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Collapsible Moped

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MEMS 411 Final Report

Moped Team IV

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The ultra-light, collapsible street-legal moped combines the desired qualities of a motorcycle, a bicycle, and a skateboard. This innovative design allows the user to travel distances with a speed up to 30 miles per hour on a standard street, but also to navigate safely around a pedestrian-dominated college campus. Weighing less than 30 lbs, this moped allows the user to carry it wherever without the being burdened by the bulk or size of the vehicle. The user can fold up the moped in less than 60 seconds to fit under his or her arm for easy transportation and storage. Like a bicycle, this moped can be easily locked and stored on any bike rack, but if needed, can also be carried into lecture halls and classrooms with ease. Moped IV provides functionality and transportability without sacrificing convenience.

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1 Introduction

1.1 Problem Statement

Mopeds are the perfect mode of transportation for college students and professors who must travel to and around campus. However, current mopeds on the market are bulky in size, difficult to transport, and inconvenient for storage. The user (Dr. Mark Jakiela, PhD, The Lee Hunter Professor of Mechanical Design, Washington University in St. Louis) seeks a street-legal, electric moped that can travel up to distances of 20 miles. This foldable, sprung-seated moped transforms from ready-to-ride to fully folded in under 80 seconds. With dimensions of 27.37x15.64x5.97 inches and weighing 21.4 lbs, this bike can easily be collapsed and stored inside the trunk of a car, or carried into campus buildings and lecture halls. Equipped with a Bafang BBS02 mid-drive, the moped provides the latest E-bike technology while maintaining its simplicity for easy maintenance. Due to the limitations

1.2 List of team members

Margaret Liu, Kyle Seymour, David Southmayd, Chris Mertens

2 Background Information Study

2.1 A short design brief description that defines and describes the design problem

Current modes of transportation to and from campus are limited to walking, driving, or riding a device such as a moped, bike, skateboard, or scooter. Once on campus, these modes of transportation require either off-site storage such as parking, on campus storage such as a bike rack, or they need to be carried at all times. Lighter modes of transportation such as skateboard or scooter would be convenient to carry, but may not be an efficient method of transportation over a long distance. Those that can travel a longer distance, such as a car, cannot be used on a closed campus, and required separate storage. Bikes and mopeds can both be used to travel the distance of a car, and can be storage on a closed campus. However, they are not easily transportable by the user, unless the user is riding it, and they cannot be brought into a building. The user (Mark Jakiela, PhD, The Lee Hunter Professor of Mechanical Design, Washington University in St. Louis) seeks an improved street-legal moped that can both be used to travel longer distances and around campus, but also be capable of convenient folding and storage. This moped should be folded down to storage size within 90 seconds, and should easily fit inside the trunk of a car.

2.2 Summary of relevant background information (such as similar existing devices or patents, patent numbers, URL's, et cetera)

Patent #	Publication date	Inventors	Title	Keywords
US 4732403 A	03/22/1998	Renzo Grattapaglia	Folding moped with collapsible support for the saddle	folding moped
US 2594034 A	04/22/1952	King Keith T	Collapsible motor scooter	collapsible scooter
US 7077229 B2	07/18/2006	Shuei-Yuan Lee	Folding and portable electric scooter	collapsible scooter
EP 2106993 A1	10/07/2008	Robert Hugo Sluijter *et al.*	Motorized foldable scooter	foldable scooter
US 5183129 A	02/02/1993	Robert M. Powell	Collapsible scooter	collapsible scooter
US 6443470 B1	09/03/2002	Nathan T. Ulrich *et al.*	Folding scooter	folding scooter
US 2910130 A	10/27/1959	Erwin D. Schlaphoff	Foldable electric scooter	folding scooter

Other relevant URLs:

1. http://www.spinlife.com/critpath/match.cfm?categoryID=293
2. http://www.powersportsmax.com/index.php/cPath/38
3. http://www.foldingmotorbike.com/

3 Concept Design and Specification

3.1 User needs, metrics, and quantified needs equations. This will include three main parts:

3.1.1 Record of the user needs interview

Table 1: User Needs Interview

Customer Data: Ultralight Collapsible Street Legal Moped (CM) Customer: Dr. Jakiela Address: Washington University in St. Louis			Date: 15 September 2015
Question	Customer Statement	Interpreted Need	Importance
How small would you like the moped to collapse to?	Rest comfortably at the back of a classroom Fit easily in the back of a car	Folded moped needs to be no more than 36 in long Folded moped needs to be no more than 24 in wide Folded moped height needs to be no more than 16 in	5 5 5
How fast do you need the moped to travel?	20 mph no more than 30 mph. Needs to be street legal	Needs to have a top speed between 20-30MPH Moped has no more than 3bhp	5 5
How light do you need the moped to be?	No more than 30 lbs	Weight should be no more than 30 lbs	3
How far do you need the moped to travel?	20 miles. Since this concept can easily be folded up and carried/rolled around. It isn't the biggest deal if you run out of range.	Moped needs to be able to travel 20 miles on one battery charge or one tank of gas.	2
Does the moped need to be electric powered or gas powered?	Electric preferred. If it is gas, 4 stroke is preferred	Moped should be electric	2
How quickly would you like the moped to fold and unfold?	De-helmet to driving car in 90 seconds	Can collapse the moped or reassemble in no more than 80s	3

Does the moped need to have suspension or at least a sprung seat?	This is less of a road vehicle than other concepts. Having only a sprung seat is acceptable.	Seat must be sprung	3
Does the moped need to have pedal-power capability?	A combination powertrain is not necessary.	No need	

Table 2: Final User Needs

Need Number	Need	Importance
1	CM is under 36 in long	5
2	CM is under 24 in wide	5
3	CM is under 16 in in height	5
4	CM needs a top speed between 20-30MPH	5
5	CM has no more than 3 hp	5
6	CM is under 30 lbs	3
7	CM can travel 20 miles on one charge/tank	2
8	CM is electric	2
9	CM can collapse/reassemble in 80 seconds	3
10	CM's seat must be sprung	2

3.1.2 List of identified metrics

Table 3: Identified Metrics

Design Metrics: Collapsible Moped					
Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	1,2,3	Length	in	22	40
2	4	Speed	mph	20	30
3	5	Horsepower	hp	1	3
4	6	Weight	lbs	1	30
5	7	Distance	miles	20	25

6	8	Is Electric	Binary	0	1
7	9	Time	s	1	80
8	10	Seat is Sprung	Binary	0	1

3.1.3 Table/list of quantified needs equations

Table 4: Quantified User Needs

Collapsible Moped		Metric													
		Length	Width	Height	Weight	Motor Power	Motor Range	Speed	Time	Electric Motor	Sprung Seat	Need Happiness	Importance Weight	Total Happiness Value	Importance
	Need	1	2	3	4	5	6	7	8	9	10				
1	Folded length no more than 36 in.	1										0	0.135	0	5
2	Folded width no more than 24 in.		1									0	0.135	0	5
3	Folded height no more than 16 in.			1								0	0.135	0	5
4	Weight is no more than 30 lbs				1							0	0.081	0	3
5	Moped is street legal					1						0	0.135	0	5
6	Motor range is at least 20 miles						1					0	0.054	0	2
7	Top speed is at least 20 MPH							1				0	0.135	0	5
8	Folding/Unfolding time is less than 80 seconds								1			0	0.081	0	3
9	Moped motor is electric									1		0	0.054	0	2
10	Moped seat is sprung										1	0	0.054	0	2
Units		in.	in.	in.	lbs	hp	Miles	MPH	Second	Binary	Binary	Total Happiness		0	37
Best Value		21	13	7	15	1	30	29	10	1	1		1.000		
Worst Value		40	30	20	40	3	2	10	300	0	0				
Actual Value															
Normalized Metric Happiness															

3.2 Four (4) concept drawings

Concept 1:

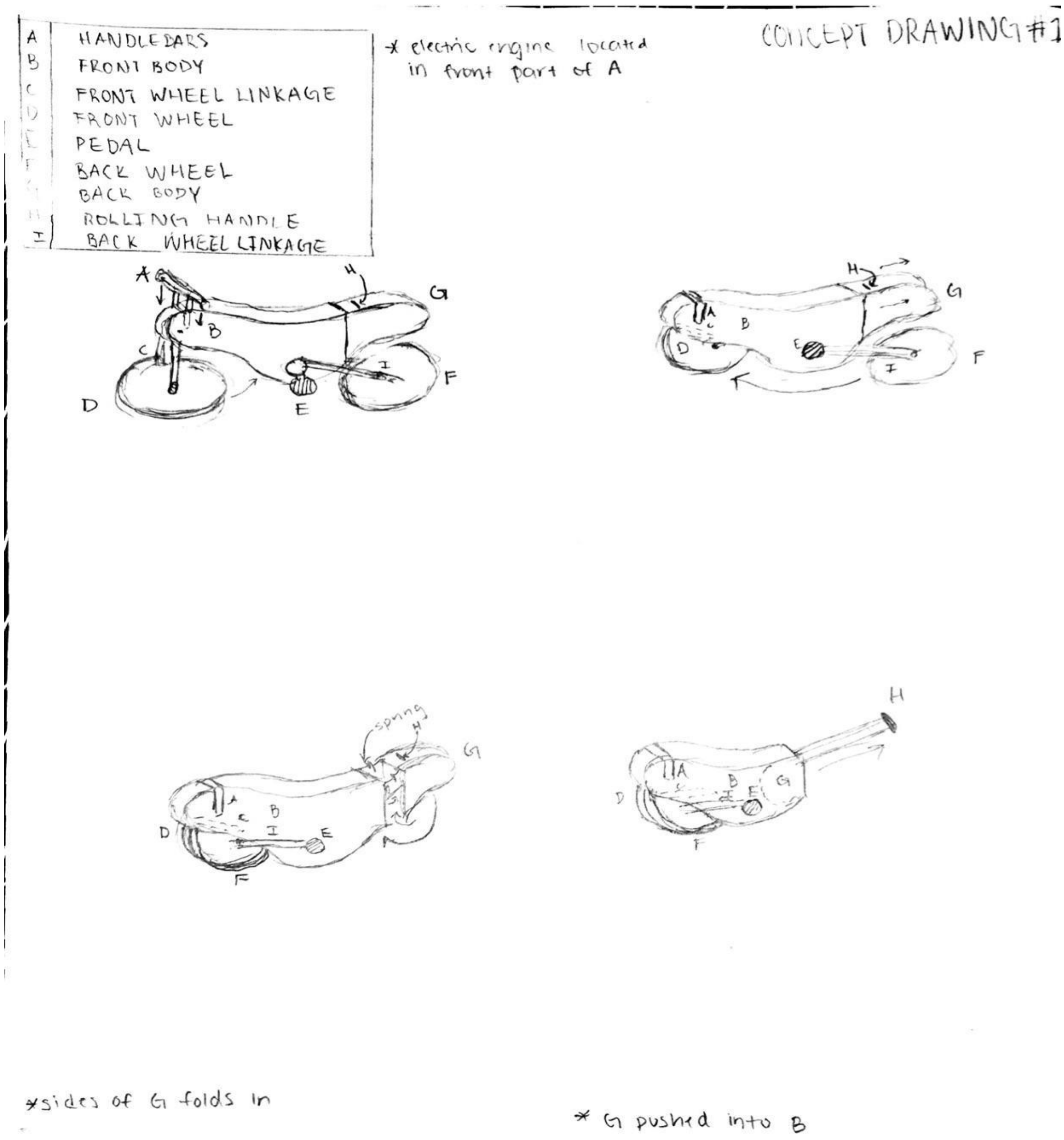

Figure 1: Concept 1. Roller suitcase

Concept 2:

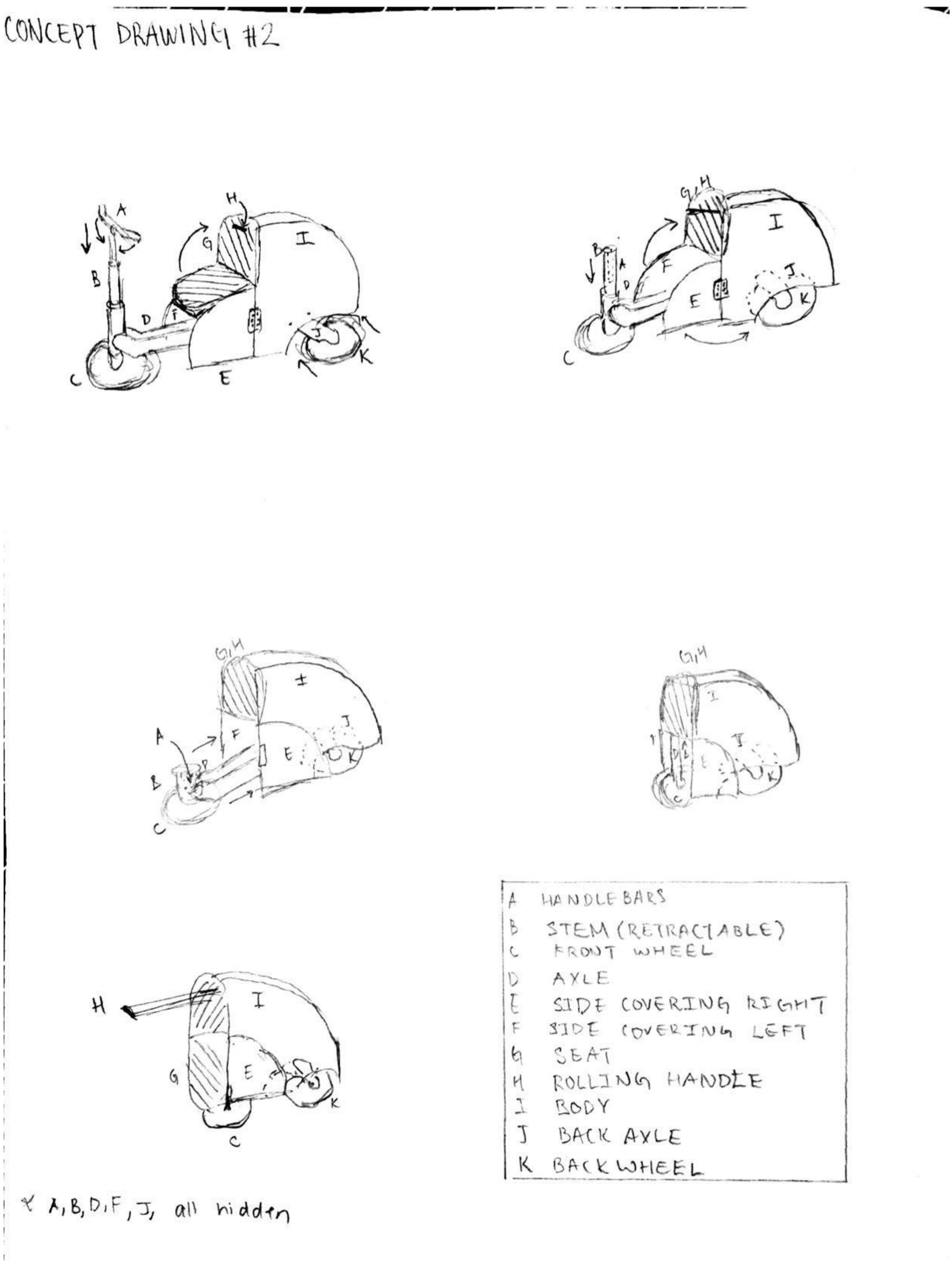

Figure 2: Concept 2

Concept 3:

Concept 4

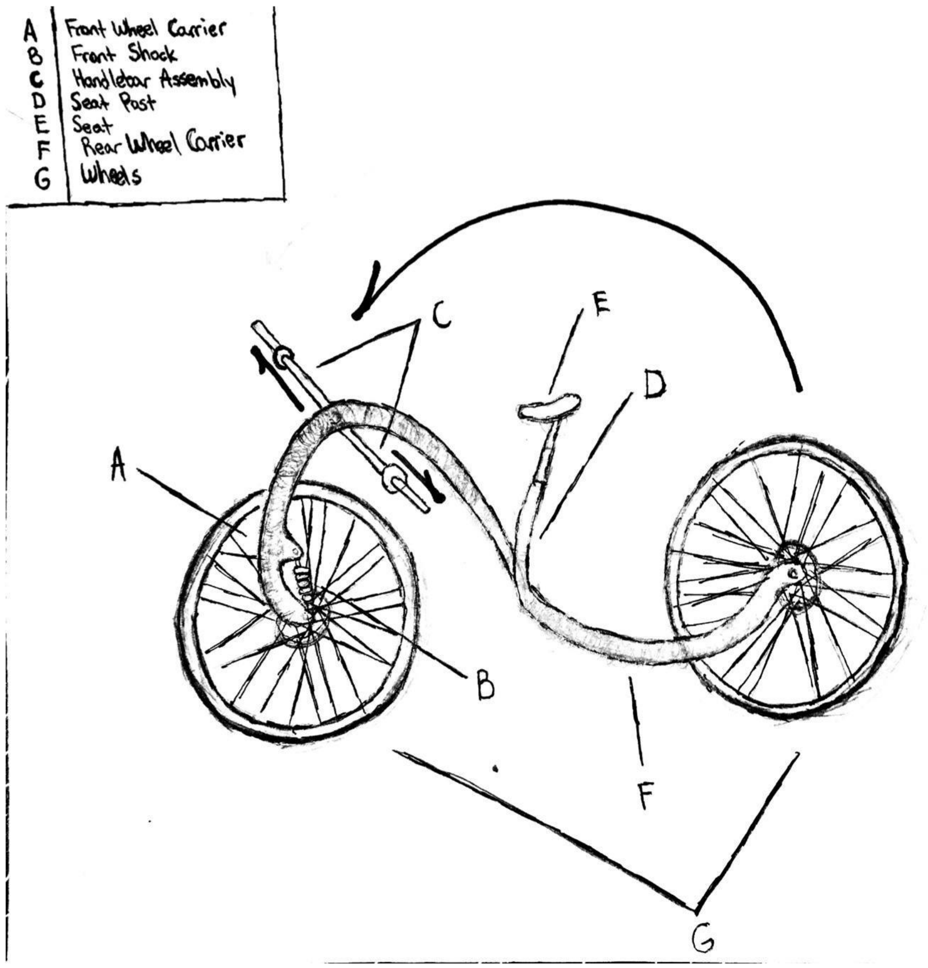

Figure 3: Concept 3. "S" shape

Concept 4:

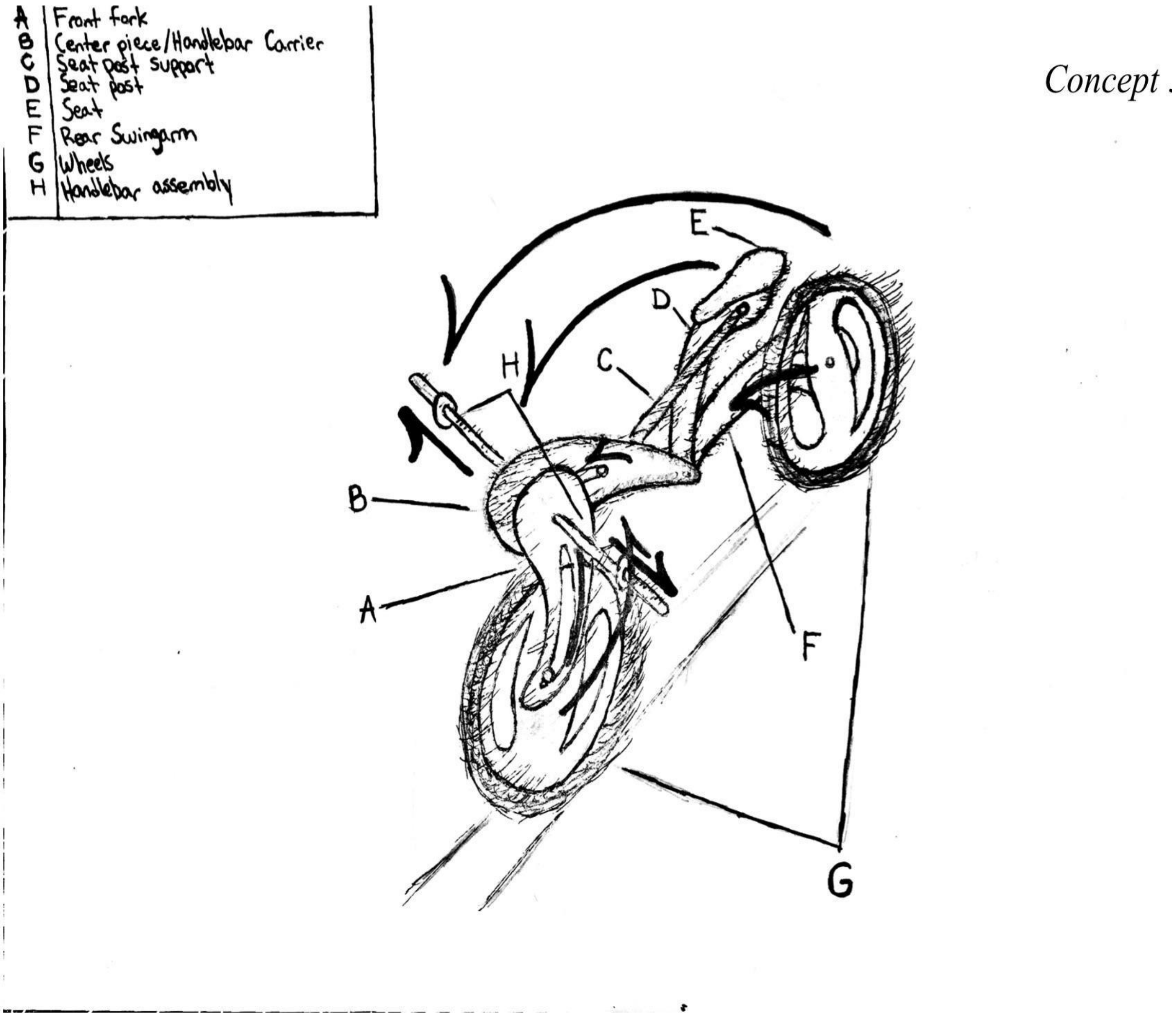

Figure 4: Concept 4. 3-Wing design

3.3 A concept selection process. This will have three parts:

3.3.1 Concept scoring (not screening)

Concept 1:

	Collapsible Moped Concept 1	Length	Width	Height	Weight	Motor Power	Motor Range	Speed	Time	Electric Motor	Sprung Seat	Need Happiness	Importance Weight	Total Happiness Value	Importance
	Need	1	2	3	4	5	6	7	8	9	10				
1	Folded length no more than 36 in.	1										0.21052631	0.135	0.02844950	5
2	Folded width no more than 24 in.		1									0.47058823	0.135	0.06359300	5
3	Folded height no more than 16 in.			1								0.76923076	0.135	0.10395010	5
4	Weight is no more than 30 lbs				1							0.2	0.081	0.01621621	3
5	Moped is street legal					1						0.5	0.135	0.06756756	5
6	Motor range is at least 20 miles						1					1	0.054	0.05405405	2
7	Top speed is at least 20 MPH							1				1	0.135	0.13513513	5
8	Folding/Unfolding time is less than 80 seconds								1			0.86206896	0.081	0.06989748	3
9	Moped motor is electric									1		1	0.054	0.05405405	2
10	Moped seat is sprung										1	0	0.054	0	2
	Units	in.	in.	in.	lbs	hp	Miles	MPH	Second	Binary	Binary	Total Happiness		0.592917121	37
	Best Value	21	13	7	15	1	30	29	10	1	1		1.000		
	Worst Value	40	30	20	40	3	2	10	300	0	0				
	Actual Value	36	22	10	35	2	30	29	50	1	0				
	Normalized Metric Happiness	0.2105	0.4705	0.7692	0.2	0.5	1	1	0.8620	1	0				

Figure 5: Concept 1 scoring

Concept 2:

Collapsible Moped Concept 2		Metric													
		Length	Width	Height	Weight	Motor Power	Motor Range	Speed	Time	Electric Motor	Sprung Seat	Need Happiness	Importance Weight	Total Happiness Value	Importance
	Need	1	2	3	4	5	6	7	8	9	10				
1	Folded length no more than 36 in.	1										0	0.135	0	5
2	Folded width no more than 24 in.		1									0.11764705	0.135	0.0158982	5
3	Folded height no more than 16 in.			1								0.15384615	0.135	0.0207900	5
4	Weight is no more than 30 lbs				1							0.08	0.081	0.0064864	3
5	Moped is street legal					1						0	0.135	0	5
6	Motor range is at least 20 miles						1					1	0.054	0.0540540	2
7	Top speed is at least 20 MPH							1				1	0.135	0.1351351	5
8	Folding/Unfolding time is less than 80 seconds								1			0.86206896	0.081	0.0698974	3
9	Moped motor is electric									1		1	0.054	0.0540540	2
10	Moped seat is sprung										1	1	0.054	0.0540540	2
Units		in.	in.	in.	lbs	hp	Miles	MPH	Second	Binary	Binary	Total Happiness		0.41036953	37
Best Value		21	13	7	15	1	30	29	10	1	1		1.000		
Worst Value		40	30	20	40	3	2	10	300	0	0				
Actual Value		40	28	18	38	3	30	29	50	1	1				
Normalized Metric Happiness		0	0.1176	0.1538	0.08	0	1	1	0.8620	1	1				

Figure 6: Concept 2 scoring

Concept 3:

Collapsible Moped Concept 3		Metric													
		Length	Width	Height	Weight	Motor Power	Motor Range	Speed	Time	Electric Motor	Sprung Seat	Need Happiness	Importance Weight	Total Happiness Value	Importance
	Need	1	2	3	4	5	6	7	8	9	10				
1	Folded length no more than 36 in.	1										0	0.135	0	5
2	Folded width no more than 24 in.		1									1.41176470	0.135	0.190779	5
3	Folded height no more than 16 in.			1								0.30769230	0.135	0.041580	5
4	Weight is no more than 30 lbs				1							0.76	0.081	0.061621	3
5	Moped is street legal					1						0	0.135	0	5
6	Motor range is at least 20 miles						1					1.35714285	0.054	0.073359	2
7	Top speed is at least 20 MPH							1				0.26315789	0.135	0.035561	5
8	Folding/Unfolding time is less than 80 seconds								1			1	0.081	0.081081	3
9	Moped motor is electric									1		1	0.054	0.054054	2
10	Moped seat is sprung										1	0	0.054	0	2
Units		in.	in.	in.	lbs	hp	Miles	MPH	Second	Binary	Binary	Total Happiness		0.5380367	37
Best Value		21	13	7	15	1	30	29	10	1	1		1.000		
Worst Value		40	30	20	40	3	2	10	300	0	0				
Actual Value		40	6	24	21	3	40	15	10	1	0				
Normalized Metric Happiness		0	1.4117	0.3076	0.76	0	1.3571	0.2631	1	1	0				

Figure 7: Concept 3 scoring

Concept 4:

Collapsible Moped Concept 4		Metric													
		Length	Width	Height	Weight	Motor Power	Motor Range	Speed	Time	Electric Motor	Sprung Seat	Need Happiness	Importance Weight	Total Happiness Value	Importance
	Need	1	2	3	4	5	6	7	8	9	10				
1	Folded length no more than 36 in.	1										0.84210526	0.135	0.11379800	5
2	Folded width no more than 24 in.		1									1.05882352	0.135	0.14308426	5
3	Folded height no more than 16 in.			1								0.38461538	0.135	0.05197505	5
4	Weight is no more than 30 lbs				1							0.8	0.081	0.06486486	3
5	Moped is street legal					1						0	0.135	0	5
6	Motor range is at least 20 miles						1					1.35714285	0.054	0.07335907	2
7	Top speed is at least 20 MPH							1				0.26315789	0.135	0.03556187	5
8	Folding/Unfolding time is less than 80 seconds								1			0.94827586	0.081	0.07688723	3
9	Moped motor is electric									1		1	0.054	0.05405405	2
10	Moped seat is sprung										1	0	0.054	0	2
Units		in.	in.	in.	lbs	hp	Miles	MPH	Second	Binary	Binary	Total Happiness		0.613584423	37
Best Value		21	13	7	15	1	30	29	10	1	1		1.000		
Worst Value		40	30	20	40	3	2	10	300	0	0				
Actual Value		24	12	15	20	3	40	15	25	1	0				
Normalized Metric Happiness		0.8421	1.0588	0.3846	0.8	0	1.3571	0.2631	0.9482	1	0				

Figure 8: Concept 4 scoring

3.3.2 Preliminary analysis of each concept's physical feasibility

Concept 1:

Concept One requires an electric motor that is supplemented by human pedaling. This design is bulky in size, but can be made lightweight, if made with a lightweight composite materials. This design is similar to a motorcycle, so the user will be able to travel the needed distance comfortably. It is also aesthetically pleasing. The moped can be folded into the size of a carry-on, and this design will accommodate for easy transportation and storage. The folding of the bike is not the most efficient, nor will it be the fastest due to the size of the body of the bike. This design concept is highly possible, but not the most efficient. There are a good number of parts required, which include sturdy springs, lightweight but strong materials, as well as a lightweight electric engine. This moped, after folding, is smooth in design and transportable like a carry-on.

Concept 2:

Concept Two accommodates for a larger engine that has more horsepower. In order to also be of reasonable weight, the bike itself needs to be made out of an ultra lightweight composite material. The folding process may take additional time, but once folded, the bike is easily transportable and can easily fit into a luggage rack or trunk. The bike is comfortable for the user to ride, and is very stable while riding. This design can accommodate for people of various sizes as well as age. Multiple parts are required, and the body of the bike is bulky in size, but there are no special requirements aside from being built from a lightweight composite material. The design is also highly doable, but not as aesthetically pleasing.

Concept 3:

This concept was designed based off of a "reverse hula hoop" idea in the sense that the back end of the moped would fold around the horizontal axis to rest next to the scooter's front half. The frame rails would be made from bent chrome moly steel tubing. Because of the frame's simplicity, a small shock absorber would be placed on the front wheel carrier to mitigate handling losses due to natural vibrations. This design would likely fit best with a non-pedal drive transmission since their central, rotating position in between the two frame rails would likely induce an uncomfortable "up-and-down" motion at the seat post.

Concept 4:

Our fourth concept was made with efficiency in mind. The frame rails would hopefully be a molded carbon fiber "wing," closely resembling an aerofoil shape.

Similar to our third design, this model would also feature a single-sided fork and swingarm to promote easier folding. Slots would be cut into the fork and swingarm to allow the wheels to move closer to the center of the moped. The handlebars would then pop out of their positions and move downwards, the fork would fold in line with the centerpiece, the seat would post fold in line with the swingarm, and then two halves would meet together. This design would be driven solely by a simple lipo battery-powered, shaft-drive transmission to the rear wheel.

3.3.3 Final summary

We chose our fourth concept design as our final project selection. This design seems to us to be the lightest and to have the most efficient folding action when compared to our other concepts. The composite frame design also leaves us a large amount of room to work with in terms of building systems, such as the transmission, into the frame to make this design even more compact than it already is. In addition, the “aerodynamic” look and feel of this concept really makes it stand out from others in a positive way without looking too flashy. In addition, the fourth design will be the easiest to design and produce. This is the only one of our four designs that will feature any kind of composite modeling. Understanding the molding process, we feel that making the frame in this way will substantially reduce our margin of error compared to working with machined metal parts. Our reasoning behind this is that, while making the molds for the frame will be an arduous task, the actual molding process is a relatively easy one. This will allow us to focus a large amount of our energy on creating the molds to very tight tolerances since nearly our entire product will be made from those molds. The other designs were either too bulky for our design specifications, or were simply not practical enough. We feel that our other three concepts mimic current scooter and bicycle too closely to be able to produce the desired levels of collapsibility and lightness. The unique modular frame design of the fourth concept gives our moped the potential to weigh less than and be carried in the same way as most textbooks, and it is something that we feel could be a viable product by the end of the semester.

3.4 Proposed performance measures for the design

1. If prototyped, the moped will have a length less than 36 in.
2. If prototyped, the moped will have a width less than 24 in.
3. If prototyped, the moped will have a height less than 16 in.
4. If prototyped, the moped will have a top speed between 20 mph and 30 mph.
5. If prototyped, the moped will have no more than 3 hp.

6. If prototyped, the moped should be less than 30 lbs.
7. If prototyped, the moped will be able to travel up to 20 miles.
8. If prototyped, the moped will have an electric motor
9. If prototyped, the moped will have a collapsing time and reassembling time, both less than 80 seconds.
10. If prototyped, the moped will have a sprung seat.

3.5 Design constraints (include at least one example of each of the following)

3.5.1 Functional

- Overall Geometry (Unfolded): height= 71 inches, inseam = 33 inches
- Overall Geometry (Folded): height= 36 inches, length= 24 inches, width= 16 inches
- Overall Geometry: weight<30 lbs
- Motion of Parts: 20-30 mph
- Motion of Parts: under 50 cc motor
- Control System: Electric motor
- Energy Needed: human pedaling/ motor output
- Motion of Parts: under 3 hp
  Materials to be Used: durable yet light

3.5.2 Safety

- Operational: has brakes
- Human: Can be operated by a human who has the ability to ride a normal bicycle
- Environmental: collapsible moped is an all-weather vehicle [except during severe weather]
- Environmental: moped can travel on a multitude of terrains such as flat ground, hills, concrete, sidewalks etc.
- Operational: user should wear helmet while operating moped
- Operational: moped can be operated next to cars as well as pedestrians

3.5.3 Quality

- Reliability: Life span is around 3,700 miles
- Quality Assurance: moped is fully street legal
  - Under 50 cc
  - Under 30 mph
  - Must have brakes
  - Under 3 hp

3.5.4 Manufacturing

- Assembly: welding needed for gooseneck

- Production of components: producer should have access to a CNC machine in order to produce the RES

- Purpose of components: aluminum must be ½ inch in thickness
- Production of components: producer must have reliable machinist or factory that can produce the RES with precision
- Production of components: producer must have access to a basic machine shop
- Production of components: producer must have access to water jet cutting machine for the aluminum body frames

3.5.5 Timing

- Development schedule: must have 2 weeks after initial prototype in order to update design
- Design schedule: must have 3-4 days for RES design updates if needed
- Production schedule: must give producer at least 2 weeks for the production of the RES
- Production schedule: production of entire moped from concept generation to final prototype needs 12 weeks time
- Production schedule: must have supplier 2 weeks to ship the electric engine

3.5.6 Economic

- Manufacturing costs: entire moped must be built in under $500
- Development costs: $12/RES if manufactured individually
- Development costs: $535.95 for the moped

3.5.7 Ergonomic

- Ergonomic design: user should be able to ride the moped comfortably like a bicycle
- User needs: moped can be folded and carried by an average size person
- User needs: moped must be able to be easily operated such as a regular street-legal moped
- Ergonomic design: moped should have a sprung seat

3.5.8 Ecological

- Sustainability: moped should be able to have recyclable frames
- Sustainability: engine should be electric
- Environmental impact: no carbon footprint should be left while operating the moped
- Environmental impact: should use recycled material in the manufacturing of the frames

3.5.9 Aesthetic

- Customer appear: appearance should be sleek and compact
- Customer appear: moped should be light to carry
- Fashion: appearance should be modernistic
- Future expectations: motor should be electric
- Future expectations: moped should be able to have a longer life span as electric motor technology improves

- Future expectations: moped should decrease in weight when the weight of an electric motor decreases with technological improvements

3.5.10 Life cycle

- Operation: moped should be able to be ridden in quiet neighborhoods while creating less noise pollution than an average lawn mower
- Disposal: aluminum frames from moped should be recyclable metal
- Operation: moped can be ridden in every-day clothing
- Maintenance: cleaning of aluminum framing should be regular, and moped should not be left in exposed weather in order to prolong the moped's life span

3.5.11 Legal

- Ethics: moped should have brakes in order to guarantee the welfare of the rider and nearby pedestrians and vehicles
- Regulations: DMV moped regulations
- Intellectual Property: RES is patented and cannot be used for any other function except to lock and unlock the main body of the moped

4 Embodiment and fabrication plan

4.1 Embodiment drawing

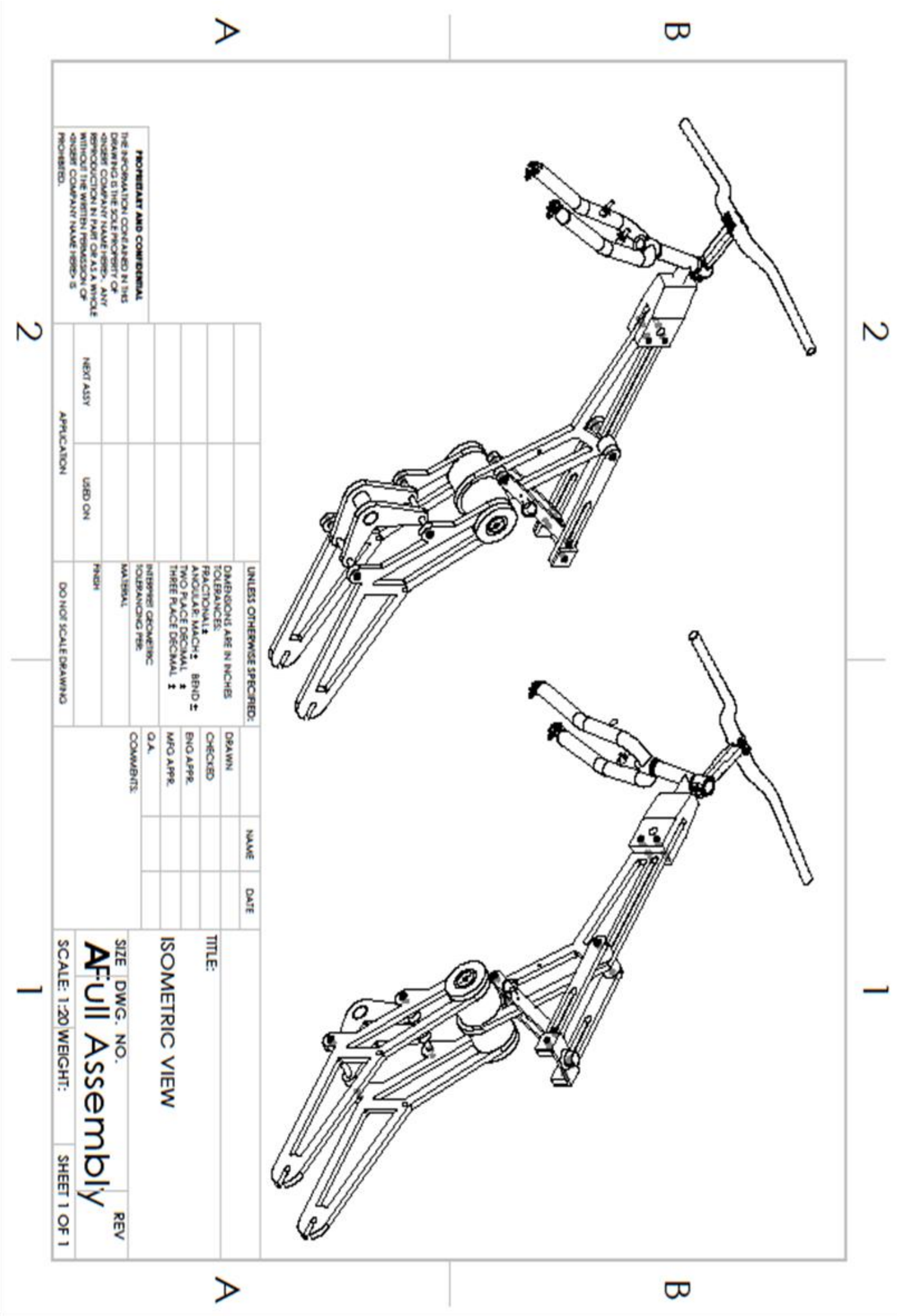

Figure 9: Embodiment isometric assembly drawing

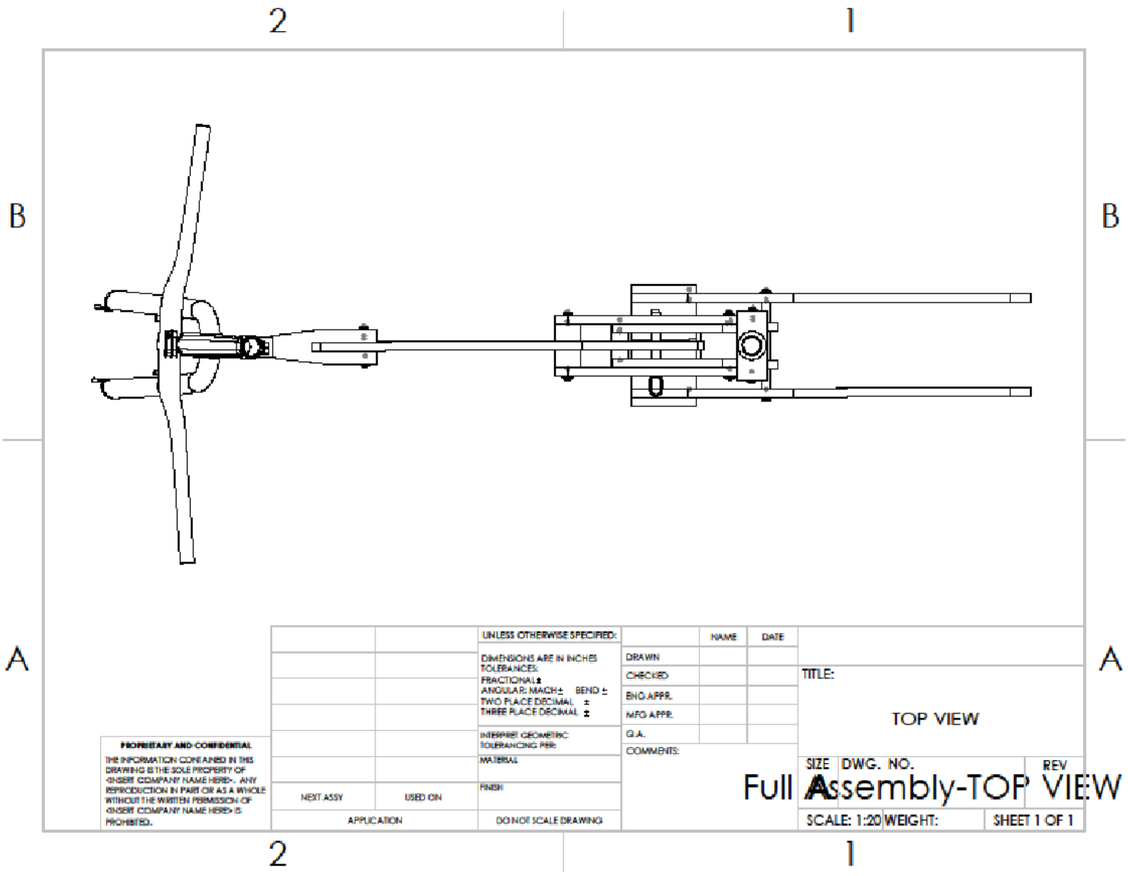

Figure 10: Embodiment assembly drawing top view

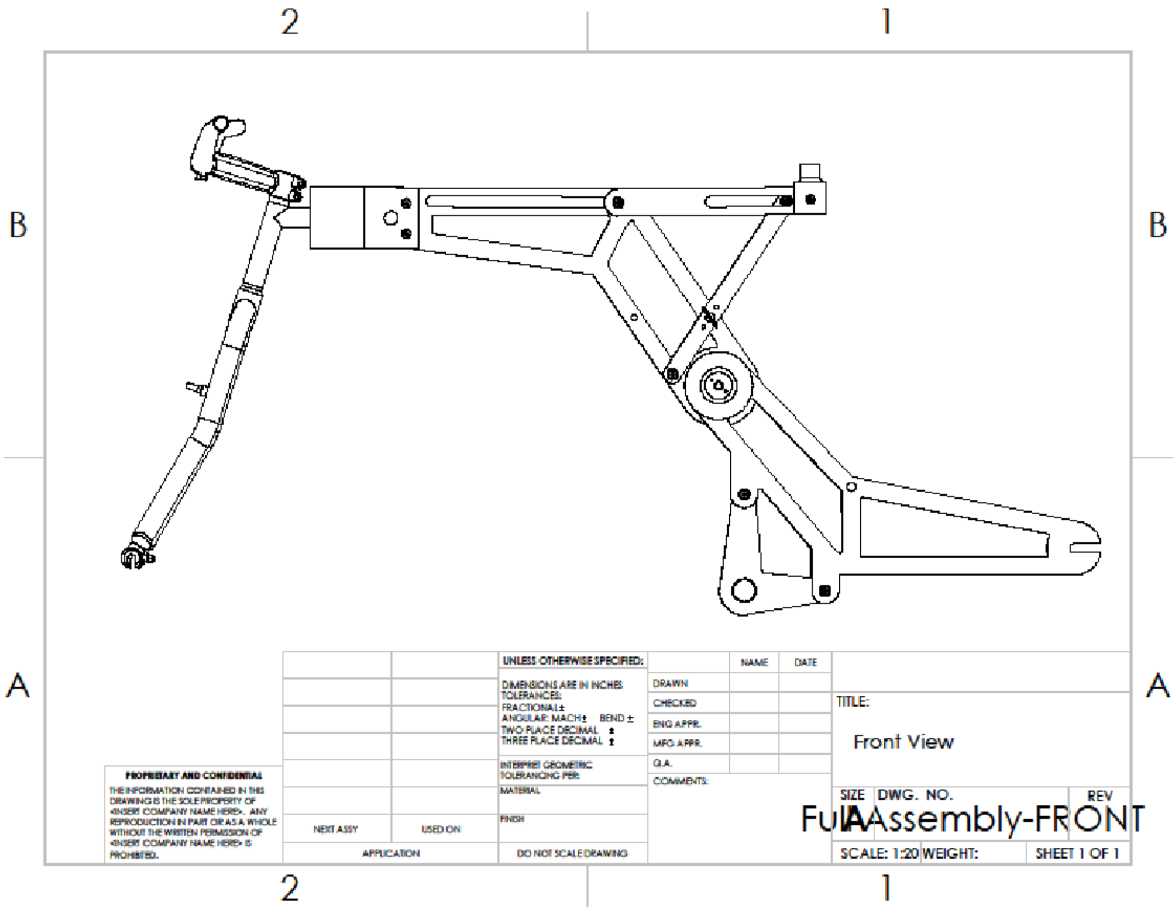

Figure 11: Embodiment Assembly Drawing front view

4.2 Parts List

Microsoft Excel Worksheet

Figure 12 - Parts List

4.3 Draft detail drawings for each manufactured part

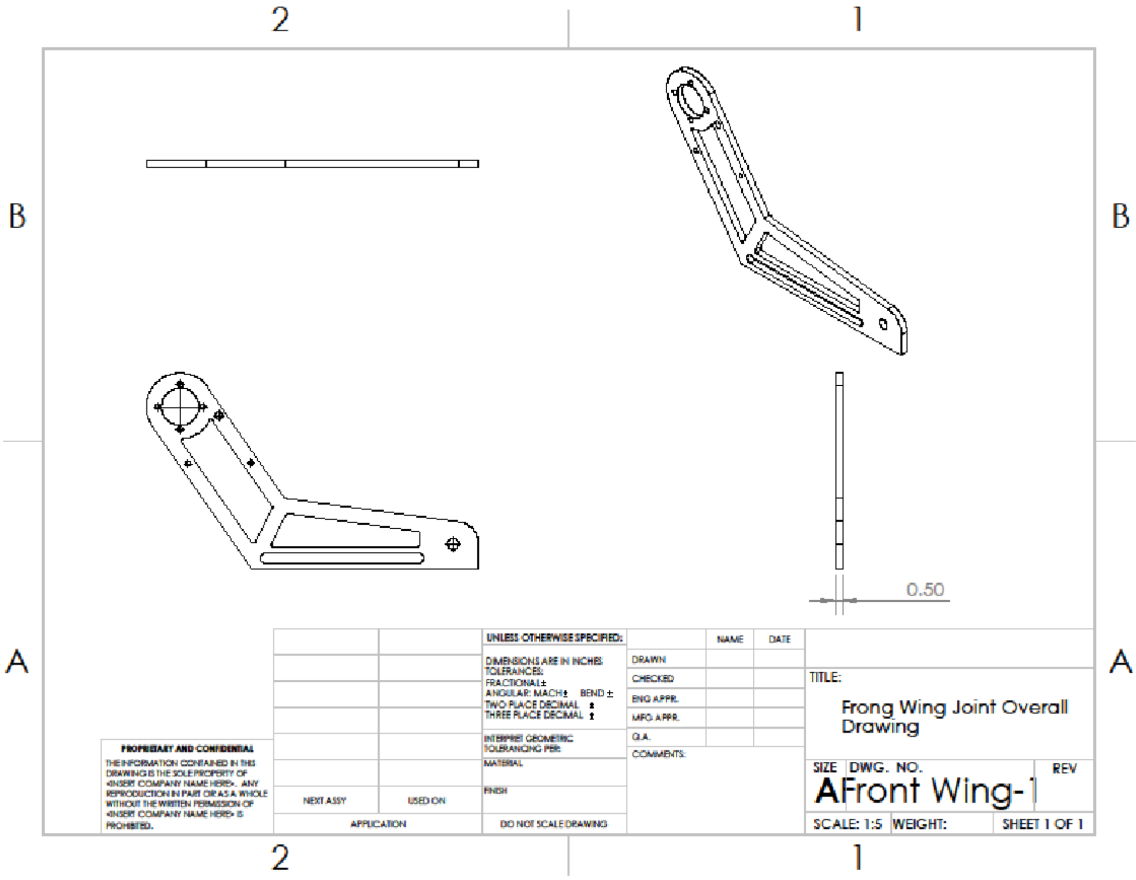

Figure 13: Front Wing Drawing 1

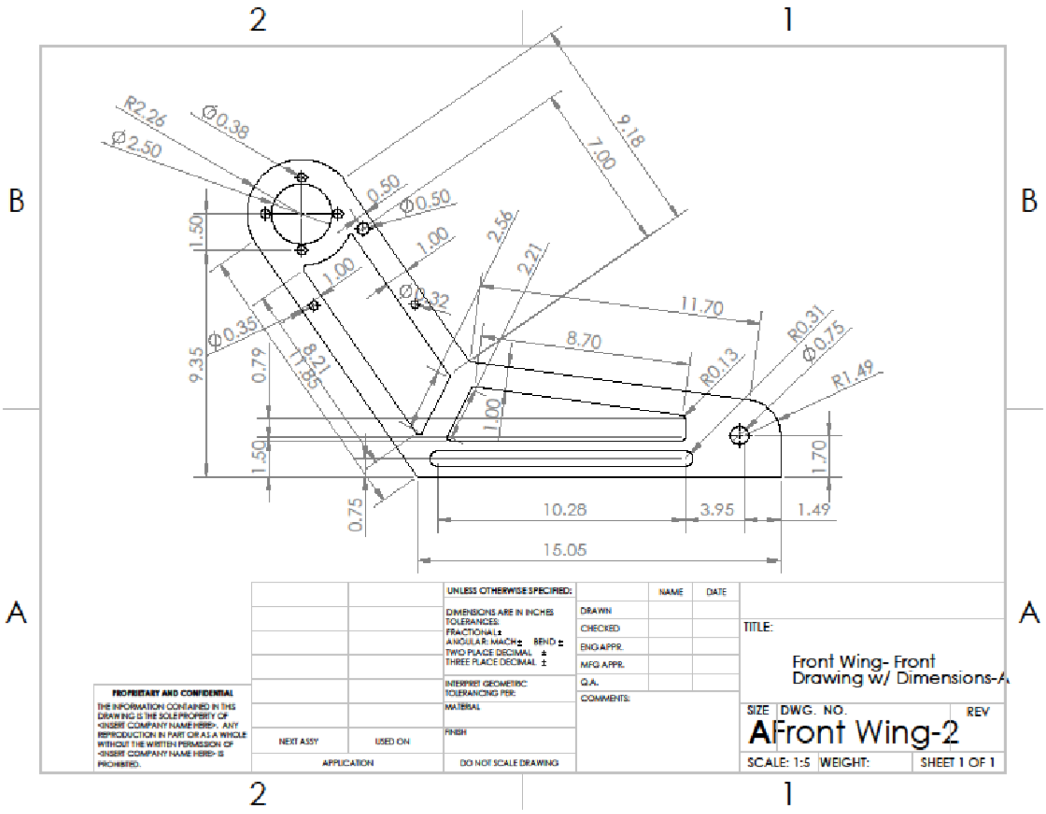

Figure 14: Front Wing Drawing 2

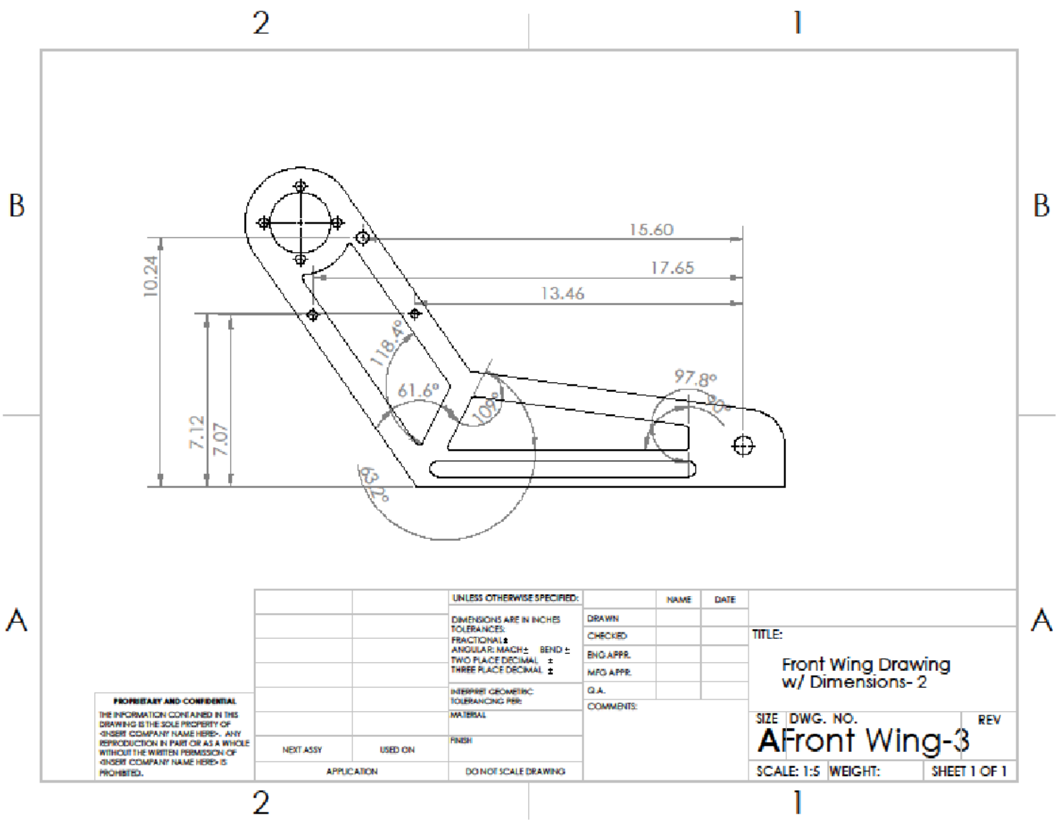

Figure 15: Front Wing 3

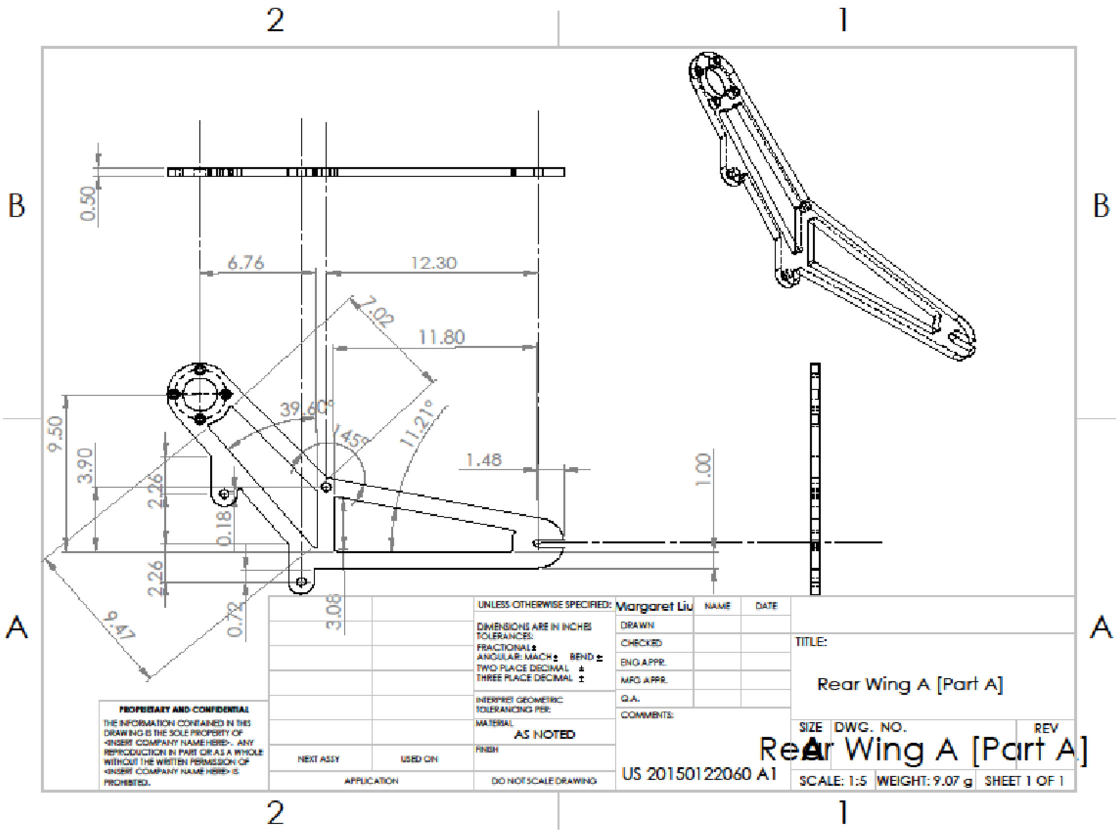

Figure 16: Rear Wing A Drawing 1

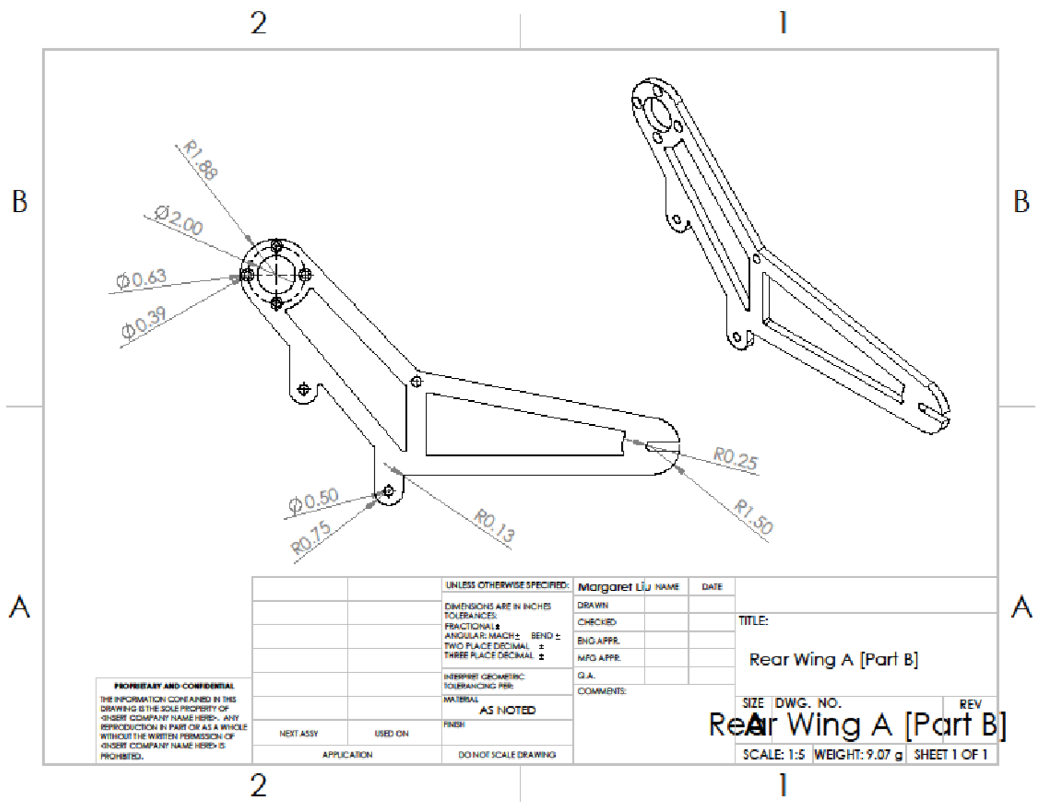

Figure 17: Rear Wing A Drawing 2

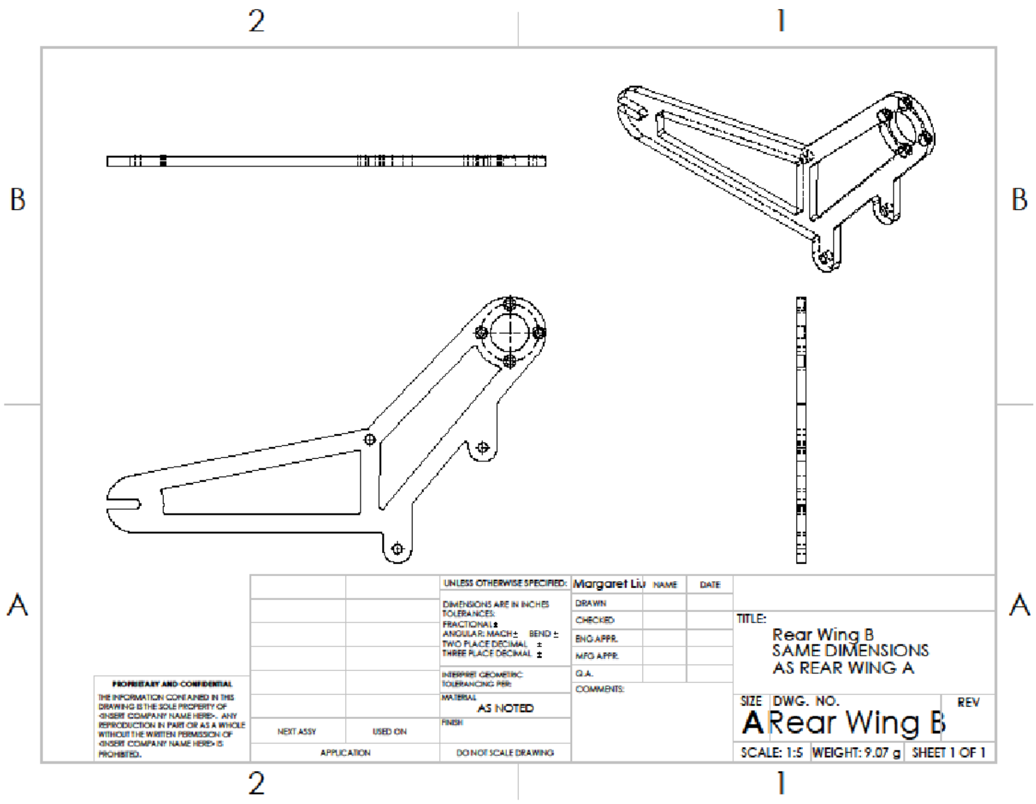

Figure 18: Rear Wing B Drawing

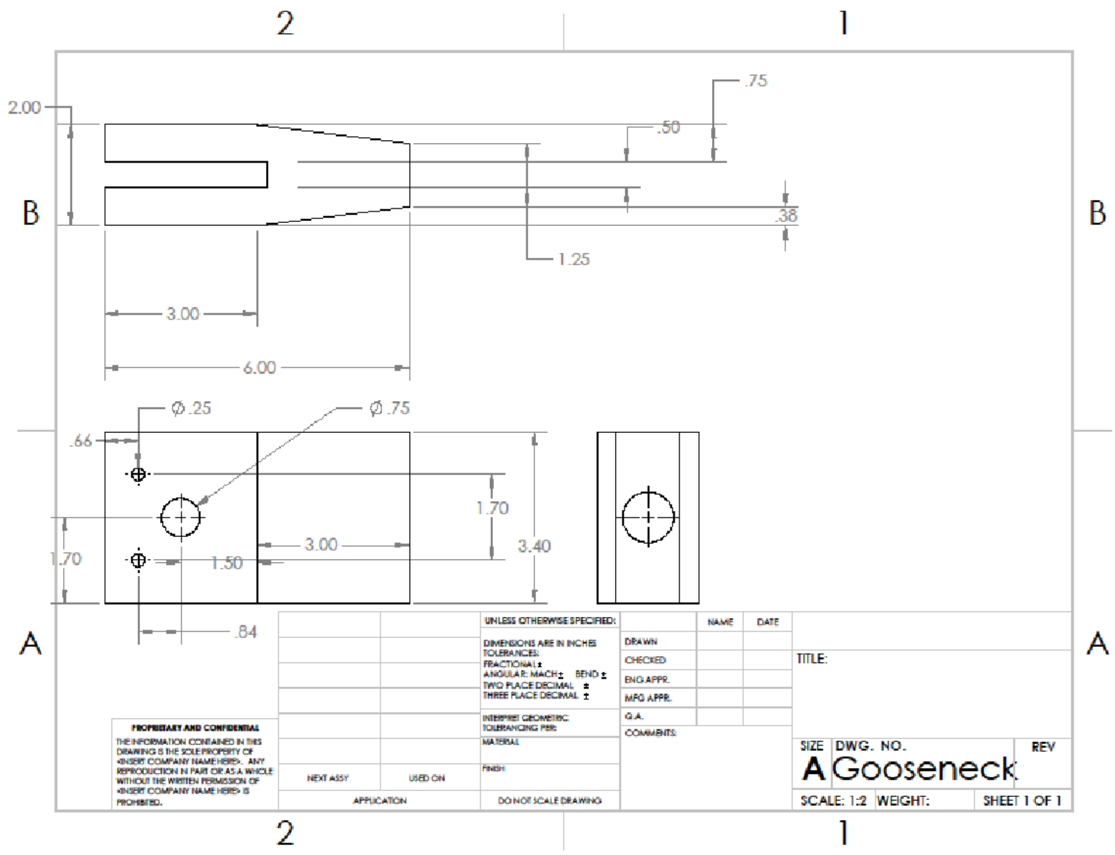

Figure 19: Gooseneck Drawing

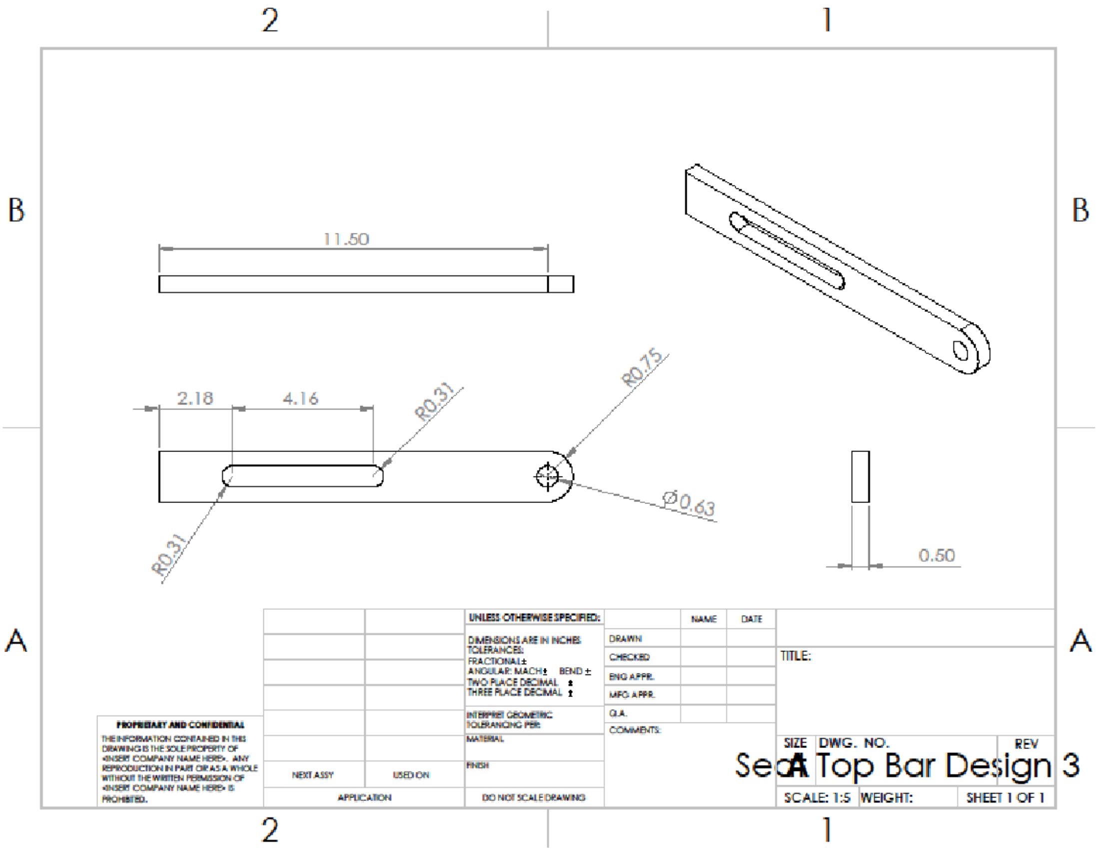

Figure 20: Seat Top Bar Drawing

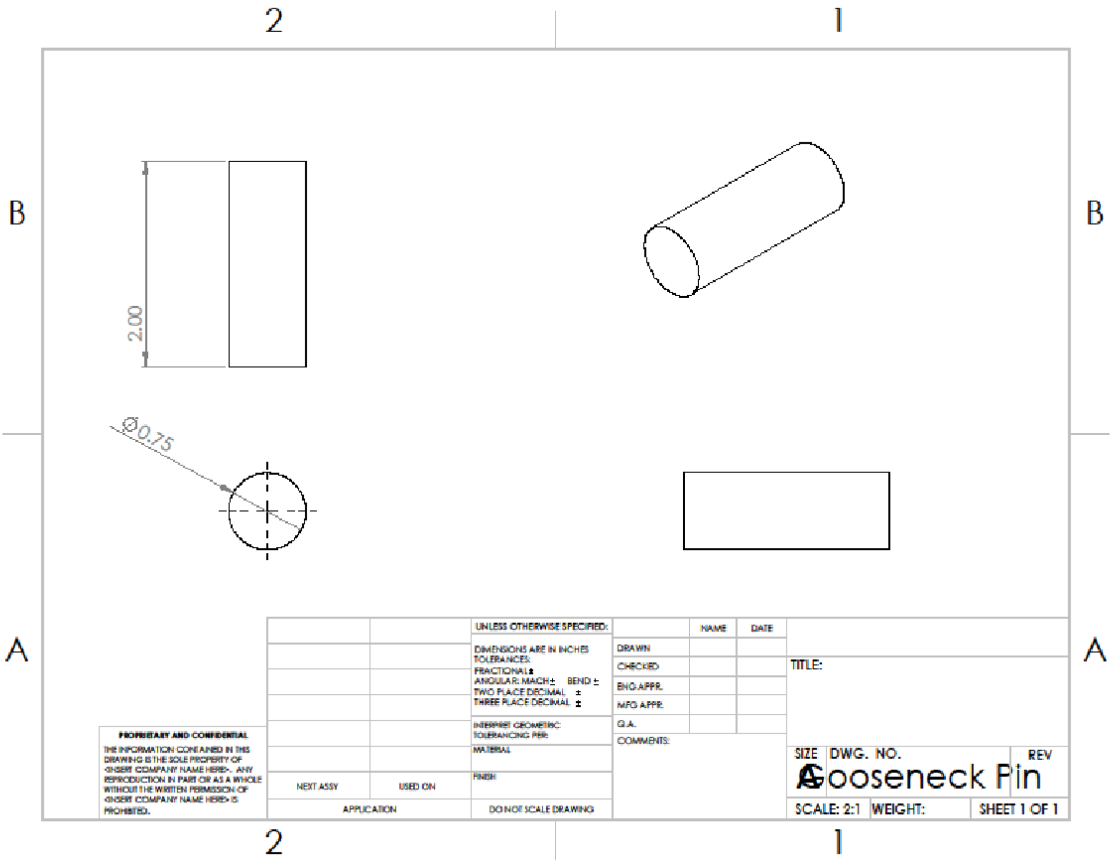

Figure 21: Gooseneck Pin Drawing

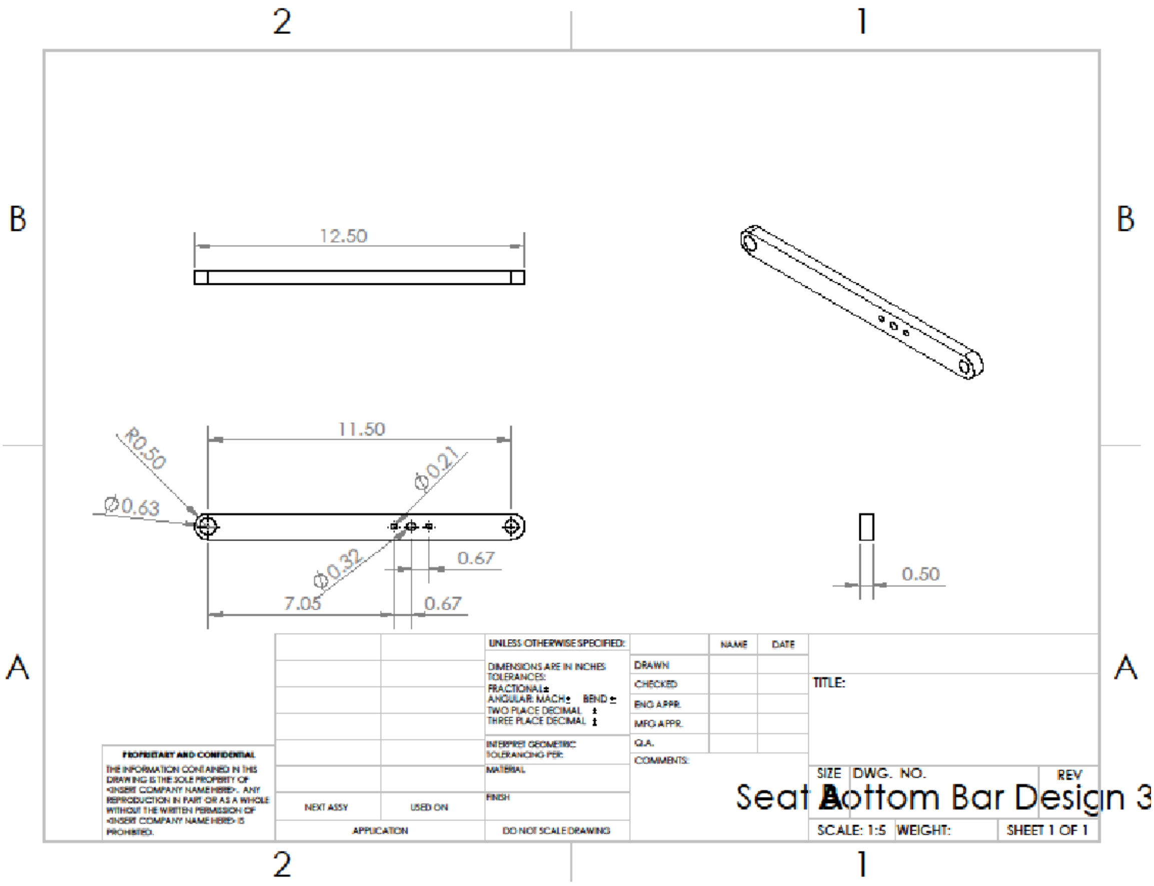

Figure 22: Seat Bottom Bar Drawing

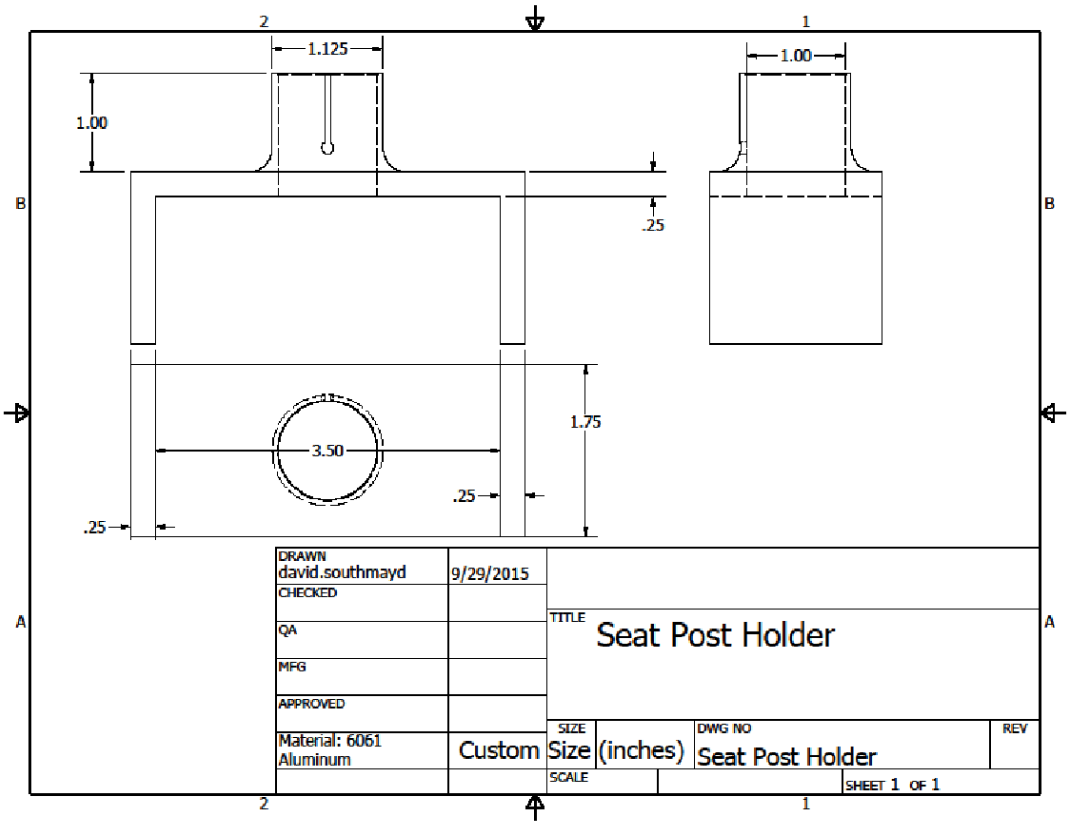

Figure 23: Seat Post Holder Drawing

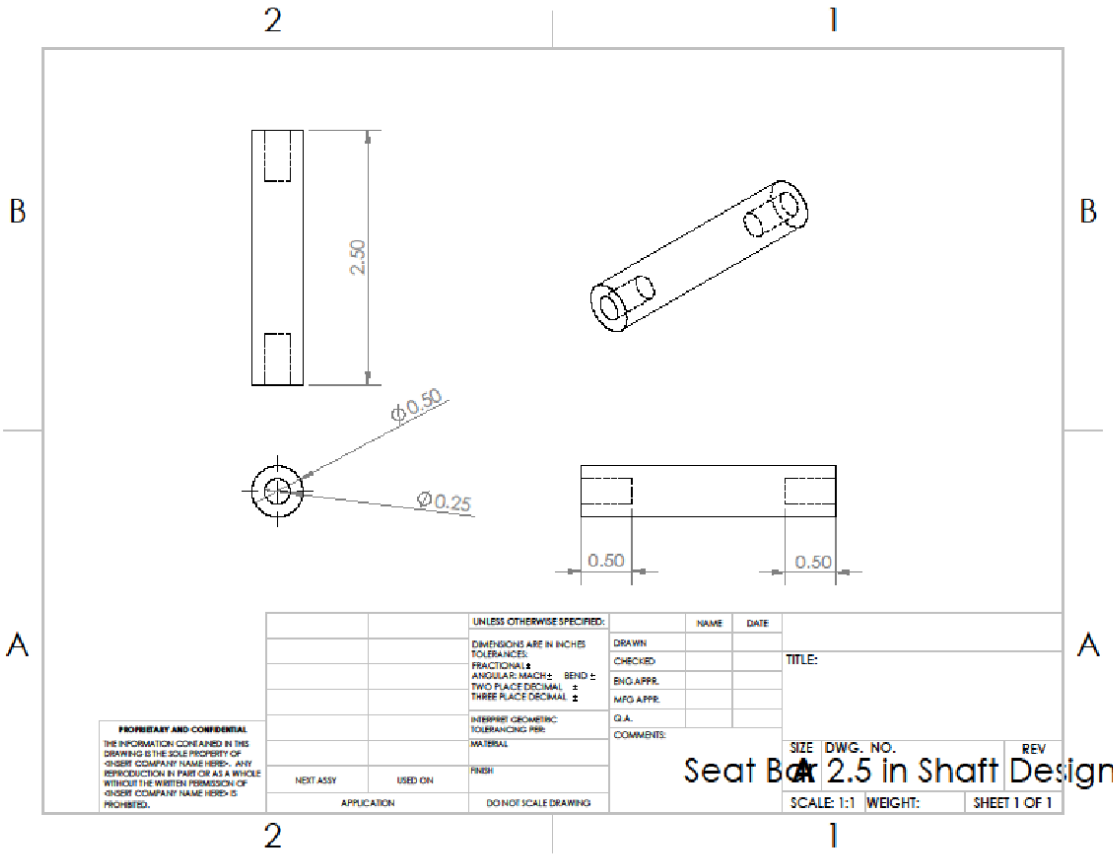

Figure 24: Seat Bar Shaft Drawing

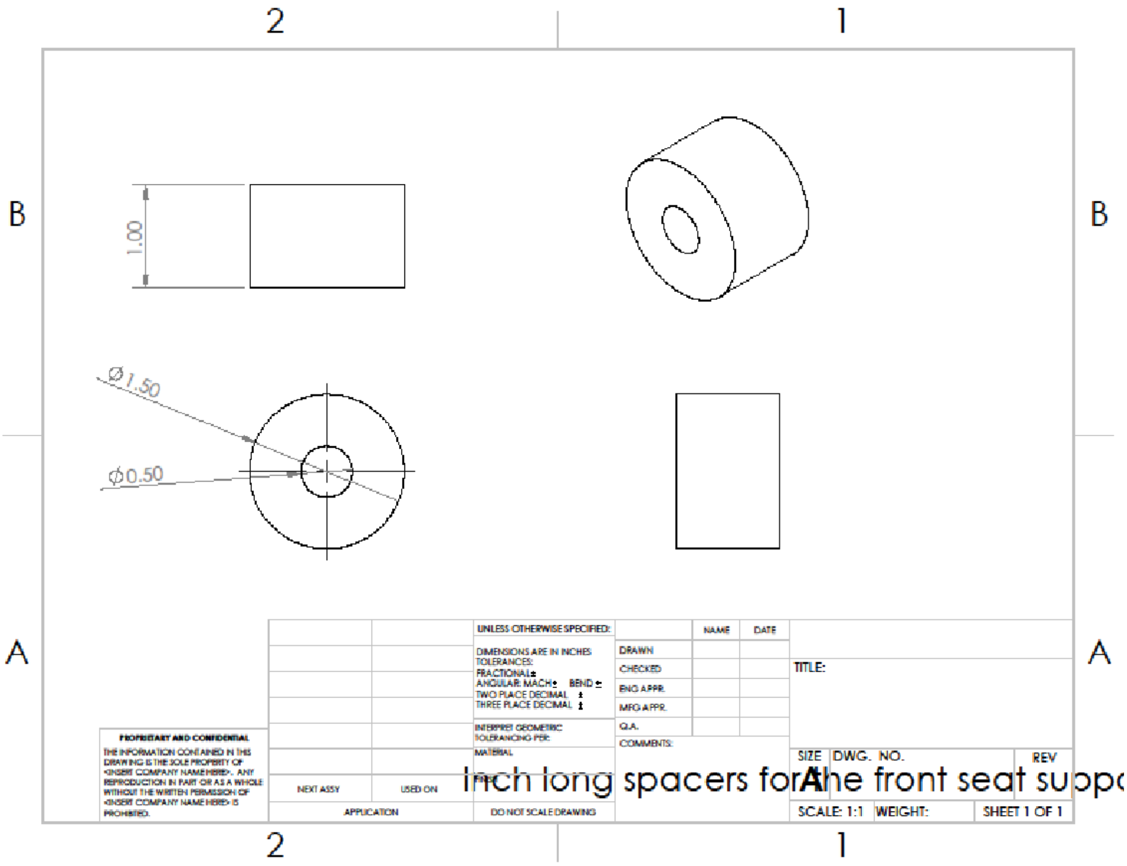

Figure 25: Front Seat Support Spacer Drawing

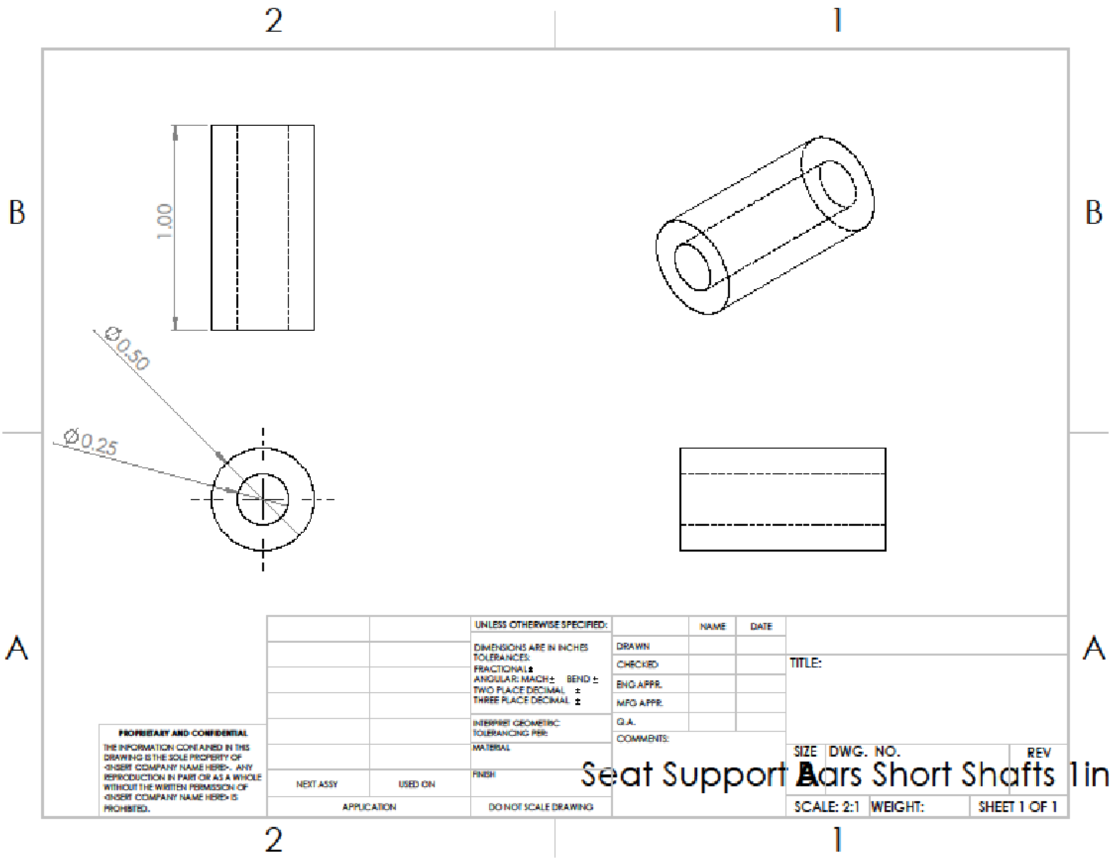

Figure 26: Seat Support Bar Shaft Drawing

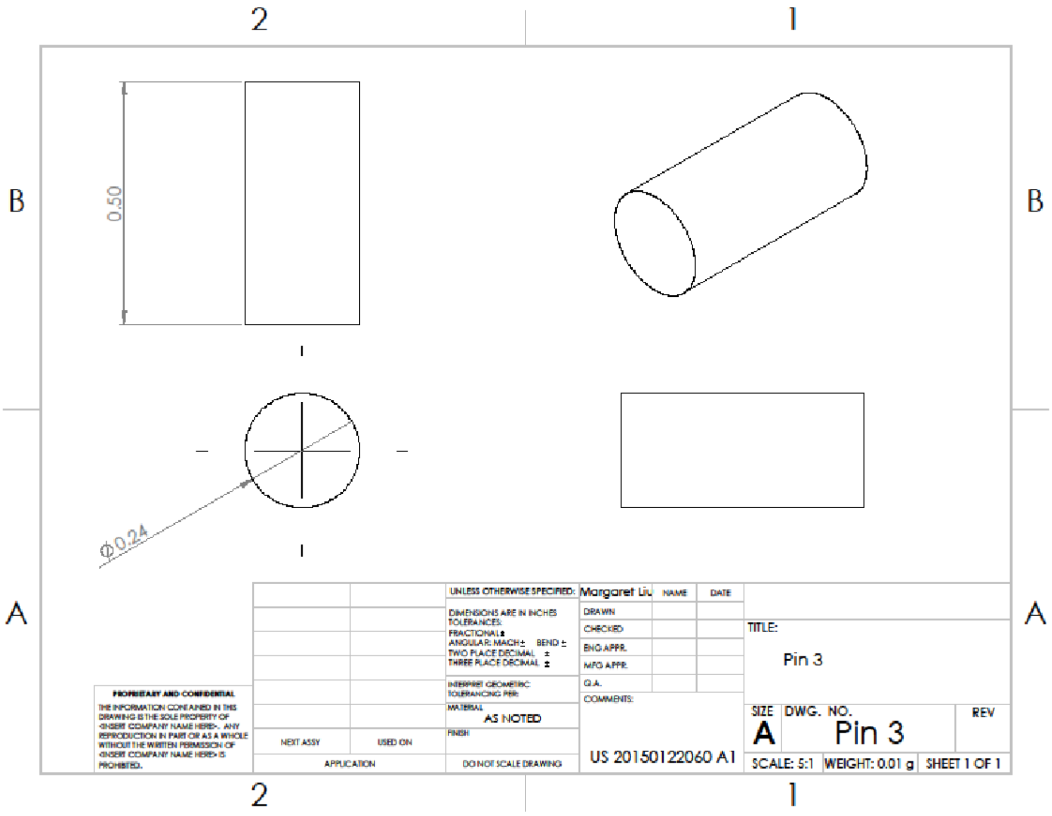

Figure 27: Pin 3 Drawing

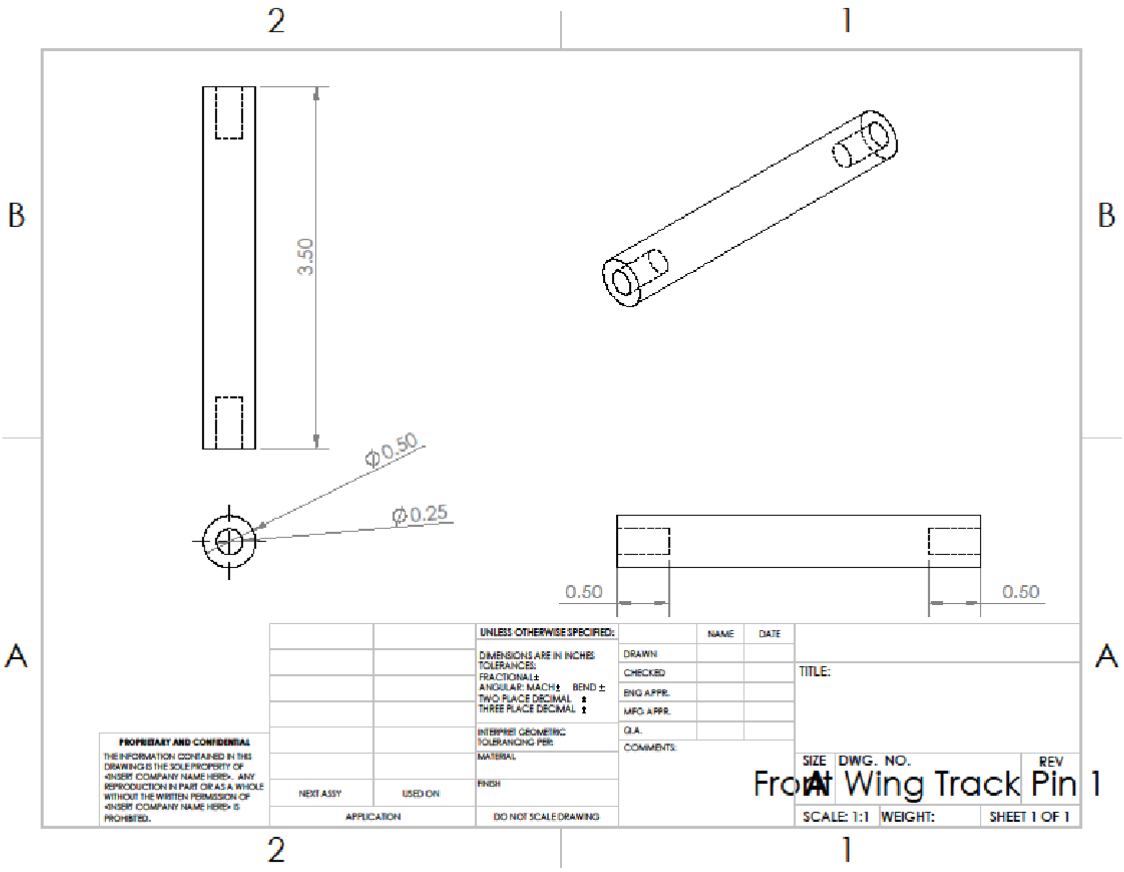

Figure 28: Front Wing Track Pin Drawing

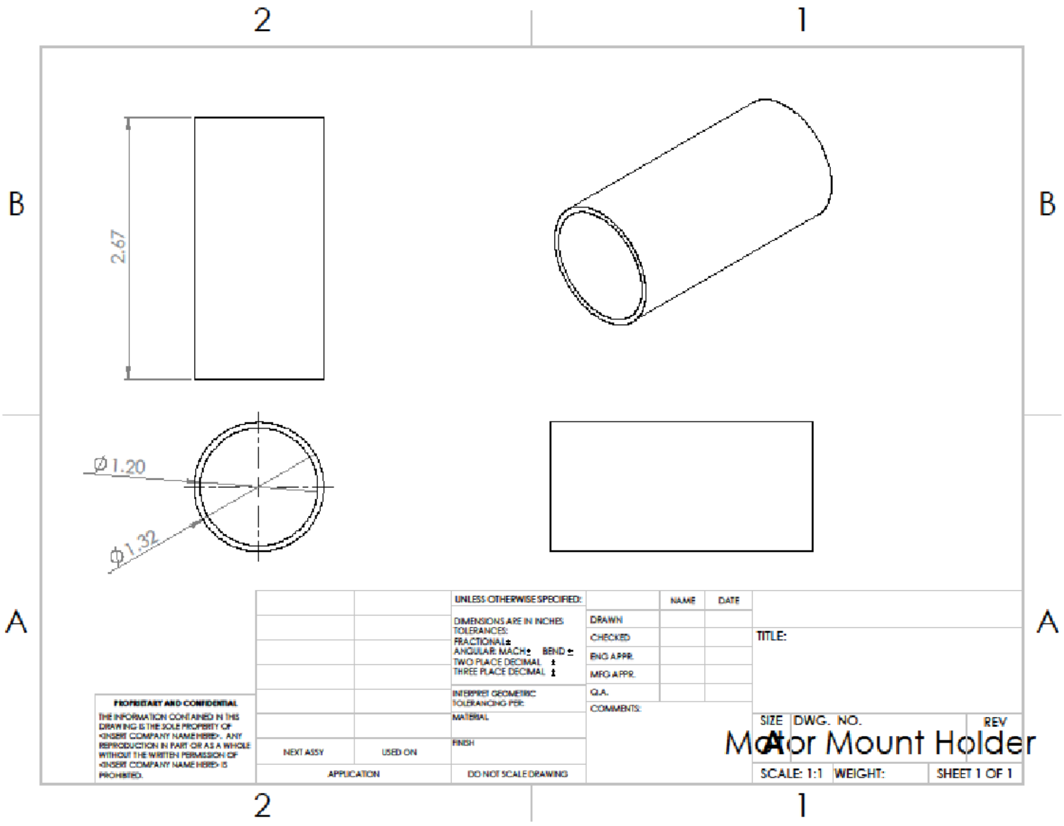

Figure 29: Motor Mount Holder Drawing

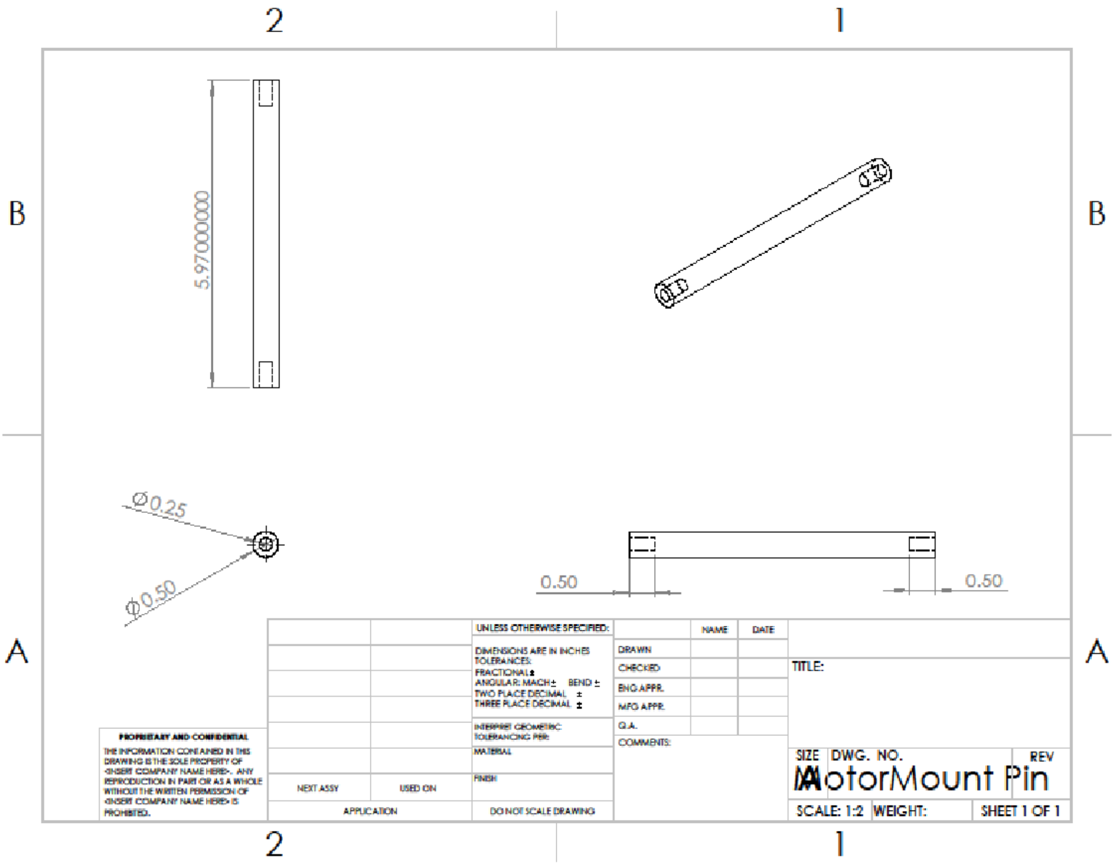

Figure 30: Motor Mount Pin Drawing

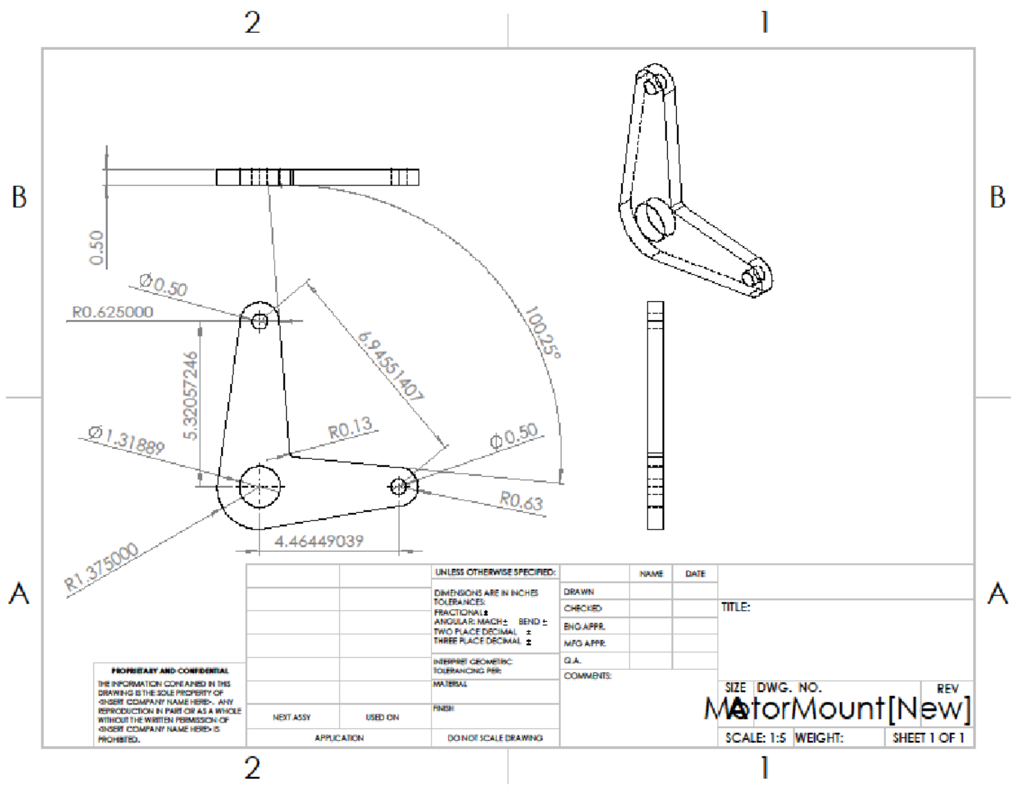

Figure 31: Motor Mount Drawing

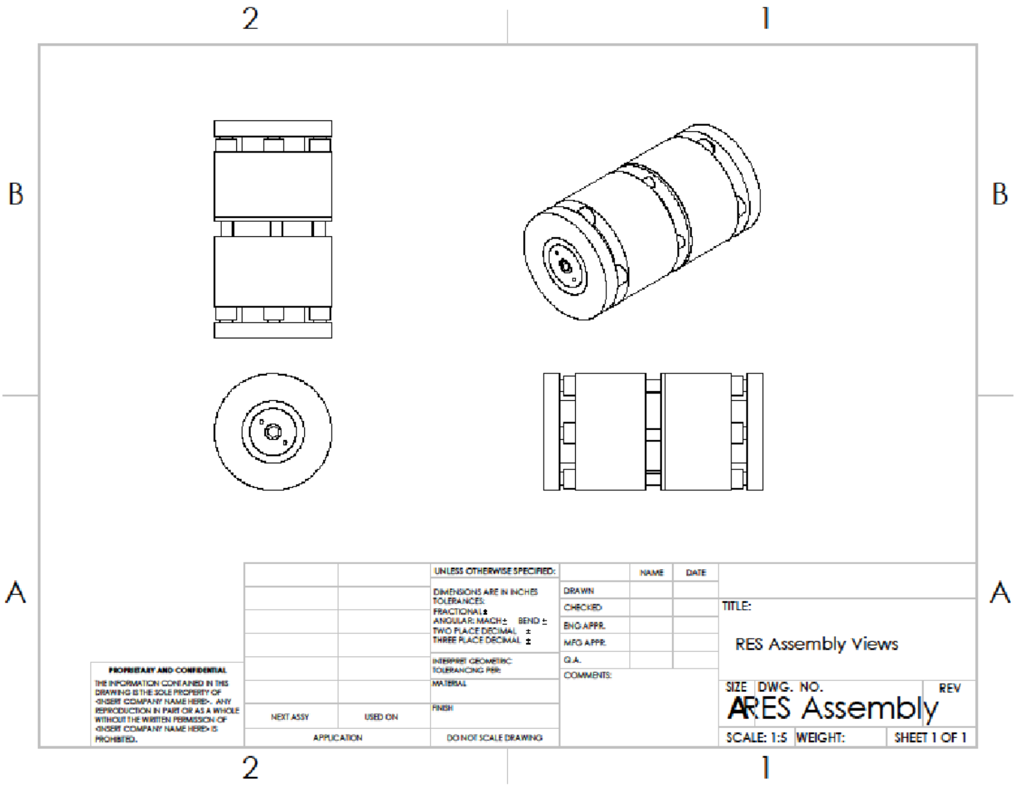

Figure 32: RES Assembly Drawing

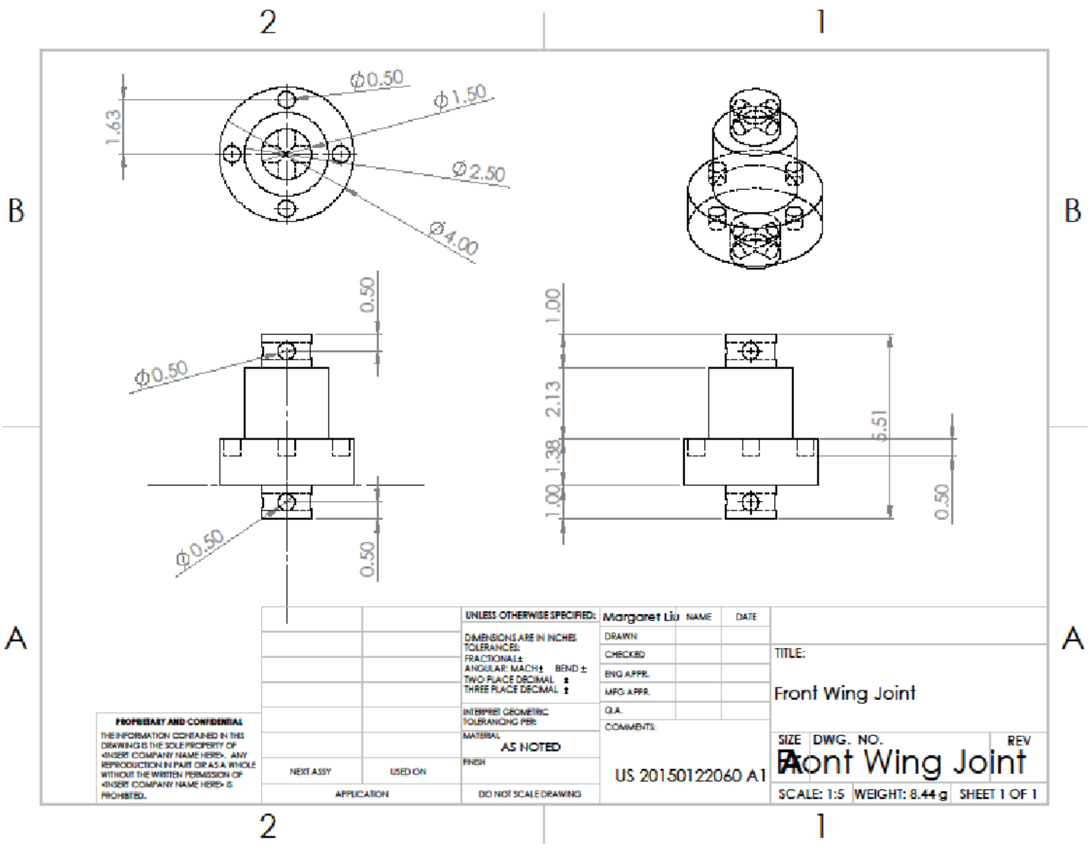

Figure 33: Rotor Wing Joint Drawing

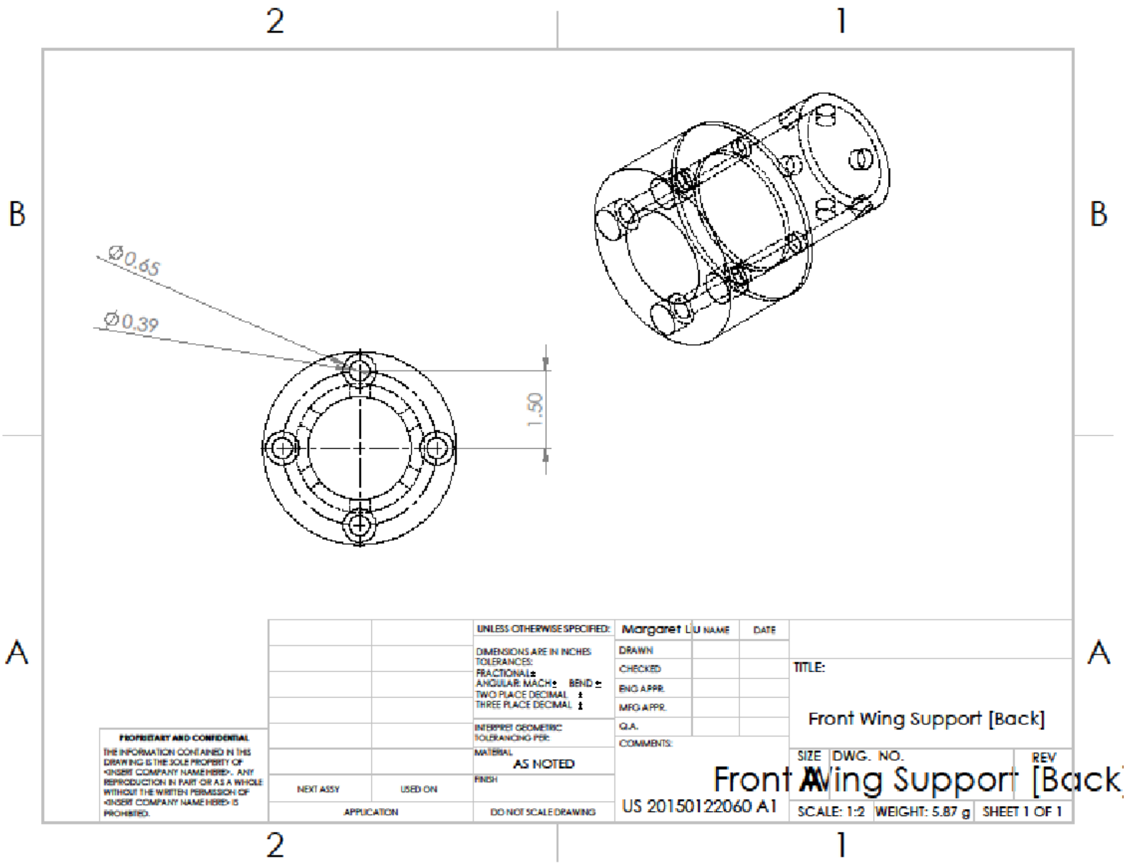

Figure 34: Front Wing Support Drawing (Back)

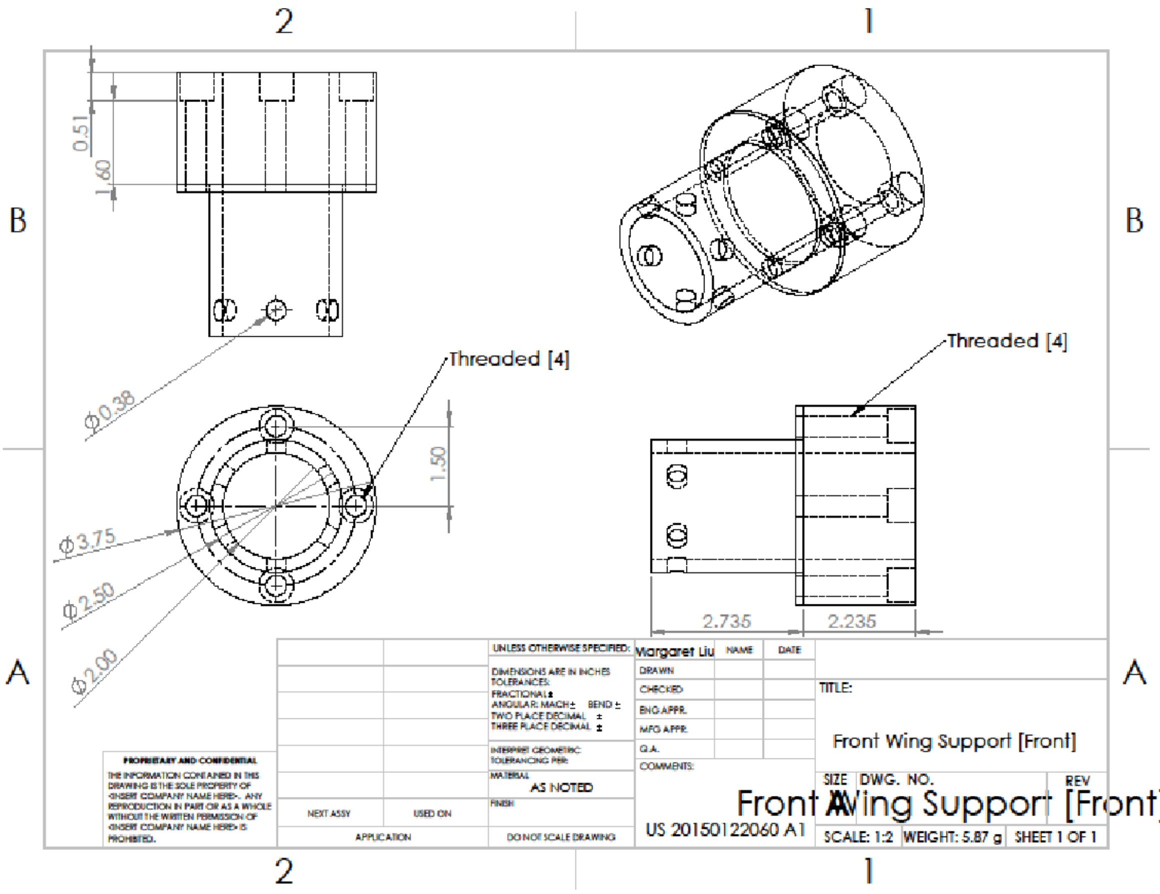

Figure 35: Front Wing Support Drawing (Front)

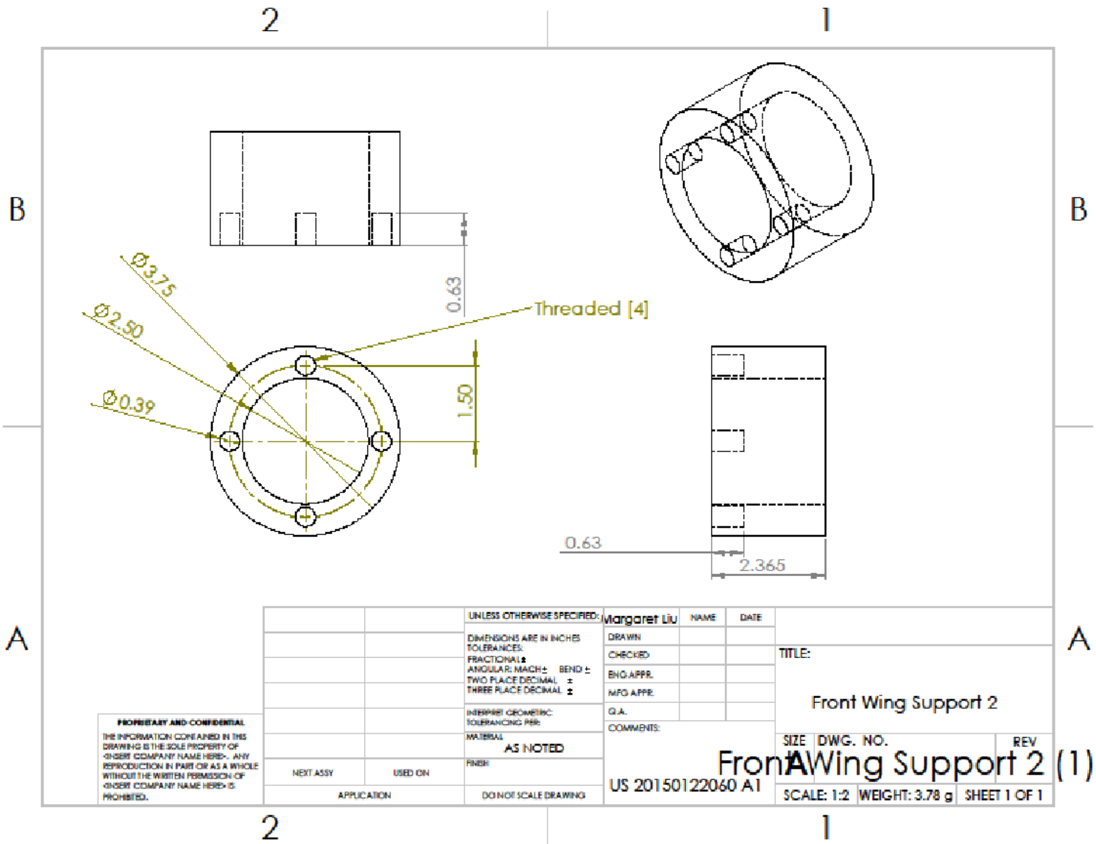

Figure 36: Front Wing Support 2

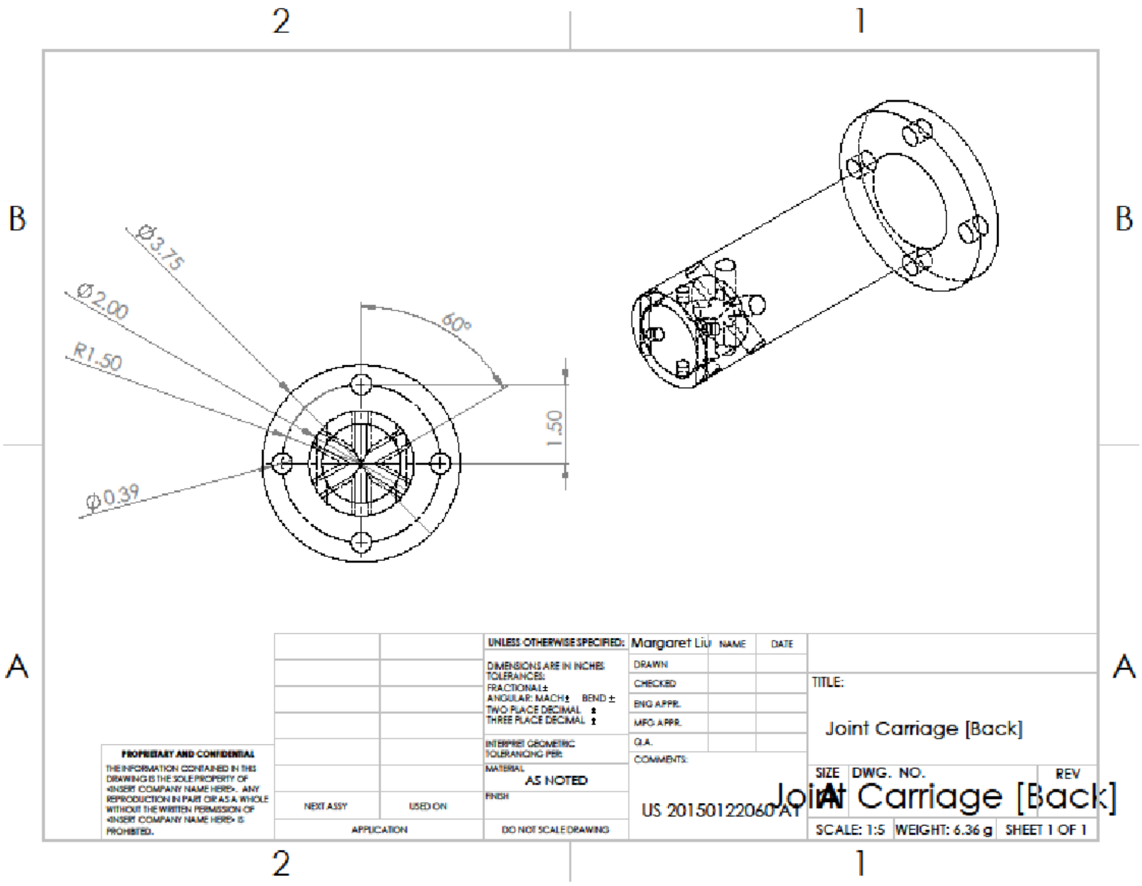

Figure 37: Joint Carriage Drawing (Back)

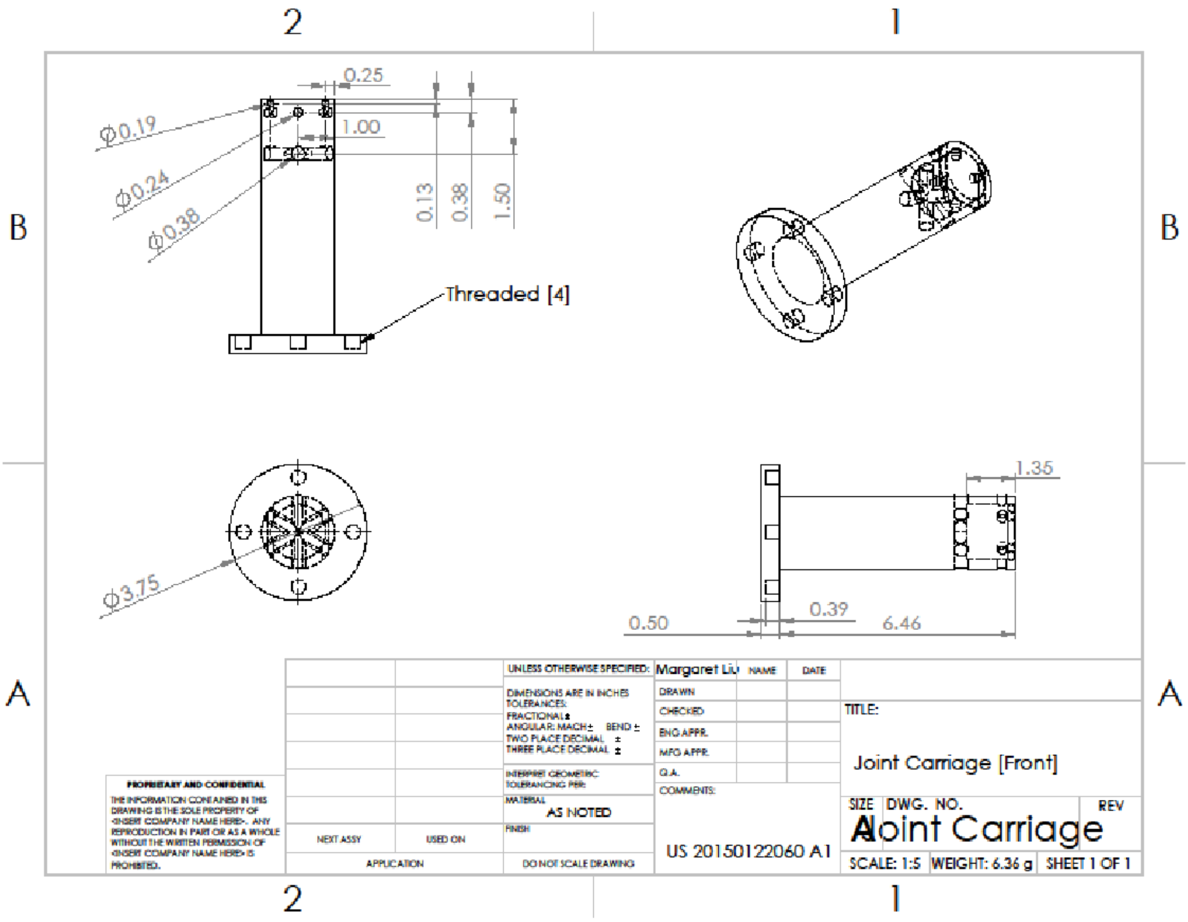

Figure 38: Joint Carriage (Front)

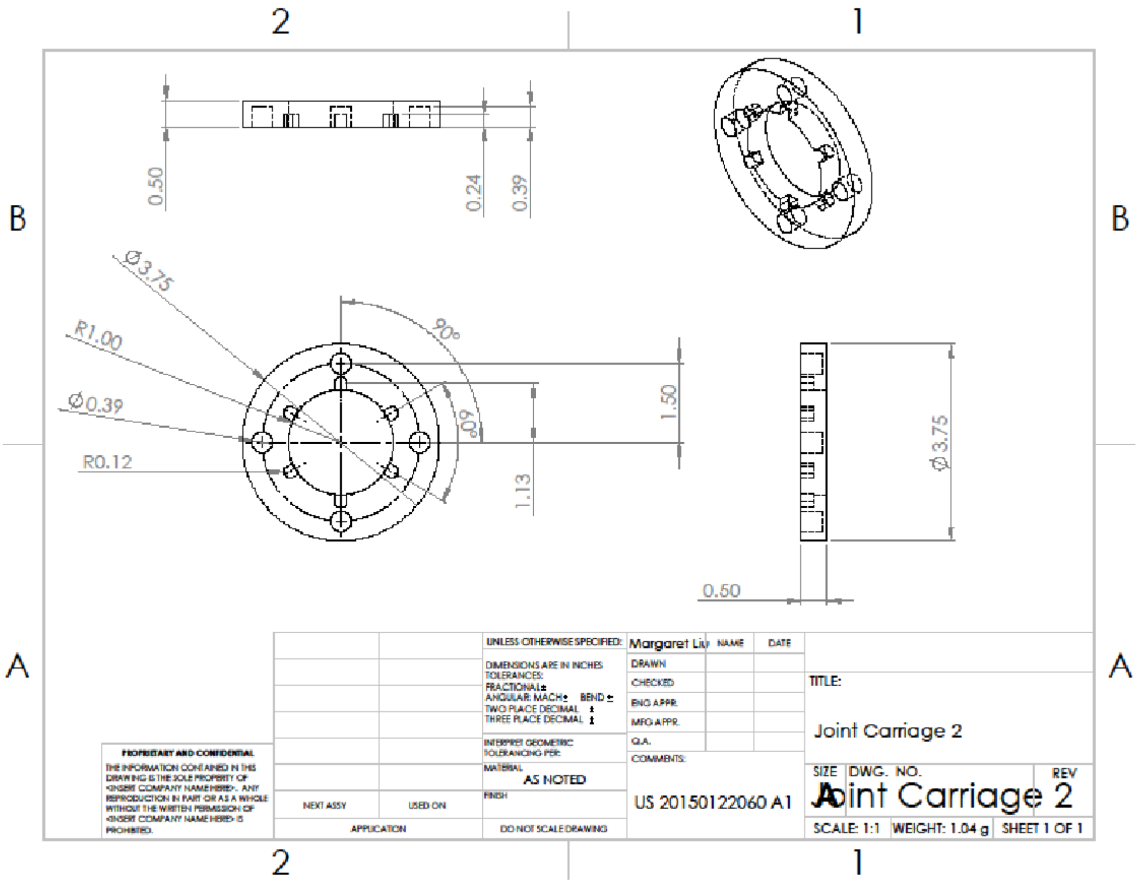

Figure 39: Joint Carriage 2 Drawing

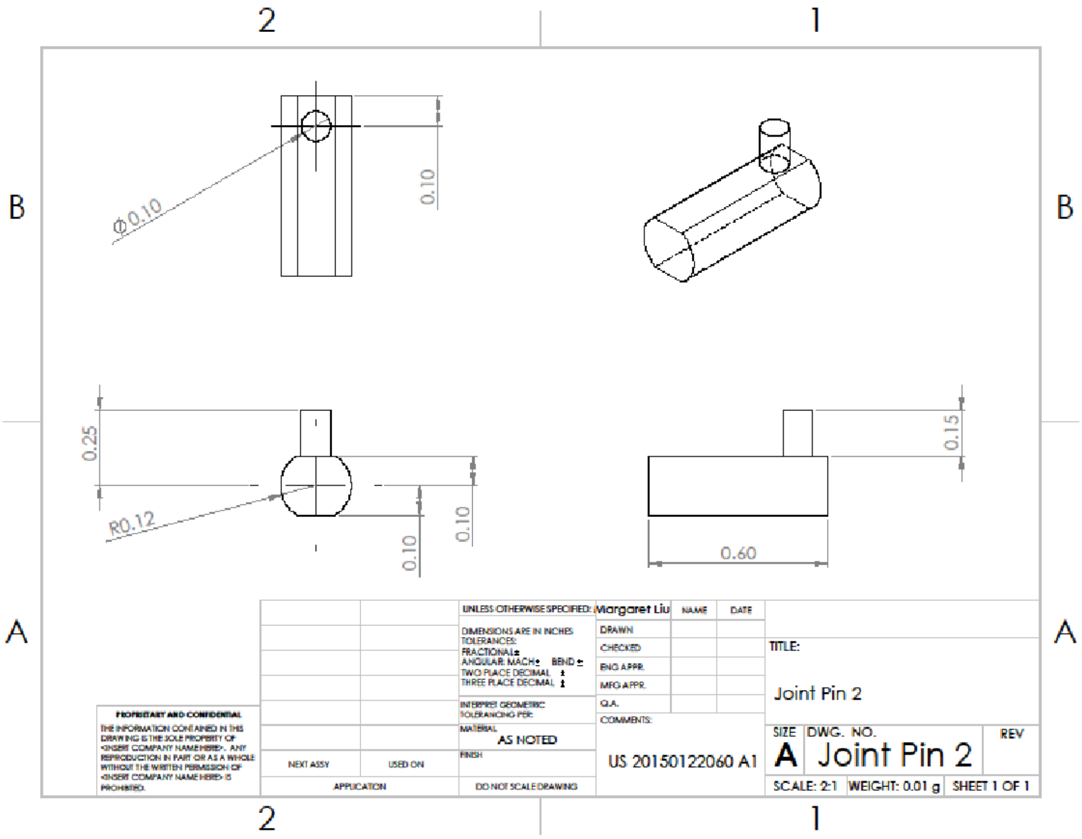

Figure 40: Joint Pin 2 Drawing

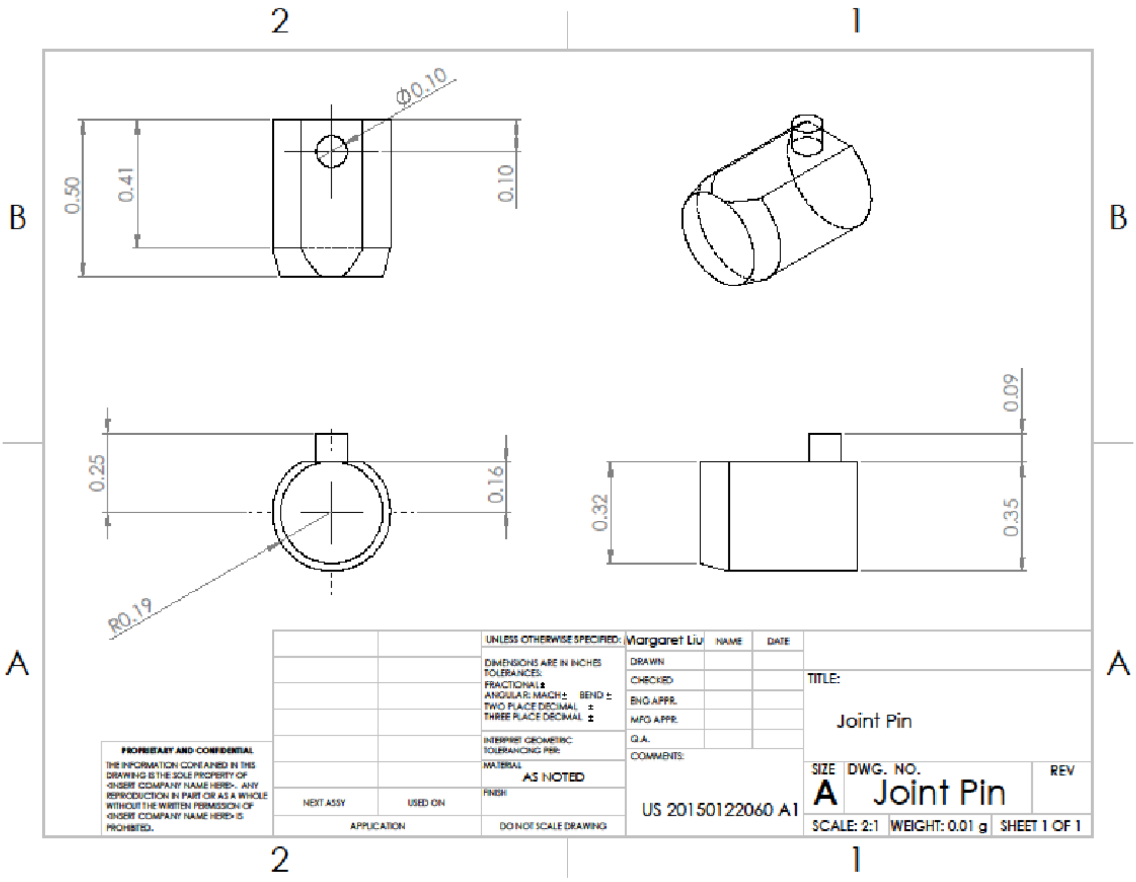

Figure 41: Joint Pin Drawing

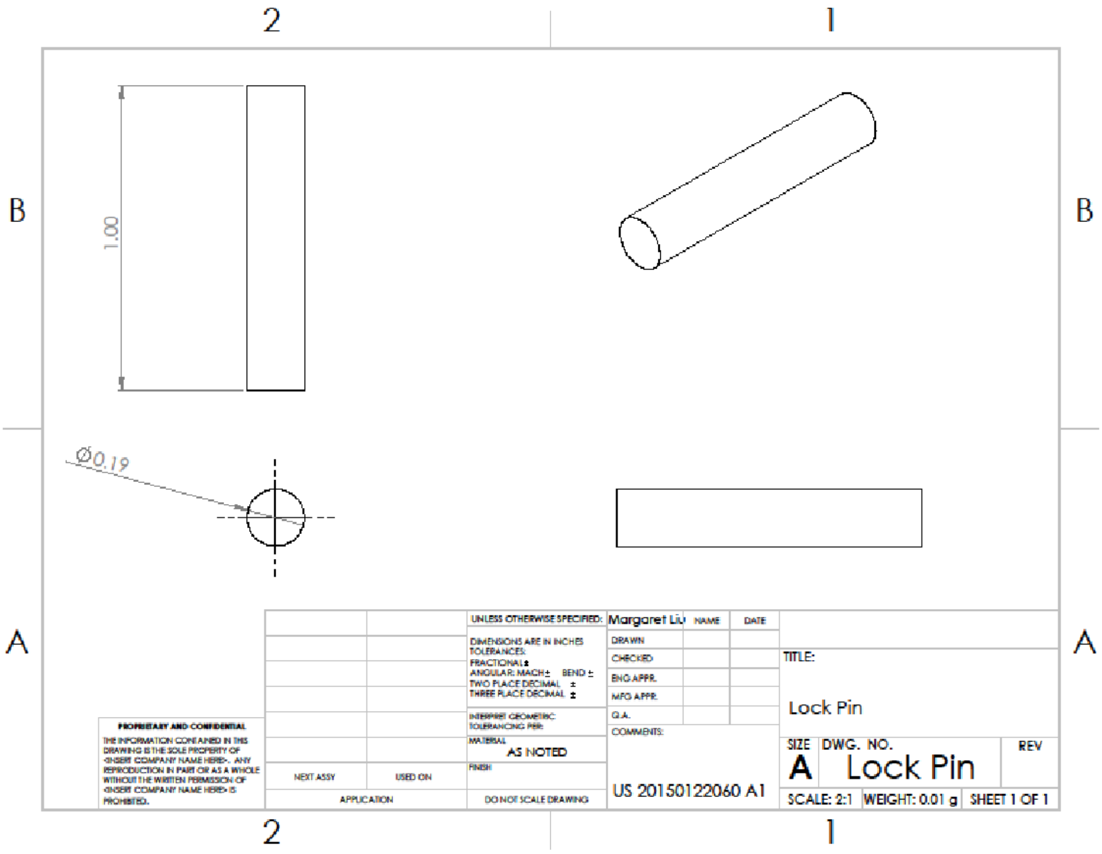

Figure 42: Lock Pin

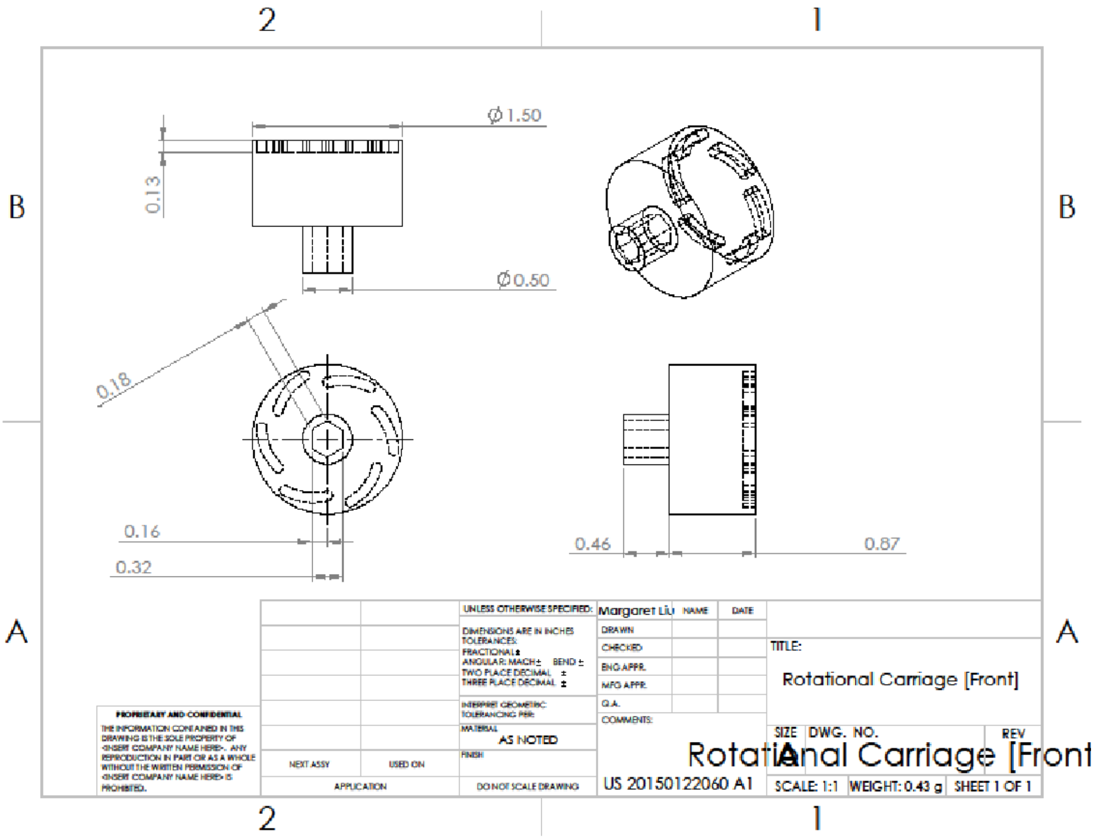

Figure 43: Rotational Carriage Drawing (Front)

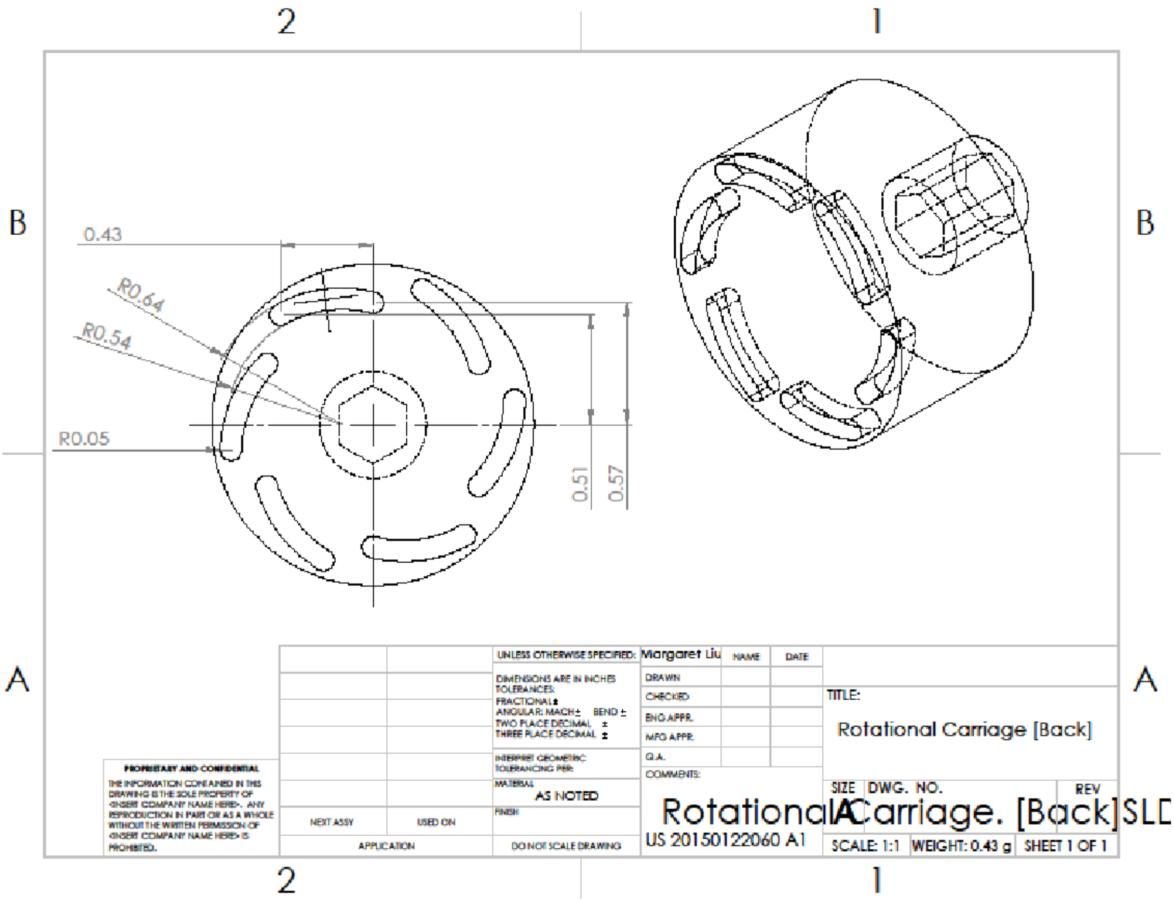

Figure 44: Rotational Carriage (Back)

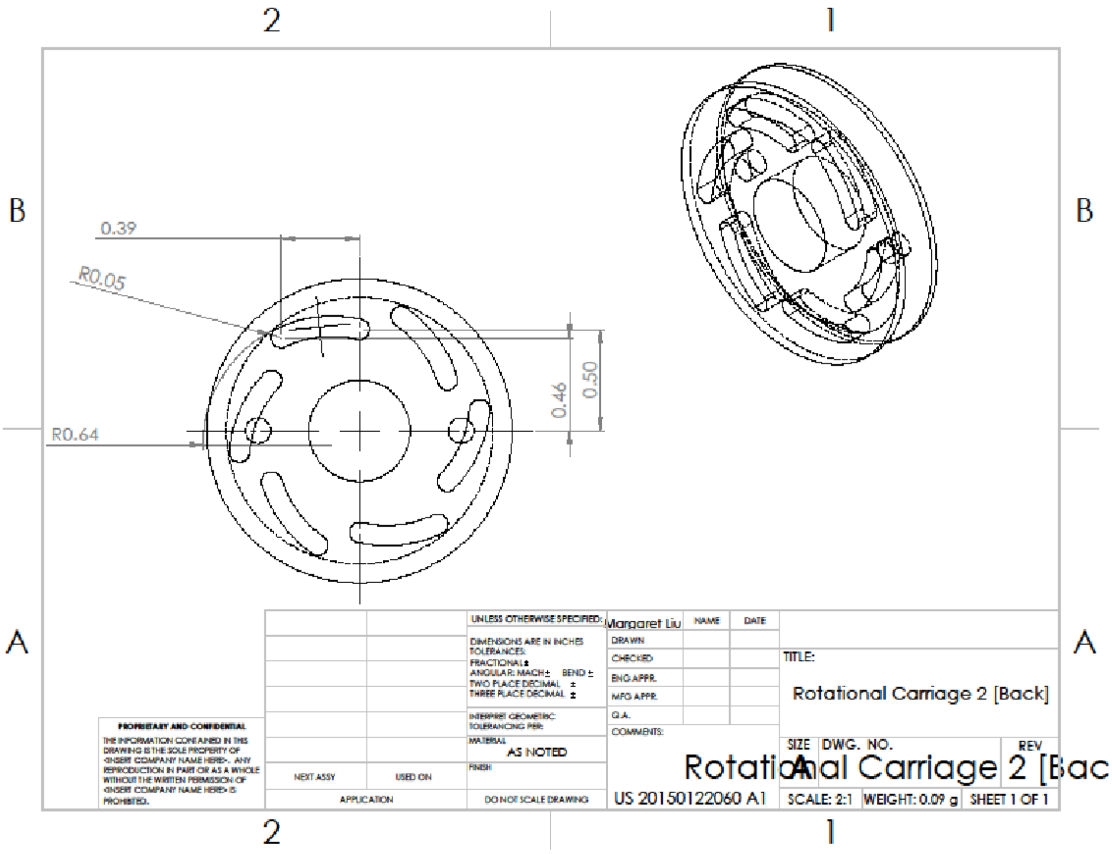

Figure 45: Rotational Carriage 2 Drawing (Back)

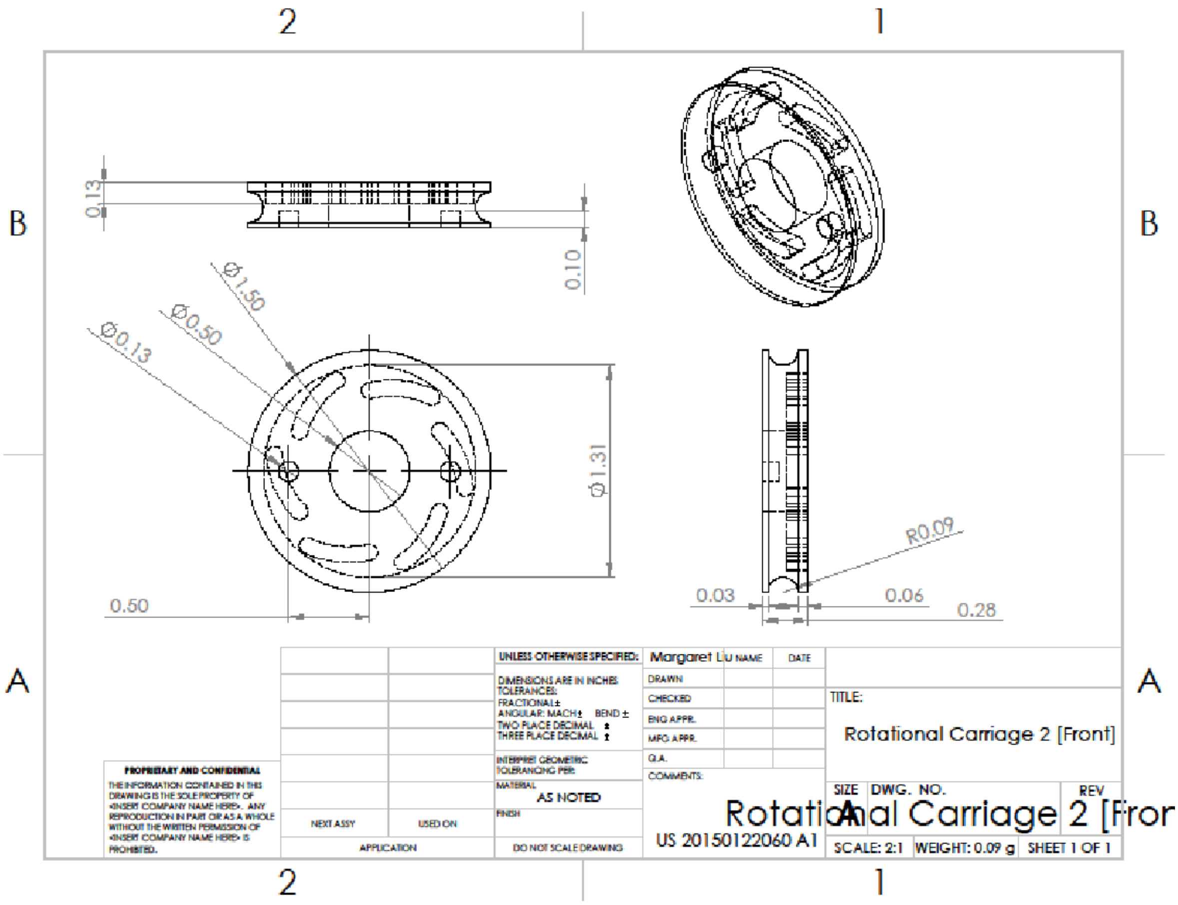

Figure 46: Rotational Carriage 2 Drawing (Front)

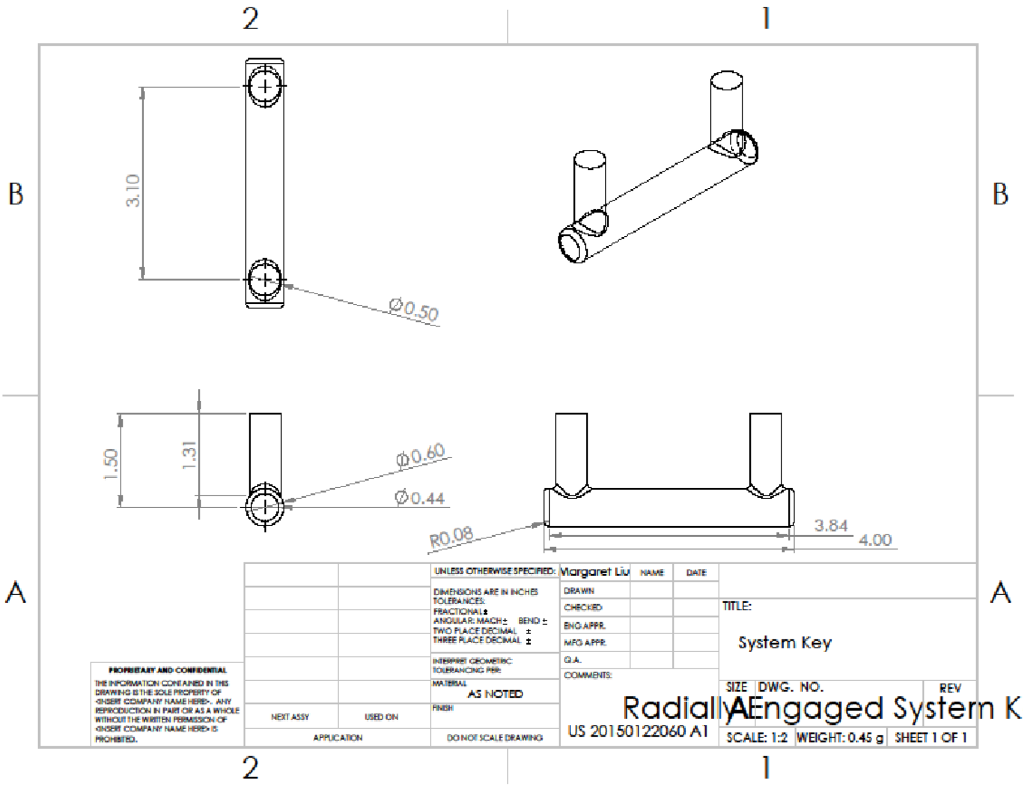

Figure 47: RES Key Drawing

4.4 Description of the design rationale for the choice/size/shape of each part

4.4.1 Bicycle Seat Post Clamp

The material of this clamp is aluminum alloy, which will help with limiting the weight of the moped since the total weight is .05 kg. This seat post clamp is the same as those on a regular bike, which will keep the moped user friendly and the adjustment of the seat simple.

4.4.2 Wheel Quick Release

The material is stainless steel, which will weather well in outside conditions. These skewers are user friendly, and easy to remove, which will ensure the time it takes to collapse the moped will be within the time constraints.

Bicycle Seat and Seat Post

The bicycle seat and seat post was recycled from an old bicycle. Because seat posts are standardized parts (in general) any generic bicycle will have a seat post that is the correct diameter in order to fit into our fabricated seat post holder. Seat posts can be removed from bicycles without tools, therefore this is an extremely easy part to obtain.

4.4.9 Fork – Handlebar – Gooseneck

The fork-handlebar-gooseneck assembly was obtained from an old bicycle. The diameter of the gooseneck is generally standardized; therefore, any old bicycle will do. In order to obtain this assembly, one should remove the front portion of the bicycle using an applicable tool. The decision to obtain this assembly from an old bicycle as opposed to fabricating it was made in order to save on overall costs.

4.4.12 Motor/Drive Train

For the motor and drive train assembly, we chose a mid-drive system. The mid-drive is a popular emerging product in E-bike technology and is highly praised for its simplicity and power. A mid-drive is essentially an electric motor inside the transmission assembly that generates additional torque on the drive train to compliment that generated by the user. What this accomplishes is an effectively perfect gear ratio at all times with less effort from the person riding the moped when compared to a standard mechanical-drive hub. The specific mid-drive that we chose for our design is the Bafang BBS02. The BBS02 comes complete with everything needed to mount the mid-drive directly through the driveshaft carrier on the forward portion of the rear frame wing and can be purchased with a 44-, 46-, 48-, or 52-tooth front sprocket. The only other components needed to complete the drive train assembly are a rear sprocket and a chain. For our gear ratio, we decided to take advantage of the mid-drive's purpose: to help generate torque. This begs a large gear ratio due to the fact that it's easier on the user to physically maintain this ratio, so we chose a 52-13 front-rear sprocket combination.

Seat Post Holder

The seat post holder will be machined from 6061 aluminum. It will be mounted to the bike seat support arm with 2 screws. The seat post will slide into the slot on the back of the holder and will be secured in its position by the seat post clamp that will fit around the seat post holder.

4.4.14 Radially Engaged System Patent No. US 9,103,419 B2 (i.e. Joint Assembly)

This joint was chosen in accordance to the folding and unfolding time specifications. The joint will be 4 inches in outer diameter and 3.74 inches in inner diameter. Total thickness will be 1.5 inches. In our current design, there will be two Radially Engaged Systems (RES) force fitted into the two back wings. These two RES's will then lock to the Front Wing Joint (forced fitted into the front wing). When the moped needs to be unlocked and folded, the pins in the

RES will retract through the tracks and into the RES itself. When the RES is locked, the pins will extend into the holes already manufactured onto the Front Wing Joint, thus locking the body of bike in place. The design is superior to any other locking device because all locking mechanisms are inside the body of the bike, thus eliminating any external trauma or weather exposure. With a simple turn of the Joint Lock Key, the pins can extend or retract, taking only mere seconds. Had we used another locking device, the time it would take to fold and unfold the moped would be greatly increased. We used 6 pins, each with a .75 inch diameter spaced 60 degrees apart, in the RES so the body of the moped will be strongly rigid, even under various road conditions. The basis of this design is the Archimedean spiral. The pins move through a short section of the Archimedean spiral, constrained through a straight line and results in the pins of the RES to move linearly. To find the angle of the track in which the pins moved, and the distance in which the pins traveled, we used the equation $\rho = \alpha\theta$. The distances and angles we used in this design were found similarly to the figure below, where 5 points within circles of the same diameter were lined up in a section of the Archimedean Spiral.

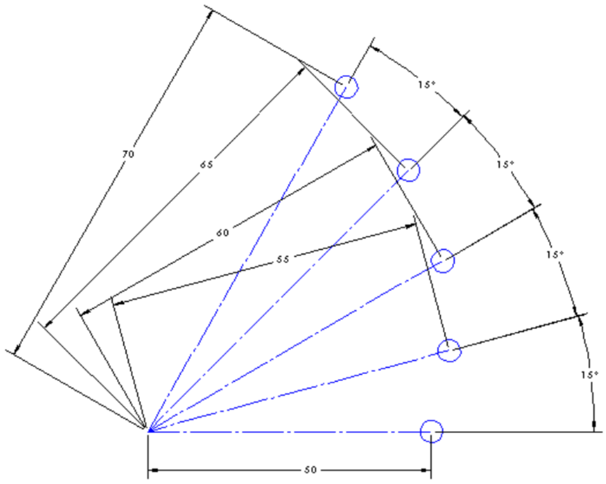

Figure 48: Archimedes Folding

Further modifications to this design will be made as we continue to develop the moped. Additional explanations for the RES may be found at http://www.uspto.gov/web/patents/patog/week32/OG/html/1417-2/US09103419-20150811.html.

Currently, the RES will be fabricated out of Carbon Steel to constrain costs. However, the RES can also be manufactured out of Aluminum to ensure a lower weight.

4.4.15 Joint Lock Key

The Joint Lock Key will be manufactured out of Carbon Steel. The reason for manufacturing the key ourselves is due to the fact that our RES system is also manufactured to the design specifications that we need. The key has a horizontal bar to ensure a comfortable grip for the user. The two vertical bars can be inserted into the two circular holes in the RES system. With a simple turn, the RES system can be locked or unlocked. This eliminates the need to spend time screwing and unscrewing a screw.

4.4.16 Front Wing Joint

The Front Wing Joint will be force fitted into front body of the bike. General dimensions may be found on the drawing for this part. This part will be manufactured out of Carbon Steel. The middle section is 4 inches in diameter to ensure the stability of the front wing. The larger diameter section, 4.5 inches, will be used for the same purpose as the Front Wing Support. The two 3.74 diameter ends will be inserted into the RES and the pins of the RES will extend into the holes that are spaced 60 degrees apart with a .75 inch diameter. This will ensure no movement from the body of the bike when the bike is fully locked, whether it be folded or assembled.

4.4.17 Front Wing Support

The Front Wing Support will be used to keep the front body of the bike from moving, and to create a gap between the two back bodies of the back to ensure plenty of space for the back wheel. This piece will be manufactured out of Carbon Steel as well. The outer diameter is 4.5 inches, the inner diameter is 4 inches, and the thickness is 1.375 inches.

4.4.18 Bike Seat Support Arm (bottom) /Bike Seat Top Bar

Both the bike seat support arm and bike seat top bar were designed using similar rational and for a similar purpose. Both pieces are used to create a support for the seat to comfortably rest above the moped frame (comprised of the Front Wing, Rear Wing A, and Rear Wing B). Both pieces are designed to connect to the frame using a pin and hinge to allow for free rotation about 360 degrees. The bike seat support arms were designed to be relatively thin in order to save on material costs due to their length. The top bar is pinned to the Front Wing and the support bars are pinned into Rear Wing A and B respectively. This was designed so that while the moped is collapsing, the bars smoothly push the seat behind the Rear Wings and out of the way of the Front Wing (which folds between Rear Wing A and B). Both pieces are to be fabricated using 6061-Aluminum, in order to maximize strength while minimizing the weight.

4.4.19 Moped Frame: Front and Rear Wings

Our moped frame was designed primarily around the expectation that it could be folded down into a very compact size. However, the effects of integrating numerous hinges and connections in order to compactly collapse the frame are quite detrimental to other aspects of the design. Firstly, a frame constructed of a single piece is by nature much stronger than one constructed with multiple pieces connected by joints and hinges, which means too much collapsibility would result in a weak frame design. In order to make up for this structural deficiency we would have to use stronger and/or larger components, which would result in a much heavier frame design. For these reasons, we opted to keep our moped frame simple by implementing only one primary folding point.

The moped frame was designed around typical bicycle frame geometry measurements. Four points - the rear wheel connection, the front fork connection, the seat, and the crankshaft housing – were dimensioned to make our moped similar in size to a medium bike frame. The initial design concept included the front wing and only one back wing. These two wings would fold around some pivot point to be aligned directly next to each other, effectively reducing the length and height of the moped in half after folding. This folding action requires both the front and rear wheels to be removed prior to folding. After taking into consideration the complexity of a removable one-sided wheel hub connection we opted to switch to a double-sided rear frame design. This gave us the opportunity to use a common quick release back wheel assembly that could simply be purchased from a supplier. This also gave the moped more structural stability.

The front and rear wings of the frame are connected though a radially engaging locking mechanism. Aware that there would be a large amount of torque on this connection, we had to make several considerations for the locking mechanism. Since the radially engaging locking mechanism uses pins under shear loading to restrict rotation, we opted to make the diameter of our connection very large. This reduces the shear on each pin because the moment arm from the center of the locking mechanism to each pin was greater.

Each frame wing will be machined from 6061 Aluminum plates using a mill. The front wing is ¾” thick and the rear wings are each ½” thick. At the back of the rear wings are c-shaped openings that will accept a standard quick release assembly for a bicycle wheel axle. The bottom brackets of the two rear wings include a 1.31” diameter hole. A 1.31” ID pipe will be welded between the rear wings to connect these two coaxial holes. This will act as our driveshaft housing through which our motor will be mounted.

4.5 Gantt Chart

Figure 49: Gantt Chart

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. Describe why/how the before analysis is the most important thing to study at this time. How does it facilitate carrying the project forward?

Compared with the behavior of our final prototype, we can conclude that our initial analysis of our 3D model was a very good predictor of the location of the major stress points in the frame. For example, most of the downward force of a seated rider is concentrated in the center of the main rotational joint. This was shown in the form of some slight flex in the wooden system produced to represent this joint on our final prototype, but it did not prevent the moped from working properly. Since our planned Rotationally Engaged System would be manufactured out of aluminum, we can safely conclude that our analysis of that held true, and that an aluminum joint would certainly be able to handle the necessary load to support a rider in the proposed weight range.

However, our efforts in moving forward with this project should be focused in analysis of materials selection. Initially, we wanted to make the frame wings out of molded carbon fiber resin, but we quickly learned that this was not feasible for several reasons. After making our prototype out of aluminum, though, it is clear that a carbon fiber frame would truly make this a potentially marketable design. Our frame's folding action functioned perfectly, but the heavy aluminum parts put unnecessary stress on both the RES and the gooseneck, the two most critical frame joints.

While these joints would be able to physically handle the stress of an aluminum frame, a carbon fiber frame would not only relieve a huge amount of this stress, but offer several other benefits as well. First, and most obvious, would be overall weight savings without compromising structural integrity. Our aluminum frame, while extremely rigid and durable, was very heavy. Carbon fiber would allow for much stronger frame wings and also reduce the weight of the moped to a fraction of the aluminum model.

In addition, carbon fiber could also improve upon the already successful folding action of our prototype. Carbon fiber can be much more easily molded into complex, natural shapes than aluminum can be, and a more edgeless design (such as the one shown in our selected initial concept design) would undoubtedly improve ergonomics when in the folded position. As an example, the sharp edges of the aluminum frame prevented us from making a truly successful handle to carry the moped when folded. With the smooth edges that carbon fiber provides, however, a comfortable handle could easily molded into one of the frame wings to give the user an easier way to transport the moped when not riding.

5.2.2 Summary statement of analysis done. Summarize, with some type of readable graphic, the engineering analysis done and the relevant engineering equations

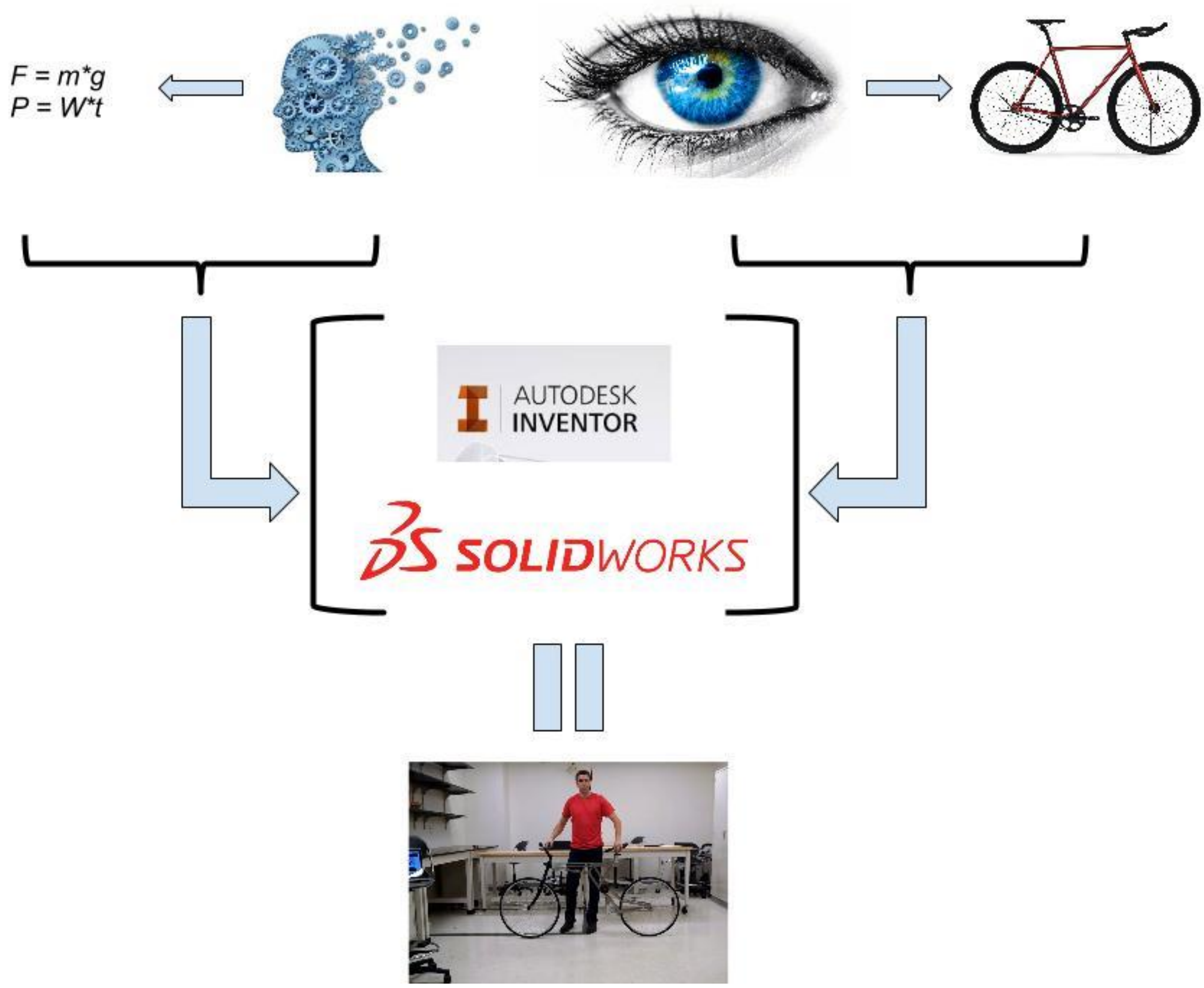

Figure 50: Conceptual Diagram of Analysis

5.2.3 Methodology. How, exactly, did you get the analysis done? Was any experimentation required? Did you have to build any type of test rig? Was computation used?

The analysis performed on the moped design did not require any physical testing. Due to the machining, budgetary, and material availability limitations, we opted to construct the majority of our moped components out of solid aluminum plates and blocks. The resulted in a moped that we knew would likely be over-engineered and be more than strong enough to support the weight of a rider. Thus, the majority of the components did not need to be analyzed as we could intuitively determine that they would meet their individual performance requirements. However, we did identify a few points of interest in our design and utilized the finite element analysis capabilities of Autodesk Inventor as well as Newtonian analysis to verify that our design would hold up to the forces it would encounter through normal usage. The FEA performed in Inventor was used to identify the points of maximum stress on the front wing and motor mount brackets and calculate a reasonable factor of safety. Newtonian analysis enabled us to predict the shear stresses that some of the smaller components within the RES would be subject to.

5.2.4 Results. What are the results of your analysis study? Do the results make sense?

The FEA results from Inventor confirmed that the frame wings would easily be able to support any extreme forces it may encounter due to the weight of even the heaviest rider. The results of the FEA computations performed on the front frame wing are displayed in Fig. 51, which shows that the maximum stress the part experiences is only 2.385 ksi. This analysis was done assuming a rider weight of 300 lbs, which is much greater than what we anticipate the weight of a typical rider would be. The deformations shown in the figure are not to scale, but are exaggerated for effect. The FEA results for the motor mounts, displayed in Fig. 52, reveal a maximum stress of only 0.778 ksi, suggesting that a much thinner piece of material could have been used. These results were fairly predictable. There is a reason standard bicycle frames are not built out of solid pieces of aluminum, but instead out of aluminum tubing. Solid aluminum is much stronger than what is necessary for this application, so a reduction in strength from the use of aluminum tubing is an easy trade-off for the savings that could be made in the weight of the product. We recognized that using aluminum tubing would be a superior option in comparison to the solid parts used in our design, but we were limited by the machine resources available to us and opted to avoid the necessity for welding at all costs.

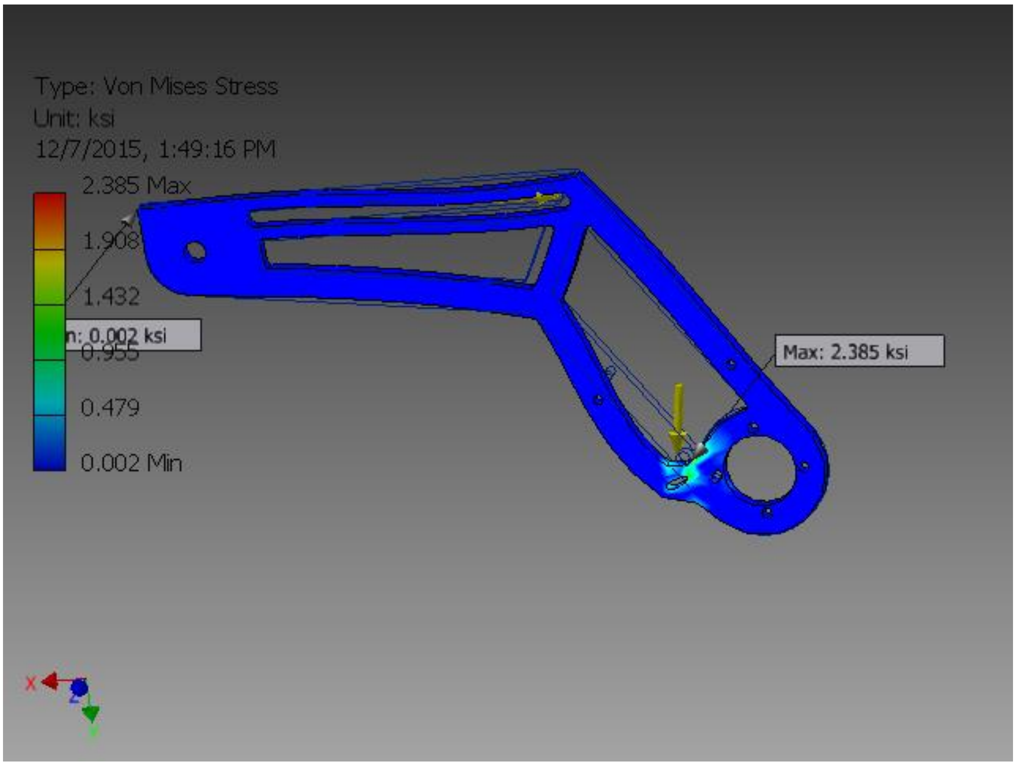

Figure 51: Von Mises Stress Analysis of Front Wing

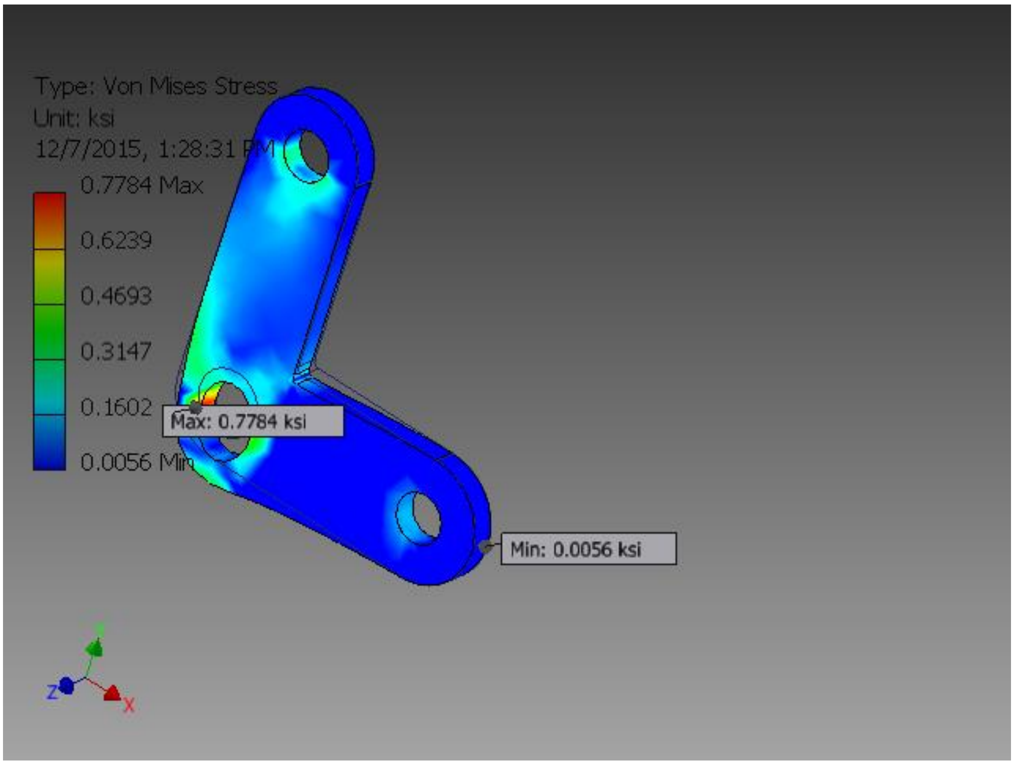

Figure 52: Von Mises Stress Analysis of Motor Mounts

We identified the six pins within the RES as components that had the potential to fail. Using simple free-body diagrams, we were able to compute the shear stresses that the pins were likely to encounter under the weight of a 300 lb rider. The maximum stress occurs at the interface of the two components the pin is designed to bridge. At this location, the shear stress is 13.2 ksi, which showed that 6061 Aluminum would be an acceptable choice of material, as its shear strength is about 30 ksi.

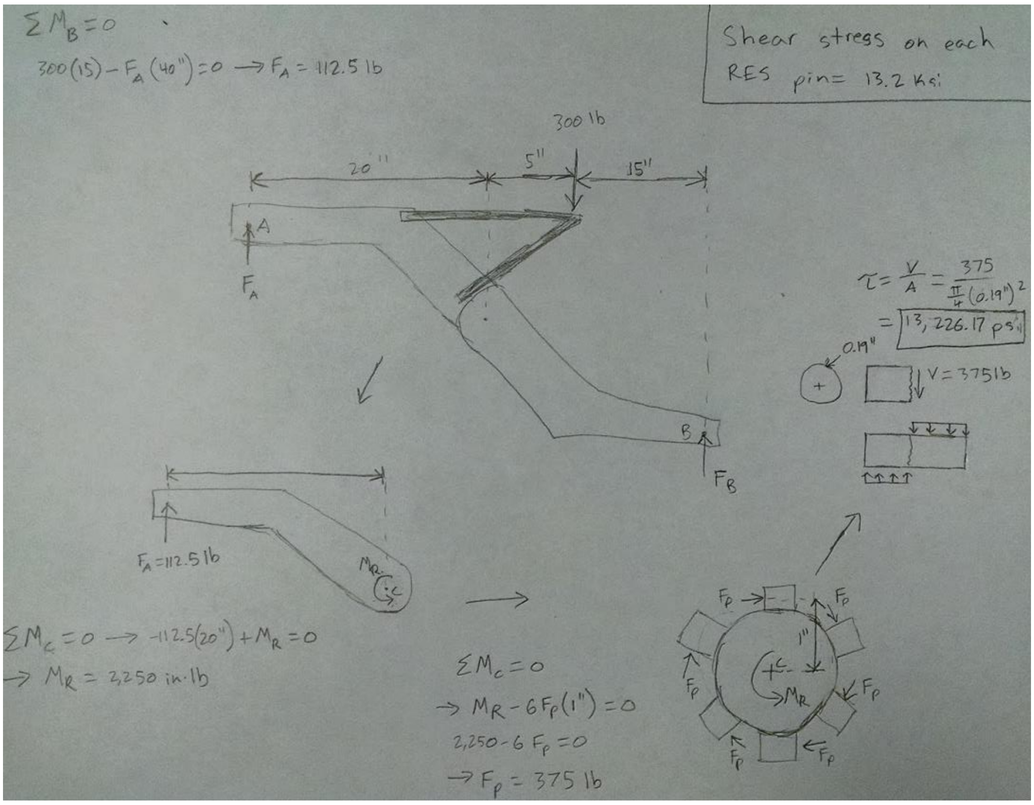

Figure 53: By-Hand Analysis of RES Pin

As described above, our analysis showed that selecting a new material was the most important change that needed to be made. This makes complete sense as carbon fiber is a much more light, strong, and capable material than aluminum. Additionally, our original concept already intended for a carbon fiber frame. Thus, given the resources, a revised prototype could be quickly produced by melding the current model with the intentions of the initial concept.

5.2.5 Significance. How will the results influence the final prototype? What dimensions and material choices will be affected? This should be shown with some type of revised embodiment drawing. Ideally, you would show a “before/after” analysis pair of embodiment drawings.

The results of the analysis made it apparent to us that our design was perhaps a bit too robust. This is definitely not a horrible problem to have, as it gives us the opportunity to reduce the amount of necessary material and thus the weight of the moped. Since the weight of our moped is not of high priority, changes will only be made to our design if time permits. The easiest change that can be made is to reduce the thickness of the motor mount brackets. This can be done to a fairly large degree without much fear of failure during use. Furthermore, the thickness of the frame pieces could be reduced. This will probably not be a priority of ours, as it would require many hours of tedious machining with little benefit. If we had not committed to the use of our ½” thick aluminum plate for the frame wings, we would likely exchange these out for either aluminum tubing or some type of lightweight composite material.

If this project were to receive the proper funding and/or facilities to perform carbon fiber molding, our group’s moped concept has the potential to be a marketable product.

Even though we had to make several design compromises to make up for machining limitations, our design still met almost all of our design specifications, and our observations of the final prototype backed up our preliminary analysis. Given the success of our prototype, and after seeing the available market of collapsible mopeds, a carbon fiber revision could make a competitive run against current products.

5.2.6 Summary of code and standards and their influence. Similarly, summarize the relevant codes and standards identified and how they influence revision of the design.

Standard #	Organization	Title	Keywords
ISO 9021:1988	ISO	Motorcycles -- Controls -- Types, positions and function	Controls
ISO 14722-1998	ISO	Moped and moped-rider kinematics -- Vocabulary	Vocabulary
ISO 8705:2005	ISO	Mopeds -- Measurement method for location of centre of gravity	Location

5.3 Risk Assessment Risk Identification

5.3.1 Risk Identification

Because the function of our team was aimed at the completion of a product prototype, we can only hypothesize on the risks a company or ourselves might inherit if we were to attempt to take this product to market. Thus, within the scope of this project, the only relevant risks we have identified are risks associated with the health and safety of the user. The results of our engineering analysis thankfully revealed that our design contained very few potential sources of failure. Under normal operation conditions, our design would have no problem supporting the weight of even a 300 lb rider. We expect the average user to weight much less than this, which further reduces any chance of failure. Operating any motorized vehicle is accompanied by a number of rather serious risks, however we can only hope to reduce the risks associated with malfunction of our product.

5.3.2 Risk Analysis

As stated previously, the chance of part failure within our design is very low. Any failure that may occur would have to be the result of some sort of large impact or complete improper use that cannot be accounted for. The impact of part failure has potential impacts that range from negligible to life-threatening. The best case scenario is that a non-load bearing part failed so that the rider was unharmed. The worst case scenario would entail the user to be operating the moped at a very high speed during a part failure, which would cause the rider to fall off and potential get injured.

5.3.3 Risk Prioritization

The safety of our users is, of course, our first priority. While there is always a chance of failure, the main risks to any user's safety when using our moped comes from factors that are beyond our control. We have and will continue to prioritize our consumers' safety, but we have produced an extremely safe vehicle for our customers.

6 Working prototype

6.1 At least two digital photographs showing the prototype

Figure 54: Final Prototype: Assembled

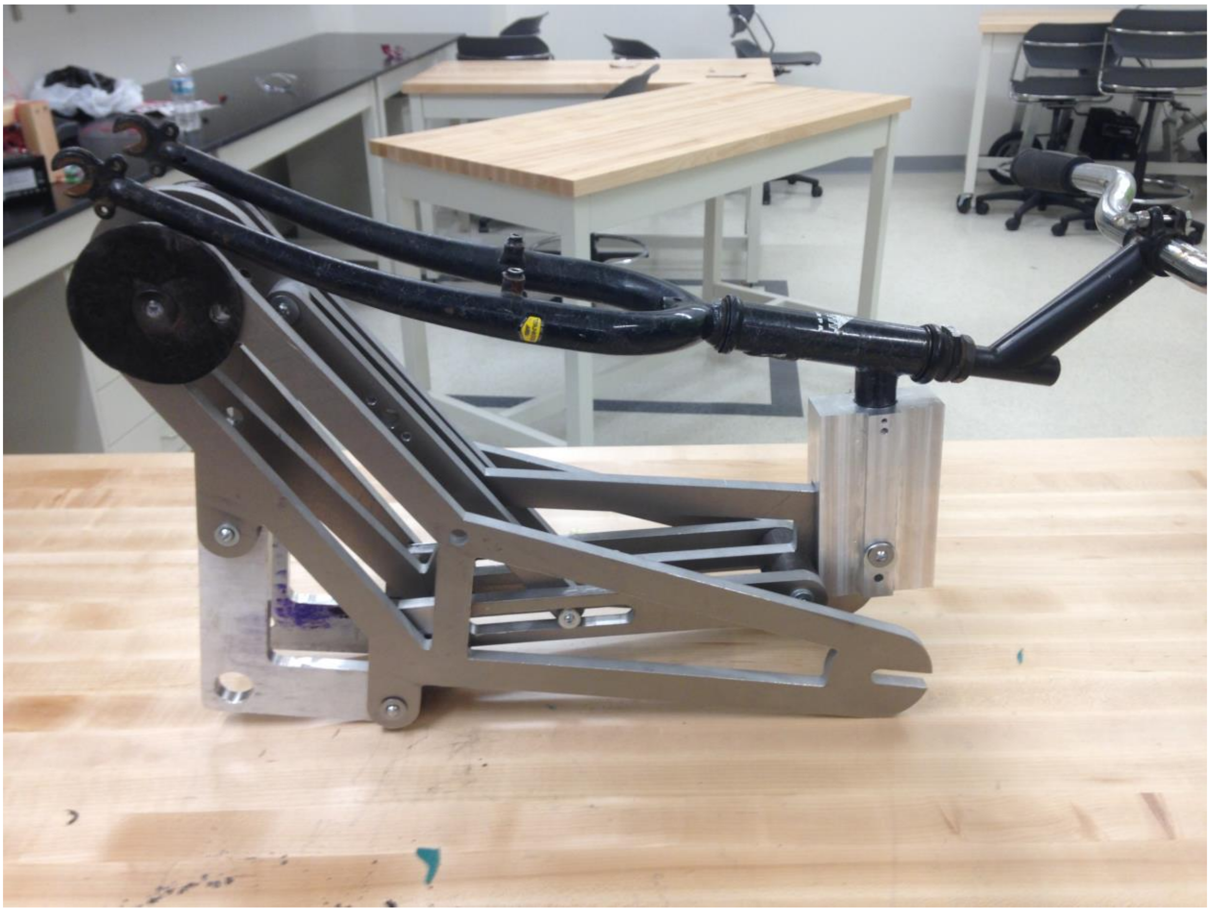

Figure 55: Final Prototype - Folded

6.2 A short videoclip that shows the final prototype performing

6.3 At least four (4) additional digital photographs and their explanations

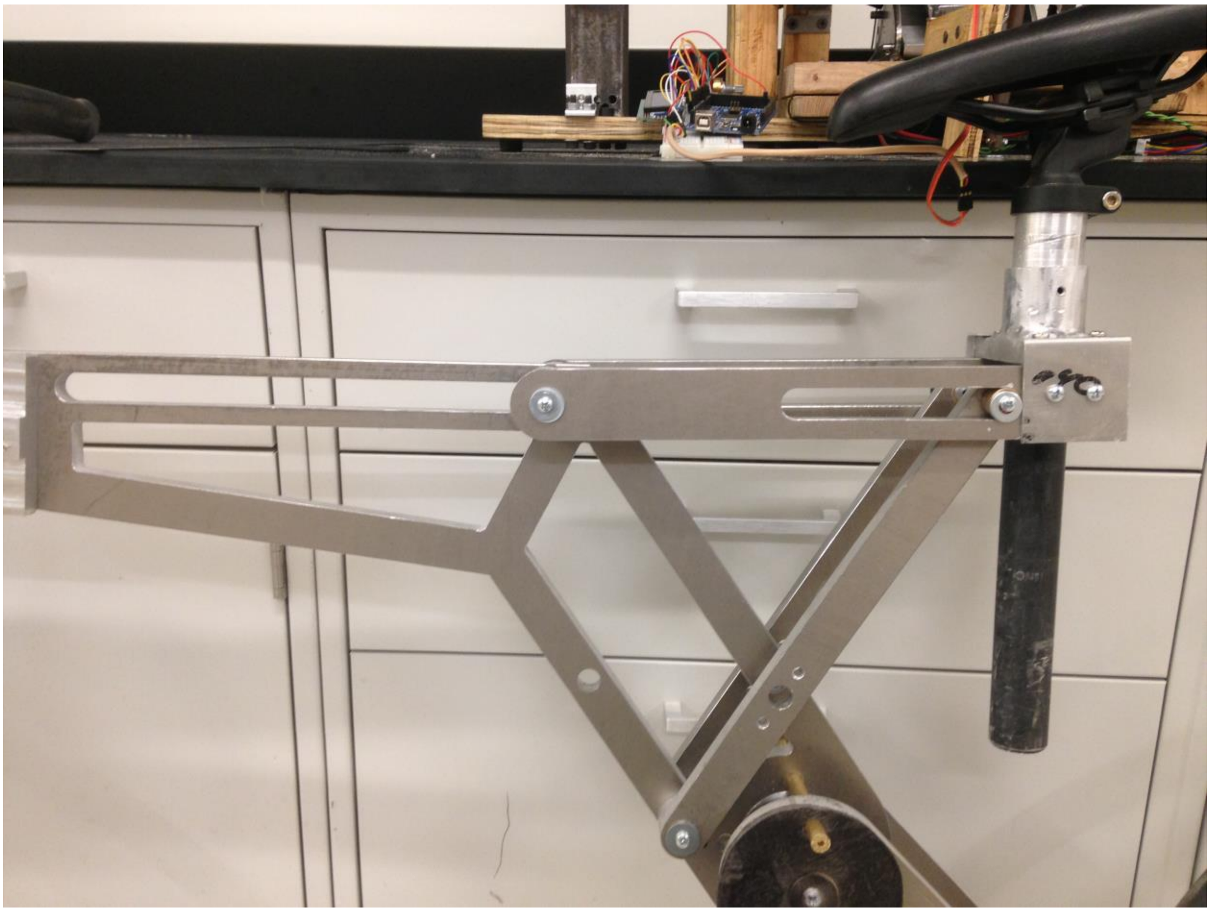

Figure 56: Seat Assembly - Unfolded

The picture above shows the seat in its fully unfolded position. Using a track along the front frame, the seat assembly has the option to fully collapse for easy storage. The seat post itself can be removed, using a seat clamp, to minimize space when folding. The base of the seat post is rectangular to improve stability in the rider. There are also additional tracks on the top of the seat assembly for the two bottom seat posts to extend forward for easy folding. In the future, a sprung seat can be implemented for the comfort of the rider. The current seat has been scourged from an used bike.

Figure 57: Seat Assembly - Folded

The photo above shows the seat assembly in the fully folded position, with the seat post removed. The two top and two bottom seat posts in the seat assembly extend forward for fully collapsibility. With the sliding tracks in place, the seat assembly can slide forward and fold without adding any additional width to the folding dimension. Having these tracks allow the seat assembly and the front wing to fit in between the two back frames of the moped. The pins that slide along the track are held in place by bushings, washers, and bolts. Aluminum 6061 is the material of the seat assembly.

Figure 58: Motor Mount Assembly

The photo above shows the motor mount brackets to house the Bafang mid-drive. The L-shaped brackets provide stability and frame for the mid-drive. The shape of the frames were chosen in order to extend the pedals, which are attached to the mid drive, underneath the user in order for maximum comfort when riding the moped. The assembly is held together with washers and bolts. The shape chosen for these brackets also do not interfere with the user's legs when riding the bike, but still provide a convenient location for the motor to sit. Aluminum 6061 is the material of the brackets.

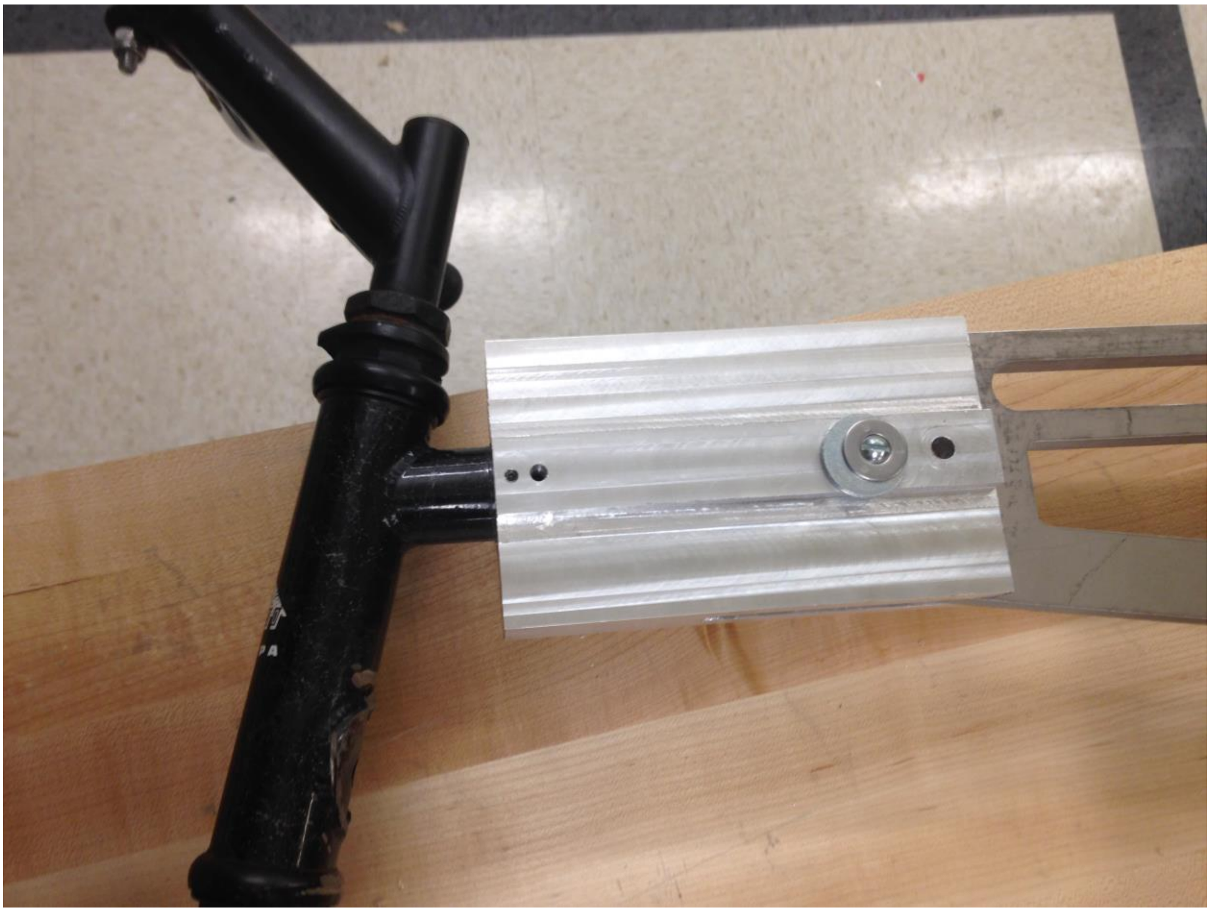

Figure 59: Gooseneck Assembly

The photo above is the gooseneck, which holds the front frame and the fork together. A hole was drilled into the front of the gooseneck to house the scourged fork. Then using the washer and bolts visible on the gooseneck, the gooseneck is attached to the front frame. The pin on the left side of the gooseneck holds the front fork from rotating while the bike is not collapsed. With the removal of the pin, the front of the bike can rotate counterclockwise under the gooseneck for easy transportation and storage. The gooseneck is made out of Aluminum 6061.

7 Design documentation

7.1 Final Drawings and Documentation

7.1.1 A set of 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.

Engineering drawings including CAD model files and drawings derived from CAD models are uploaded to the “Moped IV” file exchange. Each part is housed as a separate file. Clicking on a CAD file should initiate download of the file for the selected part. Engineering drawings of each manufactured part can also be seen in section 4.3.

7.1.2 Sourcing instructions

7.2 Final Presentation

7.2.1 A link to a video clip version of 1

https://youtu.be/i9JUZvloNh0

7.3 Teardown

TEARDOWN TASKS AGREEMENT

PROJECT: MOPED IV NAMES: Kyle Seymour KS INSTRUCTOR: Prof. Malast
Chris Mertens CM
Maggie Liu ML
David Southmayd DS

The following teardown/cleanup tasks will be performed:

- The final prototype will be removed from the student work area.
- All leftover components & materials will be gathered. Those that are reusable will be returned to the scrap material cabinets.

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: Mary Malast ; Print instructor name: Mary Malast
Date: 12/7/15

(Group members should initial near their name above.)

8 Discussion

8.1 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.

Based on the design metrics originally created, the total happiness of the final product scored a 1.297. The only criteria that the final design did not meet, was that the design did not implement a sprung seat. The need for an electric motor was met, while the final weight and dimensions of the folded moped all valued extremely close to the best possible value in accordance to the metric needs. At full power, the moped can travel 19 miles at an average of 20 miles per hour. The moped can be folded in 60 seconds, and unfolded in 45 seconds. The motor chosen has 1 horsepower. Overall, the bike weighs 21.4 lbs and folds down to 27.36 inches by 15.64 inches by 5.97 inches for easy transportation and storage. This final design is very successful at meeting all of the user's needs and far exceeds the design team's expectations. The moped meets all the requirements without compromising an aesthetic appeal.

8.2 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?

The only significant part sourcing issue that arose was the sourcing for the RES. This part is normally manufactured overseas, but due only need one RES and not multiple for mass production, it was best for the RES to either be produced by the team, or by a local machinist. The school's machine lab did not have the proper equipment to produce the parts needed, so the RES had to be manufactured by a local machine shop with a working CNC machine. The machine shop originally contacted was not able to machine the parts, but did not notify the team until the day before the prototype due date, even though they asked, and was given, a two-week period for machining. Subsequent machine shops also fell through, resulting in a stand-in RES used for the final prototype. In the future, having a working CNC machine in the machine shop at school would allow teams to personally machine their parts without having to outsource the work. No other part was delayed in the machining or ordering process.

It made sense to scourge parts needed for the moped since machining a fork, handlebars, and triple clamp would take additional aluminum and time to machine. The scourged parts used instead worked perfectly for the assignment. Buying any of these parts would have increased the cost needed to produce the final prototype, and keeping costs down was a significant factor in scourging important parts of the moped.

8.3 Discuss the overall experience:

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

The product was more difficult that we had expected. A lot more design and research was needed since we focused on meeting the user's needs the best we can, while maintaining a feasibly marketable product in mind. We also ran into complicated machining problems, in particular with the RES.

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

Yes, our final project result aligns with the project description. Our moped is both ultra-light and collapsible. We did not deviate from the original prompt, except to focus our design on being extremely collapsible and transportable.

8.3.3 Did your team function well as a group?

Yes our team worked well as a group. We each had skills to contribute and worked smoothly together.

8.3.4 Were your team member's skills complementary?

Yes our team members all contributed skills needed for the project and those skills were complementary.

8.3.5 Did your team share the workload equally?

Yes our team shared the workload equally. We each were proactive about completing the project and working together.

8.3.6 Was any needed skill missing from the group?

None of us knew how to use a CNC machine, or to weld. Had we had these skills, and a working CNC machine, the project would have ran smoother.

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

We did have to consult with our customer during the process, mainly to accommodate for the missing RES, but we stuck to the original design brief.

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

The design brief did not significantly change. Originally, the design needed to be transportable similar to a carry-on. Since we became the ultra-collapsible moped group, the design changed to focus on the folding and unfolding time, as well as a small size when folded.

8.3.9 Has the project enhanced your design skills?

Yes, the project has enhanced the design skills of every team member.

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

Yes, we all would feel more comfortable accepting a design project assignment as a job.

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

Yes, we would all be interested in doing a similar project involving other forms of transportation, as well as something similar to the SpaceX competition project.

9 Appendix A - Parts List

The parts list can be found in the Excel spreadsheet in section 4.2*, figure* 12

10 Appendix B - Bill of Materials

Part	Use	Obtained From:	Cost
0.5" thick aluminum plate	Frame Wings/Seat Supports	Machine Shop	~$250.00 (obtained for free)
6"X4"X3.5" aluminum block	Gooseneck	Shapiro	$35.00
0.125" dia. aluminum rod	Shafts/Collars	Shapiro	$5.00
0.25" dia. aluminum rod	Shafts/Collars	Shapiro	$5.50
1" dia. aluminum rod	Shafts/Collars	Shapiro	$22.16
4" dia. aluminum rod	RES collar	Shapiro	$66.47
5/8" square wooden dowels	RES representation	Home Depot	$12.00
SAE 841 Bronze sleeve bearings	Bushings	McMaster (6391K212)	$8.00
Aluminum Spacer	Seat	McMaster (92510A820)	$6.11
Quick Release Pin	Seat	McMaster (98320A510)	$2.62
M10x.5 threaded 12 mm	RES	McMaster (90128A283)	$8.82

M10x.5 threaded 32 to full	RES	McMaster (90128A291)	$6.09
Type 18-8 Stainless flat washer	Various	McMaster (92131A029)	$3.37
Brass pan head screw	Secure Pins	McMaster (94070A537)	$10.71
Total			**$191.85**

11 Appendix C - CAD Models

As described in Section 7.1, CAD model files, and drawings derived from CAD models are uploaded to the “Moped IV” file exchange as individual files. Clicking on a specific file should initiate a download of the file.