freewheeling hub was chosen because it can be converted to a fixed hub and is less expensive than a fixed hub.
#7, #8	**#14, #15**	Screws and Nuts	18-8 stainless steel pan head screws were chosen to attach the internal hub to the attachment plate because they are small enough to fit into the existing holes in the hub’s flange. The screws are 1/2" long. The nuts were chosen because they are larger than the holes in the hub and will act as a stop and, thus, secure the attachment plate to the hub.
#12	**#12**	Tee bars	PVC Tee bars were chosen because they provide the most aesthetically pleasing method for attaching the PVC pipe to the Input Plate. Rather than bolting each piece of pipe twice (a total of 6 bolted connections), bolting the tee bars (3 bolted connections) provides the same stability but with less fasteners. The pipes will be glued to the connectors.

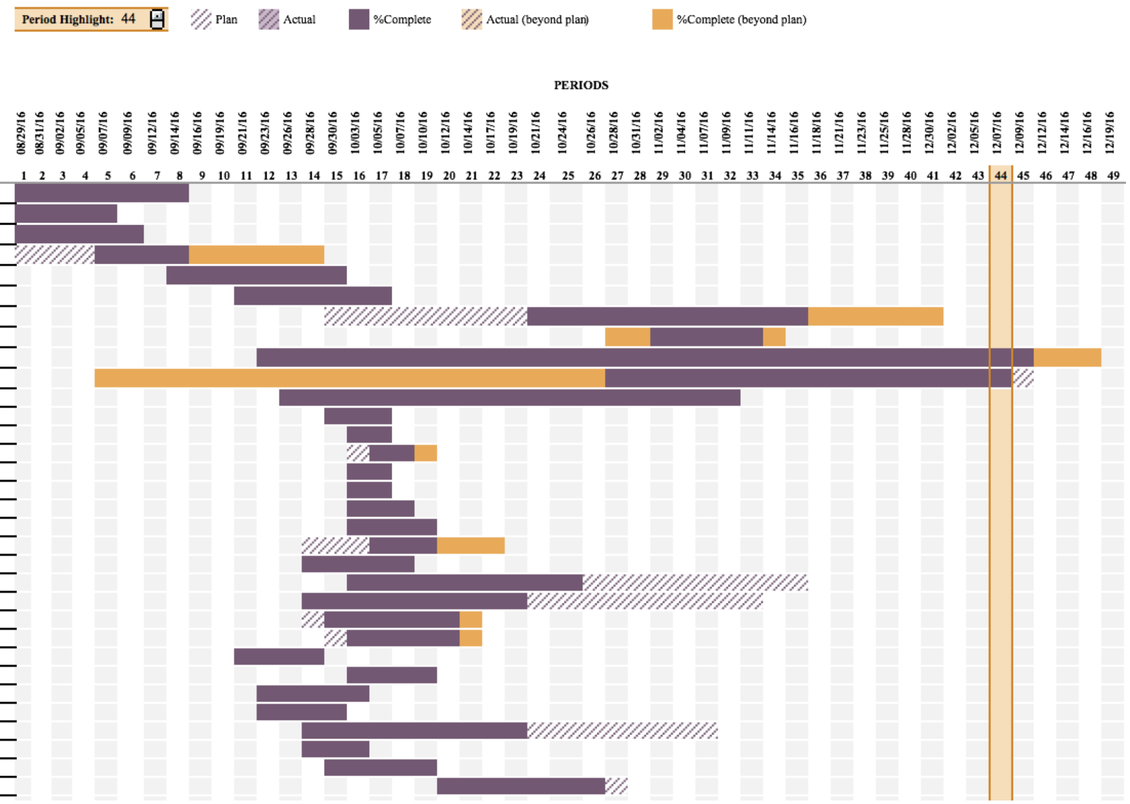
#9	**#9**	Input Plate	The Input Plate is made of 1/8” aluminum sheet metal. The 3 spoke design was chosen because it reduces weight, and also provides attachment points for the PVC pipe push rim.
#3	**#3**	Attachment Plate	The Attachment Plate is made out of 1/8” aluminum sheet metal. As opposed to a solid shape, a 6 spoke design was chosen to reduce weight. The “bowtie” shape was carefully chosen in order to make the product attachable to various models of wheel chairs. Since the number of pegs (features that connect the original push rim to the drive wheel) and angle between pegs vary between wheelchairs, the Attachment Plate has several different hole patterns. The distance between the holes patters are not uniform because some wheelchairs have pegs that are not uniformly spaced.
#4	**#9**	Angle	The Angles are made out of 1/8” aluminum scrap metal from the Attachment Plate and the Input Plate. Angles were selected because they provide a simple, cost-effective way to join parts.
NA	**#5**	Clamp	This is made from the scrap aluminum sheet metal. Its size is based off the size of the posts that compose the wheelchair frame. It

			was selected because it is the simplest way to attach the Cable Guide to the wheelchair.
NA	**#2**	Cable Guide	The Cable Guide is made of the 1/2" aluminum. It was designed to maintain the tension in the cable. It has a radial cut so it will not wear or damage the cable.

4.5 Gantt Chart

MEMS 411 Mechanically Advantageous Wheelchair

	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
	Project Statement and Background Information Study	1	8	1	8	100%
	Brain Storming	1	5	1	5	100%
	Project Selection	1	6	1	6	100%
	Research	1	8	5	10	100%
	Concept Design and Specification	8	8	8	8	100%
	Embodiment and Fabrication Plan	11	7	11	7	100%
	Engineering Analysis	15	21	24	18	100%
	Working Prototype	29	5	27	8	100%
	Final Drawings	12	34	12	37	100%
	Final Report	27	19	5	40	100%
1	Attachment method and frame	13	20	13	20	100%
1.2	Research attachments for dynamic parts	15	3	15	3	100%
1.3	Determine how to fit device to a broad range of wheelchair	16	2	16	2	100%
1.3.1	Research average wheelchair diameters	16	3	17	3	100%
1.4	Determine attachment point locations to wheelchair	16	2	16	2	100%
1.4.1	Research common number of spokes and push rim supports	16	2	16	2	100%
1.5	Research how to attach “grips” to frame of device	16	3	16	3	100%
1.5.1	Determine strength of wheelchair attachment point	16	4	16	4	100%
1.6	Research and prioritize material strength to weight ratio for frame	14	6	17	6	100%
1.7	Choose frame and clip materials able to withstand dynamic loads	14	5	14	5	100%
1.8	Model chair width and ensure product mobility	16	20	16	10	100%
2	Gear System	14	20	14	10	100%
2.1	Research different gear systems	14	7	15	7	100%
2.1.1	Compare size and cost of different gear systems	15	6	16	6	100%
2.2	Determine placement of gears	11	4	11	4	100%
2.3	Determine connection between gears and user	16	4	16	4	100%
2.4	Determine gear ratios and number of gears	12	5	12	5	100%
2.4.1	Research average wheelchair user input power	12	4	12	4	100%
3	Gear shifting system	14	18	14	10	100%
3.1	Determine shifter control type and placement	14	3	14	3	100%
3.2	Determine shifter mounting requirements	15	5	15	5	100%
3.3	Research safety standards and code requirements	20	8	20	7	100%



4.6

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 A form, signed by your section instructor

Insert your form here

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

The engineering analysis was conducted due to the uncertain point of failure occurring as a result of the geometry of the full-assembly or material selection in a sub-assembly. The full-assembly consists of the attachment plate, internal hub, input plate, and training wheels. Of these sub-assemblies, the point of failure has the greatest potential to occur in either the input plate or the internal hub. The input plate will most likely fail from shear stresses in the bolt holes connecting the plate to the hub as a result of input torque, or deflection across the plate. The internal hub may fail from deflection as a result of the load of the full-assembly and user input torque.

5.2.2 Summary statement of analysis done

Designing a robust prototype that would not fail under loading is critical for the safety of the user. In addition, the project's unconventional use of bike parts presents more safety concerns. As a result, the engineering analyses examine the stresses and deflections caused by loading. A total of 10 deflection, 5 torque, and 5 stress simulations were performed using SolidWorks. A 100 ft-lb load was used in the torque simulations, and a 100 lbf load was used in the stress simulations. The simulations not only provide reassurance about the structural integrity, but also aid in design decisions.

A main concern was how the teeth of the internal profile of the sprocket (circled in Fig. 7) would hold up to additional torque from the input plate. The contact between the profile and the grooves on the hub is responsible for transferring power from the input plate to the driven wheel. Slipping at those contact points would make the prototype inoperable. The result of the torque analysis shown in Fig. 7 verifies that the teeth do not deflect enough to cause slippage. The deflection at the points of concern is several orders of magnitude smaller than the depth of the grooves.

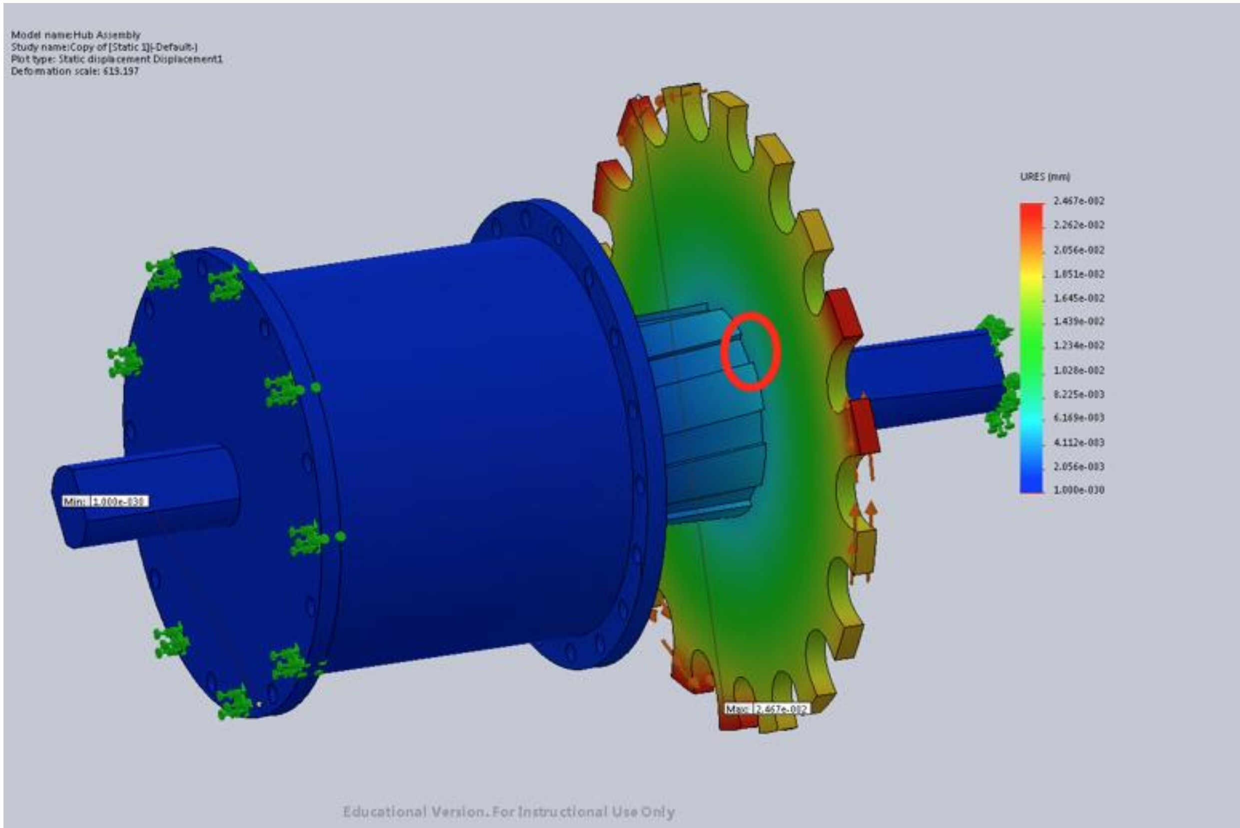


Figure 7 Torque stress analysis of the hub assembly

5.2.3 Methodology

All of our analyses were performed using the Simulation module of SolidWorks 2015. We used static analyses of both the assembled and individual components to get deflection and stress information on all of the components we felt were in danger of causing a failure. To create the analysis, we used fixed points to represent the attachment points to the main chair wheel and both force and torque inputs in separate trials along the edge of the driving wheel. Due to uncertainty with the properties of the wood, we simulated in using balsa wood, which is similar in character but likely weaker than the wood we are using. In addition, we ran separate trials on the assembly and hub section for both a system both with and without outrigger supports on the hub, to determine the important of having a load bearing support there. Due to limitations on the availability of material for the prototype, no physical experiments were run on the final assembly, so there was no need to construct a testing rig.

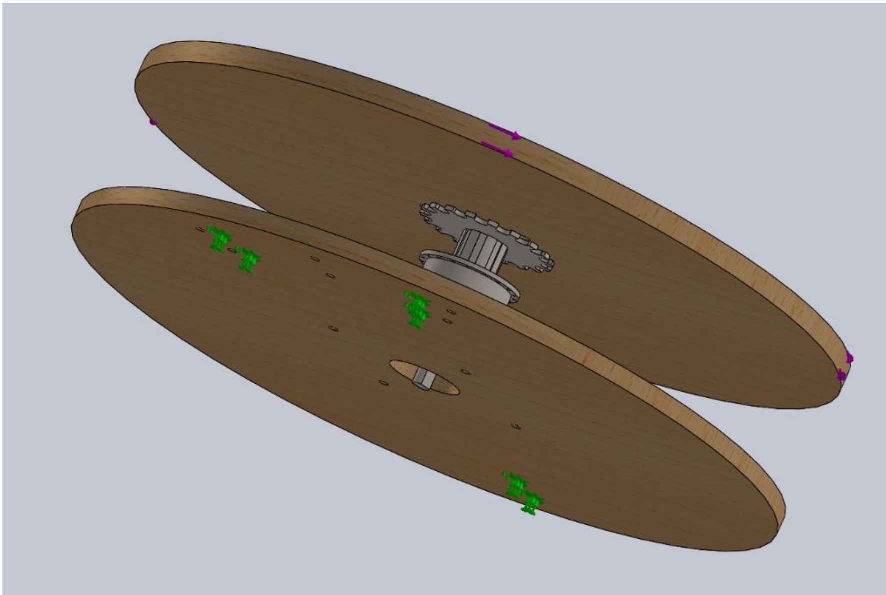


Figure 8 **The parameters for the assembly torque test. Note the fixtures representing the attachment points.**

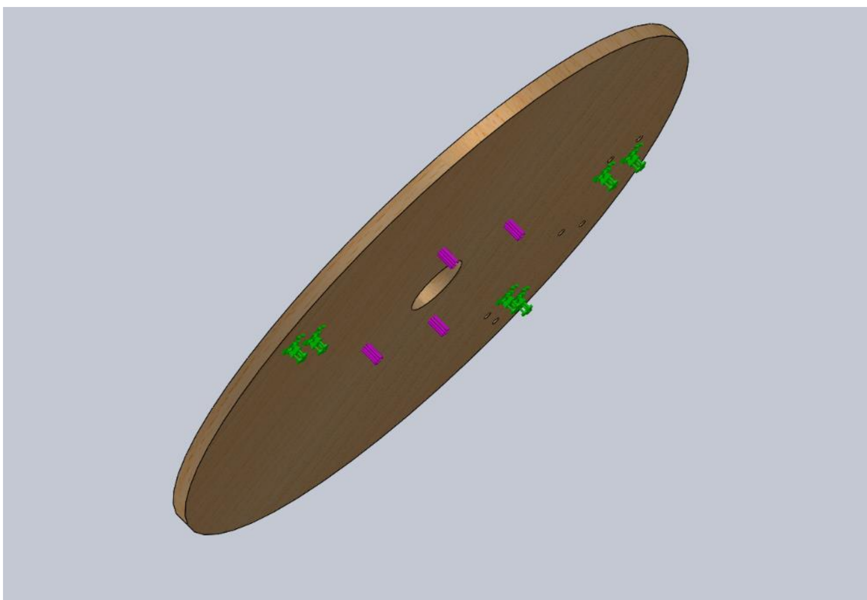


Figure 9 **The parameters for the attachment wheel centerline force test. Note the fixtures representing the attachment points and the forces representing the action of the hub on the wheel.**

5.2.4 Results

The results of the simulations were very promising. The simulations on the full assembly showed that the structure could withstand an input torque of 100 ft-lb and a sideways force of 100 lb without any of the components failing. All deflections in this case were below 1 mm. The simulations on the individual components supported this analysis, all showing that the component could support torques of 100 ft-lb with minimal deformation and that the central hub could support a downwards force on the driving wheel with minimal deformation. The analyses for the individual wheels also showed that they could support inwards forces of up to 100 lb without failing, though in those cases deflections could reach about 1 mm, which is still acceptable. These results seem solid, as the individual trial and assembly trial support each other and the stresses are high enough that the test are still indicating significant strain. In addition, all deformations are in reasonable directions. These results suggest that this design is acceptable to move forward with.

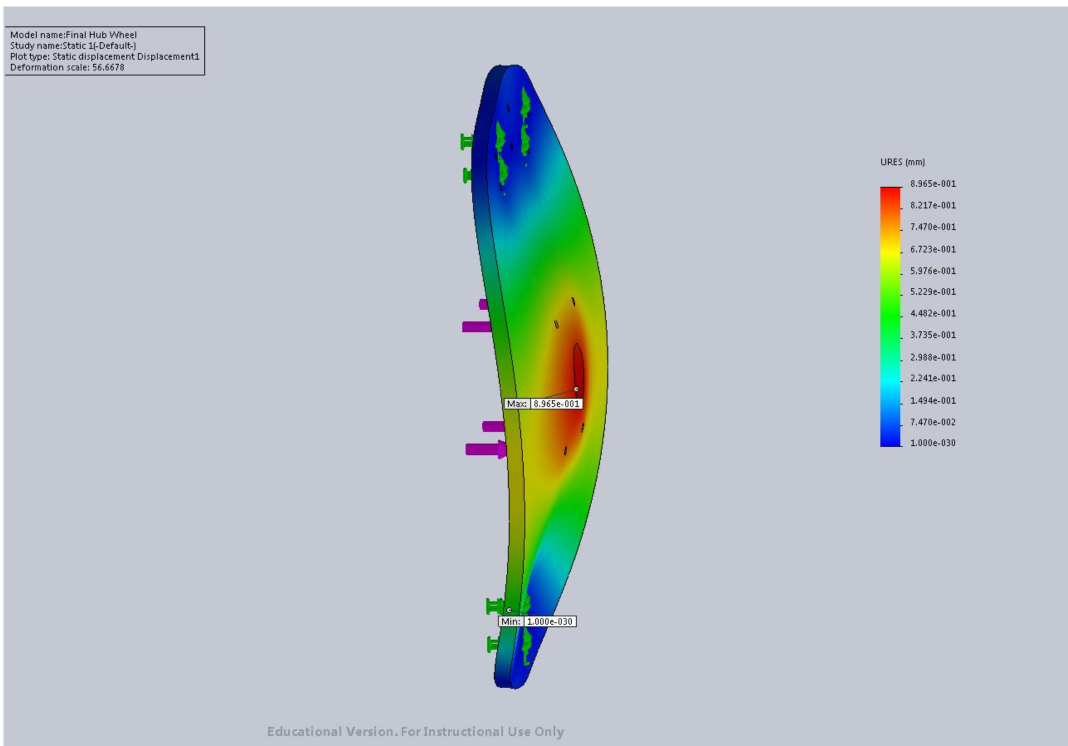


Figure 10 Deformation results from the attachment wheel force test. Deflection appear reasonable and are within 1mm.

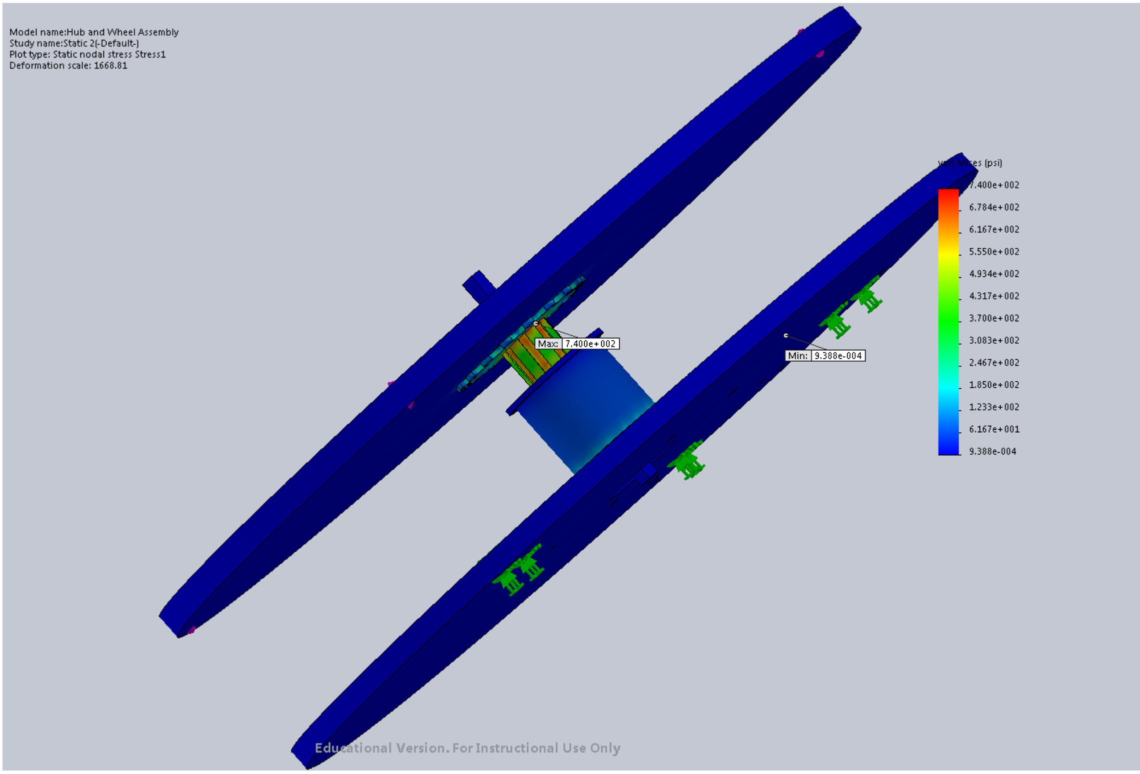


Figure 11 Stress results from the assembly torque test. Note that while there are areas of high stress, they occur in the strong steel regions.

5.2.5 Significance

Our simulation results indicated that the most vulnerable areas were the wooden discs under loads along the hub's axis, but also that they were not at risk of failure. This shows that wood will be acceptable for the final prototype, and that we could reduce the thickness of the discs, though we chose not to too have an additional factor of safety. In addition, the results show that the exterior supports only need to prevent rotation, not support significant loads.

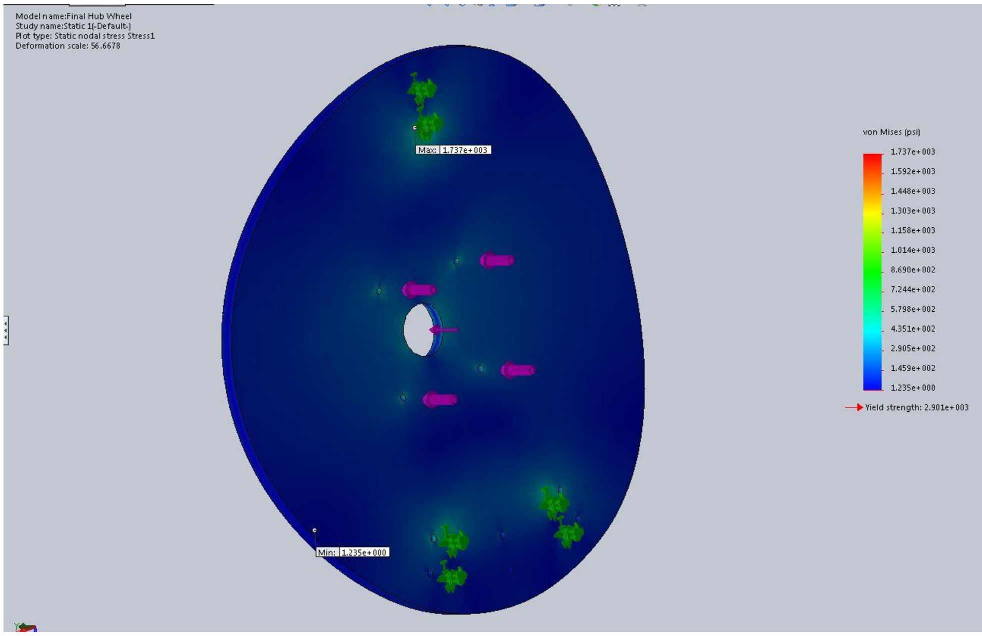


Figure 12 Deformation of 0.5" thick attachment plate

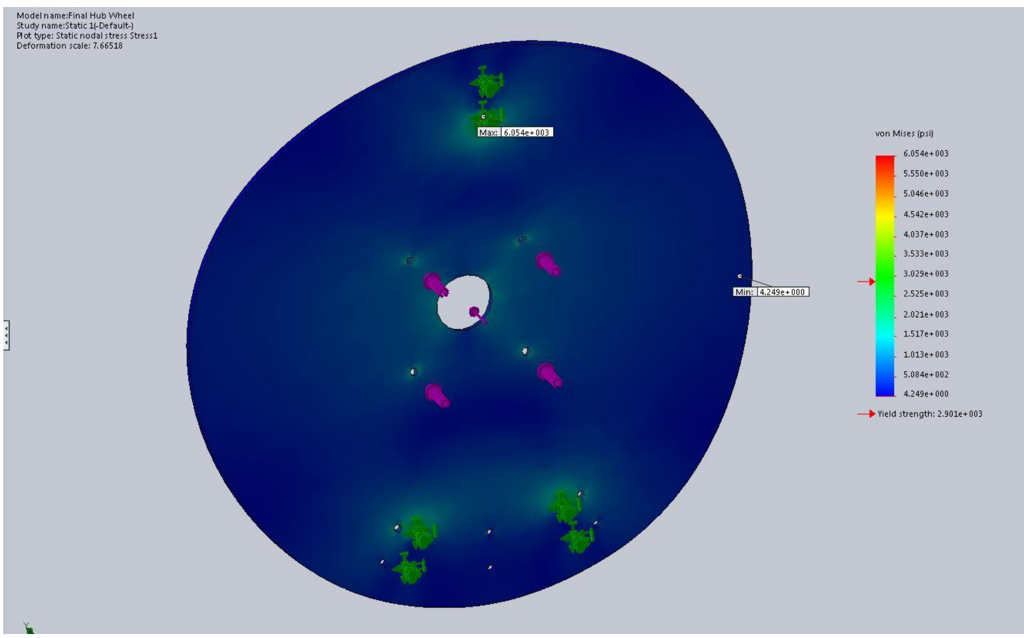


Figure 13 Deformation of 0.25" thick attachment plate

Our standard was AS/NZS ISO 7176.1:2015: Wheelchairs: Part 1: Determination of Static Stability. It states that a wheelchair is statically stable when its center of gravity is above the area supported by its contact points. The static stability characteristics of a wheelchair are important for prescription and adjustment purposes, with exact stability being user dependent.

This suggests that our attachment should be lightweight and have relatively compact geometry to avoid altering the chair's center of gravity. We will thus construct the wood disc using light plywood. In addition, any components that extend from wheelchair body should act as supports to the ground. As such the exterior supports will be the farthest components from the wheelchair, and their wheels will be positioned far from each other to provide stability.

5.3 RISK ASSESSMENT

5.3.1 *Risk Identification*

Risk identification is the critical first step of the risk management process. Its objective is the early and continuous identification of risks, including those within and external to the engineering system project. See the **Risk Assessment** document for more information. For context review source: http://www.mitre.org/publications/systems-engineering-guide/acquisition-systems-engineering/risk-management

5.3.2 *Risk Impact or Consequence Assessment*

In this step, an assessment is made of the impact each risk event could have on the engineering system project. Typically, this includes how the event could impact cost, schedule, or technical performance objectives. Impacts are not limited to only these criteria. Additional criteria such as political or economic consequences may also require consideration. In addition, an assessment is made of the probability (chance) each risk event will occur.

5.3.3 *Risk Prioritization*

At this step, the overall set of identified risk events, their impact assessments, and their occurrence probabilities are "processed" to derive a most critical to least critical rank-order of identified risks. A major purpose for prioritizing risks is to form a basis for allocating critical resources.

6 WORKING PROTOTYPE

6.1 A PRELIMINARY DEMONSTRATION OF THE WORKING PROTOTYPE

This section may be left blank

6.2 A FINAL DEMONSTRATION OF THE WORKING PROTOTYPE

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6.3 AT LEAST TWO DIGITAL PHOTOGRAPHS SHOWING THE PROTOTYPE

Figure 14 Isometric view of prototype

Figure 15 Side view of prototype

6.4 AT LEAST 4 ADDITIONAL DIGITAL PHOTOGRAPHS AND THEIR EXPLANATIONS

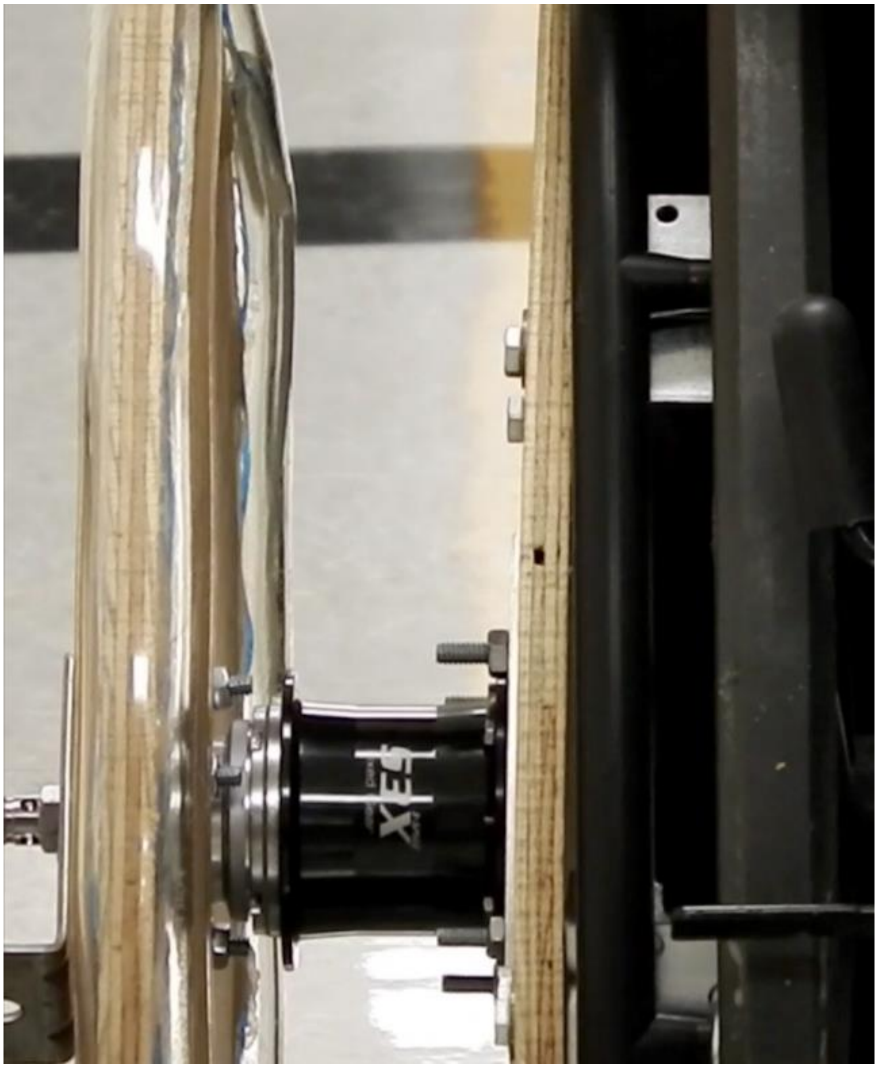


Figure 16 Close-up view of hub and its mounting

Figure 17 Close-up view of shifting mechanism

Figure 18 Front view of prototype

Figure 19 Close-up view of attachment method

7 DESIGN DOCUMENTATION

7.1 FINAL DRAWINGS AND DOCUMENTATION

7.1.1 Engineering drawings

That includes all CAD model files and all drawings derived from CAD models. *Include units on all CAD drawings.* See Appendix C for the CAD models.

7.1.2 Sourcing instructions

7.2 FINAL PRESENTATION

7.2.1 A live presentation in front of the entire class and the instructors

This section may be left blank

7.2.2 A link to a video clip

Link to youtube video

7.3 TEARDOWN

The attachments are in the MEMS basement. The wheelchair is not.

8 Discussion

8.2 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value	Prototype Value
1	7	Width added to chair	in	6	0	4	0.333	9
2	1	Number of Gears	Integer	2	6	3	0.25	3
3	3	Gearing Failure Risk	%	1	0	0.05	0.95	10
4	4	Attachment Radius Range	in	0	5	4	0.8	2
5	5	Removal/Install Time	sec	0	100	60	0.6	140
6	3	Max Handle Pull Force	lb	10	50	30	0.5	
7	9, 3	Shift Time	sec	1	0	0.2	0.8	1
8	11	Number of Exposed Gears	Integer	3	0	0	1	0
9	10	Brake Time	sec	3	0	1	0.667	1.7
10	2	1:1 Driver Always Available	Binary	0	1	1	1	1
11	8	Shifts in Motion	Binary	0	1	1	1	1
21	6	Modular	Binary	0	1	1	1	1
						TOTAL	8.9	

8.3 Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects?

8.4 Discuss the overall experience:

8.4.1 Was the project more of less difficult than you had expected?

The project proved to be more difficult than we had expected due to unforeseen obstacles such as missing indicator chain and the constrained rotation of the chain. The lack of technical specifications of some manufactured parts added complication in the creation of 3D models and the decision making process.

8.4.2 Does your final project result align with the project description?

Yes, the prototype is modular while still providing a mechanical advantage.

8.4.3 Did your team function well as a group?

In addition to producing a functional prototype, the team was able to develop their interpersonal skills and improve the team dynamic.

8.4.4 Were your team member's skills complementary?

Yes, various members provided proficient experience in modeling, manufacturing, designing, and supplementary information.

8.4.5 Did your team share the workload equally?

Yes, we delegated the workload according to each team members' area of expertise.

8.4.6 Was any needed skill missing from the group?

Yes, advanced manufacturing ability was missing from the group.

8.4.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

During the process we did not have to re-consult with our customer and worked to the original design brief.

8.4.8 Did the design brief (as provided by the customer) seem to change during the process?

The design brief did not change during the process.

8.4.9 Has the project enhanced your design skills?

Yes, the ability to consider the many factors that could go wrong and adapt to unforeseen obstacles has improved. Additionally, we learned the importance of user experience and its impact on the product.

8.4.10 Would you now feel more comfortable accepting a design project assignment at a job?

Yes, we feel better equipped to begin to tackle a professional design project.

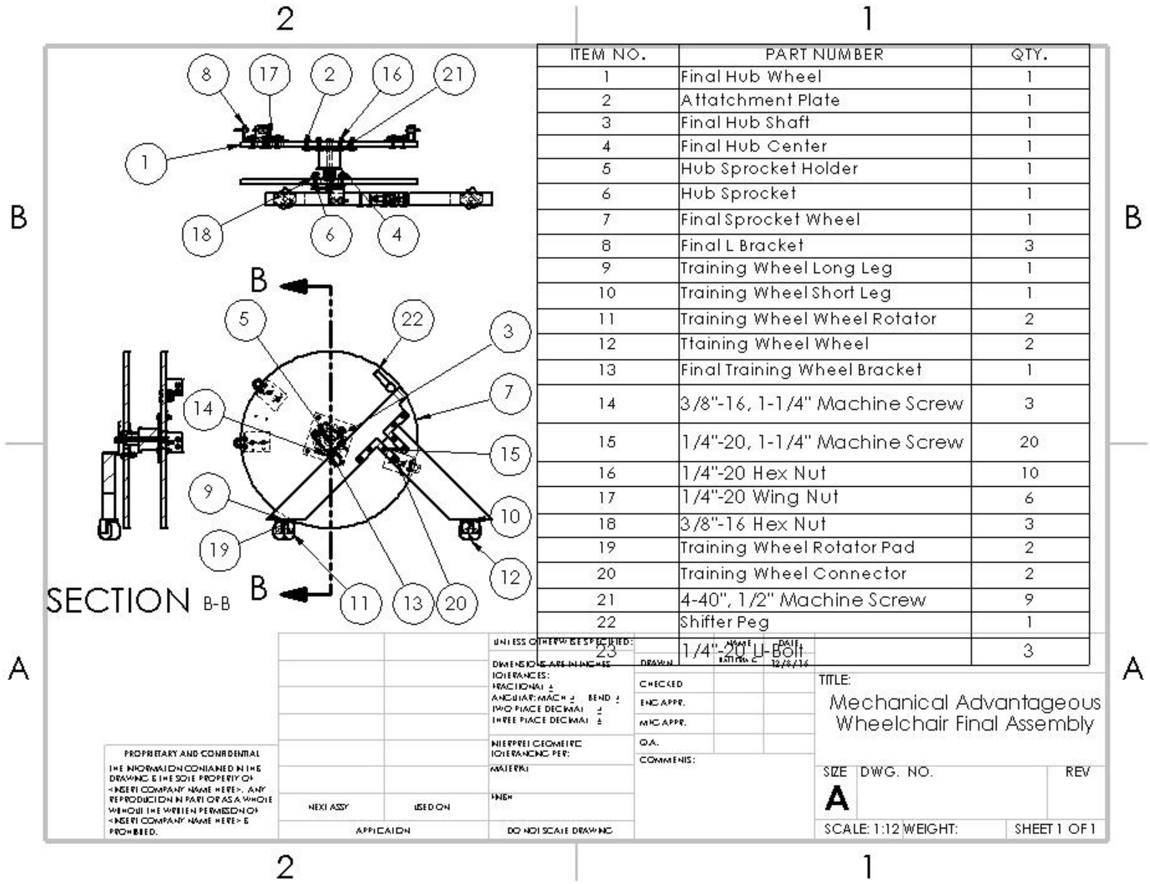
8.4.11 Are there projects that you would attempt now that you would not attempt before?

Yes, this project has strengthened our confidence in our engineering abilities.

9 APPENDIX A - PARTS LIST

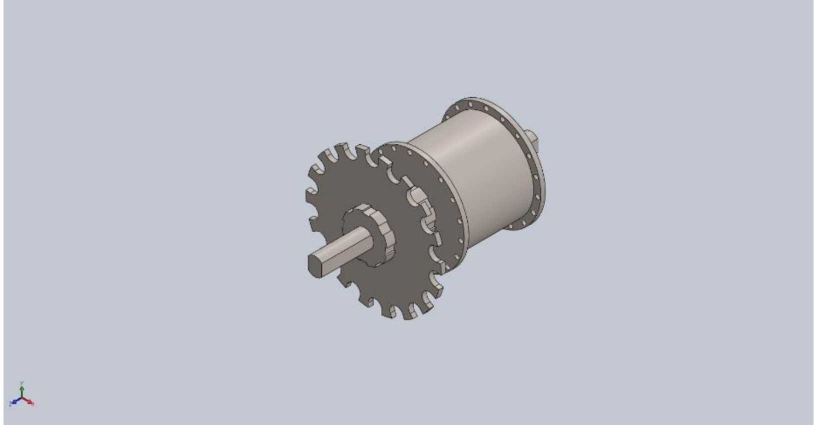
	Part	***Source Link***	***Supplier Part Number***	***Color, TPI, other part IDs***	***Unit price***	***Tax ($0.00 if tax exemption applied)***	***Shipping***	***Quantity***	***Total price***
1	Aluminum sheet metal 1/4”	Machine Shop	Supplied	NA	0	$0.00	$0.00	4	$0.00
2	Wood	MEMS basement							$0.00
3	Tubing	MEMS basement							$0.00
4	Sturmey Archer hub	Jenson USA		NA	$142.49	$0.00	$6.99	2	$291.97
5	4-40 steel screws	McMaster Carr	91772A110	NA	$13.81	$0.00	$2.76	1	$16.57
6	4-40 steel hex nut	McMaster Carr	90480A005	NA	$0.87	$0.00	$1.62	1	$9.72
7	1/4”-20 hex nuts	McMaster Carr	95462A029	NA	$4.40	$0.00	$0.88	1	$5.28
8	1/4”-20 hex head screws, 3/4” long	McMaster Carr	90401A540	NA	$12.06	$0.00	$2.41	1	$14.47
9	1/4"-20 steel wing nuts	McMaster Carr	90866A029	NA	$10.29	$0.00	$2.06	1	$12.35
10	1/4"-20 U-bolts	McMaster Carr	3043T639	NA	$0.65	$0.00	$0.13	6	$4.03
11	1/4”-20 hex screw with washer	McMaster Carr	90401A542	NA	$9.13	$0.00	$1.83	1	$10.96
12	Sprocket	Big Shark Bicycle Shop	NA	NA	$30.00		NA	1	$30.00
13	Tension Cables and Connector	Big Shark Bicycle Shop	NA	NA	$8.00		NA	2	$16.00
14	Sprocket	Mikes Bikes	NA	NA	$8.00		NA	2	$21.94
Total:									$433.29

10 APPENDIX B - BILL OF MATERIALS



ITEM NO.	PART NUMBER	QTY.
1	Final Hub Wheel	1
2	Attatchment Plate	1
3	Final Hub Shaft	1
4	Final Hub Center	1
5	Hub Sprocket Holder	1
6	Hub Sprocket	1
7	Final Sprocket Wheel	1
8	Final L Bracket	3
9	Training Wheel Long Leg	1
10	Training Wheel Short Leg	1
11	Training Wheel Wheel Rotator	2
12	Ttaining Wheel Wheel	2
13	Final Training Wheel Bracket	1
14	3/8"-16, 1-1/4" Machine Screw	3
15	1/4"-20, 1-1/4" Machine Screw	20
16	1/4"-20 Hex Nut	10
17	1/4"-20 Wing Nut	6
18	3/8"-16 Hex Nut	3
19	Training Wheel Rotator Pad	2
20	Training Wheel Connector	2
21	4-40", 1/2" Machine Screw	9
22	Shifter Peg	1
23	1/4"-20 U-Bolt	3

11 Appendix C – Simulation reports



Simulation of Hub Assembly

Date: Wednesday, December 07, 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

Table of Contents

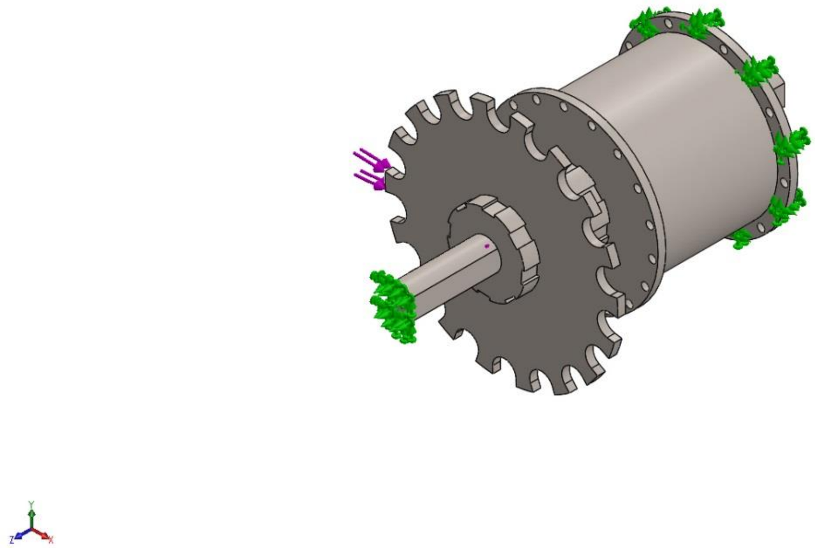
Description

No Data

Assumptions

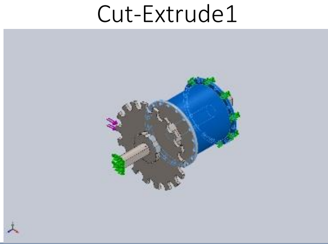
The applied forces only occurred at the screw hole positions. The pink arrow represents normal forces from the bolts. The green arrows on the internal hub axle represent the normal forces from the training wheel bracket. The green arrows on the base of the internal hub represent the normal forces from the machine screws. These forces only occur at the arrows.

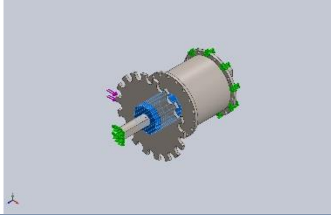
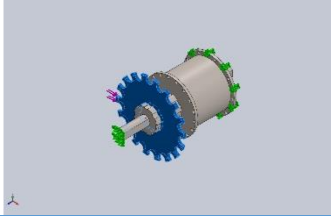
Model Information



Model name: Hub Assembly
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:2.80809 lb Volume:10.0945 in^3 Density:0.27818 lb/in^3 Weight:2.80618 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Center.SLDPRT Dec 05 15:51:52 2016
Boss-Extrude1 	Solid Body	Mass:0.280435 lb Volume:1.00811 in^3 Density:0.27818 lb/in^3 Weight:0.280245 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Shaft.SLDPRT Nov 19 14:23:40 2016
Cut-Extrude1	Solid Body	Mass:0.365331 lb Volume:1.31329 in^3 Density:0.27818 lb/in^3 Weight:0.365083 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket Holder.SLDPRT Nov 19 14:40:55 2016

			
Boss-Extrude2 	Solid Body	Mass:0.280842 lb Volume:1.00957 in^3 Density:0.27818 lb/in^3 Weight:0.280652 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket.SLDPRT Nov 19 14:40:03 2016

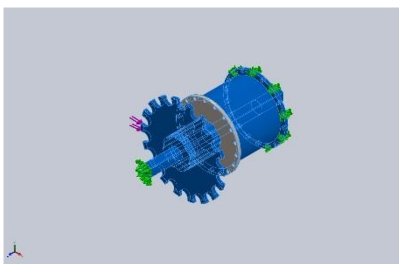
Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly)

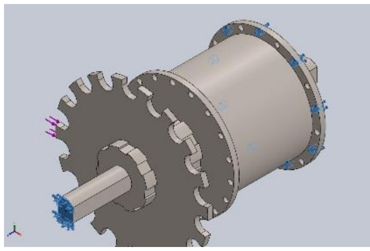
UNITS

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

MATERIAL PROPERTIES

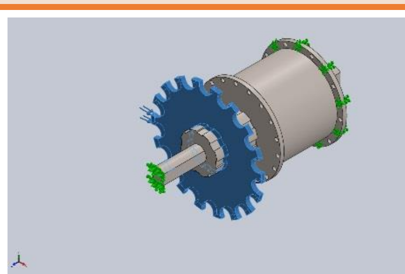
Model Reference	Properties	Components
	Name: **Alloy Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Max von Mises Stress** Yield strength: **89984.6 psi** Tensile strength: **104982 psi** Elastic modulus: **3.04579e+007 psi** Poisson's ratio: **0.28** Mass density: **0.27818 lb/in^3** Shear modulus: **1.1458e+007 psi** Thermal expansion coefficient: **7.22222e-006 /Fahrenheit**	**SolidBody 1(Cut-Extrude1)(Fina Hub Center-1), SolidBody 1(Boss-Extrude1)(Final Hub Shaft-1), SolidBody 1(Cut-Extrude1)(Hub Sprocket Holder-1), SolidBody 1(Boss-Extrude2)(Hub Sprocket-1)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 10 face(s) **Type:** Fixed Geometry

<Label_FixtResForces/>

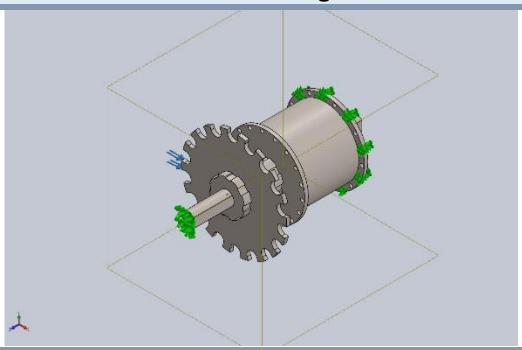
<L_FxRsForceComp/>	<L_FxRsForceX/>	<L_FxRsForceY/>	<L_FxRsForceZ/>	<L_FxRsForceRes/>
<FxRsForceType1/>	<FxRsForceX1/>	<FxRsForceY1/>	<FxRsForceZ1/>	<FxRsForceRes1/>

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s), 1 Solid Body (s) **Type:** Apply normal force **Value:** 100 lbf

Connector Definitions

No Data

CONTACT INFORMATION

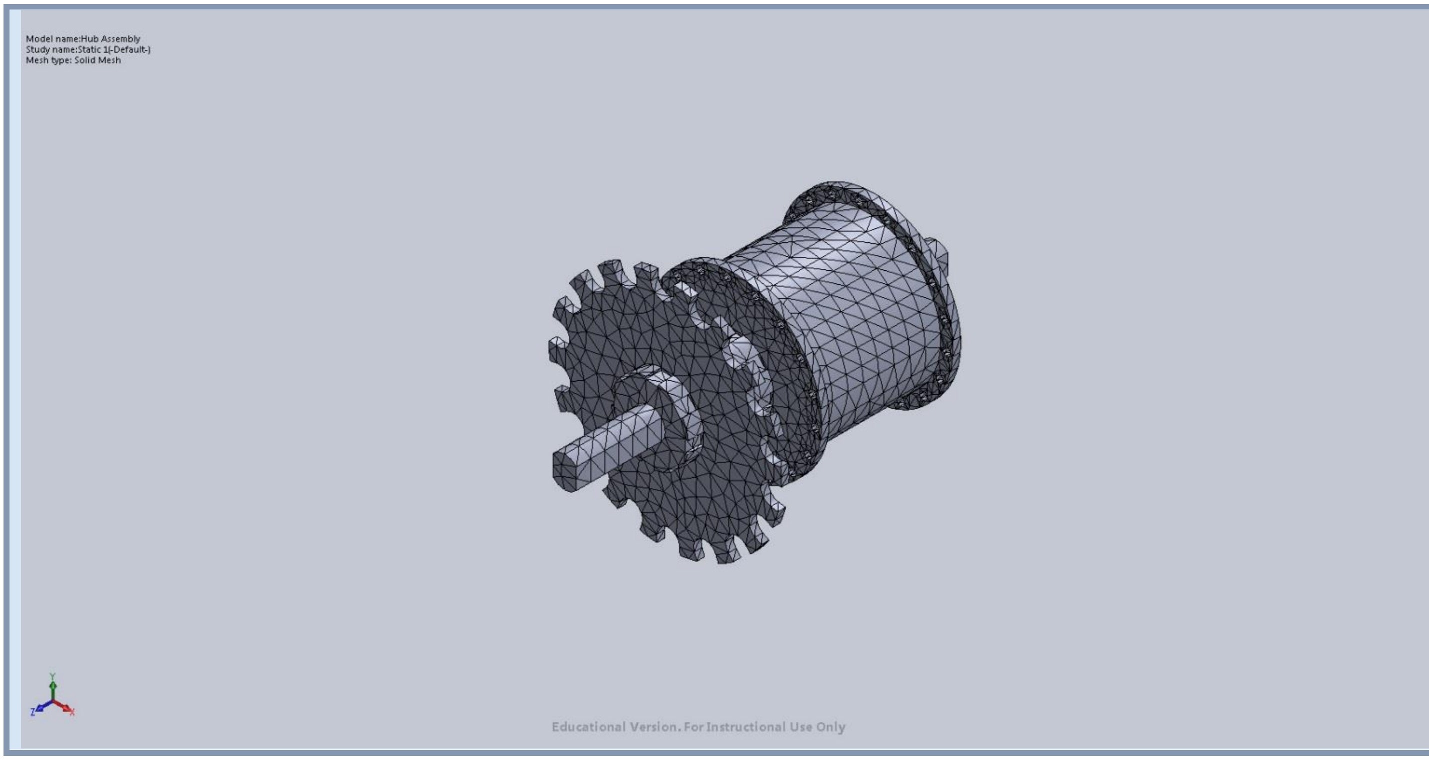
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 in
Minimum element size	0 in
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh information - Details

Total Nodes	24322
Total Elements	13926
Maximum Aspect Ratio	20.042
% of elements with Aspect Ratio < 3	80.8
% of elements with Aspect Ratio > 10	0.531
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:04
Computer name:	URB215-04



Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf	-99.8736	-2.65325	-0.00290762	99.9089

Reaction Moments

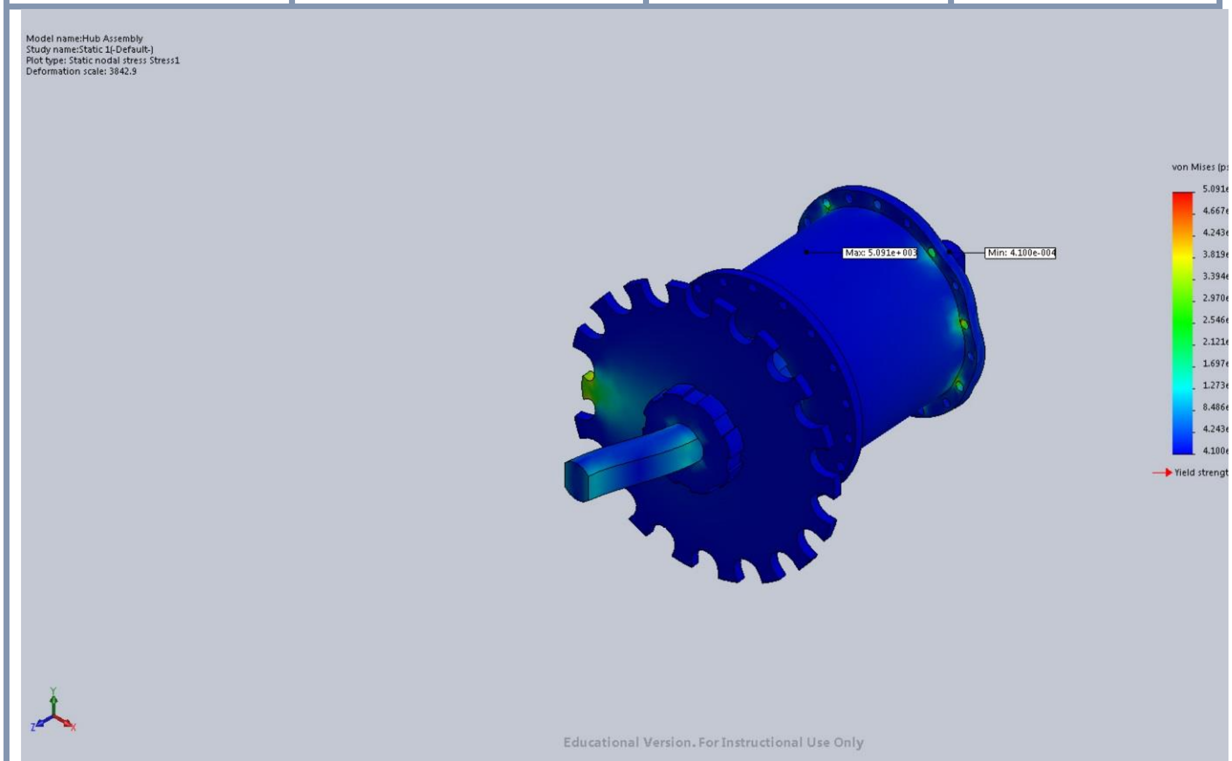
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf.in	0	0	0	0

BEAMS

No Data

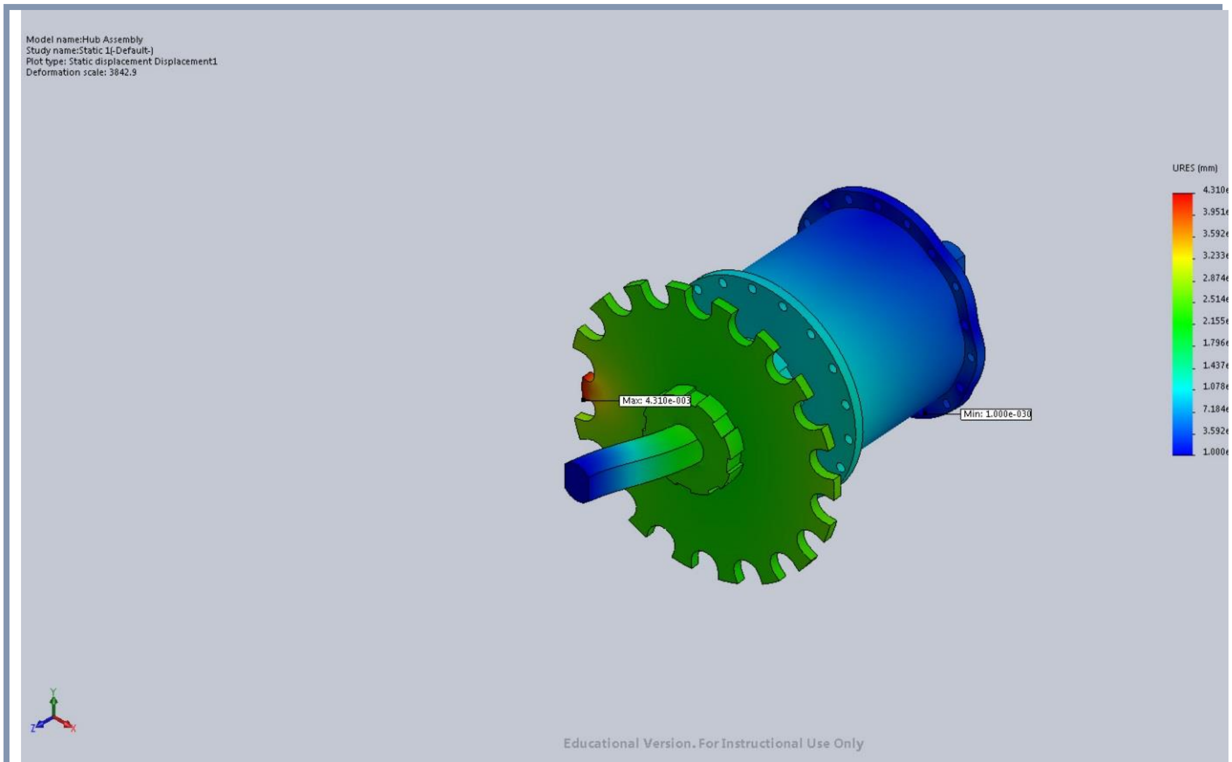
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.000409955 psi Node: 16937	5091.35 psi Node: 10002



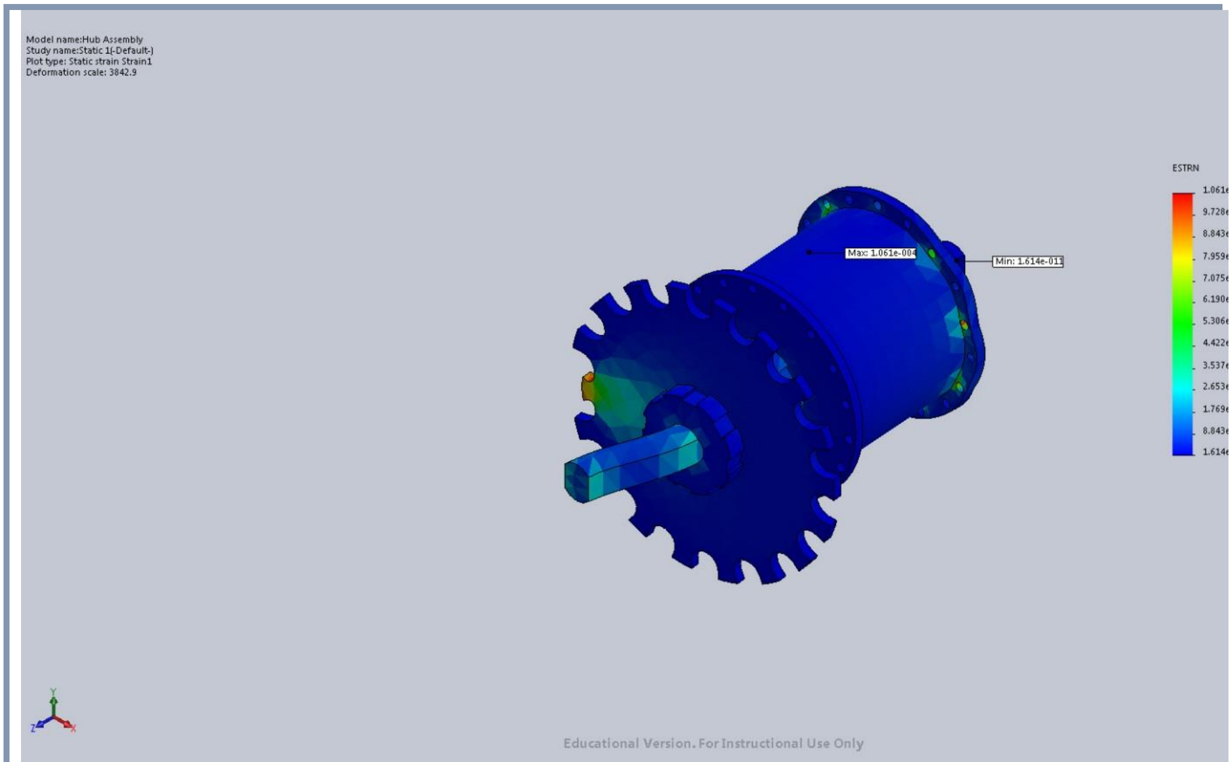
Hub Assembly-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 904	0.00431047 mm Node: 21438



Hub Assembly-Static 1-Displacement-Displacement1

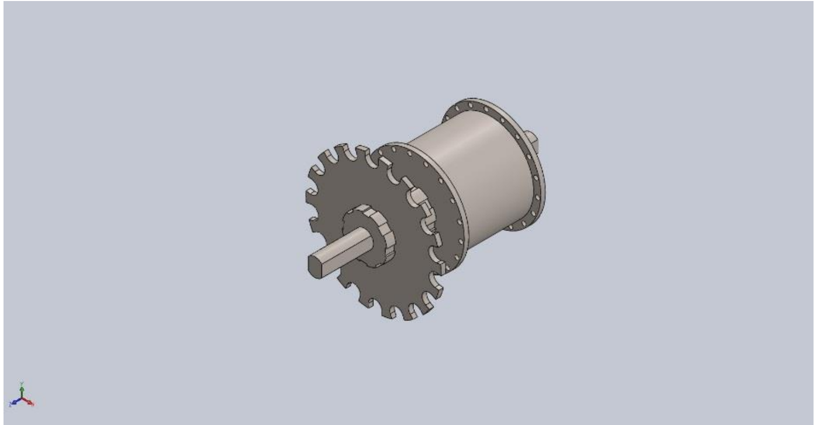
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.61389e-011 Element: 10152	0.000106119 Element: 5079



Hub Assembly-Static 1-Strain-Strain1

CONCLUSION

Failure is unlikely.



Simulation of Hub Assembly

Date: Wednesday, December 07, 2016
Designer: Solidworks
Study name: Static 2
Analysis type: Static

Table of Contents

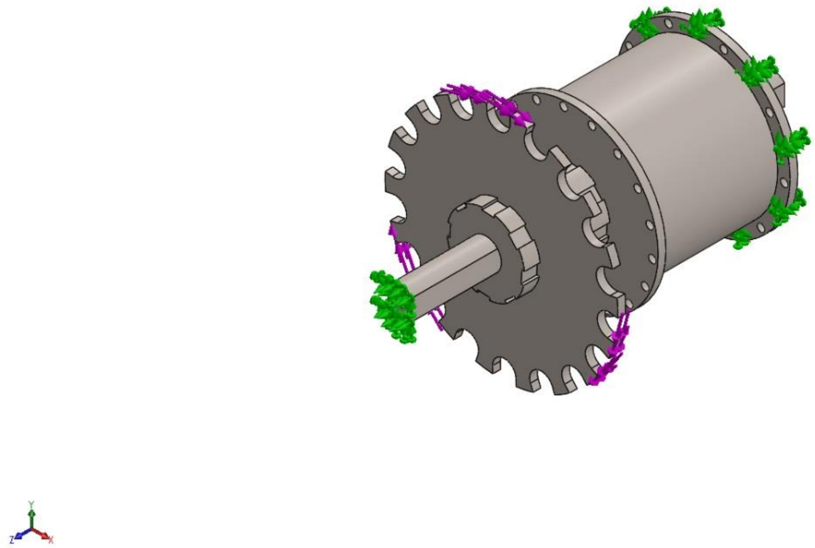
DESCRIPTION

No Data

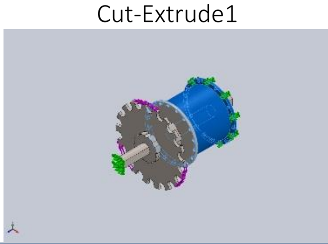
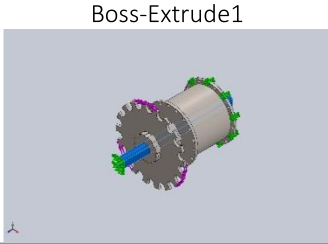
ASSUMPTIONS

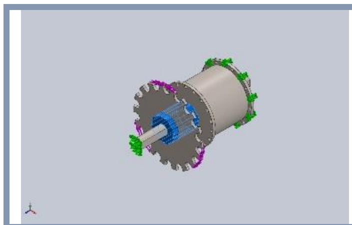
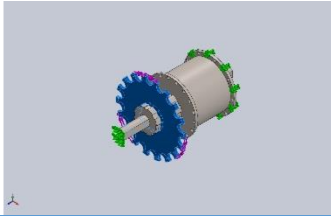
THE APPLIED FORCES ONLY OCCURRED AT THE SCREW HOLE POSITIONS. THE PINK ARROW REPRESENTS SHEAR FORCES FROM THE BOLTS. THE GREEN ARROWS ON THE INTERNAL HUB AXLE REPRESENT THE NORMAL FORCES FROM THE TRAINING WHEEL BRACKET. THE GREEN ARROWS ON THE BASE OF THE INTERNAL HUB REPRESENT THE NORMAL FORCES FROM THE MACHINE SCREWS. THESE FORCES ONLY OCCUR AT THE ARROWS.

Model Information



Model name: Hub Assembly
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:2.80809 lb Volume:10.0945 in^3 Density:0.27818 lb/in^3 Weight:2.80618 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Center.SLDPRT Dec 05 15:51:52 2016
Boss-Extrude1 	Solid Body	Mass:0.280435 lb Volume:1.00811 in^3 Density:0.27818 lb/in^3 Weight:0.280245 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Shaft.SLDPRT Nov 19 14:23:40 2016
Cut-Extrude1	Solid Body	Mass:0.365331 lb Volume:1.31329 in^3 Density:0.27818 lb/in^3 Weight:0.365083 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket Holder.SLDPRT Nov 19 14:40:55 2016

			
Boss-Extrude2 	Solid Body	Mass:0.280842 lb Volume:1.00957 in^3 Density:0.27818 lb/in^3 Weight:0.280652 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket.SLDPRT Nov 19 14:40:03 2016

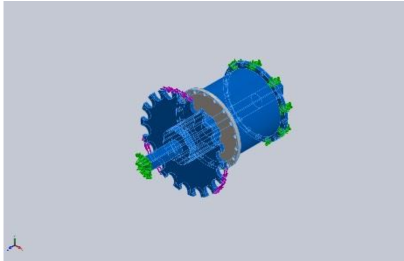
Study Properties

Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly)

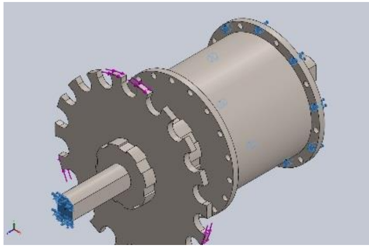
UNITS

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

MATERIAL PROPERTIES

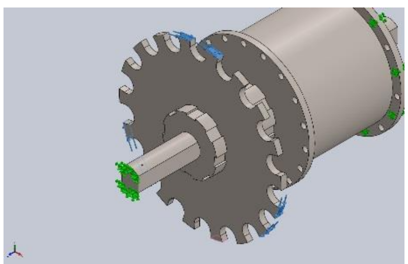
Model Reference	Properties	Components
	Name: **Alloy Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Max von Mises Stress** Yield strength: **89984.6 psi** Tensile strength: **104982 psi** Elastic modulus: **3.04579e+007 psi** Poisson's ratio: **0.28** Mass density: **0.27818 lb/in^3** Shear modulus: **1.1458e+007 psi** Thermal expansion coefficient: **7.22222e-006 /Fahrenheit**	**SolidBody 1(Cut-Extrude1)(Fina Hub Center-1), SolidBody 1(Boss-Extrude1)(Final Hub Shaft-1), SolidBody 1(Cut-Extrude1)(Hub Sprocket Holder-1), SolidBody 1(Boss-Extrude2)(Hub Sprocket-1)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 10 face(s) **Type:** Fixed Geometry

<Label_FixtResForces/>

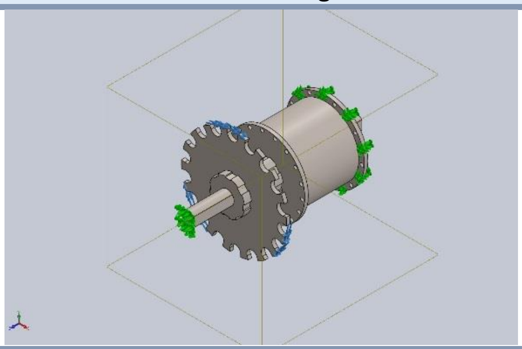
<L_FxRsForceComp/>	<L_FxRsForceX/>	<L_FxRsForceY/>	<L_FxRsForceZ/>	<L_FxRsForceRes/>
<FxRsForceType1/>	<FxRsForceX1/>	<FxRsForceY1/>	<FxRsForceZ1/>	<FxRsForceRes1/>

Load name	Load Image	Load Details
Torque-1		**Entities:** 6 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 100 lbf.in

Connector Definitions

No Data

Contact Information
<Contact_State/>

Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

<Label_ContactFrictionForces/>

<L_CtFrcForceComp/>	<L_CtFrcForceX/>	<L_CtFrcForceY/>	<L_CtFrcForceZ/>	<L_CtFrcForceRes/>
<CtFrcForceType1/>	<CtFrcForceX1/>	<CtFrcForceY1/>	<CtFrcForceZ1/>	<CtFrcForceRes1/>

<Label_ContactVisualizationPlots/>

<L_CVName/>	<L_CVType/>
<CV_Name/>	<CV_Type/>

<Image_ContactVisualizationPlot/>
<ImageCaption_ContactVisualizationPlot/>

Mesh information

<Label_MeshPropSetting/>	<Setting_MeshPropSetting/>

<Header2_MeshDetails/>

<Label_MeshProp/>	<Setting_MeshProp/>
<Image_Mesh/>	

<Header2_MeshControlsDetails/>

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<MeshContol_Name/>	**<MeshControl_Image/>**	**<MeshControl_Details/>**

<Label_MeshQualityPlots/>

<L_MQName/>	<L_MQType/>	<L_MQMin/>	<L_MQMax/>
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Sensor Details

No Data

Resultant Forces

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<L_RFSelSet/>	<L_RFUnits/>	<L_RFSumX/>	<L_RFSumY/>	<L_RFSumZ/>	<L_RFResultant/>

<Header2_ReactionMoments/>

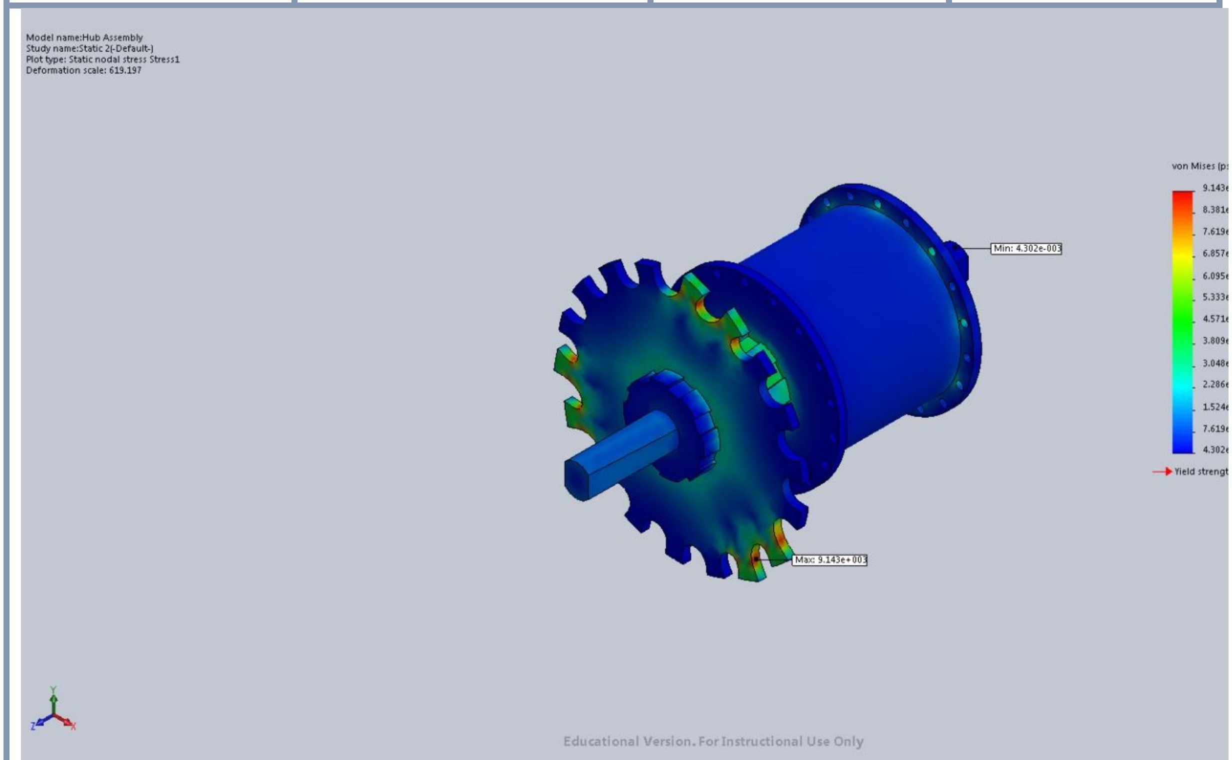
<L_RMSelSet/>	<L_RMUnits/>	<L_RMSumX/>	<L_RMSumY/>	<L_RMSumZ/>	<L_RMResultant/>

BEAMS

No Data

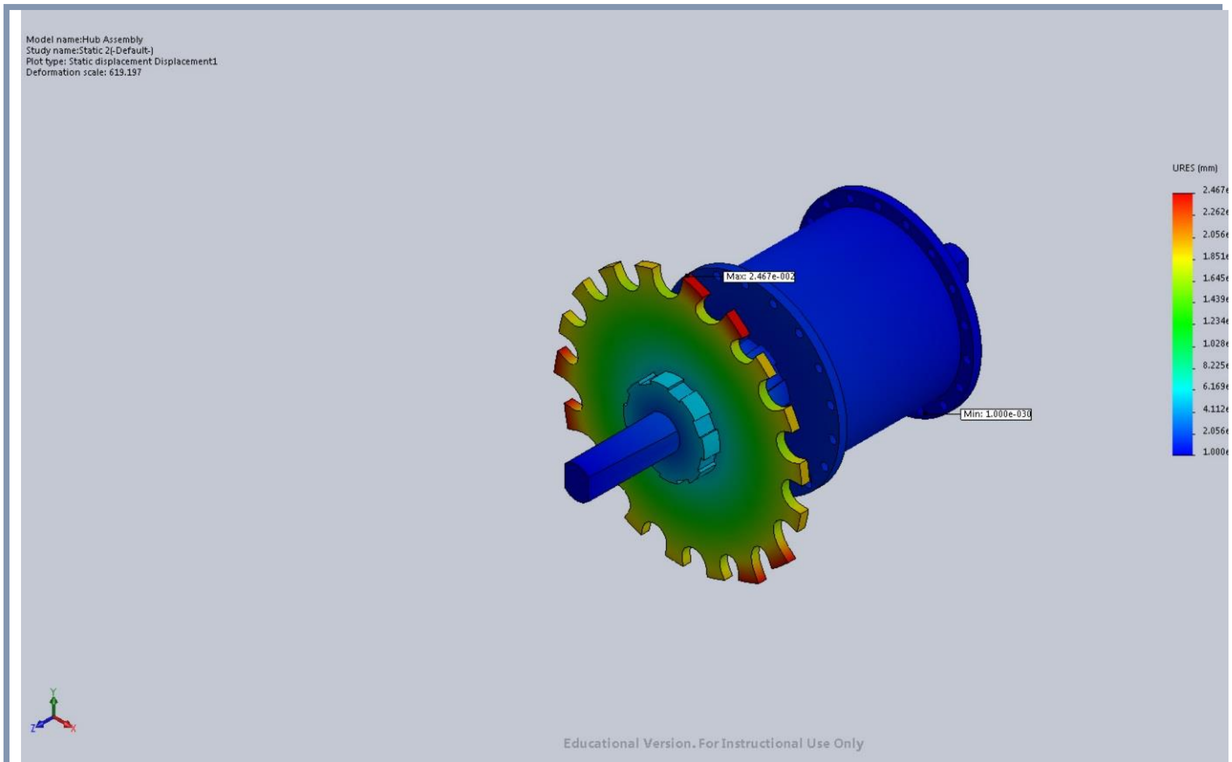
STUDY RESULTS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00430179 psi Node: 17548	9142.59 psi Node: 23640



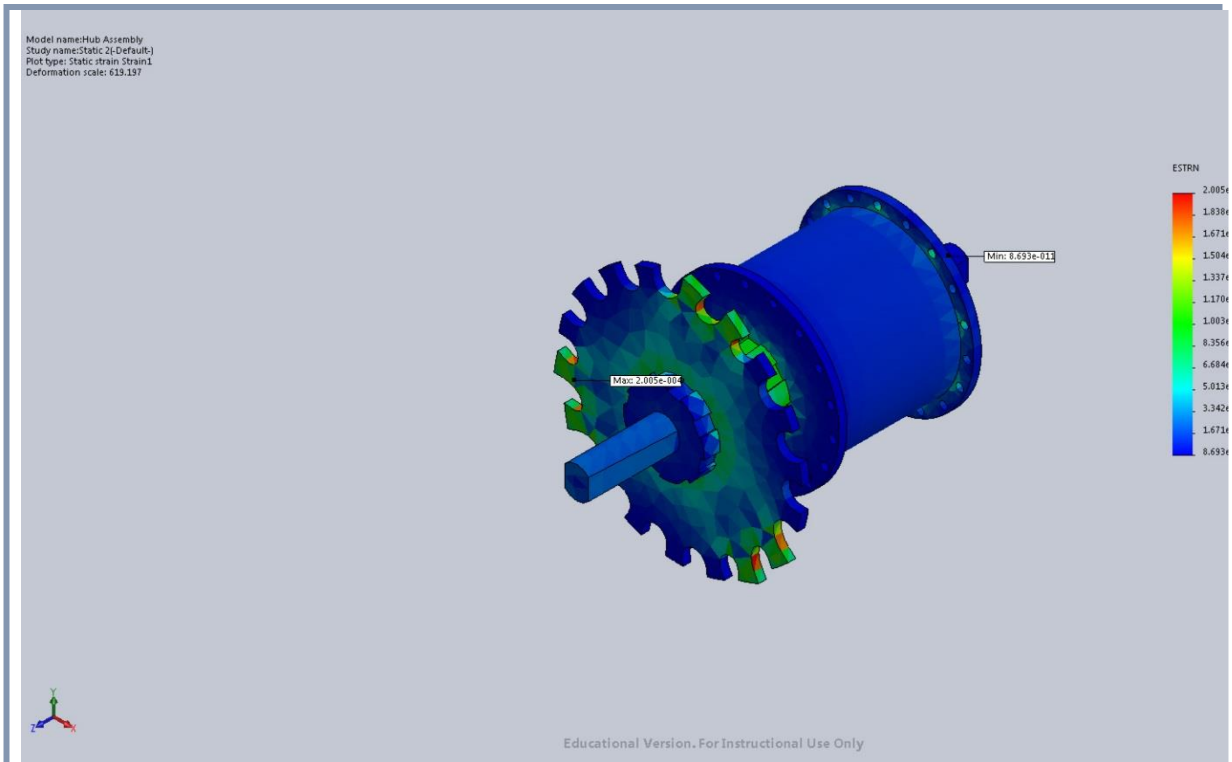
Hub Assembly-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 904	0.024674 mm Node: 23186



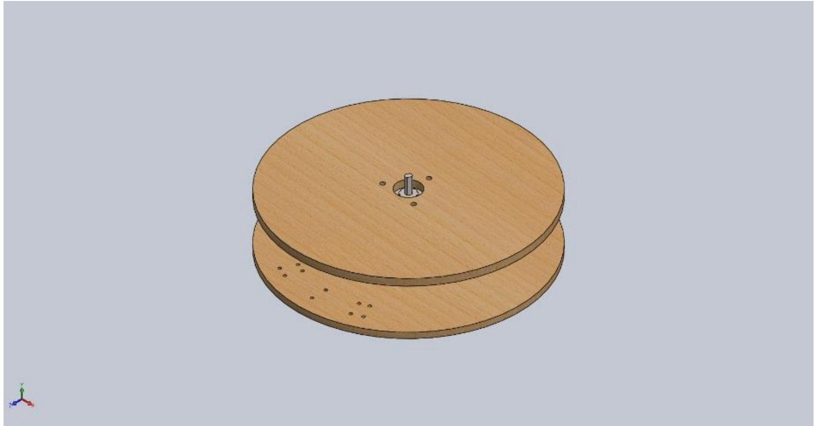
Hub Assembly-Static 2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	8.69318e-011 Element: 10084	0.000200533 Element: 12578



Hub Assembly-Static 2-Strain-Strain1

CONCLUSION



Simulation of Hub and Wheel Assembly

Date: Wednesday, December 07, 2016
Designer: Solidworks
Study name: Static 2
Analysis type: Static

Table of Contents

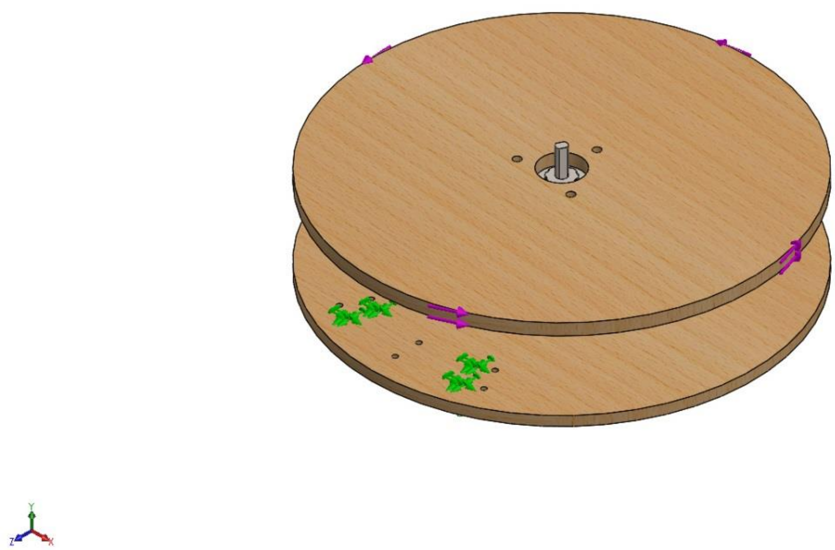
Description

No Data

ASSUMPTIONS

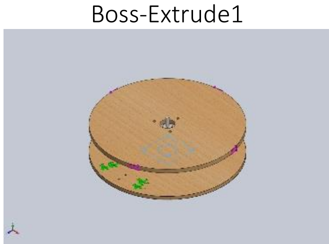
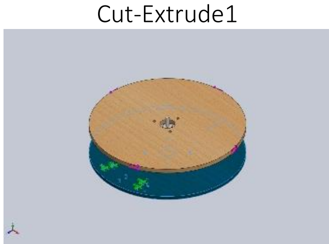
THE APPLIED FORCES ONLY OCCURRED AT THE SCREW HOLE POSITIONS. THE PINK ARROW REPRESENTS SHEAR FORCES FROM USER INPUT, WHILE THE GREEN ARROWS REPRESENT THE NORMAL FORCES FROM THE MACHINE SCREWS. THESE FORCES ONLY OCCUR AT THE ARROWS.

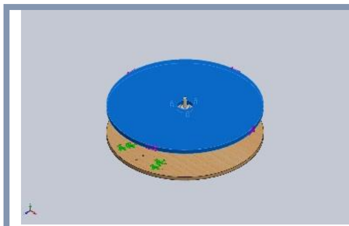
Model Information



Model name: Hub and Wheel Assembly
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1 	Solid Body	Mass:0.452672 lb Volume:4.64071 in^3 Density:0.0975437 lb/in^3 Weight:0.452365 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Attatchment Plate.SLDPRT Nov 19 14:18:28 2016
Cut-Extrude1 	Solid Body	Mass:0.896501 lb Volume:155.104 in^3 Density:0.00578 lb/in^3 Weight:0.895893 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Wheel.SLDPRT Dec 07 14:01:30 2016
Cut-Extrude1	Solid Body	Mass:1.07746 lb Volume:186.412 in^3 Density:0.00578 lb/in^3 Weight:1.07673 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Sprocket Wheel.SLDPRT Nov 21 16:10:37 2016

			
Cut-Extrude1	Solid Body	Mass:2.80809 lb Volume:10.0945 in^3 Density:0.27818 lb/in^3 Weight:2.80618 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Center.SLDPRT Dec 05 15:51:52 2016
Boss-Extrude1	Solid Body	Mass:0.280435 lb Volume:1.00811 in^3 Density:0.27818 lb/in^3 Weight:0.280245 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Shaft.SLDPRT Nov 19 14:23:40 2016
Cut-Extrude1	Solid Body	Mass:0.365331 lb Volume:1.31329 in^3 Density:0.27818 lb/in^3 Weight:0.365083 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket Holder.SLDPRT Nov 19 14:40:55 2016
Boss-Extrude2	Solid Body	Mass:0.280842 lb Volume:1.00957 in^3 Density:0.27818 lb/in^3 Weight:0.280652 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket.SLDPRT Nov 19 14:40:03 2016

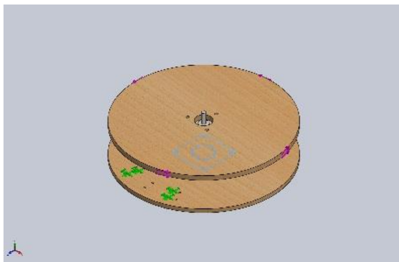
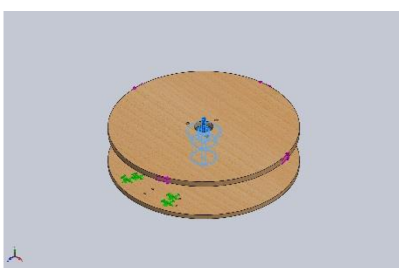
Study Properties

Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly)

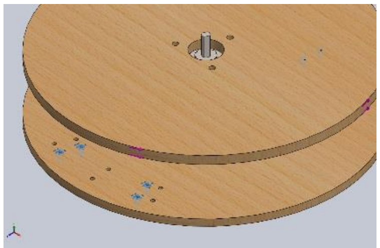
UNITS

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

MATERIAL PROPERTIES

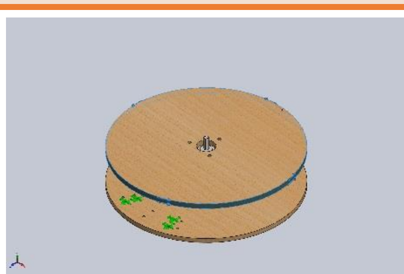
Model Reference	Properties	Components
	Name: 1060 Alloy Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 3999.3 psi Tensile strength: 9998.26 psi Elastic modulus: 1.00076e+007 psi Poisson's ratio: 0.33 Mass density: 0.0975437 lb/in^3 Shear modulus: 3.91602e+006 psi Thermal expansion coefficient: 1.33333e-005 /Fahrenheit	**SolidBody 1(Boss-Extrude1)(Attatchment Plate-1**
Curve Data:N/A		
	Name: Balsa Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 2900.75 psi Elastic modulus: 435113 psi Poisson's ratio: 0.29 Mass density: 0.00578 lb/in^3 Shear modulus: 43511.3 psi	**SolidBody 1(Cut-Extrude1)(Fina Hub Wheel-1), SolidBody 1(Cut-Extrude1)(Fina Sprocket Wheel-1)**
Curve Data:N/A		
	Name: Alloy Steel Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 89984.6 psi Tensile strength: 104982 psi Elastic modulus: 3.04579e+007 psi Poisson's ratio: 0.28 Mass density: 0.27818 lb/in^3 Shear modulus: 1.1458e+007 psi Thermal expansion coefficient: 7.22222e-006 /Fahrenheit	**SolidBody 1(Cut-Extrude1)(Hub Assembly-1/Final Hub Center-1), SolidBody 1(Boss-Extrude1)(Hub Assembly-1/Final Hub Shaft-1), SolidBody 1(Cut-Extrude1)(Hub Assembly-1/Hub Sprocket Holder-1), SolidBody 1(Boss-Extrude2)(Hub Assembly-1/Hub Sprocket-1)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 6 face(s) **Type:** Fixed Geometry

Resultant Forces

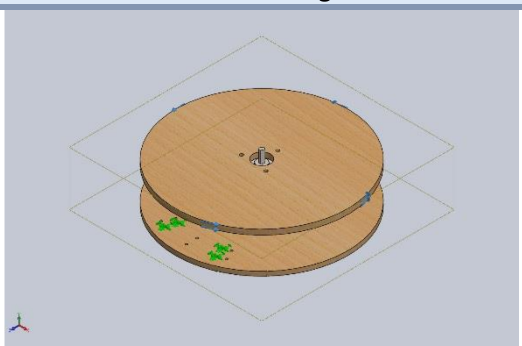
Components	X	Y	Z	Resultant
Reaction force(lbf)	**-5.3535e-005**	**-7.02728e-006**	**4.32558e-005**	**6.91841e-005**
Reaction Moment(lbf.in)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Torque-1		**Entities:** 1 face(s) **Type:** Apply torque **Value:** 100 lbf.in

Connector Definitions

No Data

Contact Information

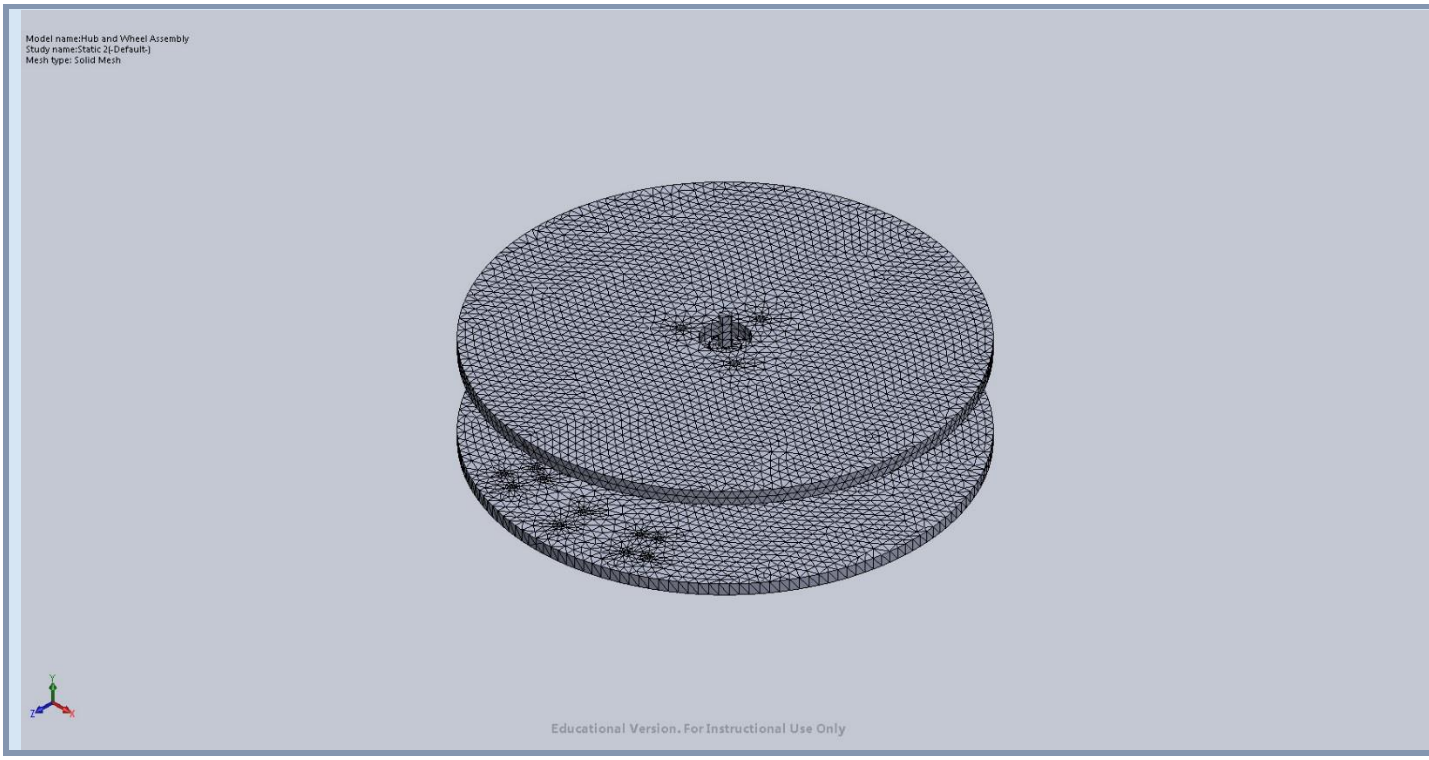
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh information - Details

Total Nodes	119946
Total Elements	71225
Maximum Aspect Ratio	29.586
% of elements with Aspect Ratio < 3	92.5
% of elements with Aspect Ratio > 10	0.14
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:15
Computer name:	URB215-04



Sensor Details
No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf	-5.3535e-005	-7.02728e-006	4.32558e-005	6.91841e-005

Reaction Moments

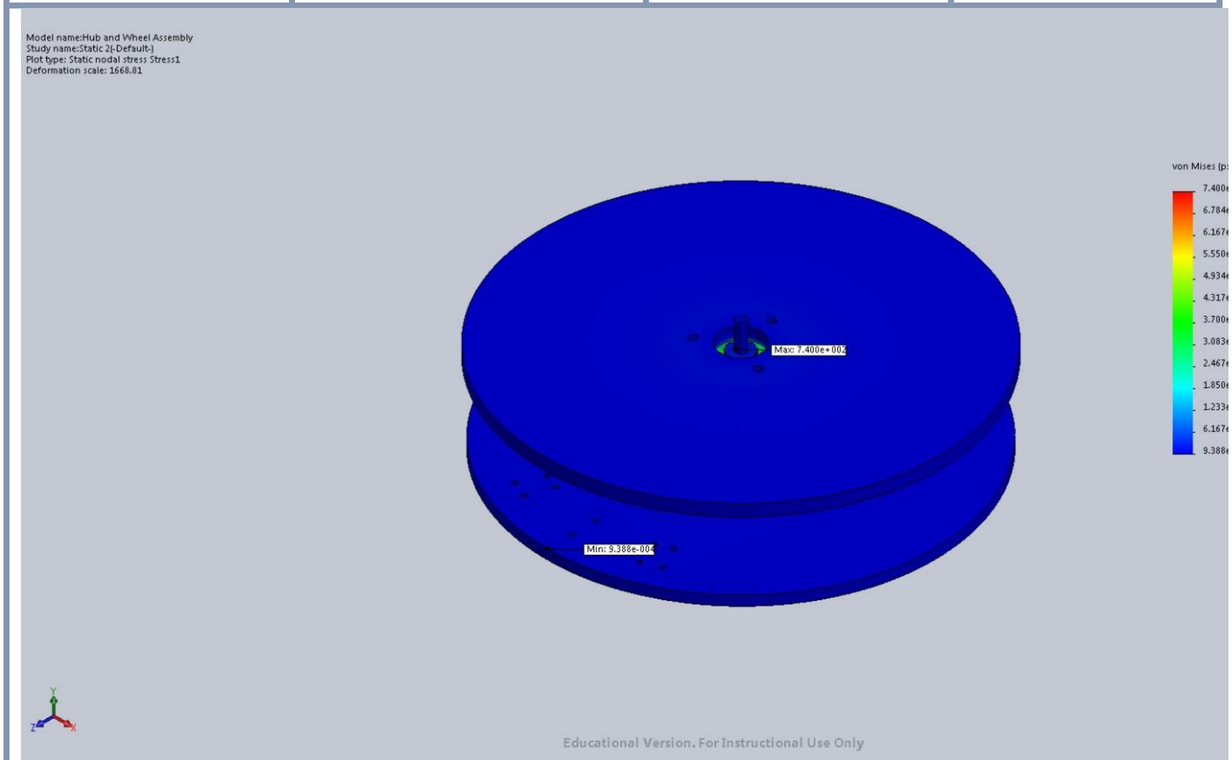
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf.in	0	0	0	0

Beams

No Data

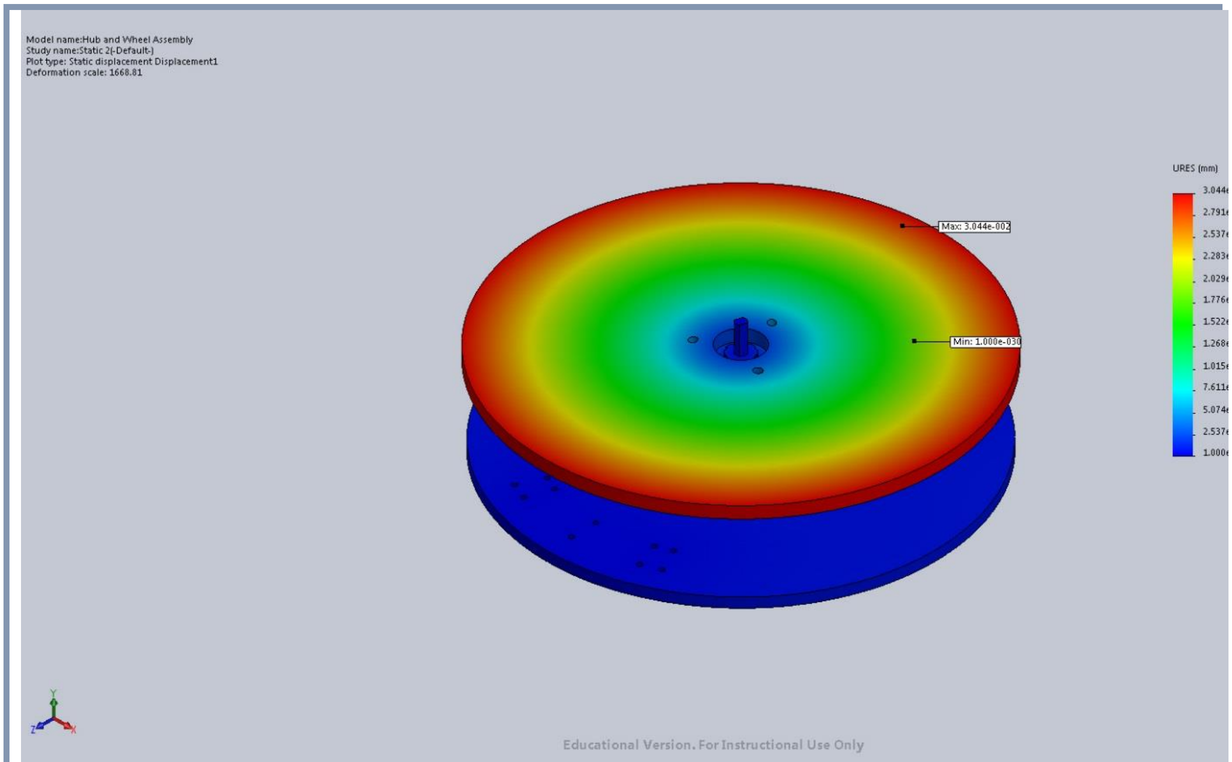
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.000938816 psi Node: 8103	740.038 psi Node: 119180



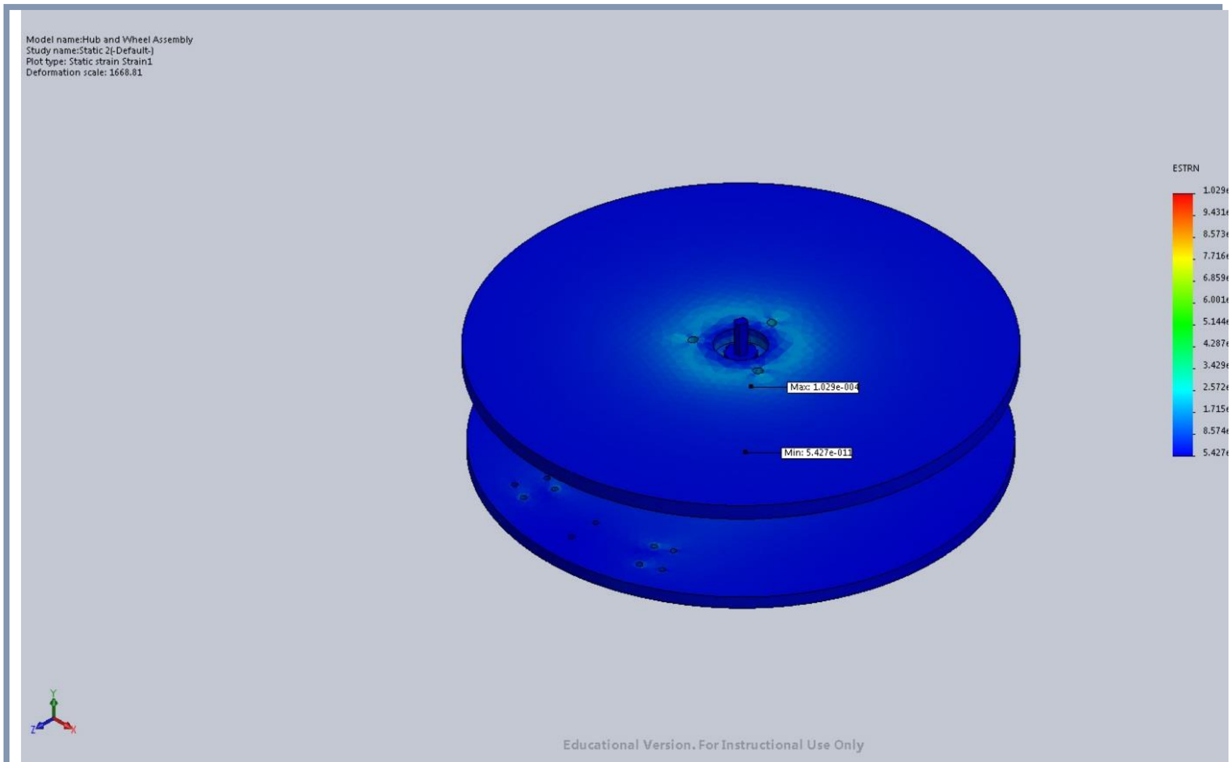
Hub and Wheel Assembly-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 8268	0.0304421 mm Node: 105524



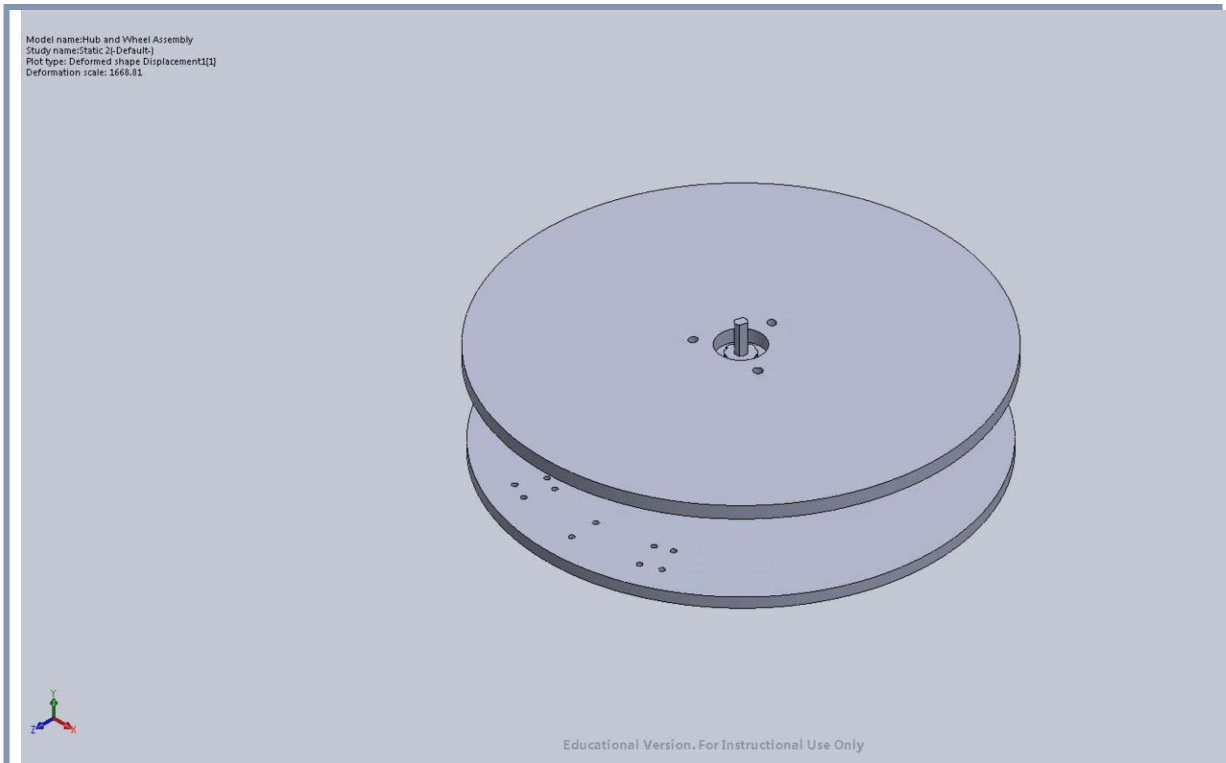
Hub and Wheel Assembly-Static 2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	5.42712e-011 Element: 68784	0.000102881 Element: 42591



Hub and Wheel Assembly-Static 2-Strain-Strain1

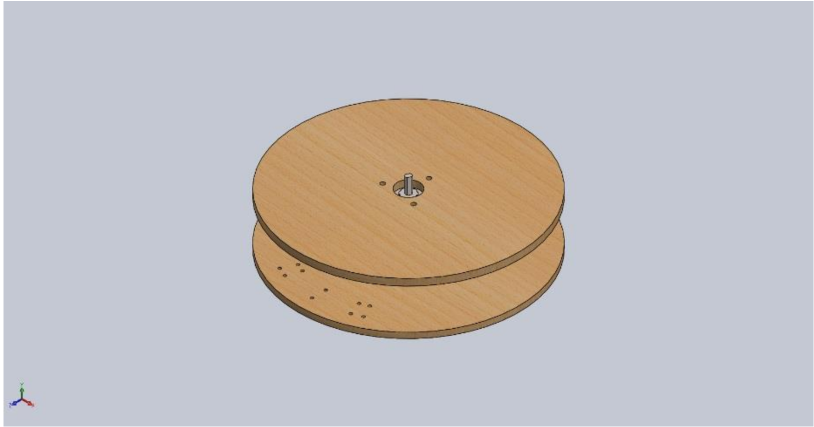
Name	Type
Displacement1{1}	Deformed shape



Hub and Wheel Assembly-Static 2-Displacement-Displacement1{1}

Conclusion

No failure will occur.



Simulation of Hub and Wheel Assembly

Date: Wednesday, December 07, 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

Table of Contents

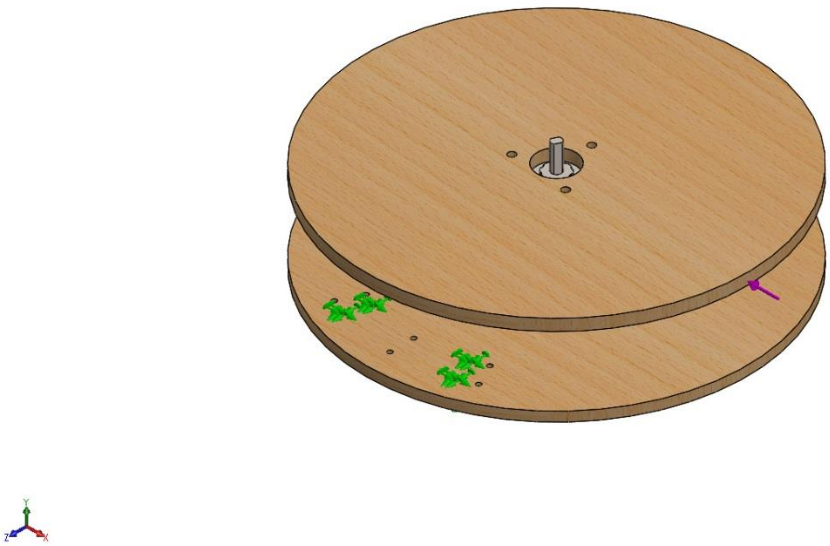
Description

No Data

ASSUMPTIONS

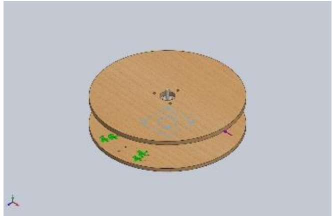
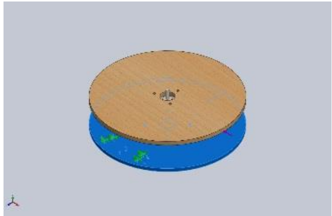
THE APPLIED FORCES ONLY OCCURRED AT THE SCREW HOLE POSITIONS. THE PINK ARROW REPRESENTS NORMAL FORCES FROM USER INPUT, WHILE THE GREEN ARROWS REPRESENT THE NORMAL FORCES FROM THE MACHINE SCREWS. THESE FORCES ONLY OCCUR AT THE ARROWS.

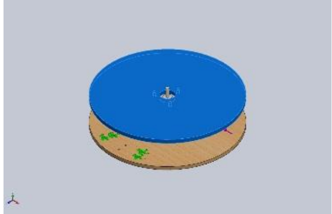
MODEL INFORMATION



Model name: Hub and Wheel Assembly
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1 	Solid Body	Mass:0.452672 lb Volume:4.64071 in^3 Density:0.0975437 lb/in^3 Weight:0.452365 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Attatchment Plate.SLDPRT Nov 19 14:18:28 2016
Cut-Extrude1 	Solid Body	Mass:0.896501 lb Volume:155.104 in^3 Density:0.00578 lb/in^3 Weight:0.895893 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Wheel.SLDPRT Dec 07 14:01:30 2016
Cut-Extrude1	Solid Body	Mass:1.07746 lb Volume:186.412 in^3 Density:0.00578 lb/in^3 Weight:1.07673 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Sprocket Wheel.SLDPRT Nov 21 16:10:37 2016

			
Cut-Extrude1	Solid Body	Mass:2.80809 lb Volume:10.0945 in^3 Density:0.27818 lb/in^3 Weight:2.80618 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Center.SLDPRT Dec 05 15:51:52 2016
Boss-Extrude1	Solid Body	Mass:0.280435 lb Volume:1.00811 in^3 Density:0.27818 lb/in^3 Weight:0.280245 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Shaft.SLDPRT Nov 19 14:23:40 2016
Cut-Extrude1	Solid Body	Mass:0.365331 lb Volume:1.31329 in^3 Density:0.27818 lb/in^3 Weight:0.365083 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket Holder.SLDPRT Nov 19 14:40:55 2016
Boss-Extrude2	Solid Body	Mass:0.280842 lb Volume:1.00957 in^3 Density:0.27818 lb/in^3 Weight:0.280652 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Hub Sprocket.SLDPRT Nov 19 14:40:03 2016

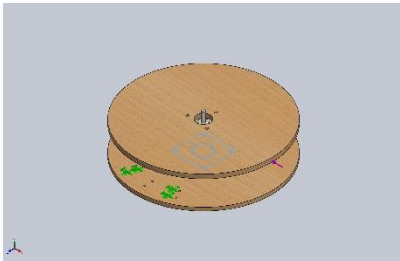
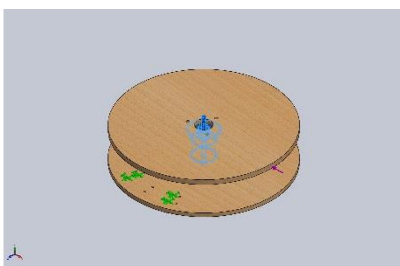
STUDY PROPERTIES

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly)

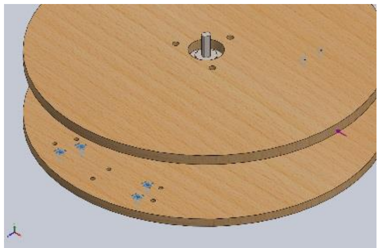
UNITS

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

Material Properties

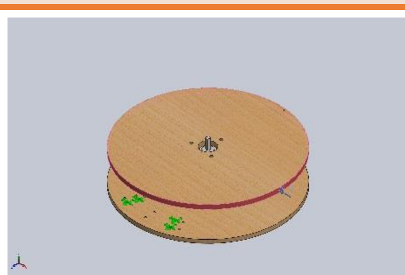
Model Reference	Properties	Components
	Name: 1060 Alloy Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 3999.3 psi Tensile strength: 9998.26 psi Elastic modulus: 1.00076e+007 psi Poisson's ratio: 0.33 Mass density: 0.0975437 lb/in^3 Shear modulus: 3.91602e+006 psi Thermal expansion coefficient: 1.33333e-005 /Fahrenheit	SolidBody 1(Boss-Extrude1)(Attatchment Plate-1)
Curve Data:N/A		
	Name: Balsa Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 2900.75 psi Elastic modulus: 435113 psi Poisson's ratio: 0.29 Mass density: 0.00578 lb/in^3 Shear modulus: 43511.3 psi	SolidBody 1(Cut-Extrude1)(Fina Hub Wheel-1), SolidBody 1(Cut-Extrude1)(Fina Sprocket Wheel-1)
Curve Data:N/A		
	Name: Alloy Steel Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 89984.6 psi Tensile strength: 104982 psi Elastic modulus: 3.04579e+007 psi Poisson's ratio: 0.28 Mass density: 0.27818 lb/in^3 Shear modulus: 1.1458e+007 psi Thermal expansion coefficient: 7.22222e-006 /Fahrenheit	SolidBody 1(Cut-Extrude1)(Hub Assembly-1/Final Hub Center-1), SolidBody 1(Boss-Extrude1)(Hub Assembly-1/Final Hub Shaft-1), SolidBody 1(Cut-Extrude1)(Hub Assembly-1/Hub Sprocket Holder-1), SolidBody 1(Boss-Extrude2)(Hub Assembly-1/Hub Sprocket-1)
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 6 face(s) **Type:** Fixed Geometry

<Label_FixtResForces/>

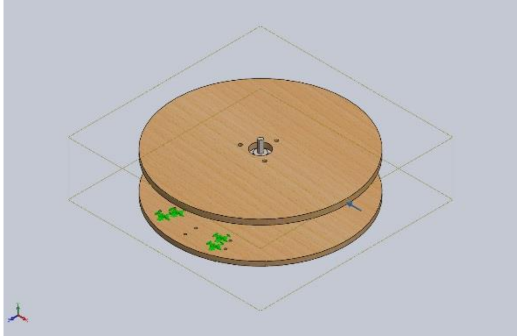
<L_FxRsForceComp/>	<L_FxRsForceX/>	<L_FxRsForceY/>	<L_FxRsForceZ/>	<L_FxRsForceRes/>
<FxRsForceType1/>	<FxRsForceX1/>	<FxRsForceY1/>	<FxRsForceZ1/>	<FxRsForceRes1/>

Load name	Load Image	Load Details
Force-2		**Reference:** Face< 1 > **Type:** Apply force **Values:** -100, ---, --- lbf

Connector Definitions

No Data

CONTACT INFORMATION

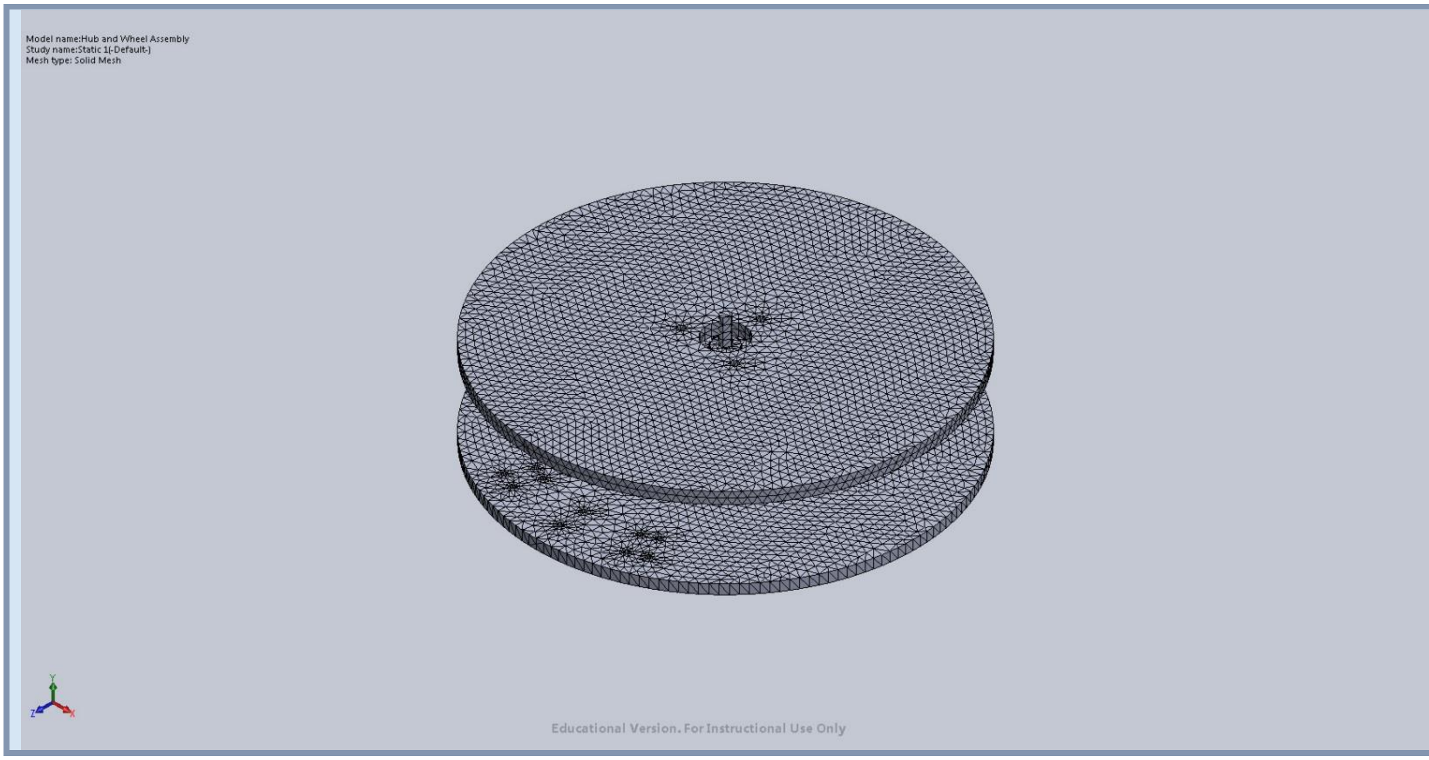
Contact	Contact Image	Contact Properties
Global Contact		**Type:** **Bonded** **Components:** **1 component(s)** **Options:** **Compatible mesh**

MESH INFORMATION

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

MESH INFORMATION - DETAILS

Total Nodes	119946
Total Elements	71225
Maximum Aspect Ratio	29.586
% of elements with Aspect Ratio < 3	92.5
% of elements with Aspect Ratio > 10	0.14
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:16
Computer name:	URB215-04



Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf	99.7822	0.0105216	6.60107	100

Reaction Moments

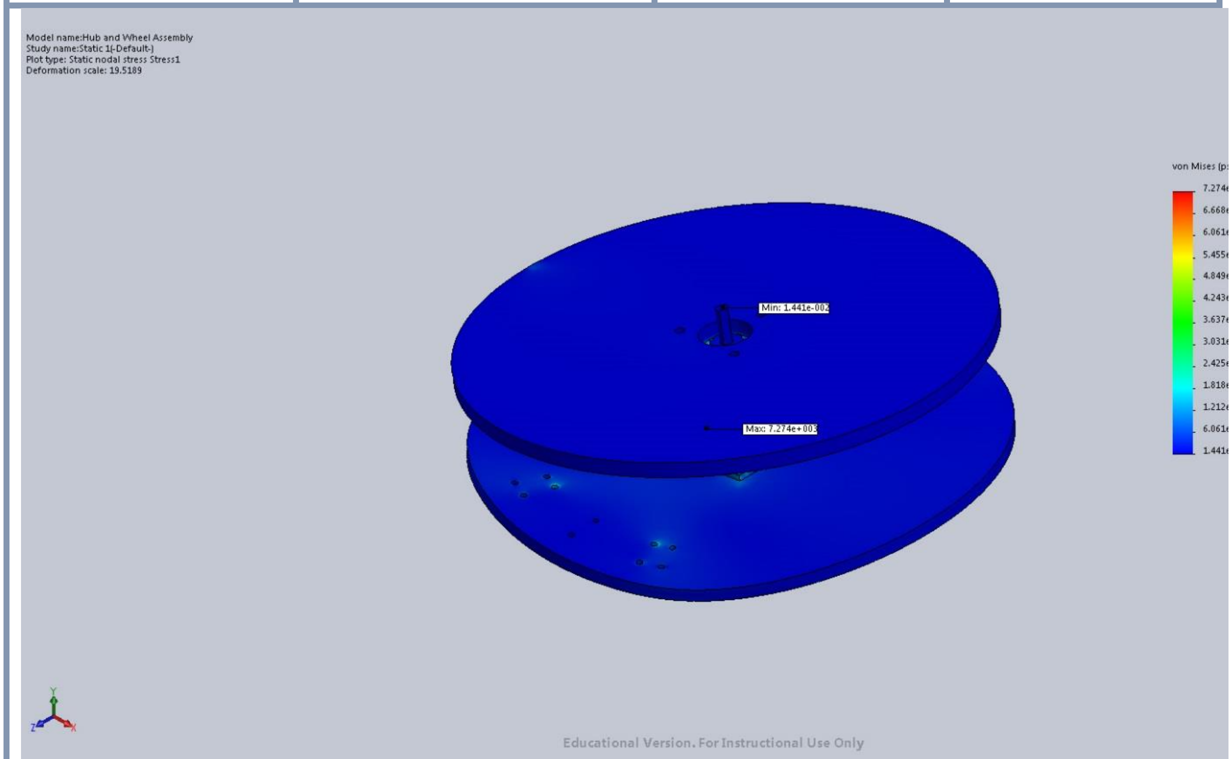
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf.in	0	0	0	0

Beams

No Data

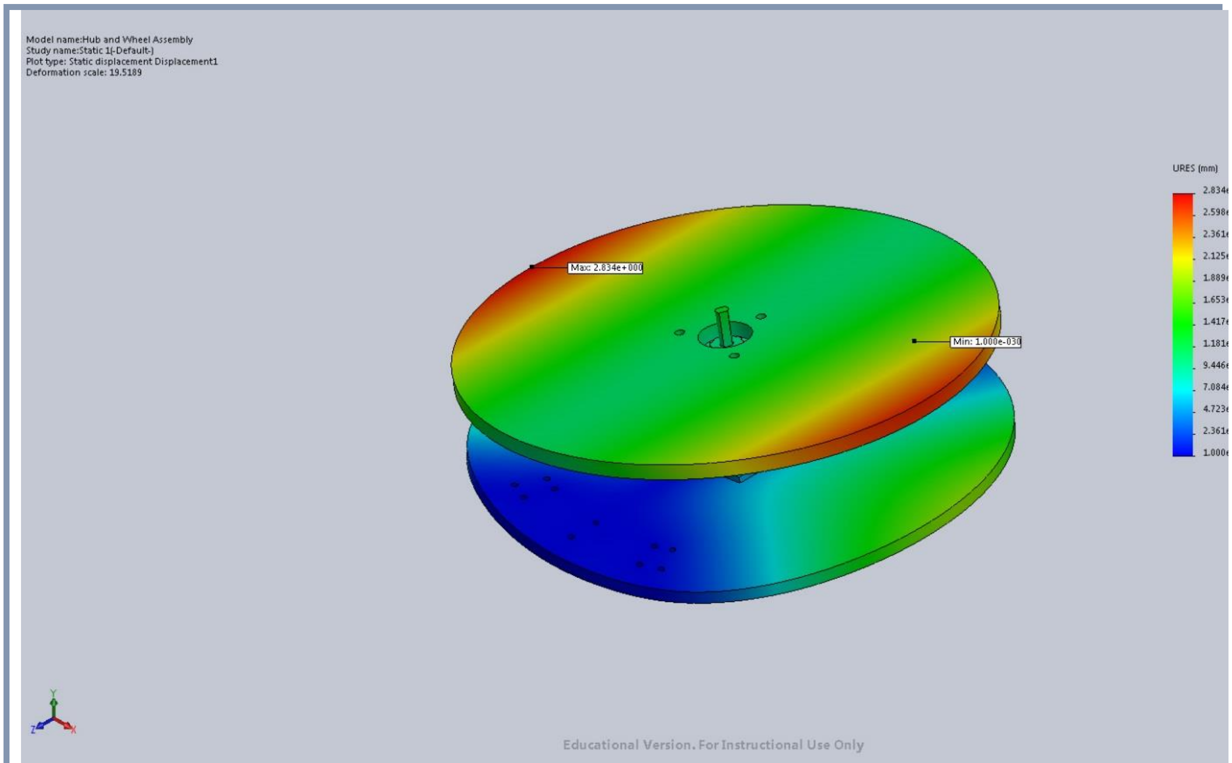
STUDY RESULTS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.0144078 psi Node: 116399	7273.63 psi Node: 111580



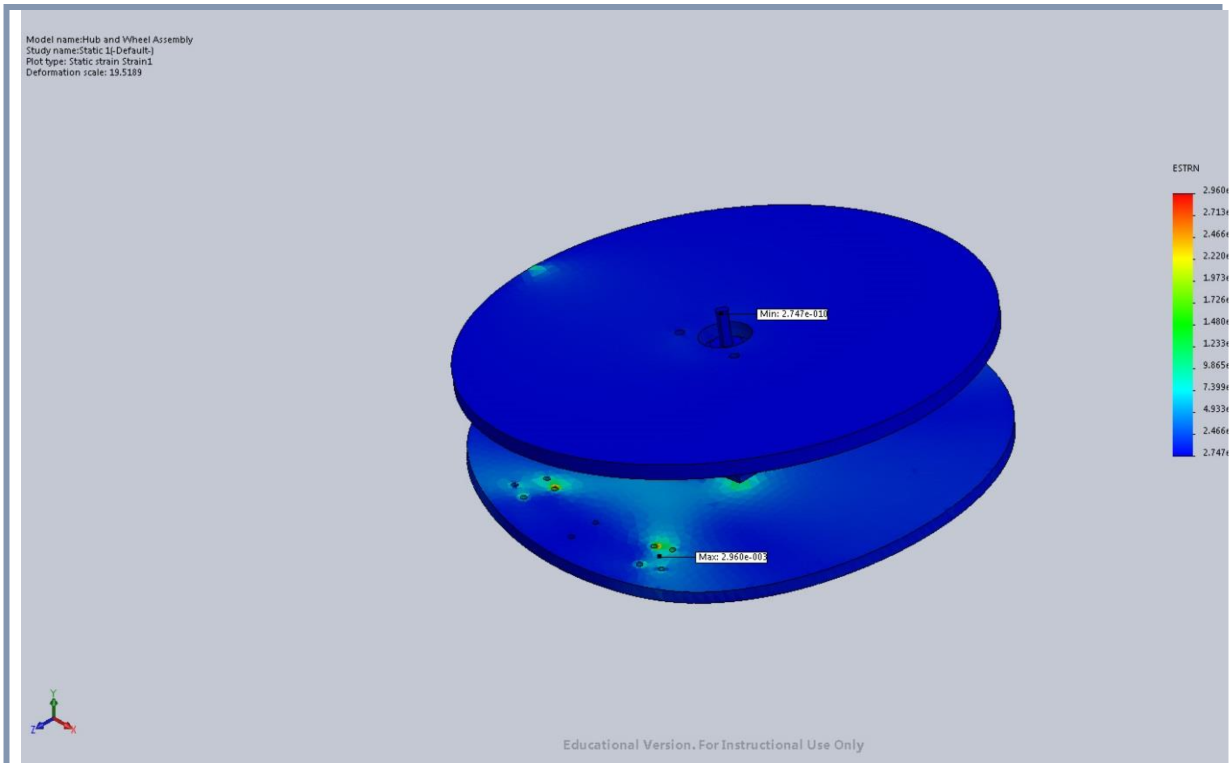
Hub and Wheel Assembly-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 8268	2.83376 mm Node: 88137



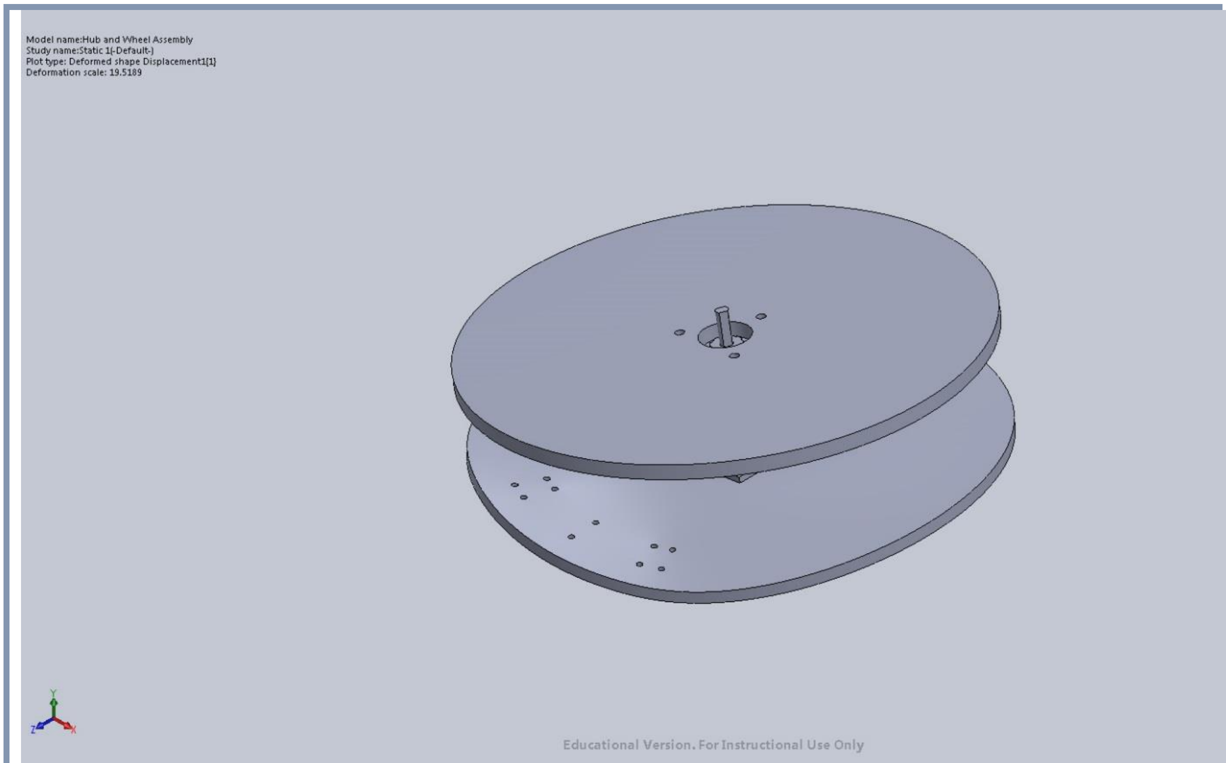
Hub and Wheel Assembly-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.74675e-010 Element: 68913	0.00295955 Element: 16078



Hub and Wheel Assembly-Static 1-Strain-Strain1

Name	Type
Displacement1{1}	Deformed shape



Hub and Wheel Assembly-Static 1-Displacement-Displacement1{1}

CONCLUSION

No failure will occur.

Simulation of Final Hub Wheel

Date: Wednesday, December 07, 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

Table of Contents

Description

No Data

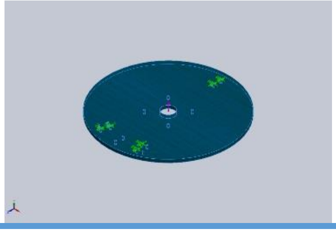
Assumptions

The applied forces only occurred at the screw hole positions. The pink arrow represents normal forces from the Hub Attachment Plate, while the green arrows represent the normal forces from the machine screws. These forces only occur at the arrows.

Model Information

Model name: Final Hub Wheel
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:0.896501 lb Volume:155.104 in^3 Density:0.00578 lb/in^3 Weight:0.895893 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Wheel.SLDPRT Dec 07 14:01:30 2016

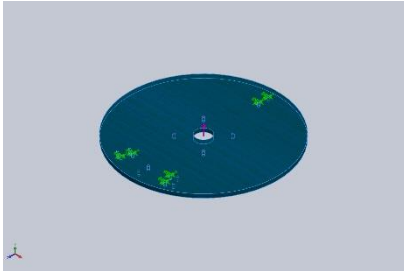
STUDY PROPERTIES

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\New Assembly)

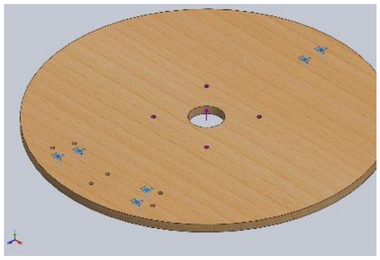
Units

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

Material Properties

Model Reference	Properties	Components
	Name: **Balsa** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2900.75 psi** Elastic modulus: **435113 psi** Poisson's ratio: **0.29** Mass density: **0.00578 lb/in^3** Shear modulus: **43511.3 psi**	**SolidBody 2(Cut-Extrude1)(Fina Hub Wheel)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-3		**Entities:** 6 face(s) **Type:** Fixed Geometry

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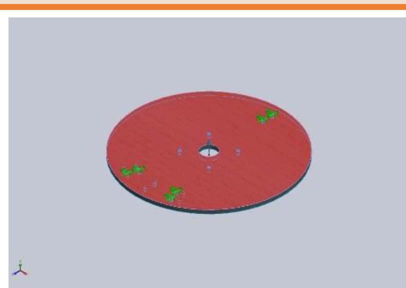
<L_FxRsForceComp/>	<L_FxRsForceX/>	<L_FxRsForceY/>	<L_FxRsForceZ/>	<L_FxRsForceRes/>
<FxRsForceType1/>	<FxRsForceX1/>	<FxRsForceY1/>	<FxRsForceZ1/>	<FxRsForceRes1/>

Load name	Load Image	Load Details
Force-1		**Entities:** 4 edge(s), 1 Solid Body (s) **Reference:** Face< 1 > **Type:** Apply force **Values:** ---, ---, 25 lbf

Connector Definitions

No Data

Contact Information

No Data

Mesh information

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<Header2_MeshDetails/>

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<Image_Mesh/>	

<Header2_MeshControlsDetails/>

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<Label_MeshQualityPlots/>

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Sensor Details

No Data

Resultant Forces

<Header2_ReactionForces/>

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<Header2_ReactionMoments/>

<L_RMSelSet/>	<L_RMUnits/>	<L_RMSumX/>	<L_RMSumY/>	<L_RMSumZ/>	<L_RMResultant/>

Beams

No Data

Study Results

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<Label_StudyResultsFrequencies/>

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<Label_StudyResultsMassParticipation/>

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Conclusion

No failure will occur.

Simulation of Final Hub Wheel

Date: Wednesday, December 07, 2016
Designer: Solidworks
Study name: Static 2
Analysis type: Static

Table of Contents

Description

No Data

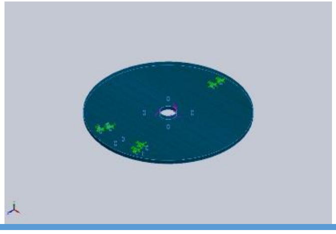
Assumptions

The applied forces only occurred at the screw hole positions. The pink arrow represents shear forces from the Internal Hub, while the green arrows represent the normal forces from the machine screws. These forces only occur at the arrows.

Model Information

Model name: Final Hub Wheel
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:0.896501 lb Volume:155.104 in^3 Density:0.00578 lb/in^3 Weight:0.895893 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Hub Wheel.SLDPRT Dec 07 14:01:30 2016

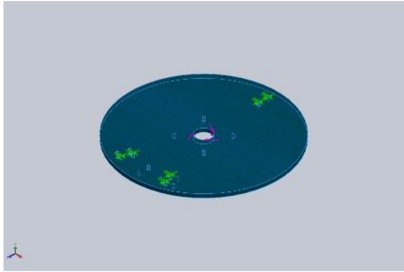
Study Properties

Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\New Assembly)

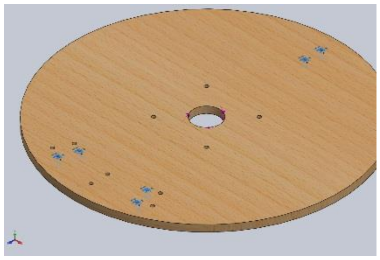
Units

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

Material Properties

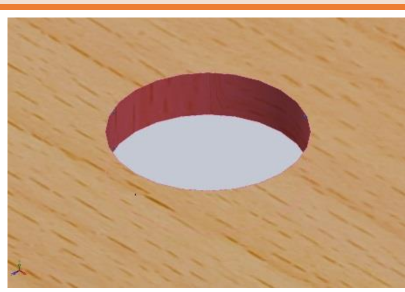
Model Reference	Properties	Components
	Name: **Balsa** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2900.75 psi** Elastic modulus: **435113 psi** Poisson's ratio: **0.29** Mass density: **0.00578 lb/in^3** Shear modulus: **43511.3 psi**	**SolidBody 2(Cut-Extrude1)(Fina Hub Wheel)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 6 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(lbf)	**0.98322**	**-7.28211**	**-18.825**	**20.2083**
Reaction Moment(lbf.in)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Torque-1		**Reference:** Face< 1 > **Type:** Apply torque **Value:** 200 lbf.in

Connector Definitions

No Data

Contact Information

No Data

Mesh information

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<Header2_MeshDetails/>

<Label_MeshProp/>	<Setting_MeshProp/>
<Image_Mesh/>	

<Header2_MeshControlsDetails/>

<L_MeshControlName/>	<Label_MeshControlImage/>	<Label_MeshControlDetail/>
<MeshContol_Name/>	**<MeshControl_Image/>**	**<MeshControl_Details/>**

<Label_MeshQualityPlots/>

<L_MQName/>	<L_MQType/>	<L_MQMin/>	<L_MQMax/>
<MQ_Name/>	<MQ_Type/>	<MQ_Min/>	<MQ_Max/>
<Image_MeshQualityPlot/> <ImageCaption_MeshQualityPlot/>			

Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf	-0.000150187	-2.40608e-006	0.000131785	0.000199823

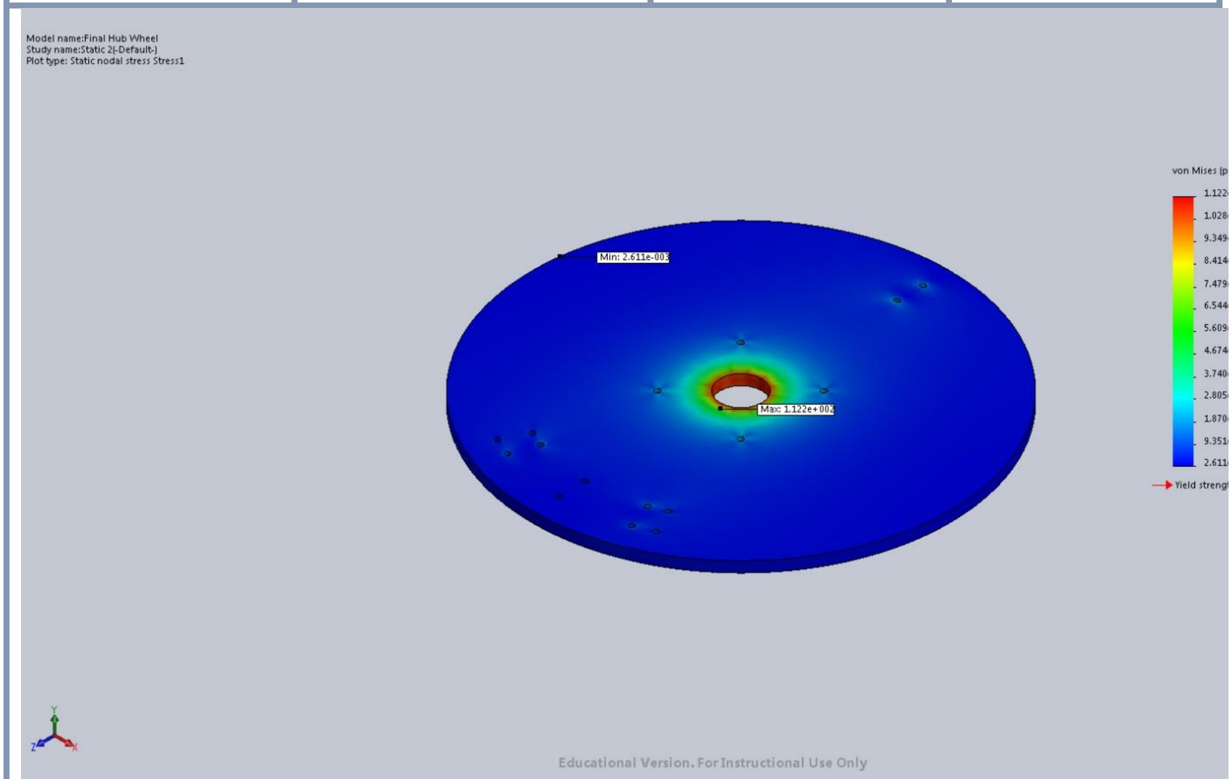
Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf.in	0	0	0	0

BEAMS
No Data

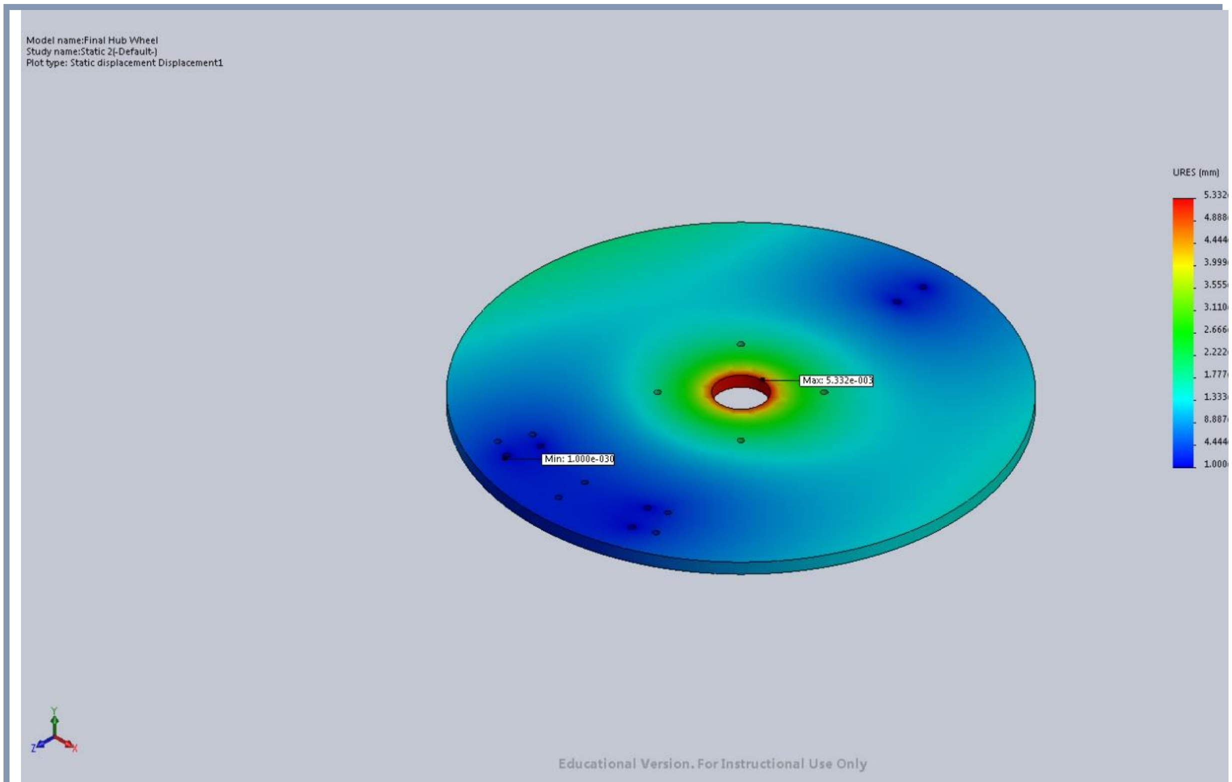
STUDY RESULTS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00261077 psi Node: 21011	112.182 psi Node: 21260



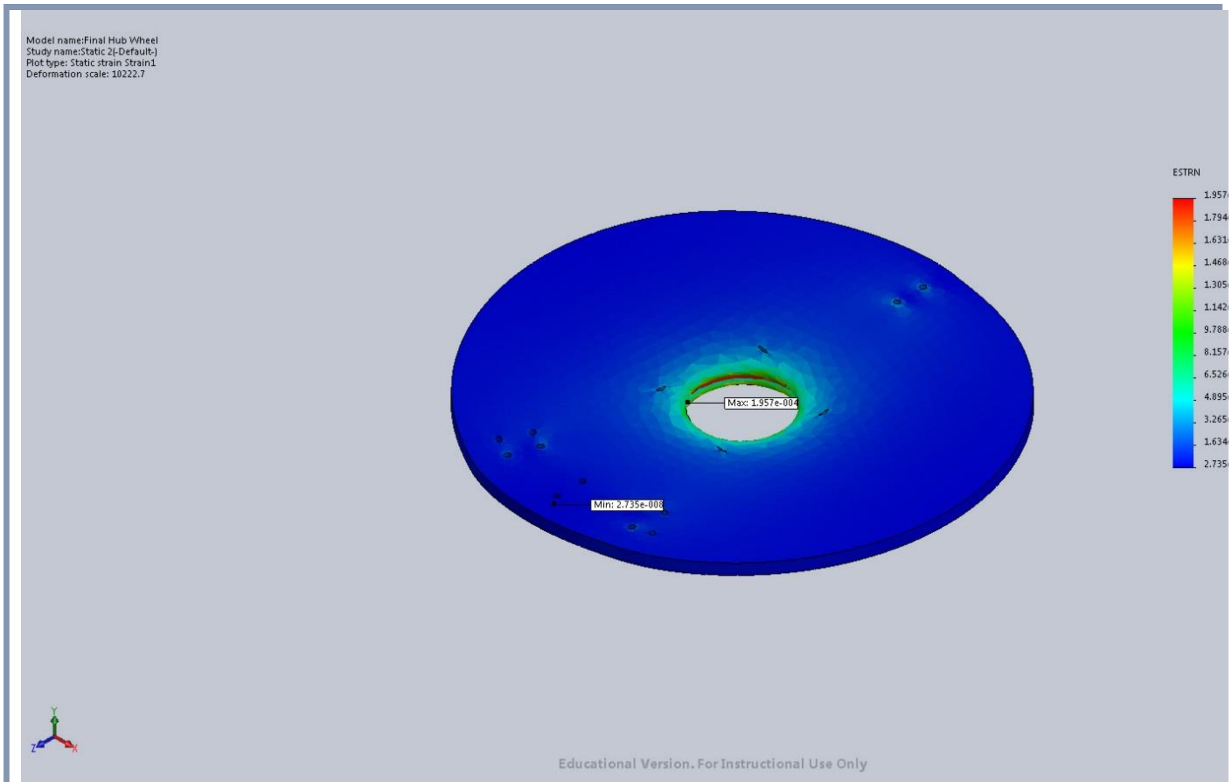
Final Hub Wheel-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 145	0.00533224 mm Node: 447



Final Hub Wheel-Static 2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.7349e-008 Element: 6202	0.000195737 Element: 10030



Final Hub Wheel-Static 2-Strain-Strain1

Conclusion

Failure is very unlikely.

Simulation of Final Sprocket Wheel

Date: Wednesday, December 07, 2016
Designer: Noah Dromgoole
Study name: Static 1
Analysis type: Static

Table of Contents

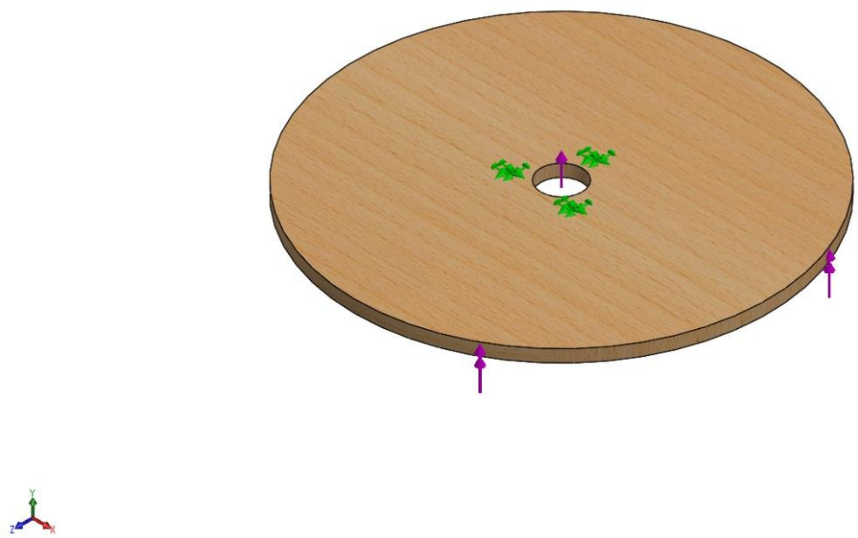
Description

No Data

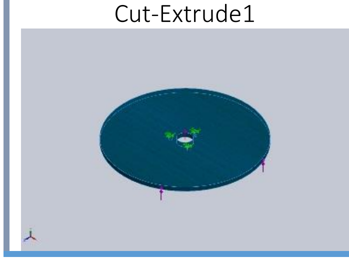
ASSUMPTIONS

THE APPLIED FORCES ONLY OCCURRED AT THE SCREW HOLE POSITIONS. THE PINK ARROWS ON THE OUTSIDE OF THE INPUT PLATE REPRESENTS NORMAL FORCES FROM OUTWARD USER INPUT, WHILE THE PINK ARROW ON THE INSIDE REPRESENT NORMAL FORCES FORM THE INTERNAL HUB. THE GREEN ARROWS REPRESENT THE NORMAL FORCES FROM THE MACHINE SCREWS. THESE FORCES ONLY OCCUR AT THE ARROWS.

Model Information



Model name: Final Sprocket Wheel
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:1.07746 lb Volume:186.412 in^3 Density:0.00578 lb/in^3 Weight:1.07673 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Sprocket Wheel.SLDPRT Nov 21 16:10:37 2016

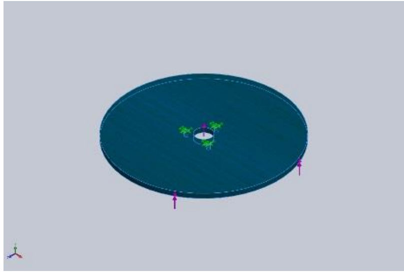
STUDY PROPERTIES

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\New Assembly)

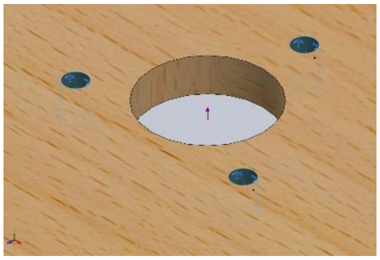
UNITS

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

MATERIAL PROPERTIES

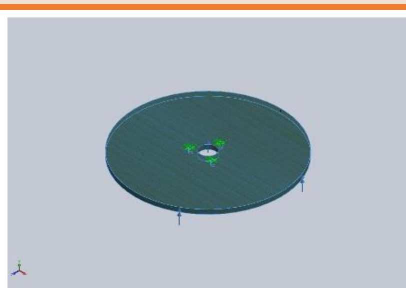
Model Reference	Properties	Components
	Name: **Balsa** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2900.75 psi** Elastic modulus: **435113 psi** Poisson's ratio: **0.29** Mass density: **0.00578 lb/in^3** Shear modulus: **43511.3 psi**	**SolidBody 2(Cut-Extrude1)(Fina Sprocket Wheel)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 3 face(s) **Type:** Fixed Geometry

<Label_FixtResForces/>

<L_FxRsForceComp/>	<L_FxRsForceX/>	<L_FxRsForceY/>	<L_FxRsForceZ/>	<L_FxRsForceRes/>
<FxRsForceType1/>	<FxRsForceX1/>	<FxRsForceY1/>	<FxRsForceZ1/>	<FxRsForceRes1/>

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s), 1 Solid Body (s) **Type:** Apply force **Values:** ---, ---, 100 lbf

Connector Definitions

No Data

Contact Information

No Data

Mesh information

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<Image_MeshQualityPlot/> <ImageCaption_MeshQualityPlot/>			

Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf	-0.00147096	-99.9988	0.00187681	99.9988

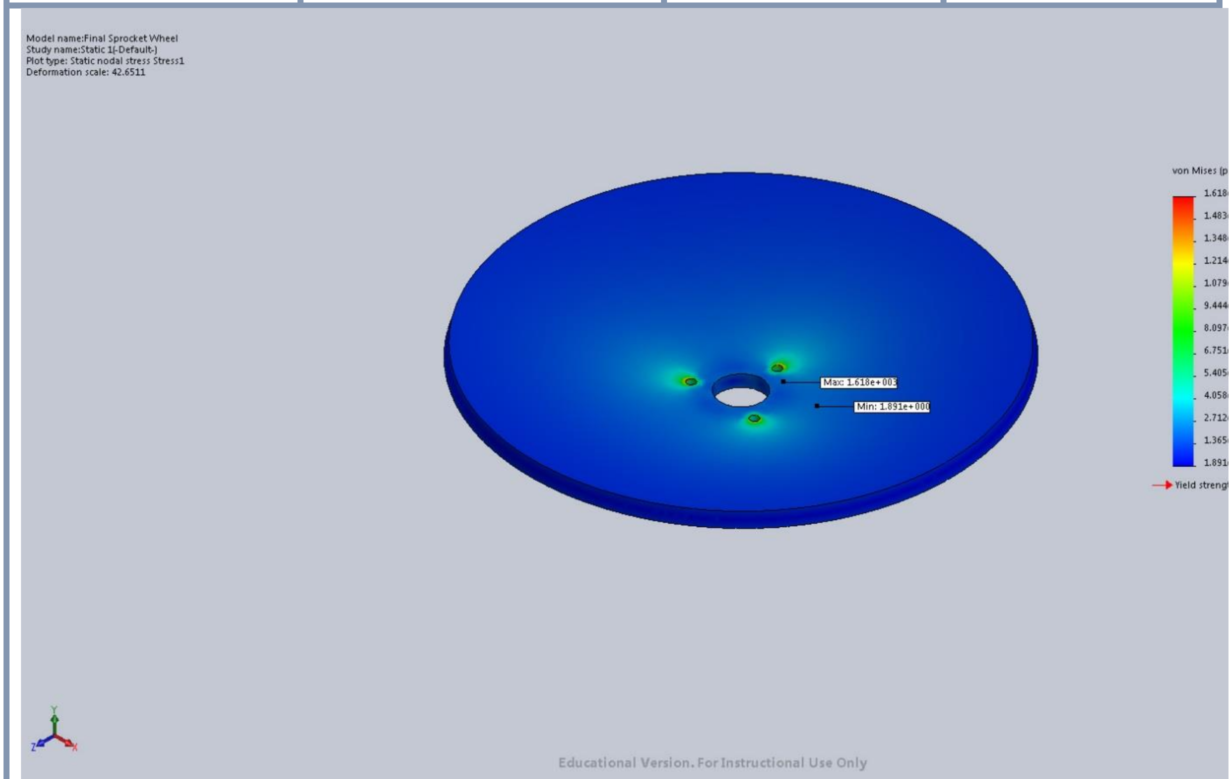
Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf.in	0	0	0	0

BEAMS
No Data

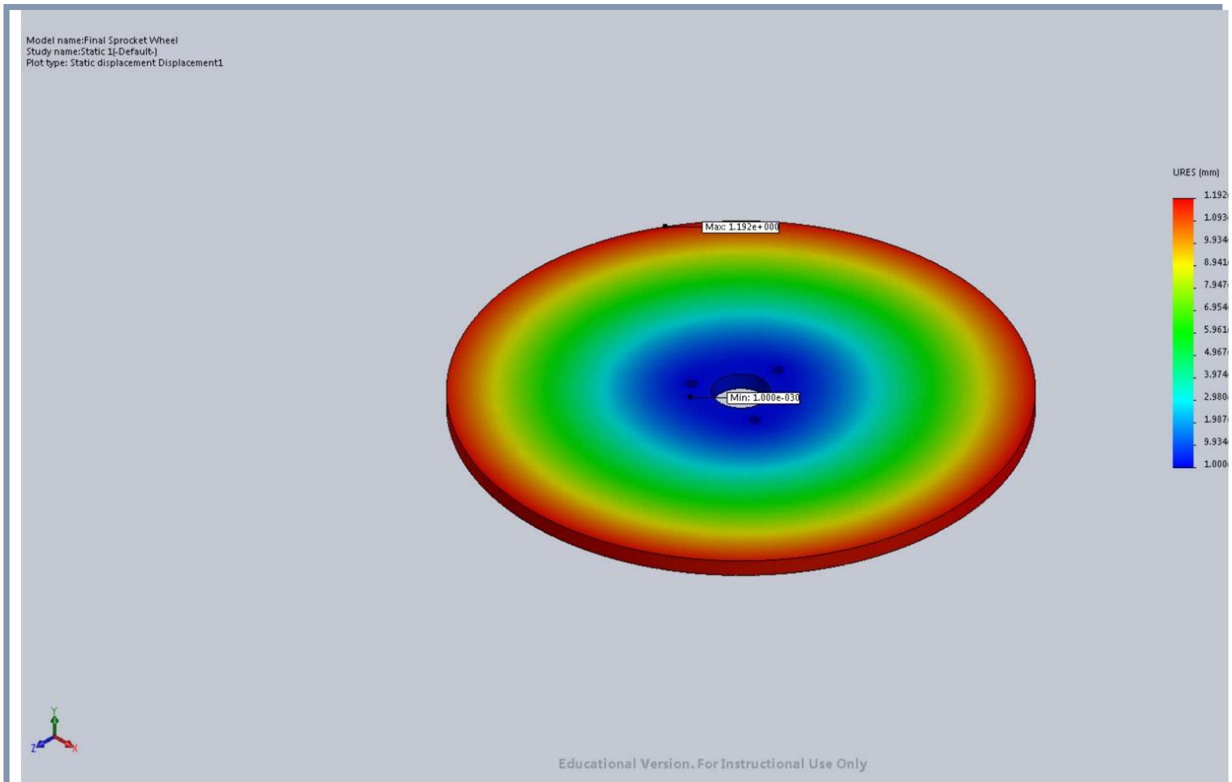
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.89136 psi Node: 18184	1617.58 psi Node: 5162



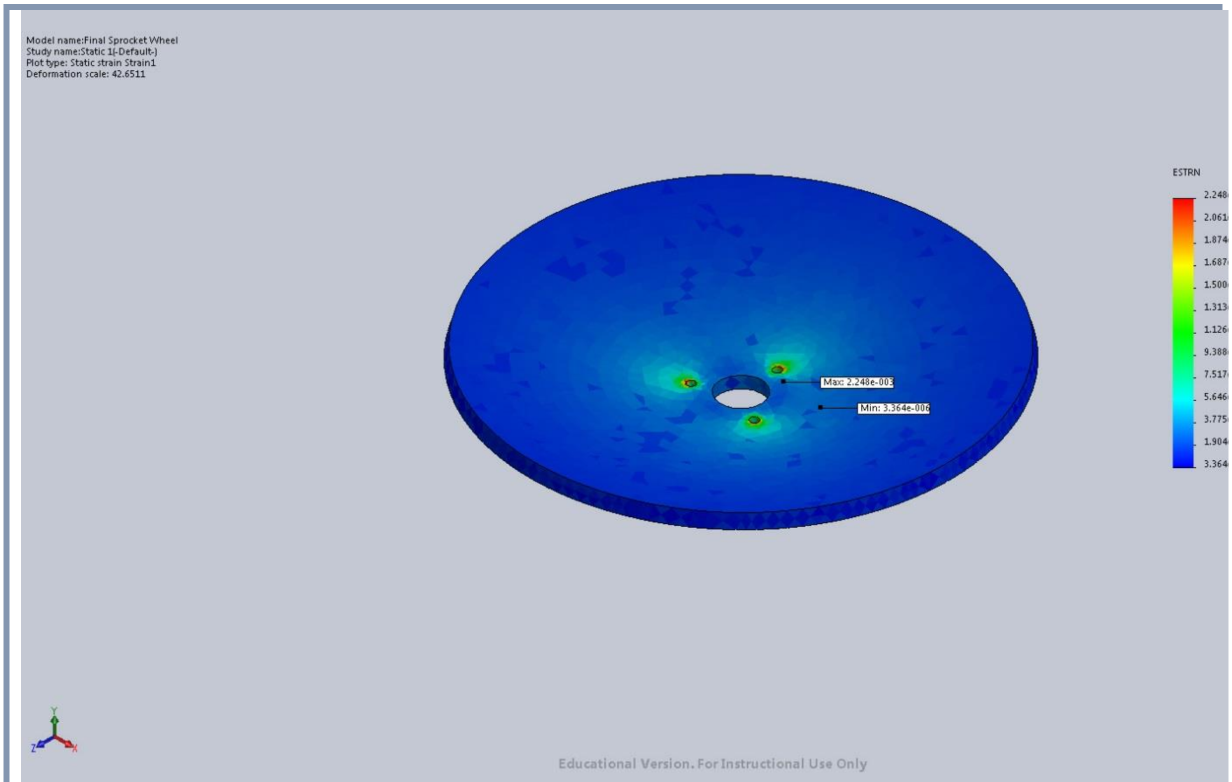
Final Sprocket Wheel-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 301	1.19211 mm Node: 180



Final Sprocket Wheel-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.36401e-006 Element: 14770	0.00224836 Element: 433



Final Sprocket Wheel-Static 1-Strain-Strain1

Conclusion

No failure will occur.

Simulation of Final Sprocket Wheel

Date: Wednesday, December 07, 2016
Designer: Solidworks
Study name: Static 2
Analysis type: Static

Table of Contents

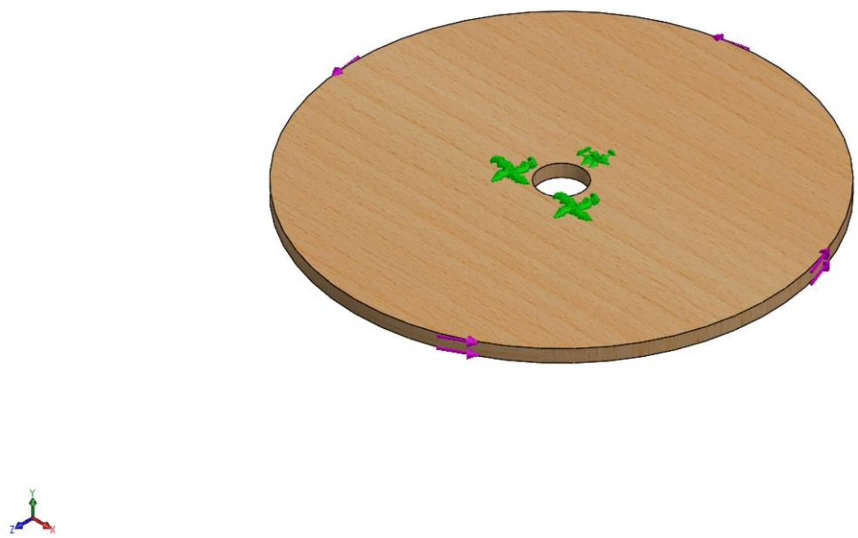
Description

No Data

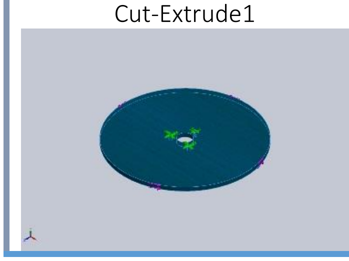
ASSUMPTIONS

THE APPLIED FORCES ONLY OCCURRED AT THE SCREW HOLE POSITIONS. THE PINK ARROWS ON THE OUTSIDE OF THE INPUT PLATE REPRESENTS SHEAR FORCES FROM OUTWARD USER INPUT. THE GREEN ARROWS REPRESENT THE NORMAL FORCES FROM THE MACHINE SCREWS. THESE FORCES ONLY OCCUR AT THE ARROWS.

Model Information



Model name: Final Sprocket Wheel
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:1.07746 lb Volume:186.412 in^3 Density:0.00578 lb/in^3 Weight:1.07673 lbf	\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly\Final Sprocket Wheel.SLDPRT Nov 21 16:10:37 2016

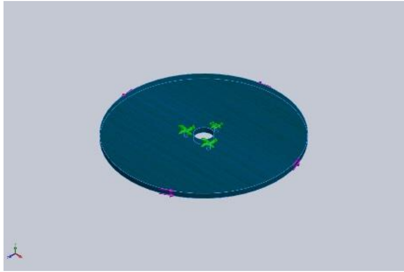
Study Properties

Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\noahdromgoole\winprofile\desktop\Final Assembly)

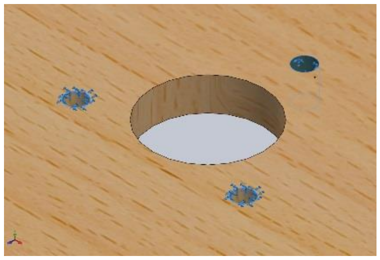
UNITS

Unit system:	English (IPS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	psi

MATERIAL PROPERTIES

Model Reference	Properties	Components
	Name: **Balsa** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2900.75 psi** Elastic modulus: **435113 psi** Poisson's ratio: **0.29** Mass density: **0.00578 lb/in^3** Shear modulus: **43511.3 psi**	**SolidBody 1(Cut-Extrude1)(Fina Sprocket Wheel)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 2 edge(s), 1 face(s) **Type:** Fixed Geometry

<Label_FixtResForces/>

<L_FxRsForceComp/>	<L_FxRsForceX/>	<L_FxRsForceY/>	<L_FxRsForceZ/>	<L_FxRsForceRes/>
<FxRsForceType1/>	<FxRsForceX1/>	<FxRsForceY1/>	<FxRsForceZ1/>	<FxRsForceRes1/>

Load name	Load Image	Load Details
Torque-1		**Entities:** 1 face(s) **Type:** Apply torque **Value:** 100 lbf.in

Connector Definitions
No Data

Contact Information
No Data

Mesh information

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<Header2_MeshDetails/>

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<Image_Mesh/>	

<Header2_MeshControlsDetails/>

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<Label_MeshQualityPlots/>

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<Image_MeshQualityPlot/> <ImageCaption_MeshQualityPlot/>			

Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf	0.00028075	-9.0106e-005	-0.000269815	0.000399675

Reaction Moments

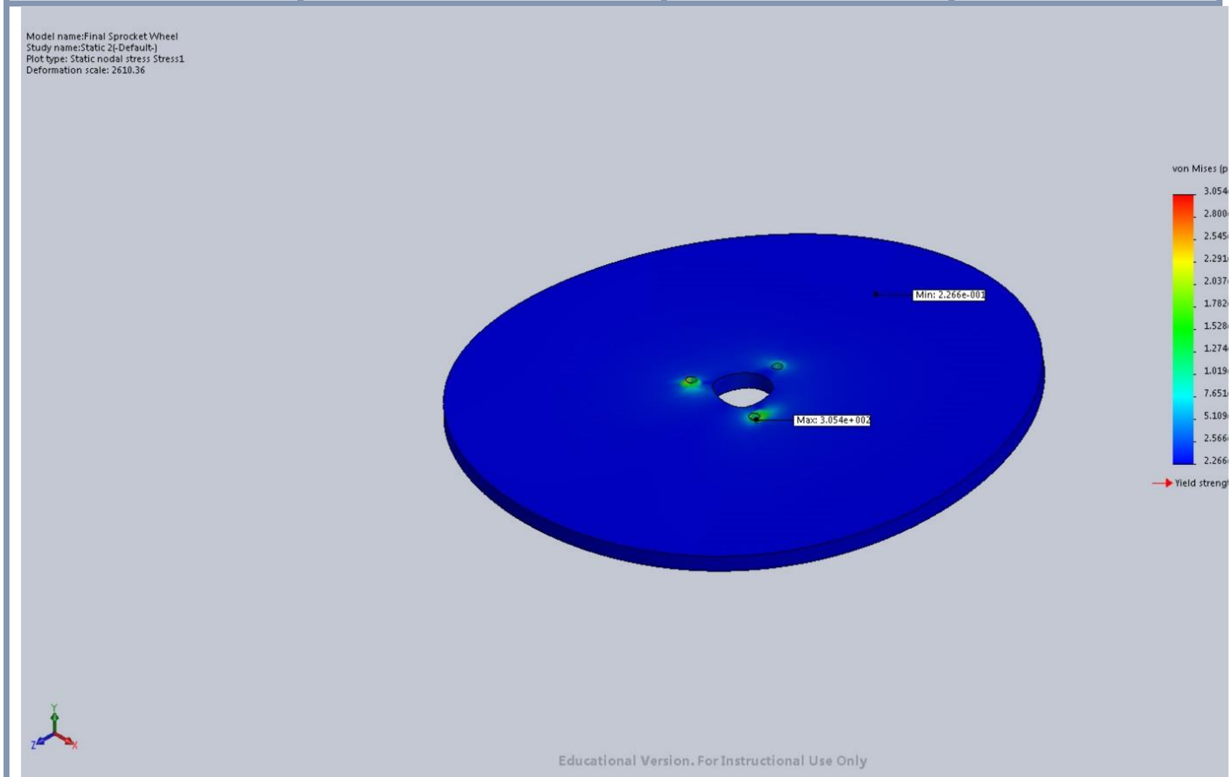
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf.in	0	0	0	0

BEAMS

No Data

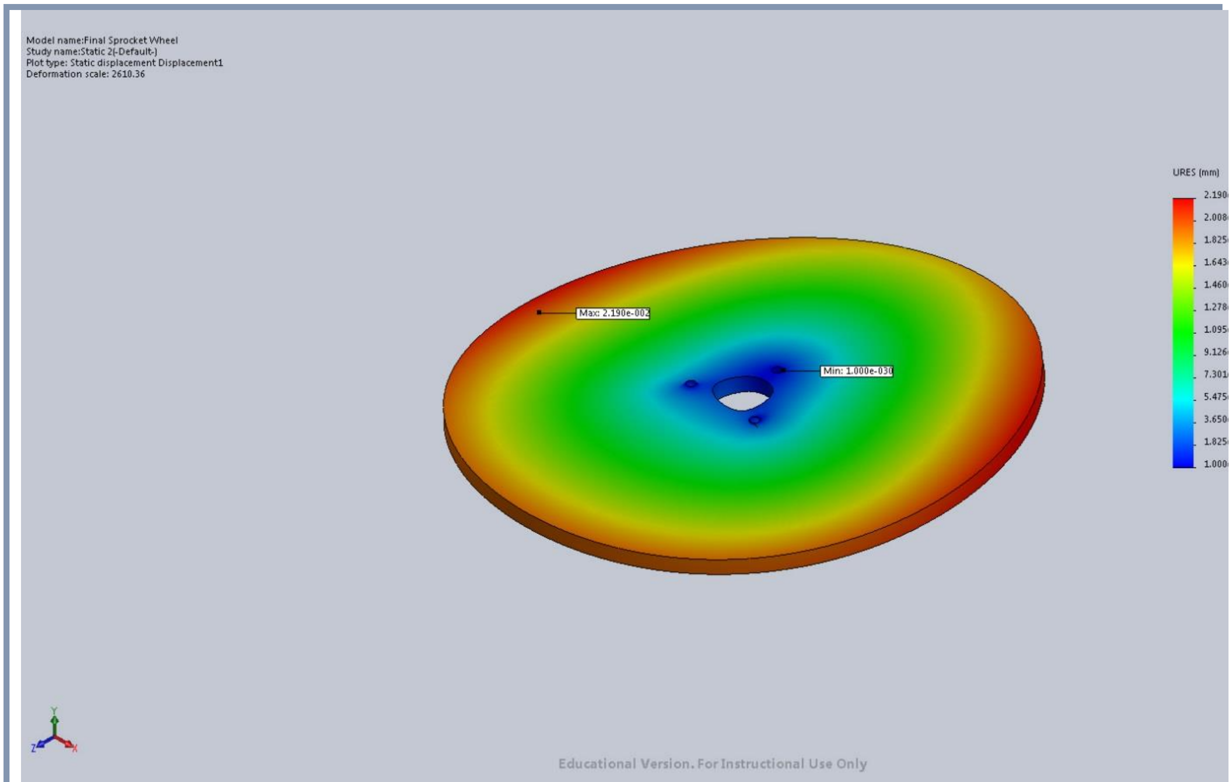
STUDY RESULTS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.226558 psi Node: 9714	305.38 psi Node: 18147



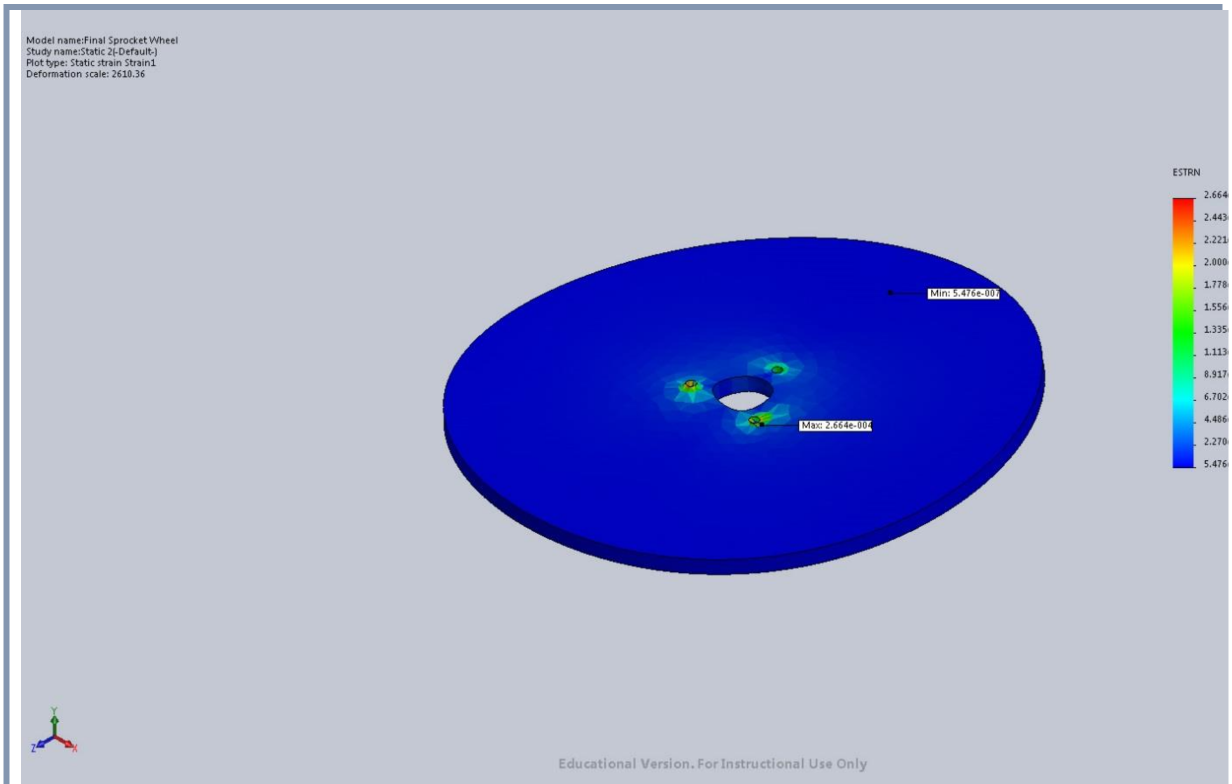
Final Sprocket Wheel-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 6	0.021902 mm Node: 10423



Final Sprocket Wheel-Static 2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	5.47649e-007 Element: 9014	0.000266427 Element: 3378



Final Sprocket Wheel-Static 2-Strain-Strain1

Conclusion

No failure will occur.

12 Annotated Bibliography

Limited to 150 words per entry